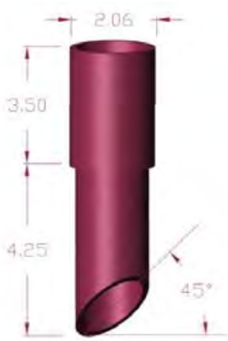
Shale Gas

By David Simpson, PE



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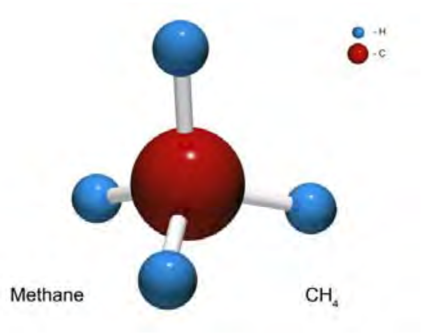
What is Unconventional Gas?

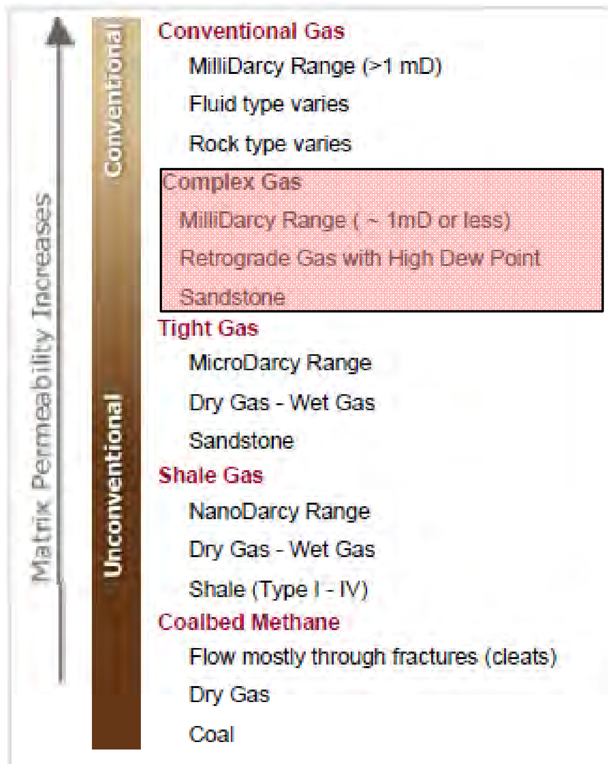
- Unconventional gas is the stuff that the industry tended to skip over when there was anything else to recover
- It requires non-oilfield techniques to exploit
- It is often very expensive to develop and produce
- So far it is primarily:
  - Tight gas
  - CBM
  - Shale Gas
- But hydrate mining, and land fill gas will eventually fit into this category

Courtesy of CSM: Ocean hydrates at the Barkley Canyon off the coast from Vancouver, CANADA.

