Unconventional Resources

Conventional vs. Unconventional Resources

- **Conventional:**
  - High-permeability reservoirs that can be produced by traditional methods
- **Unconventional:**
  - Low permeability reservoirs
  - Immature source rocks
  - Production of adsorbed hydrocarbons
  - Heavy oil that will not flow naturally
  - Hydrocarbons in weird forms

What are the Unconventional Resources?

- Shale Gas/Shale oil
- Tight Gas Sands
- Oil Shale
- Coal-bed Methane
- Tar sands
- Methane Hydrates (Not Producible....Yet)

Differences: Unconventional Shale Gas and Conventional Plays

- **Approach to exploration**
  - Not looking for “clean” units or “traps”
  - Different depositional environments
- **Key factors for success**
  - TOC (Total Organic Content)
  - Thermal maturity
  - “Fracability”
  - Structural simplicity
  - Drilling technology
  - Not worried about natural porosity and permeability

Petroleum Resource Triangle

- Conventional gas: **Source ≠ Reservoir**
- Shale gas: **Source = Reservoir**
A Revolution in the Industry

- Dramatic Increase in Oil and Natural Gas Production
  - Appalachian Gas Displaced Gas from the Gulf Coast
  - Midcontinent and Appalachian Liquids Displacing Imports
  - Insufficient Infrastructure
    - Pipeline Expansions and Reconfigurations
    - LNG Import to Export Conversions

- Challenges and Opportunities
  - Reduced Consumer Prices
  - Increased Business Investment
  - US: Net Exporter of Petroleum Products
  - Substitution of coal for gas in power generation
  - Decreased CO₂ Emissions

U.S. Natural Gas Production

- History
- 2013
- Projections

- Share gas and tight oil plays
- Other lower 48 provinces
- Tight gas
- Coalbed methane
- Shale
- Other offshore

U.S. CO₂ Emissions

- Source: US-DOE, EIA, February 2016
Change Brings Controversy

North America Shale Basins

Bakken Shale
(oil)

Utica

Marcellus

Barrett Shale

Eagleford

Worldwide Shale Potential

Global Unconventional Gas

<table>
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<tr>
<th>Region</th>
<th>Trueded Methane (Tcf)</th>
<th>Shale Gas (Tcf)</th>
<th>Tight Sand Gas (Tcf)</th>
<th>Total (Tcf)</th>
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Holditch and Ayers, 2009

Appalachian Basin is the biggest (so far)

Shale Gas Plays
West Virginia Gas Production

How Does Shale Produce?
- Low porosity (6%)
- Very low perm
- High TOC (5-15%)
- 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
- Gas Price

Improved Drilling Efficiency

Marcellus Horizontal Wells Through 2005

Marcellus Horizontal Wells Through 2006
Marcellus Horizontal Wells Through 2013

13,079 Wells

Marcellus Annual Production Normalized

2nd and 3rd Six Month Production

Estimation of Reserves

Jenkins 2009

The long-term evolution of Shale reservoirs was controversial

Industry Marcellus Decline Curve (2011)

This fits the $b=1$ harmonic case, but it is hard to find good data to support it.

5 - 10 BCF EUR per well are quoted for northern PA
5 BCF in West Virginia
Marcellus, Barnett and Eagleford are not all the same

Depositional Environments: Black Shale

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

Black Shale Modern Analogs: Black Sea

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.
Shell break at A and B.

Key Data Resources: Sahle Unconventional Plays
- GeoChem
  - TOC data is essential
- Thermal maturity
- Log Data
- 3D Seismic
  - For optimal well design to avoid structural complexity

Surface to Sub-Surface
- GR Density PE Deep Resistivity
- Marcellus Shale
- Marcellus Interval Gross Thickness
Drilling Depth to Base Marcellus

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

Spectral Gamma Ray Analysis
Oxidation

Spectral Gamma Ray Calibration Curve

Estimating TOC from logs
Shale composition

- High quartz favors fracking
- High TOC favors microporosity

Regional Mapping of TOC

Organic Rich Marcellus at 15 ppm U

Qualities of the Marcellus:
- High TOC 5-15%
- Very brittle (i.e., fracable)
- Relatively shallow
- Wide extent
- Possibly 4,359 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

Utica/Point Pleasant Shale Stratigraphy

- Late middle to early upper Ordovician
- 1,000 to 5,000' below Marcellus
- Organic rich marl (shaley limestone)

Utica: Regional source

Utica Point Pleasant - source rock for lower Paleozoic petroleum system
Organic Matter Map
- Organic-rich depocenter broadens
- Highest organics to southeast

Utica Organic Matter Map

Oils Content and Percent Liquids
- Thermal Maturity determines oil content
- Best Production from Condensate Belt
- Oil is too viscous to be produced

Bakken Shale- Williston Basin
- Antelope Field 1953, 90 vertical wells, produced 46 million BO from Sanish reservoir (under the Bakken)
- Horizontal drilling and fracking started in 2000
- Now ~3.6 billion barrels of oil (recoverable) USGS estimate
  - Porosity 5%
  - Perm 0.05 milli Darcy
  - Recovery Factor 1-5%
  - 41 API gravity oil
  - Daily production ~ 800,000 BO per day

Bakken Shale, Williston Basin, North Dakota

Modeled TOC Curves
- Both models close fit
- ΔLogR model on well by well basin
- Resistivity varies with LOM

Zazimovsky, 2012
Production is best along structural highs:
- Nesson Anticline
- Margins of the basin

The Bakken is not really a shale play
Wells produce from the Middle Bakken

Price sensitivity of drilling
Well Efficiency

Take Home Points
- Unconventional resources are not focused on traps and high permeability reservoirs
- For shale gas, the keys elements are thickness of high TOC rock, thermal maturity, good response to fracking
- Shale gas plays cover very large areas
- Thermal maturity determines the area of the basin that is productive
- Bakken produces light oil from a tight reservoir sandwiched in the shale
- Production from Shale Reservoirs has changed to global energy outlook