What are Unconventional Resources?
- Shale Gas/Shale oil
- Tight Gas Sands
- Oil Shale
- Coalbed Methane
- Methane Hydrates (Not Producible….Yet)

Differences: Unconventional Shale Gas and Conventional Plays
- Approach to prospecting
  - i.e. Not looking for “clean” units
  - Depositional Environments
- Deposition of units
- Driving factors of production
  - i.e. not porosity
  - TOC is the driving geologic factor

US Unconventional Gas Projections

Unconventional Resources: USA
- Marcellus Shale
- Barnett Shale
- Bakken Shale (oil)

Global Shale Gas
Worldwide Shale Potential
Preliminary studies have identified over 550 shale plays in 145 basins.
Global Unconventional Gas

<table>
<thead>
<tr>
<th>Region</th>
<th>Coiled Horizontal (ft)</th>
<th>Shale Gas (Tcf)</th>
<th>Tight Gas (Tcf)</th>
<th>Total (Tcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>3,017</td>
<td>3,640</td>
<td>1,374</td>
<td>8,225</td>
</tr>
<tr>
<td>Latin America</td>
<td>59</td>
<td>2,136</td>
<td>1,318</td>
<td>3,648</td>
</tr>
<tr>
<td>Western Europe</td>
<td>157</td>
<td>969</td>
<td>386</td>
<td>1,219</td>
</tr>
<tr>
<td>Central &amp; Eastern Europe</td>
<td>110</td>
<td>22</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>3,197</td>
<td>627</td>
<td>396</td>
<td>5,403</td>
</tr>
<tr>
<td>Middle East &amp; North Africa</td>
<td>3,547</td>
<td>823</td>
<td>813</td>
<td>5,183</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>192</td>
<td>274</td>
<td>70</td>
<td>1,146</td>
</tr>
<tr>
<td>Central &amp; South Asia &amp; China</td>
<td>1,275</td>
<td>3,399</td>
<td>386</td>
<td>5,204</td>
</tr>
<tr>
<td>Other Pacific Asia</td>
<td>2</td>
<td>34</td>
<td>70</td>
<td>2,419</td>
</tr>
<tr>
<td>South Asia</td>
<td>33</td>
<td>9</td>
<td>16</td>
<td>58</td>
</tr>
<tr>
<td>World</td>
<td>9,051</td>
<td>18,185</td>
<td>7,206</td>
<td>32,565</td>
</tr>
</tbody>
</table>

Holditch and Ayers, 2009

How Does Shale Produce
- Low porosity (6%)
- Very low perm
- High TOC
- Brittle rock
- Natural fractures

Economic Problems: Unconventional Resources
- Cost of Drilling ($4 million for Marcellus wells)
- Pipe and casing cost
- Completion
- Environmental Restrictions
- Estimation of Reserves

Depositional Environments: Black Shale
- Oxidic Environment
  - Aerobic bacteria use oxygen to break down organic matter
- Sub-Oxic Environment
  - Oxygen is virtually exhausted
  - Anaerobic bacteria use nitrates as an oxidant
  - Process is slower
- Anoxic Environment
  - No oxygen present
  - Anaerobic bacteria use sulfates as an oxidant
  - Process is very slow

Black Shale Modern Analogs: Black Sea
- We don't know how wells will evolve

Estimation of Reserves

- No oxygen present
- Anaerobic bacteria use sulfates as an oxidant
- Process is very slow

Jenkins 2009

Need a low amount of sediment input, low circulation and a high amount of organic input in order for a stratified water column to develop

http://blacksea-education.ru/images/map.jpg
Black shale is deposited across the study area.
Shale appears to be sourced primarily from the NE.
Thicker Marcellus deposits exist in Onondaga lows and to the NE.
Organic matter extends across the study area, however more organic matter accumulates in the paleo-topographic lows.
Shelf break at A and B.

Data Resources:
Unconventional Plays
- Lithostratigraphy
- Petrophysical Data
  - Spectral Gamma Logs
  - XRD and SEM
  - Permeability
  - Water Saturation
- GeoChem
  - TOC data is essential
  - Thermal maturity
- 3D Seismic
  - For optimal well design to avoid structural complexity

Surface to Sub-Surface
- 3D Seismic
  - For optimal well design to avoid structural complexity

Thickness Maps: Marcellus Shale

Spectral Gamma Ray Suite
Th/U ratio is linked to TOC
**Spectral Gamma Ray Analysis**

