A Review of Three North American Shale Plays: Learnings from Shale Gas Exploration in the Americas*

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Key Comments

- Shale Gas in North Americas has caused a paradigm shift.
- Shale Gas is very different from conventional gas plays.
- Shale Gas production tends to fall dramatically and then produce for tens of years.
- **Shale Gas plays are all different.**
- Most shale plays have a “sweet spot.”
- Resource classifications matter.
- Evaluation techniques are evolving.
- Economics vary.
- Break-even price for Shale Gas currently varies between US$4 and $10 plus / mcf.
- Well costs vary depending on the play.
- LNG is a big driver in worldwide gas pricing.
- The future price of gas is a major unknown.
- Land access in populated areas is challenging.
- Environmental issues are key everywhere.
- North America Shale Gas exploitation is leading the way.
- There are numerous Shale Gas opportunities outside the Americas.
- Many lessons are still to be learned.

References

DOE NETL, 2011, A Comparative Study of the Mississippian Barnett Shale, Fort Worth Basin, and Devonian Marcellus Shale, Appalachian Basin: The Energy Lab DOE/NETL-2011/1478. Web accessed 20 May 2012. http://www.netl.doe.gov/technologies/oil-gas/publications/brochures/DOE-NETL-2011-1478%20Marcellus-Barnett.PDF