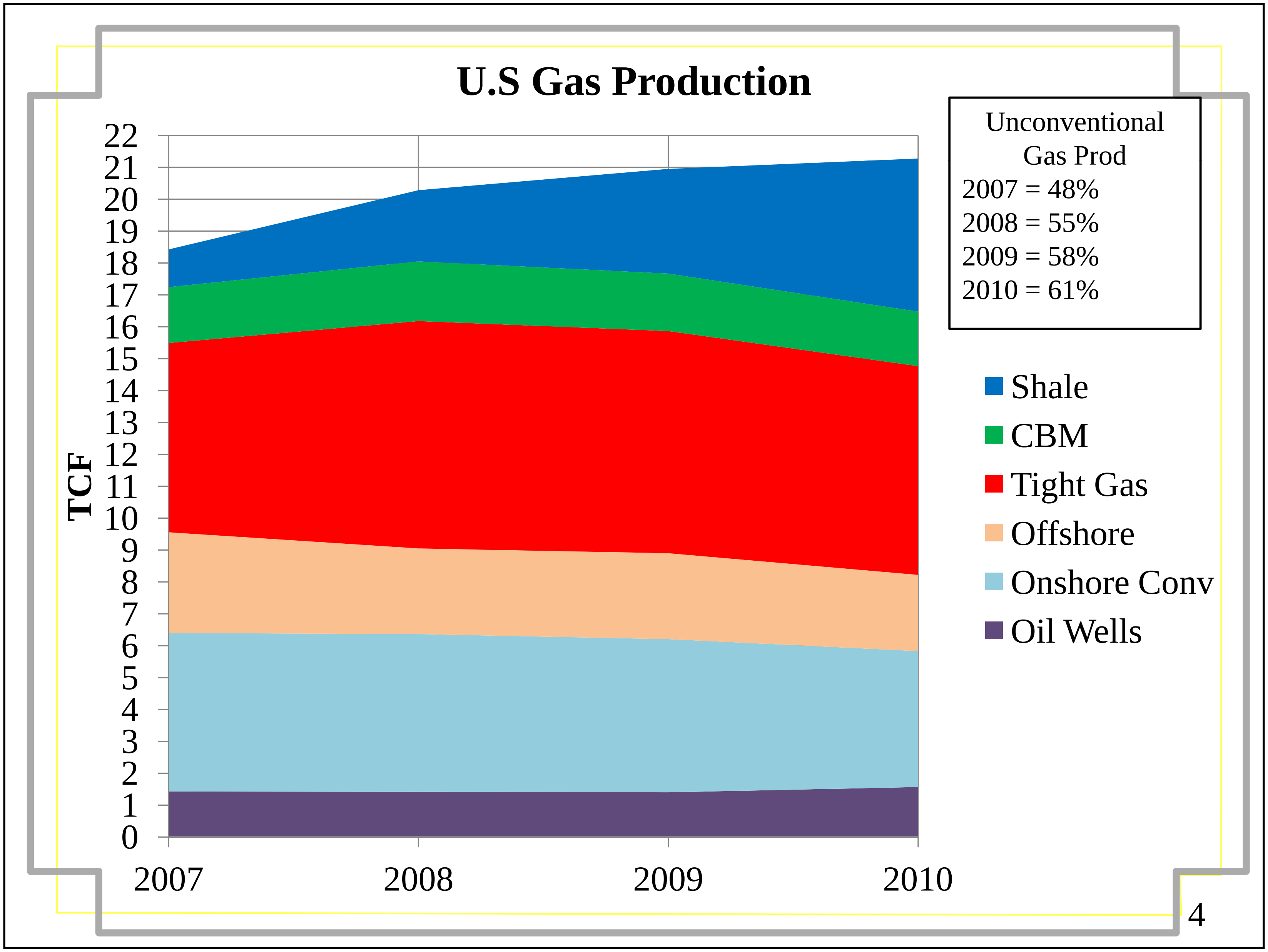


Gas Reservoir Continuum

- The lines are not very clear between the various kinds of gas production
- Halliburton breaks the continuum down into five types of gas by adding a "Complex Gas" between "Conventional Gas" and "Tight Gas"
  - This extra category helps to differentiate where Conventional Gas ends and Unconventional Begins
  - Complex gas is reasonably rare and quite difficult to produce
  - Complex gas performance is predictable with the application of extraordinary techniques



Courtesy of Halliburton Inc.


U.S Gas Production
TCF
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2007
2008
2009
2010
Unconventional Gas Prod
2007 = 48%
2008 = 55%
2009 = 58%
2010 = 61%
Shale
CBM
Tight Gas
Offshore
Onshore Conv
Oil Wells
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Top 10 US Fields in 2009

(Ranked by 2009 Production)

Basin	Type Reservoir	State	2009 Production (BCF/day)
Newark East	Shale Gas (Barnett)	TX	4.913
San Juan Basin	71% Coal, 29% Tight	NM/CO	3.546
Powder River Basin	CBM	WY/MT	1.530
Fayetteville Shale	Shale	AR	1.415
Pinedale	Conventional	WY	1.336
Jonah	Tight Gas	WY	1.071
Hugoton	Tight Gas	KS/OK/TX	0.898
Carthage	Tight Gas	TX	0.747
Natural Buttes	CBM	UT	0.614
Haynesville	Shale	LA	0.558