- Th/U Ratio
- Oxidized
- Illite-Pink
- Smectite-Green

**Spectral Gamma Ray**

- TOC vs. Uranium

**XRD and TOC**

- Establishes if rock can be fractured
- Establishes TOC or Reservoir potential

**Regional Mapping**

- Organic Rich Marcellus at 15 ppm

**Summary on Marcellus:**

- High TOC 5-15%
- Very brittle (i.e. fracable)
- Relatively shallow
- Wide extent
- Possible 4,350 trillion cubic feet of gas (Engelder 2001)
- Overall economics can make one Marcellus well more profitable than three shallow wells
- Price of gas is a big issue

**Bakken Shale - Williston Basin**

- ~3.6 billion barrels of oil (recoverable)
- Porosity 5%
- Perm 0.05 milli Darcy
- Recovery Factor 1-5%
Coal Bed Methane
- Coal is the most abundant fossil fuel
- Produce Methane adsorbed to coal surfaces
- Coal stores 6 times more gas than a conventional reservoir by volume
- Gas content is 100-800 SCf/ton of coal
- Economic production from 0.5 ft-thick coal is possible

Water/Gas production history
- Water Production: 170K bbls/day
- Coal-Bed-Methane Produced Waters

Coal Bed Methane Extraction
- Drill well
- Pump water out to decrease pressure
- Produce desorbed gas

<table>
<thead>
<tr>
<th>Dataset</th>
<th>N or wells</th>
<th>Avg water production (bbls/day)</th>
<th>WID/GOR ratio (B/MCF)</th>
<th>Primary disposal method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black W.</td>
<td>2.317</td>
<td>56</td>
<td>0.55</td>
<td>Deck</td>
</tr>
<tr>
<td>Powder</td>
<td>Wine</td>
<td>2.377</td>
<td>406</td>
<td>2.75</td>
</tr>
<tr>
<td>River</td>
<td>Coles</td>
<td>458</td>
<td>296</td>
<td>1.34</td>
</tr>
<tr>
<td>Saw</td>
<td>Coles</td>
<td>3,089</td>
<td>25</td>
<td>0.011</td>
</tr>
<tr>
<td>Unit</td>
<td>Utah</td>
<td>393</td>
<td>213</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Water Production
- 170K bbls/day
- 1 Million bbls/day

Coal-Bed-Methane Produced Waters

Average Water Composition

- **Total dissolved solids (TDS)**
  - **Fresh Water**
    - 11000 ppm
  - **Sediment**
    - 2340 ppm
  - **Groundwater**
    - 1550 ppm
- **Total dissolved solids (TDS)**
  - **Fresh Water**
    - 11000 ppm
  - **Sediment**
    - 2340 ppm
  - **Groundwater**
    - 1550 ppm

- **Other Components**
  - **Acidity**
    - 20-30 pH units
  - **Bolus**
    - 20-30 Btu units
  - **Chlorides**
    - 2-8 mg/L
  - **Sulfates**
    - 2-8 mg/L
Tar Sands

Athabaska Tar Sands (or oil sands)

Reserves: 1.7 trillion barrels (assuming 10% recovery)

Venezuelan Oil Sands:
500 billion barrels

Tar Sand Extraction method
- Open Pit Mining
- Crush
- Mix with hot water
- Bitumen floats (60% bitumen, 30% water, 10% solids)
- 1200 SCF of gas needed to process 1 bbl of bitumen (about 5x energy gain)
- Upgrading: remove water, sand, impurities, sulfur, catalytic hydrocracking, hydrogenation

Bitumen Separation Cell, Alberta
**Canadian Tar Sand Production**

- Total Production: 2,600,000 Barrels/Day
- Exports to US: 2,500,000 Barrels/Day
- Today, about half is from the Oil Sands
- #1 foreign supplier for USA

**Oil Shale**

- Kerogen-rich immature shale
- Heating the shale releases oil by pyrolysis

**Green River Shale Resource**

- 1.2 to 1.8 trillion barrels in place
- Recoverable?
- Global Resource: 2.8 to 3.3 trillion barrels

**Green River Shale- USA**

**Oil Shale Production Method**

- Mining and crushing
- Retorting
- Oil Upgrading
- Refining
- Disposal and reclamation
**Economics**
- Viable at $70 to $95/bbl in USA
- Energy Produced/Energy Used = 3 to 4
- Environmental impact is significant
- Water usage is a problem

**Stuart Oil Shale Facility, Queensland, Australia**

**In-Situ conversion (unproven)**
- Electric heaters in holes
- 2-3 years heating to 650-700 degrees C

**Methane Hydrates (Clathrates)**
- 1 mole methane for 5.75 moles water
- 1 liter hydrate = 168 liters methane at STP

**Crystal Structures**
Gas Seeps on the Seafloor

Gas Hydrate Occurrence

Resource
- Twice the amount found in all fossil fuels
- How can we produce it?