EIA, 2011, Review of emerging resources: U.S. shale gas and shale oil plays: Analysis & Projections: EIA, July 8, 2011. Web accessed 20 May 2012. http://www.eia.gov/analysis/studies/usshalegas/

EIA AEO, 2012, AEO2012 Early Release Overview: Web accessed 20 May 2012. http://www.eia.gov/forecasts/aeo/er/executive_summary.cfm

Kuskraa, V., S. Stevens, T. Van Leeuwen, and K. Moodhe, 2011, World shale gas resources: An initial assessment of 14 regions outside the United States: Advanced Resources International, Inc. (ARI) / U.S. Energy Information Administration (EIA), 353 p. Web accessed 20 May 2012. http://www.adv-res.com/unconventional-resources-news-events.asp

Wrightstone, G., 2008, Marcellus Shale: Geologic controls on production: Presentation at AAPG Eastern Section Meeting, October 14, 2008. Web accessed 20 May 2012. http://www.papgrocks.org/wrightstone_p.pdf

A Review of Three North American Shale Plays

Learnings from Shale Gas Exploration in the Americas

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Content

- Why is Shale Gas Important?
- What has shale gas exploration brought to the Americas?
- What are the most important characteristics of a shale gas play?
- Let’s look at three of these plays
  - Barnett
  - Eagle Ford
  - Marcellus
- What have we learned?

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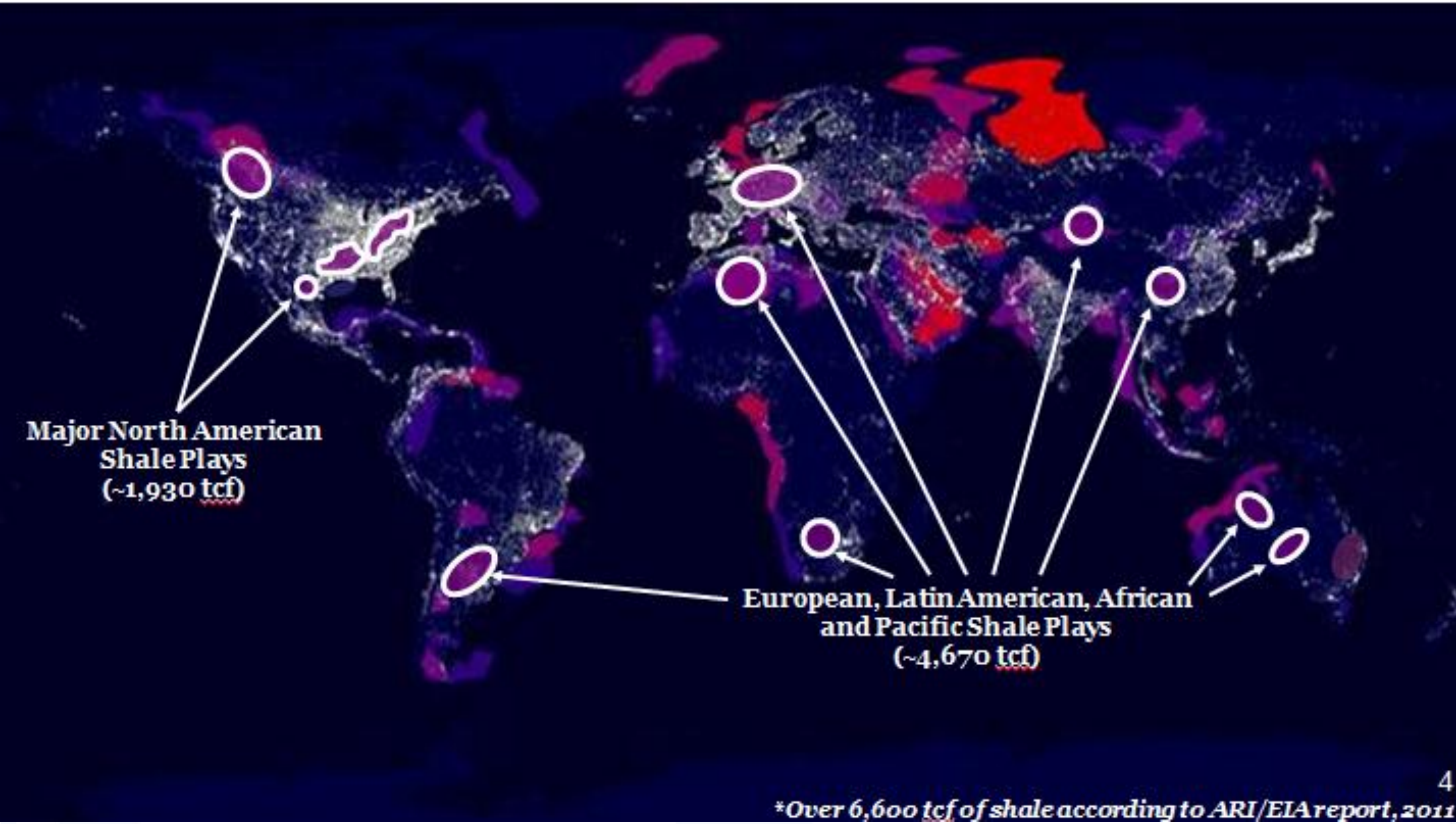
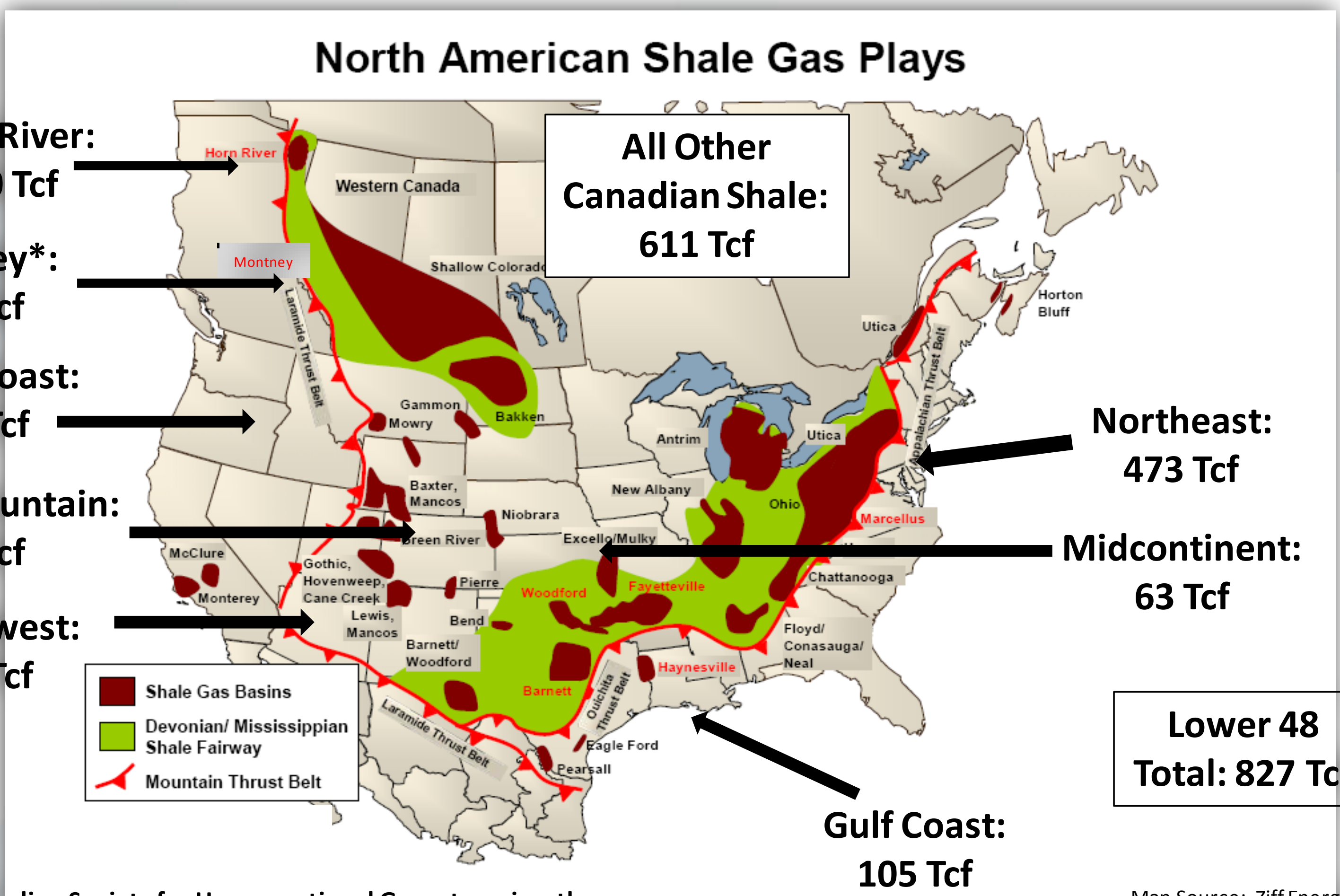
Why is shale gas important?