Data from EIA 2009 Top 10 Fields Report

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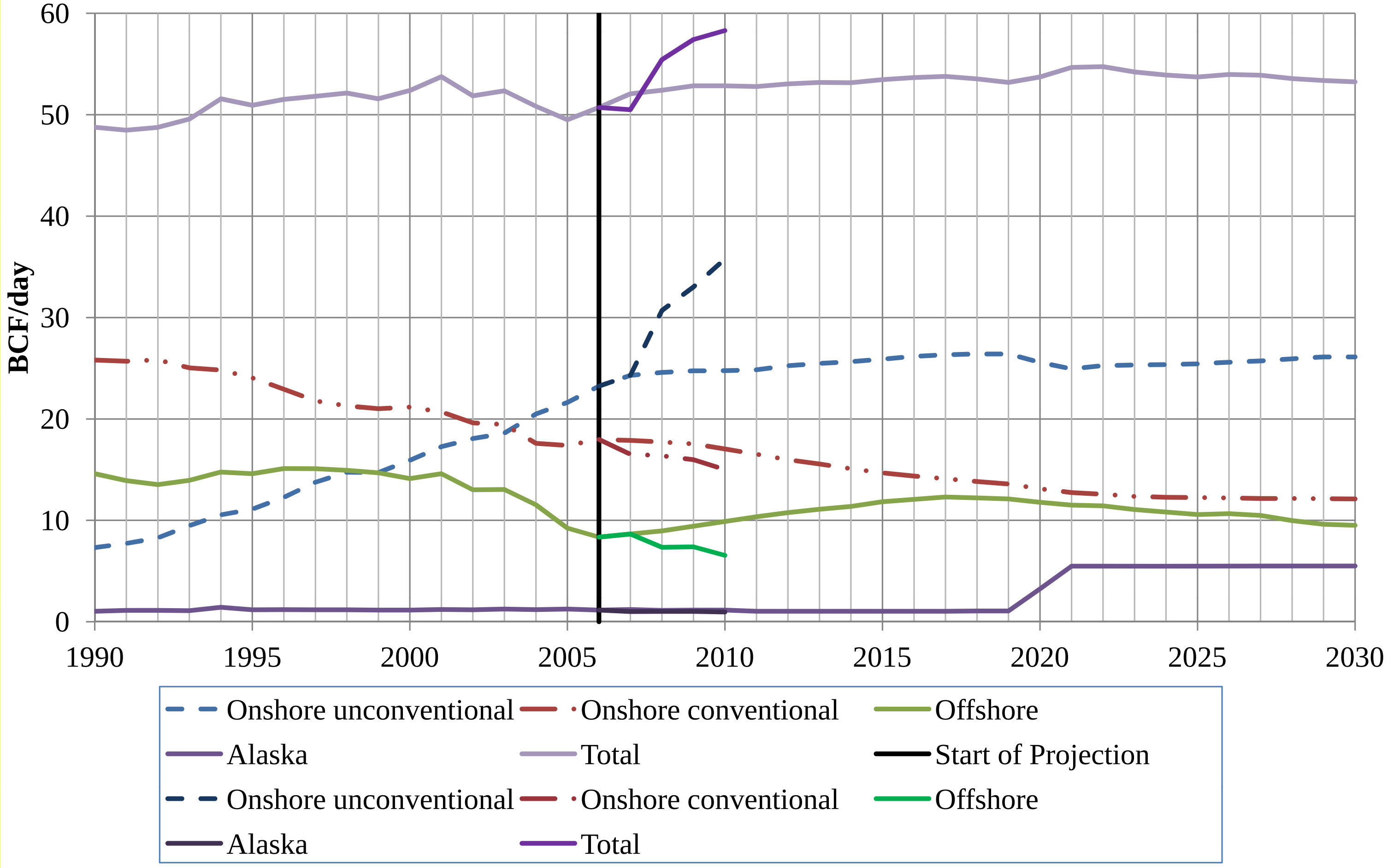
U.S. Natural Gas Production



Source: EIA 2008 Energy Outlook

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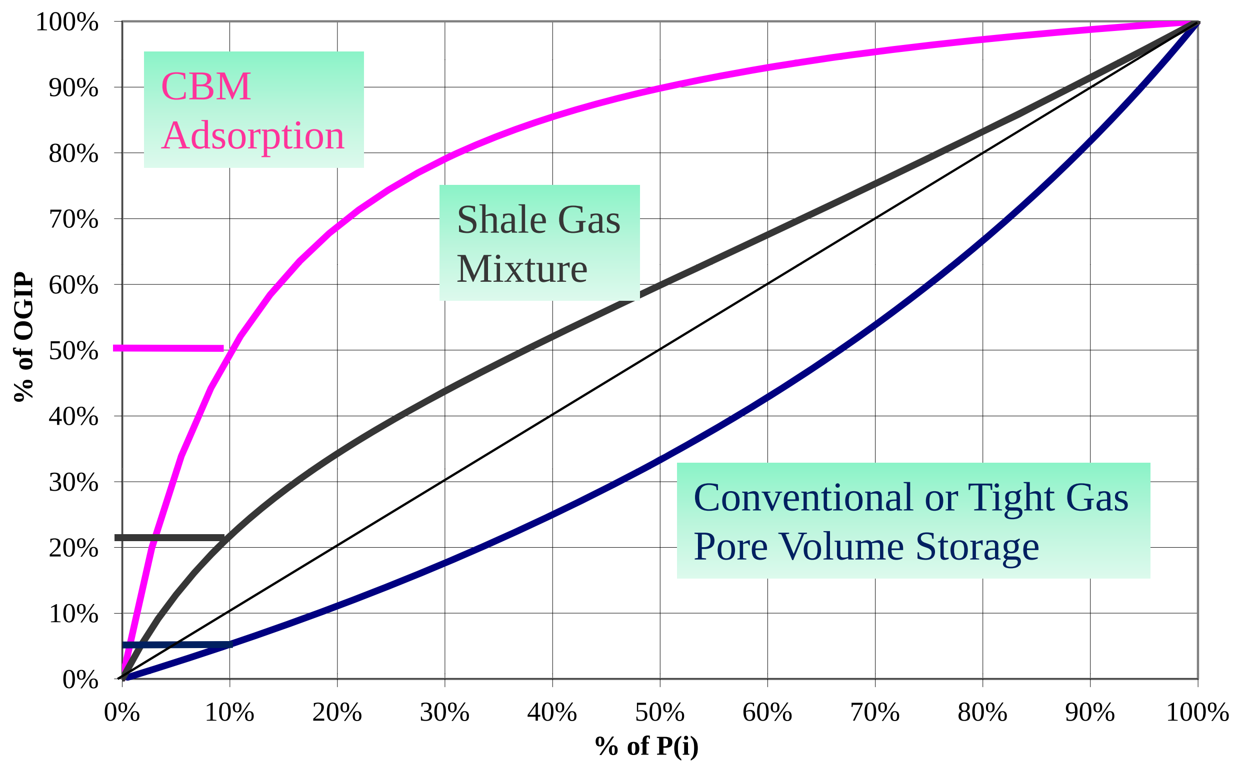
Reservoir Pressure vs. OGIP