Do we want to keep the lights on?



So what has been found thus far?

The values stated are rough in-place estimates



Horn River: 500 Tcf

Montney*: 500 Tcf

West Coast: 41 Tcf

Rocky Mountain: 58 Tcf

Southwest: 87 Tcf

All Other Canadian Shale: 611 Tcf

Northeast: 473 Tcf

Midcontinent: 63 Tcf

Gulf Coast: 105 Tcf

Lower 48 Total: 827 Tcf

***Note: The Canadian Society for Unconventional Gas categorizes the Montney play as tight sands rather than shale gas.**

Map Source: Ziff Energy Group
US Shale Resources Estimates: EIA, 2011
Canadian Shale Resource Estimates: Canadian Society for Unconventional Gas, 2010

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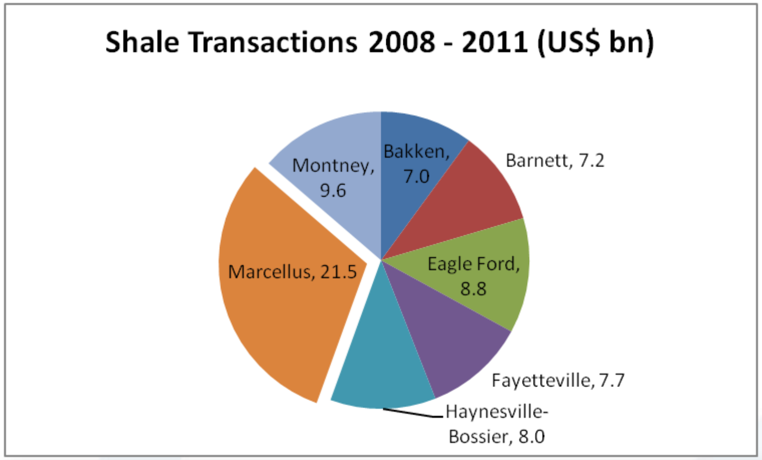
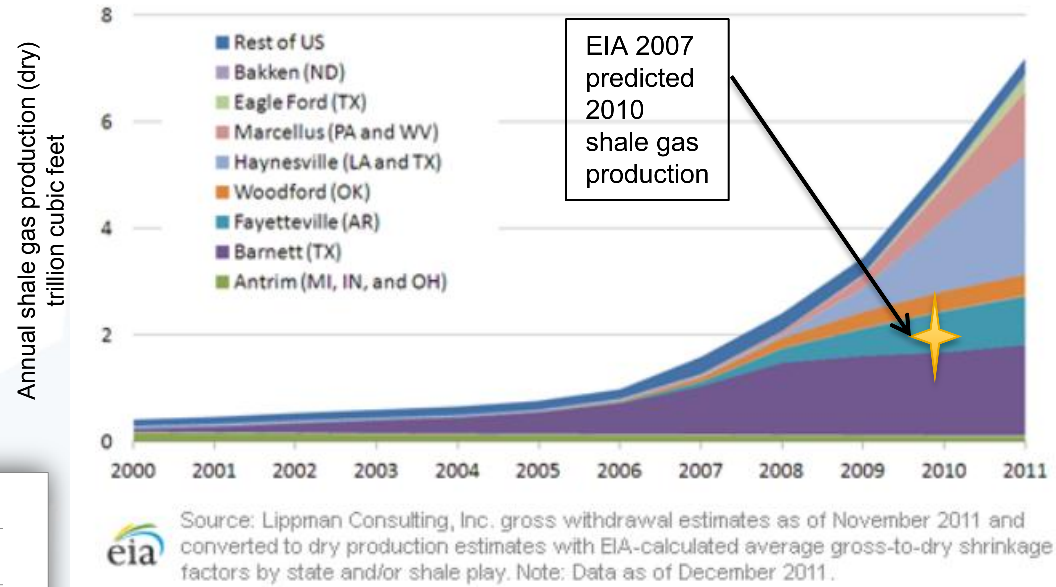
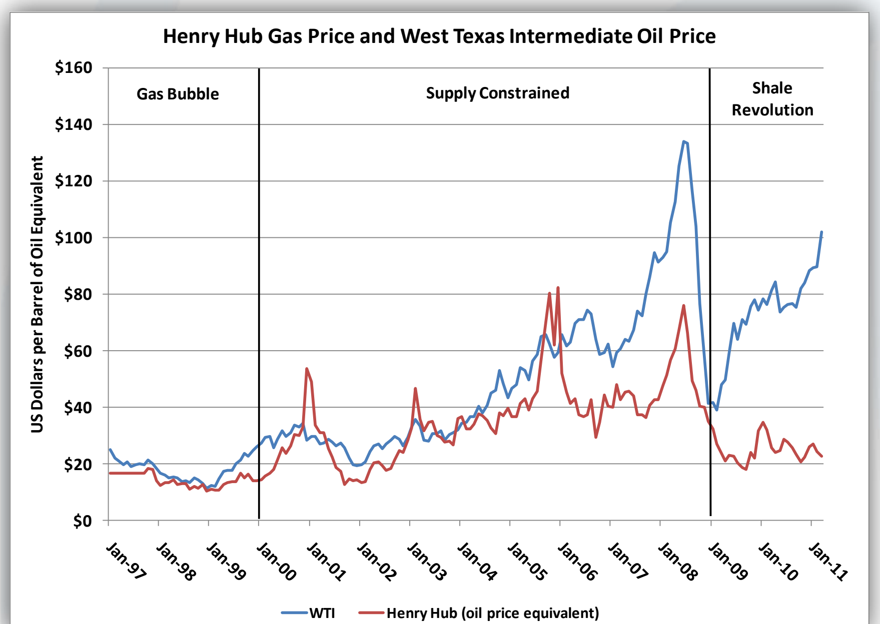
Has shale gas made any difference?







Since 2000, U.S. shale gas production has increased 17 – fold and now comprises ~ 30% of total U.S. dry gas production

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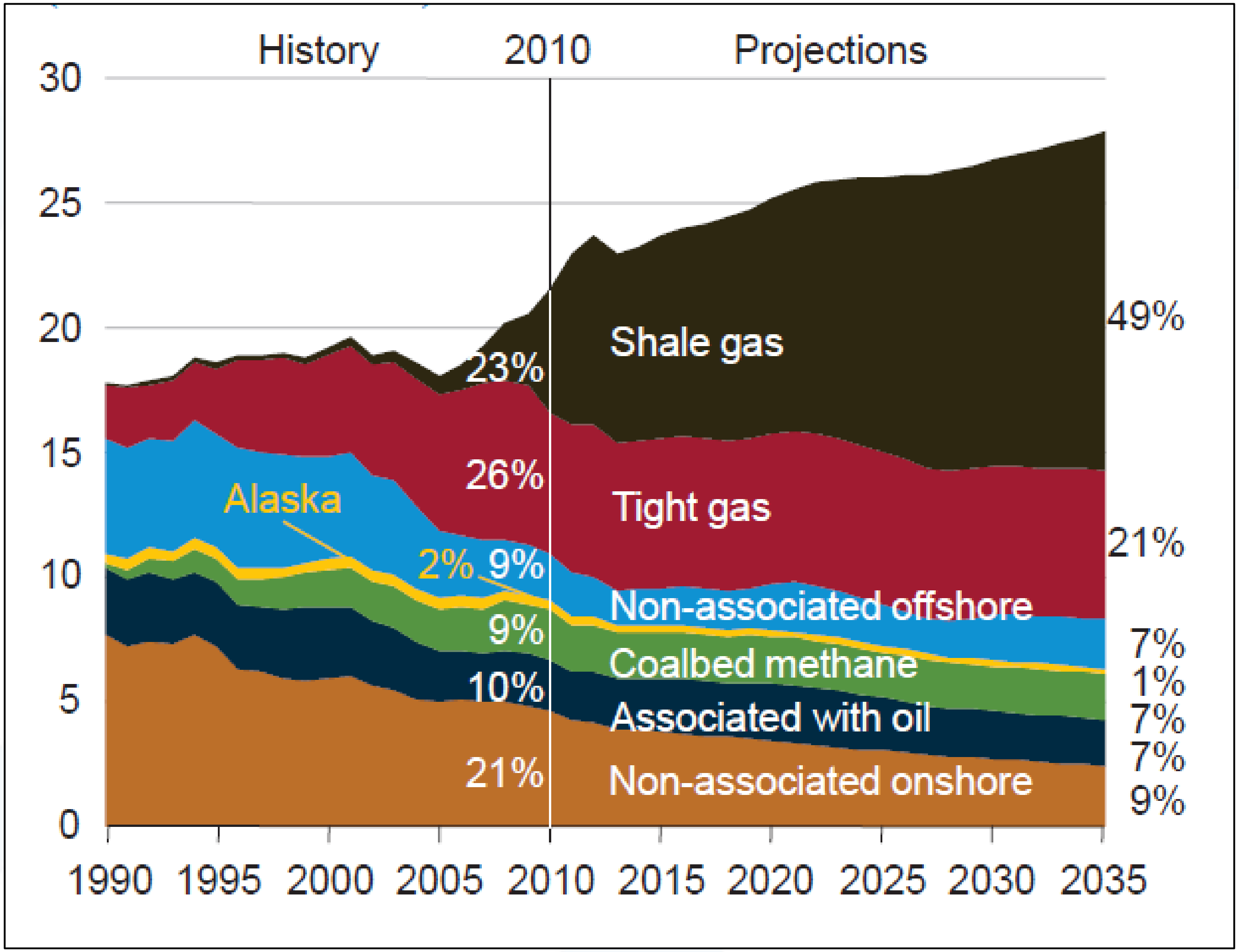
US Natural Gas Production by source, 1990 – 2035 (tcf)

shale gas has transformed the US from an expected importer to a possible exporter of natural gas



EIA AEO2012 Early Release

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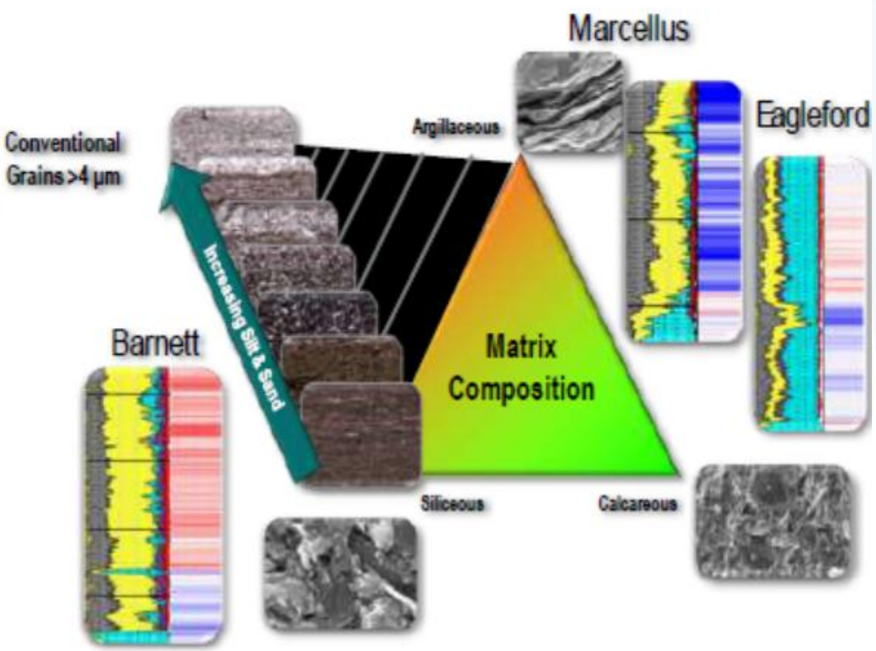
Shales are all different

Even in the same basin, shales vary and a fundamental understanding of each resource is needed

- All shales are different and complex
- Understanding of both reservoir quality and completion quality is critical
- Achieving efficiencies in all aspects of development is needed for success
- Technology requirements vary across plays
- Application of appropriate technology leads to improved production, improved efficiencies, and ultimately improved economic results



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So if they are all different what matters?

Criteria for technically evaluating shale gas plays....

PARAMETER	OPTIMAL TARGET
Source Rock Quality	TOC 2-5+% by weight Minimum 15-20 m thick with high TOC levels Typically Type II/III Kerogen, Porosity 3-6+%, 400 nanodarcy permeability
Source Maturity	Ro >1.4 for dry gas Ro 1.1-1.4 for wet gas Ro 0.6-1.1 for oil (higher risk of ductile rock) Hydrocarbon Index HI = 1.0 (S2*100)/TOC T Max 450+ Deg C
Gas Quality	Ideally <2% CO_2, <5% N2, no H_2S
Structural Complexity	Monocline <5 Deg dip, simple structural architecture – minimal faults, folds
Timing of Burial/uplift	Ideally at peak maturity present day, no inversion & uplift-induced fractures of top seal
Clay content/ brittle index	<40% Vclay (XRD analysis), direct measurement of brittle index required
Presence of water-filled aquifers	Separated from target source intervals by ductile barriers
Geomechanics (stress regime)	Knowledge required for orientation of laterals and subsequent frac orientation
Pore pressure	Pressure gradient from 1.75 to 2.5 psi/m (0.55-0.75 psi/ft) Knowledge required to select frac fluids and proppants

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What else matters?
It is more than the geology to make a shale gas play work

- Environment
  - These are long-term projects that will have a major environmental impact
    - Being a good neighbor is important
- Requires a large source of available water
- Requires a large quantity of proppant
- Infrastructure
  - Both roads for exploitation activity and pipelines for egress
- Manpower and equipment
  - Requires a large number of trained personnel and a large amount of very specialized equipment
- Community/Government support
  - Long-term project requires acceptance by community

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So what does it look like?

A review of three North American Shale Gas plays

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Location map Cretaceous Eagle Ford, Mississippian Barnett and Devonian Marcellus shales

DOE NETL-1478 paper

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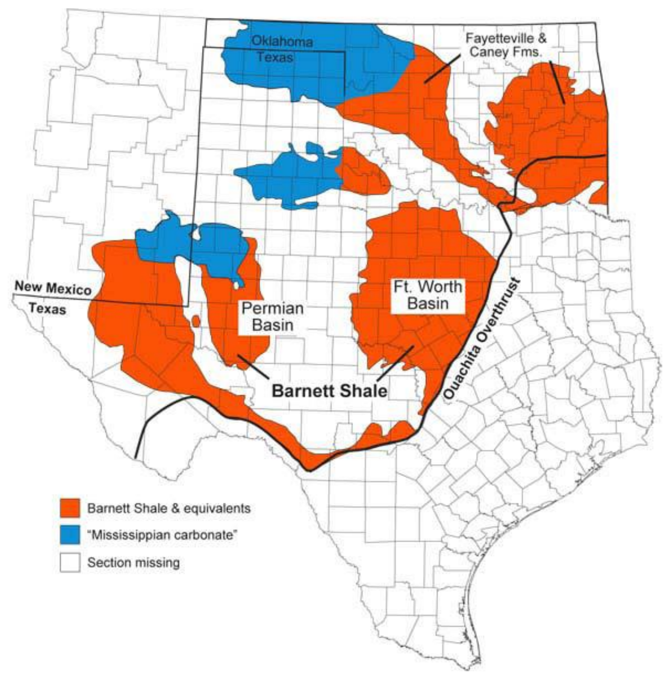
Texas Barnett Shale - History

- Proven area for finding gas
- First commercial shale gas well in US: 1821
- First Barnett Shale well: 1981
- Fracing with high press. water + sand: 1980s
- Drilling activity increased with higher gas prices: 1990s
- Horizontal drilling combined with multiple fractures: 2000s
- Gas price challenging development opportunities in 2009
- Well / production statistics
  - 65% of gas produced in 1st year
  - 80% of gas produced in 1st two years
  - Need to keep drilling more wells
- Reservoir / development risks:
  - Deliverability: Low trapped gas content or lack of natural fractures
  - Project economics