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Key Points

	Tight Gas	Shale	CBM
Gas content (SCF/ton)	N/A	50-400	300-1,000
Storage mechanism	Pore Volume	Mixed	Adsorption
Ultimate Recovery	30% of OGIP	70% of OGIP	95+% of OGIP
Flow Method	Darcy	Channel	Channel
Permeability	10 µD-1 mD	<10 nD to 10 µD	<10 nD
Porosity	0.5-10%	0.1-4%	<0.1%
Response to low pressure	Minimal	Good	Excellent
Liquid Hydrocarbons	Some	Occasional	None
Water production	Low	Variable	Variable
Water Quality	Tends to be poor	Variable	Variable
Price to develop	$0.80/MCF	$6.84/MCF	$2.00/MCF

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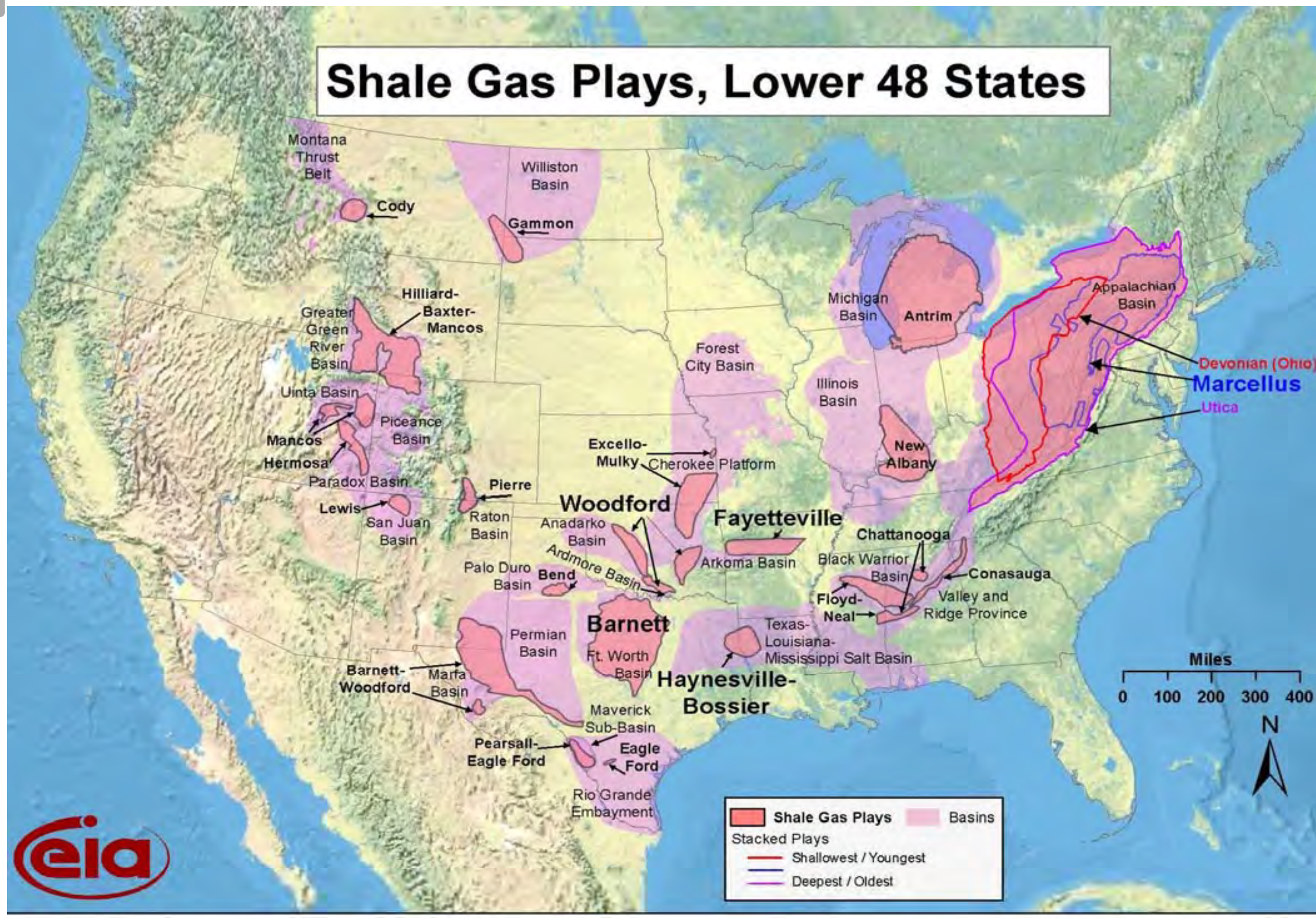

Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

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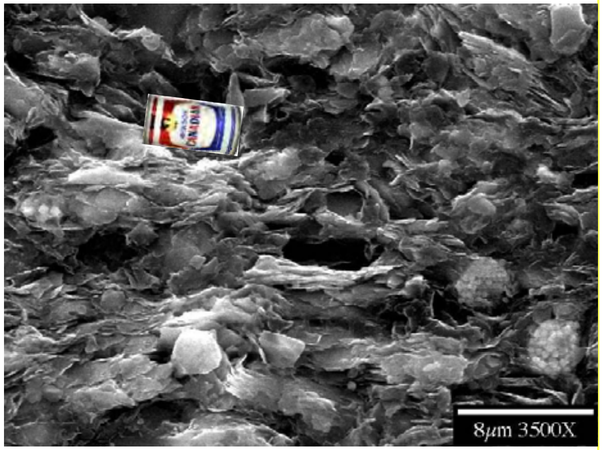
Shale Gas Introduction

- The first commercial well in the U.S. was a Gas Shale well in Fredonia, New York in 1821 (30 years before the first oil well in Pennsylvania)
  - 27 ft deep in Devonian Shale
  - D'Arcy flow was so slow that the output was only suitable for gas lights
  - Water production could be ignored (flow rate so low little water moved)
- Photomicrograph shows sand, quartz, organic material (peat, coal, etc.), beer cans(?)



Shale Gas Introduction

- Gas from Shale is a mixture
  - Thermogenic gas (gas from breaking down organic material under high temperature and high pressure) which can start as oil and heavy gases and ends up as methane
  - Biogenic gas (gas from biological processes that has not been modified by heat and pressure) tends to be primarily methane
- The more mature the reservoir, the larger percentage of methane
- Important Producing Areas
  - Antrim Shale in Michigan (first prod 1965) produces nearly 400 MMCF/d
  - Barnett Shale in Texas (1981) produces 3 BCF/d
  - Fayetteville Shale in Arkansas (2004) produces 250 MMCF/d
  - Marcellus Shale covers 95,000 square miles and has an OGIP around 550 TCF. No significant production as of 2008