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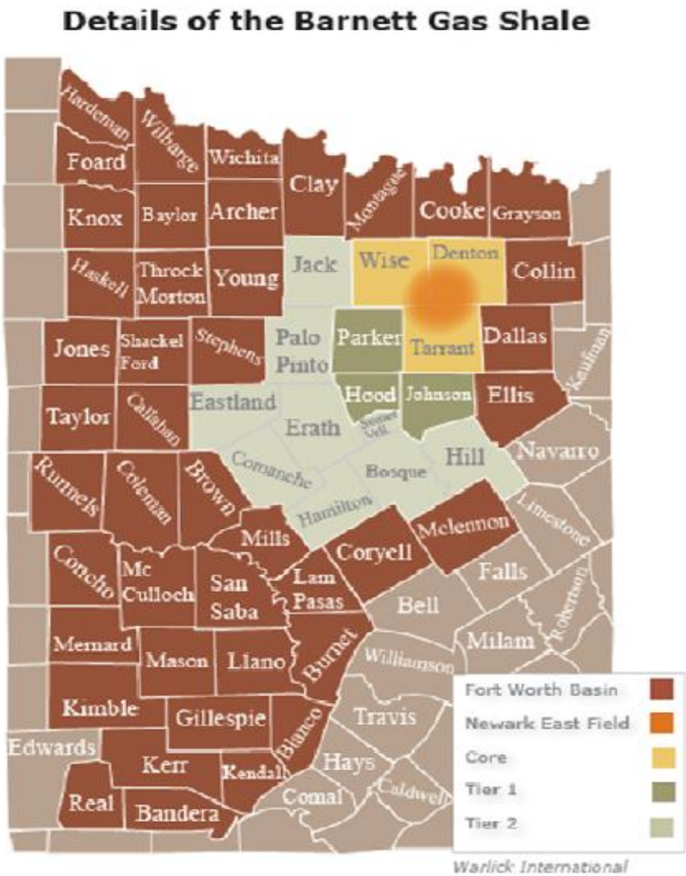

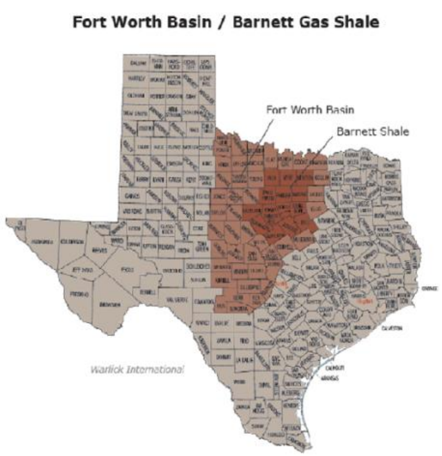

Barnett Shale

- Late Mississippian age (Paleozoic Era)
- Basin Area = 5,400 mi² (~14,000 km2)
- Reported recoverable volumes = 44 Tcf
- Depth = 6,500 – 8,500 ft
- Thickness – 100 – 600 ft (~30-200 m)
- Avg. Well IP = 4.0 MMcfd
- Lateral lengths = 3,500 – 5,000 ft
- Largest onshore gas shale basin in the world and largest gas field in Texas

Proving ground for shale gas technology
First place for slick water fracs, multistage horizontals, Refracs
Water hazard - Ellenburger

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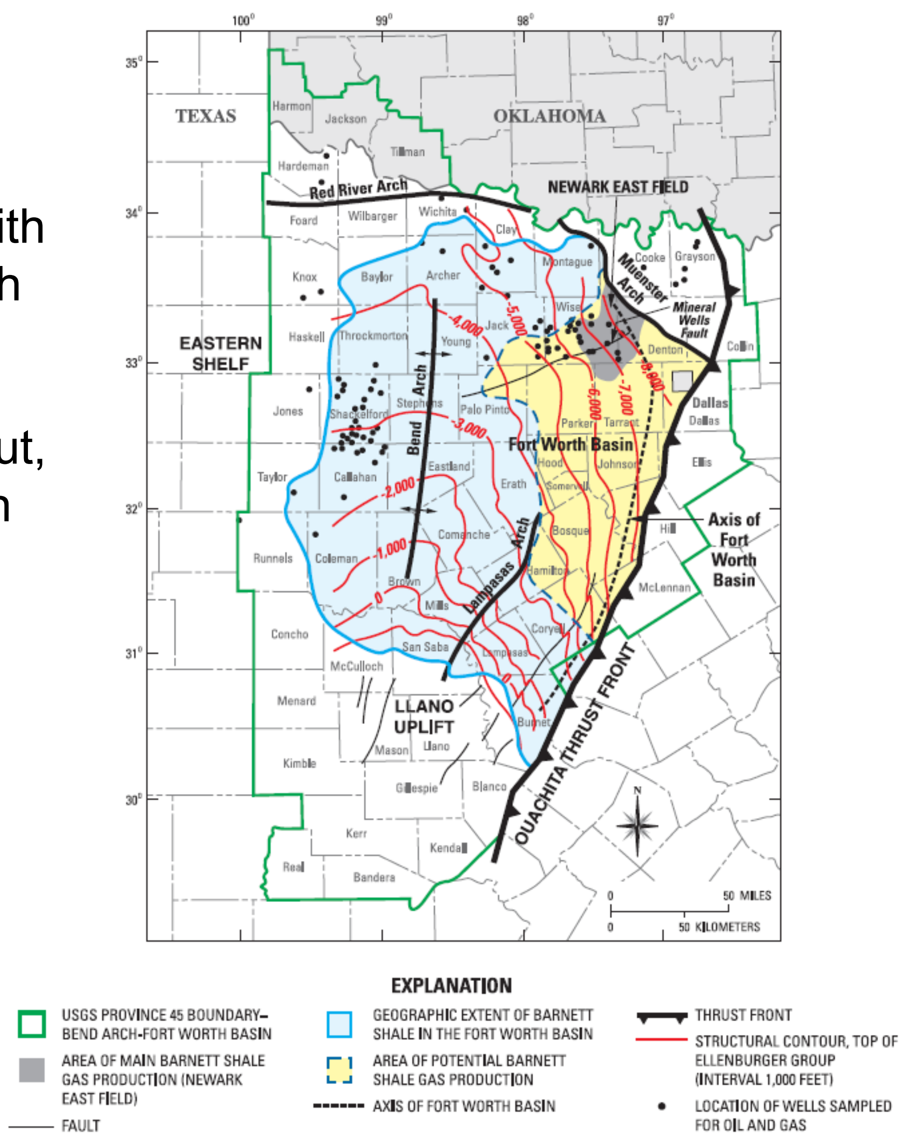
Gentle monoclinal north dip in a forearc position

- No structural trap required
- “Sweet spot” associated with Ro which is associated with depth of burial
- Entire area is productive but, some areas are better than others



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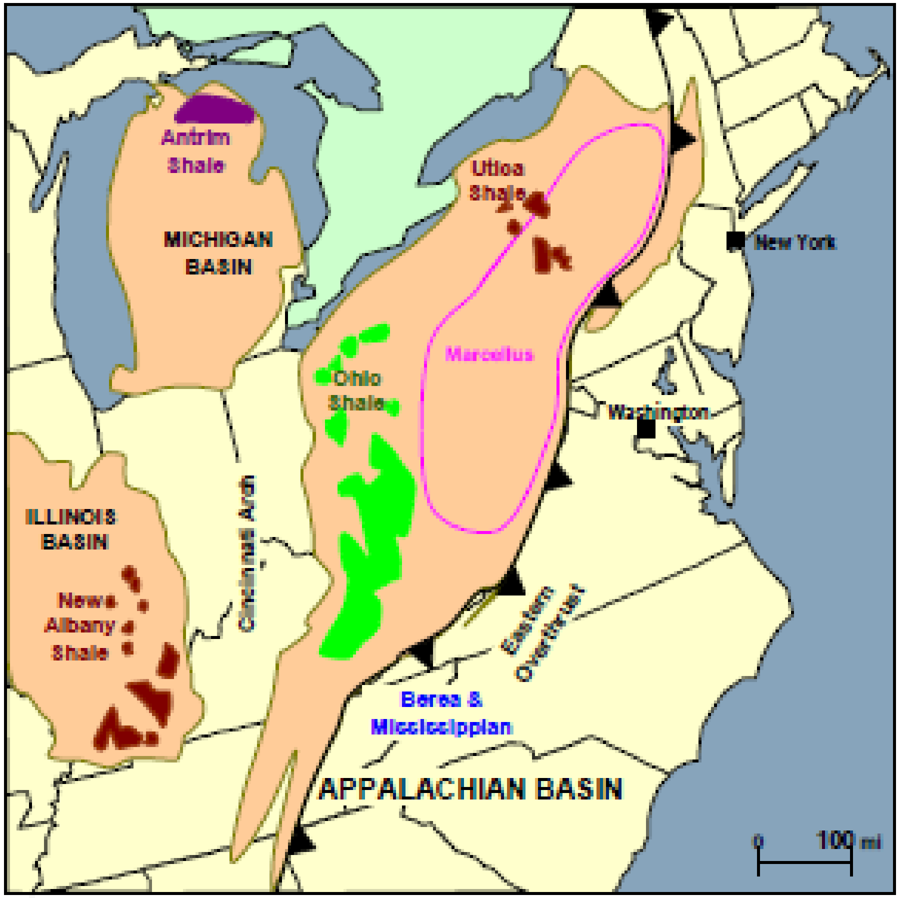
Marcellus Location Map



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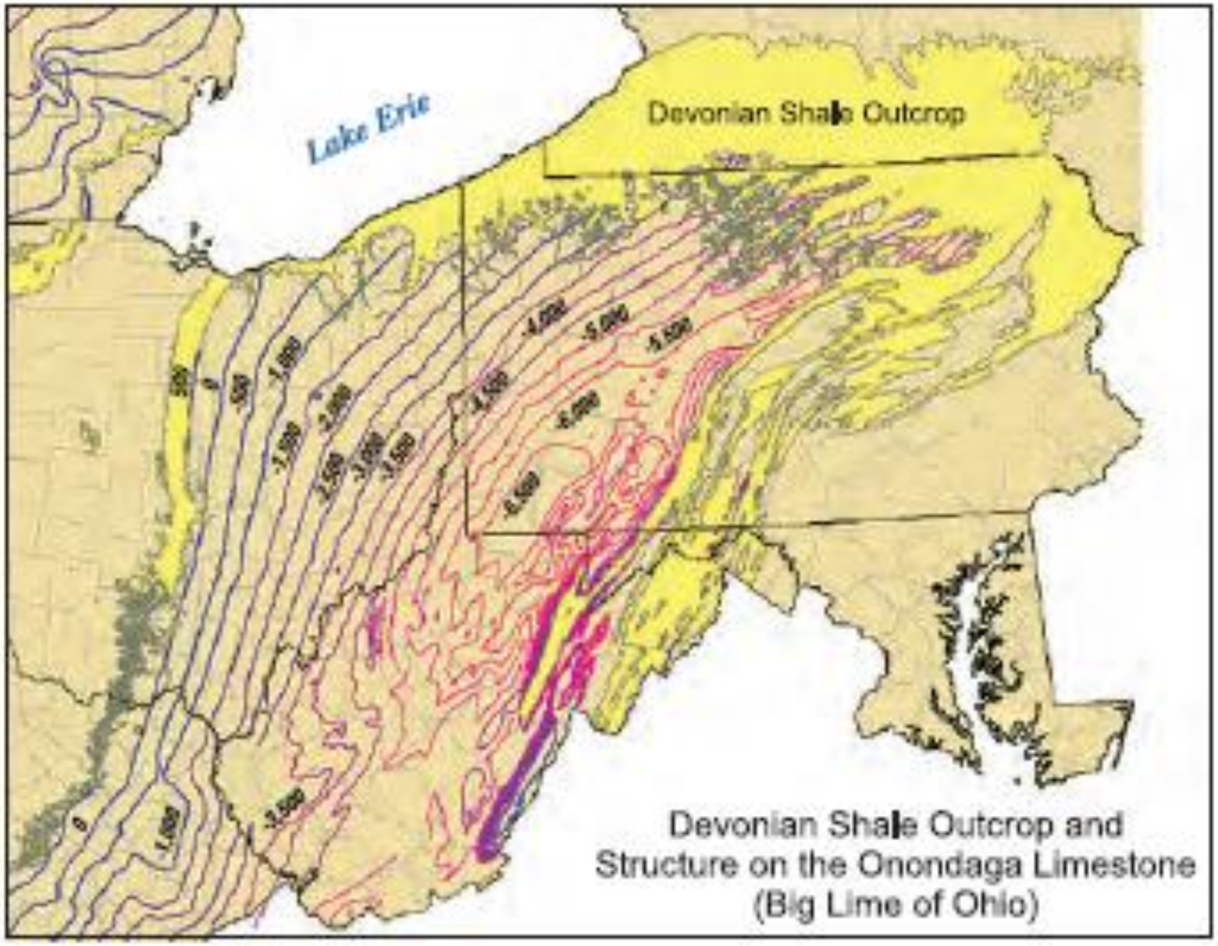
Marcellus structure