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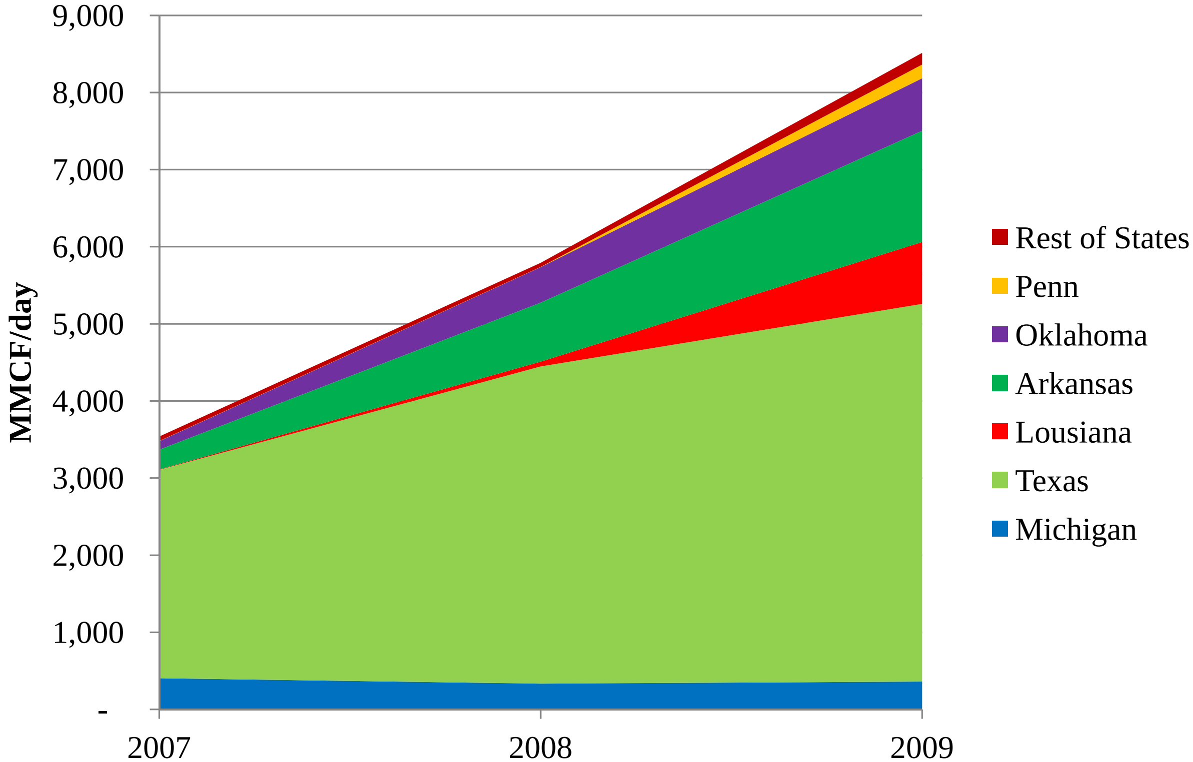
U.S. Shale Gas Production



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Shale Gas Key Issues

- Without fracture stimulation, flow through pore throats is very slow (<10nD-10 μD permeability)
- Gas storage:
  - Some gas is stored in Pore Volume (largest component at discovery)
  - Some gas is adsorbed to the matrix (largest component late in life)
  - Some gas is stored in the natural fractures (smallest component)
- Mechanical strength of Shale considerably higher than CBM so:
  - Horizontal wells are less risky, and
  - Proppant is much more effective
- Shale Gas is a technology play:
  - Wasn't exciting until high-accuracy horizontal drilling was possible
  - Production requires massive hydraulic fracture stimulation

Shale Key Issues

- Shale tends to be very thick
  - 100-300 ft minimum to be productive
  - Some wells in the Barnett have over 1,000 ft of shale
  - Thickness suggests very long well lives (50-75 years is predicted for Horn River and Marcellus)
- Gas Shale tends to be quite variable from basin to basin
  - Antrim Shale has 30 SCF/ton and acts like a tight gas field
  - Barnett Shale has 300 SCF/ton and acts like a CBM field
  - Shallow shales (800-3,000 ft) have water rates and quality much like CBM
  - Deep shales (2,500-8,000 ft) tend to have much poorer quality water and it can sometimes be excessive (1,000 bbl/day of 150,000 mg/L TDS is common in the Barnett when fraced into Ellenburger)

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Shale Reservoirs

- Applying the Conventional Reservoir definitions to Shale Gas:
  - Source rock—Shale is rich in organic matter and meets the definition
  - Reservoir rock—Shale has a significant void volume and meets the definition
  - Cap rock—the Shale matrix is very resistant to gas flows and meets the definition
- Gas Storage
  - Significant gas in a Shale reservoir is in the void space ($PV=ZnRT$ for that part)
  - Much of the gas is part of the solid and does not follow the gas laws (i.e., $PV \neq ZnRT$)
- Pressure
  - Gas in the void space flows like conventional gas (push to wellbore)
  - Gas on the organic material flows like CBM (pull from wellbore)
- Matrix permeability is very low
- Porosity is low
- Isotherm, like everything else, is a mixture