Similar to Barnett monoclinal dip in a forearc setting



Modified from Wrightstone, 2008

Top structure map Onondaga Limestone (Base of the Marcellus shale)

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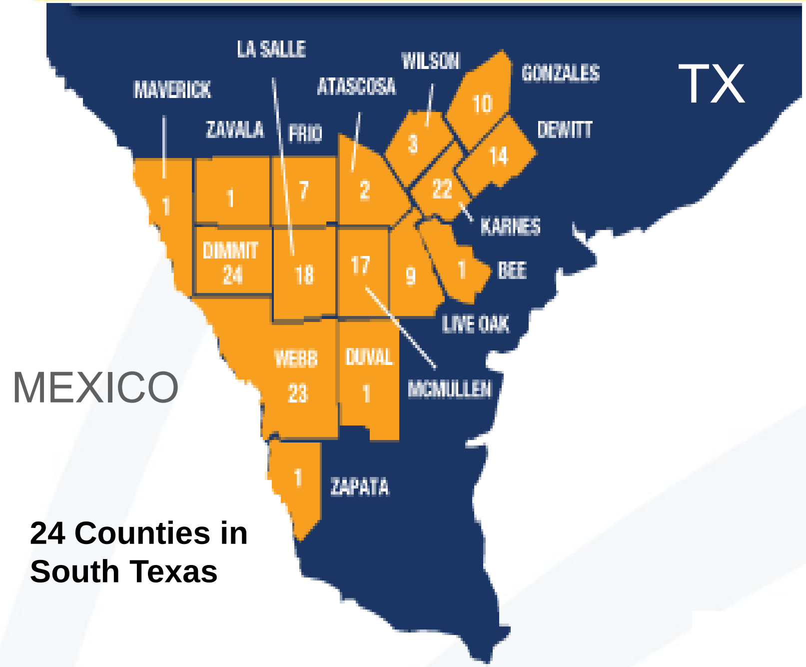
Eagle Ford Shale



- Lower Cretaceous (Mesozoic Era)
- Basin Area = ~3,800 mi² (~10,000 km^2)
- Reported recoverable volumes = **21 Tcf**
- Depth = **4,000 – 12,000 ft**
- Thickness = 100 – 475 ft (30 – 150 m)
- TOC = 3-5%
- Vitrinite Reflectance = 1.0 - 1.27 %R_o
- Porosity = 9-12%
- Permeability = Nanodarcy Range
- Pressure Gradient = 0.43 – 0.70 psi/ft
- Avg. Well IP = **7.0 MMcfd + Cond**
- Cond Ratio ~ **50 Bbl/MMcf**
- First Production ~2008

Oil Wells

- Well IP Range = **400 – 1,800 Bopd**
- API Gravity = **41.5°**

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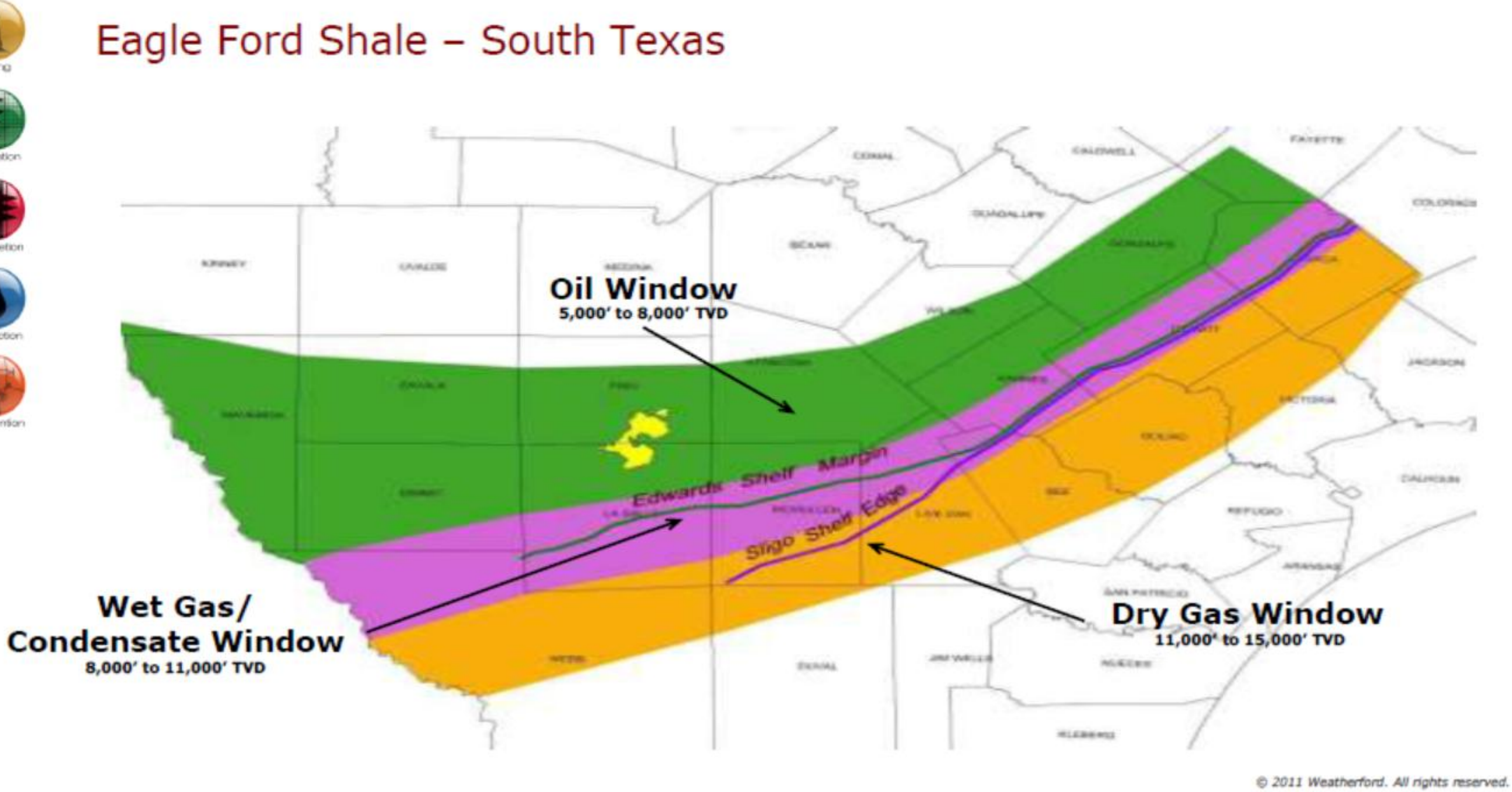
Lateral hydrocarbon transition in the Eagle Ford shale