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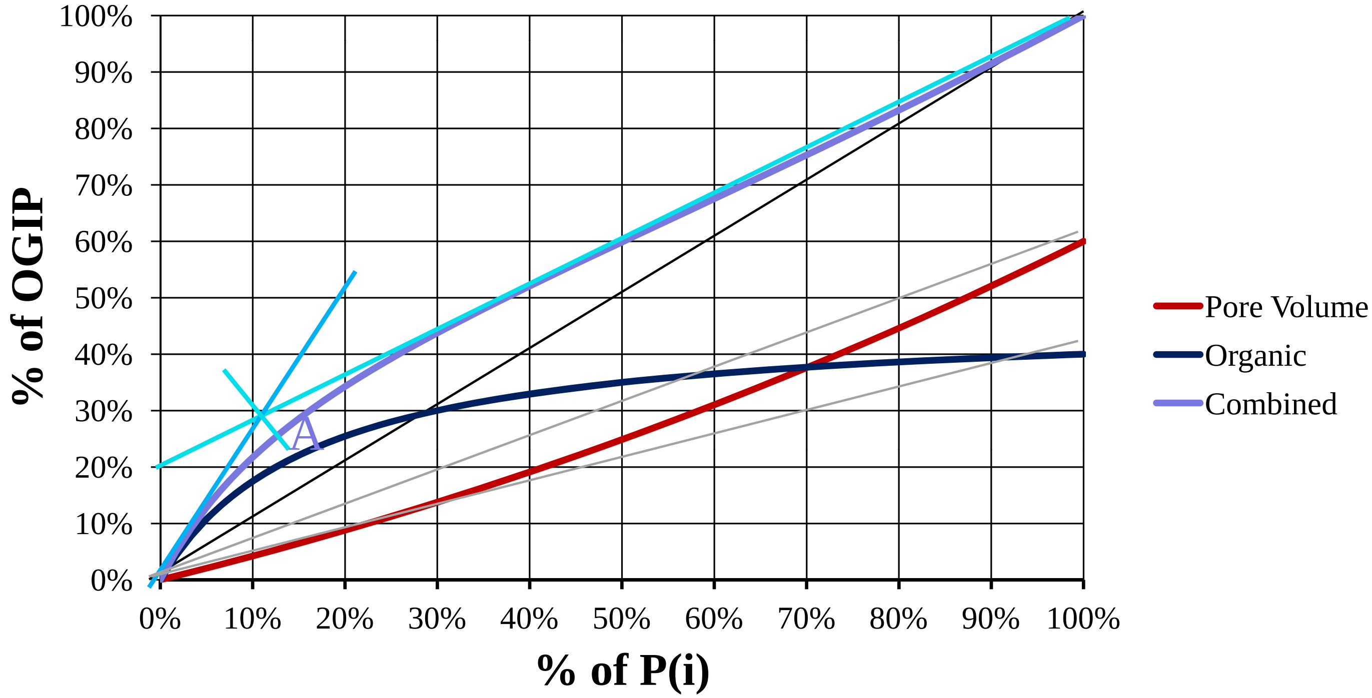
Shale Gas Storage



Shale Ultimate Recovery

- EIA estimates less than 20% of OGIP is recoverable
  - This is the same value they assigned to CBM in 1991
  - It will certainly be revised upwards over time
- It is difficult to predict well-response to deliquification and pressure reduction, but:
  - Wells with high organic content should act like CBM wells earlier in their life, and low pressures should recover a very large percentage of OGIP
  - Wells with lower organic content should act like tight gas wells until much later in their life—they respond to a steady pressure, and if you can minimize variability you should be able to get above 60% of OGIP

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Active Shale Plays

Play	Country	GIP (TCF)	Organic Content (SCF/ton)	Depth (ft)	Expected rates (MCF/d)
Antrim	USA	76	30	600-2200	200
Barnett	USA	327	300	6500-8500	350
Fayetteville Shale	USA	52	150	1500-6500	550
Horn River Basin	Canada	500	450	8000-10000	5,000+
Marcellus	USA	550	90	4000-8500	3,000
Utica Shale	Canada	40	65	6000-9000	700

Potential Shale Plays

Play	Country	GIP (TCF)	Primary Developer
Lower Saxony	Germany	30	ExxonMobil
Makó Trough	Hungary	40	ExxonMobil
Baltic Basin	Poland	700	ConocoPhillips
Alum Shale	Sweden	60	Shell Oil
Weald Basin	England		Eurenergy Resource
Horton Bluff	Canada		Triangle Petroleum
South China Basin	China		Shell & Petro China
Dnieper-Donents Basin	Ukraine		
Gambay Basin	India		
Vienna Basin	Austria	240	OMV

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Shale Specific Challenges

- Abrasive solids
- Water Acquisition
- Infrastructure

Abrasive Solids

- Both the nature of the Shale and the massive hydraulic fractures in the shale contribute to abrasive solids getting to surface
  - Frac sand production tends to taper off with time
  - Formation solids tend to be smaller volumes that are manageable
- Sands can
  - Cut pipes
  - Damage valve internals
  - Prevent flow through dump valves and other nozzles
- Options
  - Downhole options (screens, frac pack, gravel pack etc.)
  - Basket strainers on surface (need to be around 4 micron)
  - Separators (need cleanout ports)
- Should try to reduce damage prior to removal point (e.g., if strainer on surface, then use hot bends instead of fittings)