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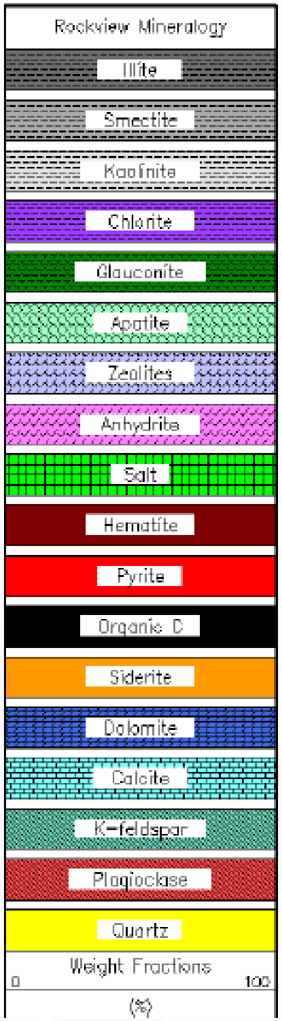
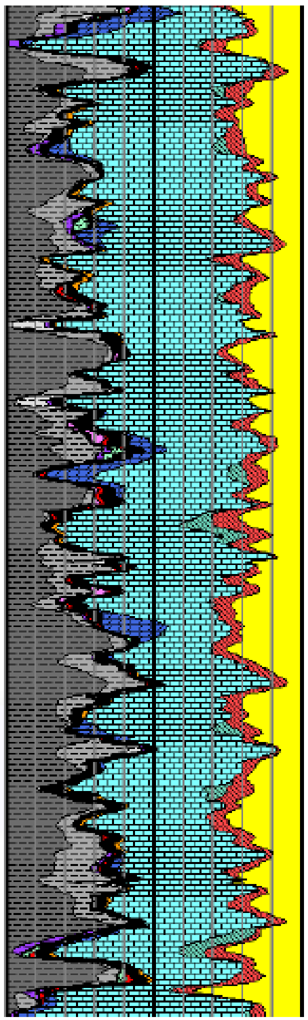
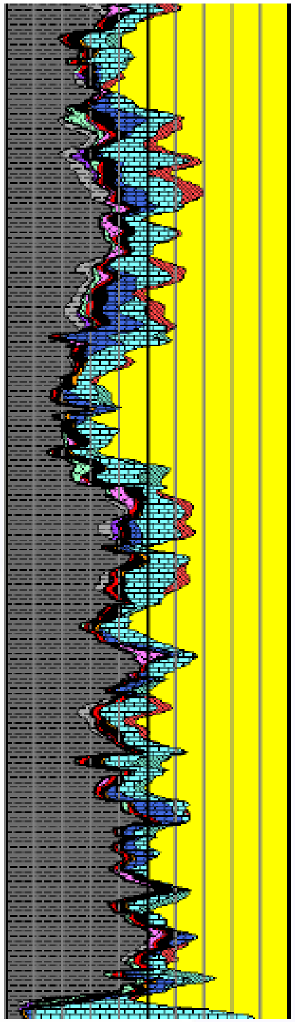
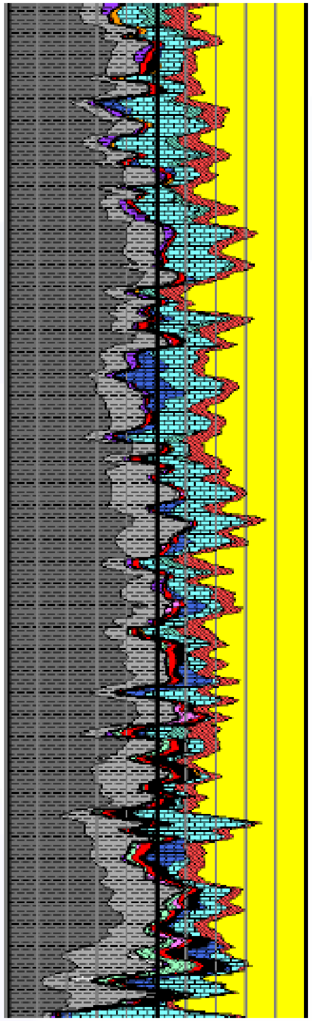
How do these three compare Lithology and Minerology









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Some Key Take-A-Ways (1 of 3)

- Shale Gas in North Americas has caused a paradigm shift
  - Large resource base
  - Low geologic risk
  - Technologically driven
- Shale Gas is very different from conventional gas plays
  - Lower geologic risk
  - Requires different exploitation methods
  - Production curves are very different
    - Shale Gas production tends to fall dramatically and then produce for tens of years
- Shale Gas plays are all different
  - Though similar in a "big picture" sense, formations and current environments are different and require unique evaluations
  - Not only are different shale plays different, but there are significant differences within the same play
    - Most shale plays have a "sweet spot"
- Resource classifications matter
  - Value of a property is directly related to its resource classification
- Evaluation techniques are evolving

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Some Key Take-A-Ways (2 of 3)

- Economics vary
  - Exploitation costs vary depending on a multitude of elements
    - Break-even price for Shale Gas currently varies between US$4 and $10 plus / mcf
    - Well costs vary depending on the play
      - Well costs can represent 50% of a project's CAPEX
      - In general well costs are coming down due to increased experience and technology advancements
  - Prices vary depending on market
    - LNG is a big driver in worldwide gas pricing
    - The future price of gas is a major unknown
  - There are other value drivers beyond costs and prices
    - Land access in populated areas is challenging
    - Environmental issues are key everywhere
      - Availability of large sources of water and access rights are vital to shale gas developments
  - Economics are improving due to technology advancements

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Some Key Take-A-Ways (3 of 3)

- North America Shale Gas exploitation is leading the way
  - Lessons learned in North America will benefit newer projects in the rest of the world

- There are numerous Shale Gas opportunities outside the Americas
  - Care / planning needs to be given in order that “lessons learned” in the Americas are put to use

- Many lessons still to be learned but a/the key learning is:

“SHALE GAS PLAYS ARE ALL DIFFERENT”

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THANK YOU

Typical “fracing” job in south Texas

- 4, 4, 5 stages
- 55,200HHP
- 14.7MM gals ($56,000\ m^3$)
- 5.5MM lbs prop (2.5 million kg)

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