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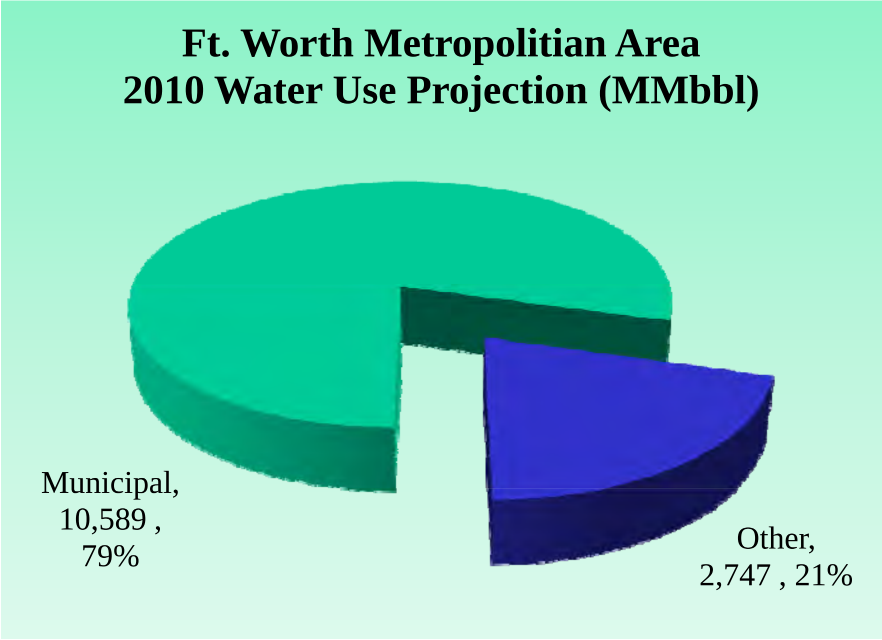
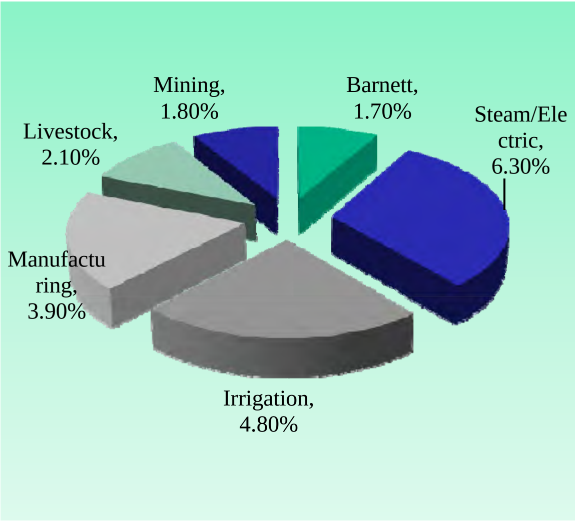
Example Water Usage





Source: Gas Technology Institute 4/2007

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Water Acquisition

- A slickwater frac can take as much a 250,000 bbl of water
- Removing water from a water supply for several wells in a short period can cause disruption in municipal availability or river flow
- Start with relatively pure water, then add up to one half percent of the volume in chemicals (friction reducers, biocides, scale inhibiters, etc)
- Techniques to minimize water supply disruption include
  - Stockpiling water during wet periods
  - Treating and reusing flow-back water
- It is always appropriate to try to work with local jurisdictions to minimize impacts of water acquisition

Source: Oil & Natural Gas Technology Report
Argonne National Laboratory

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Infrastructure

- Shale Gas development is happening in places that have not historically had natural gas production
- This creates barriers to development
  - Pipelines can take years to permit and build
  - Plants and compressor stations can be very difficult to permit in places where Oil & Gas operations are new
  - States without a tradition of Oil & Gas will often try to apply regulations from other industries that can be unreasonably restrictive
  - Water management infrastructure causes regulators considerable difficulty
- All of the barriers can be overcome, but it often requires significant time, money, and public-relations effort

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Shale Gas Conclusion

- Shale Gas development is in its early stages
  - We don't know how the wells will respond over time
  - We don't know how the water rates will change with time
  - We don't have a clear strategy for what pressures will be required over time
  - We don't know how we are going to do mid-life and late-life deliquification
- Some of this information may require 30-50 years to develop
- Beware of the idea that you can design your Shale Gas field once and facilities will last forever—we will make about the same number of mistakes in Shale as we made in CBM, but hopefully they will be different mistakes

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Thank you for your attention.
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