Water Management in Unconventional Natural Gas Exploration & Production

An Important and Long-Term Challenge

May 2011

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Introduction

- Massive expansion of shale gas development requires reliable water sources and effective water management
- This **multi-faceted challenge requires multi-faceted solutions**, and the purpose of this presentation is to explain and emphasize the importance of this fact
- My perspective

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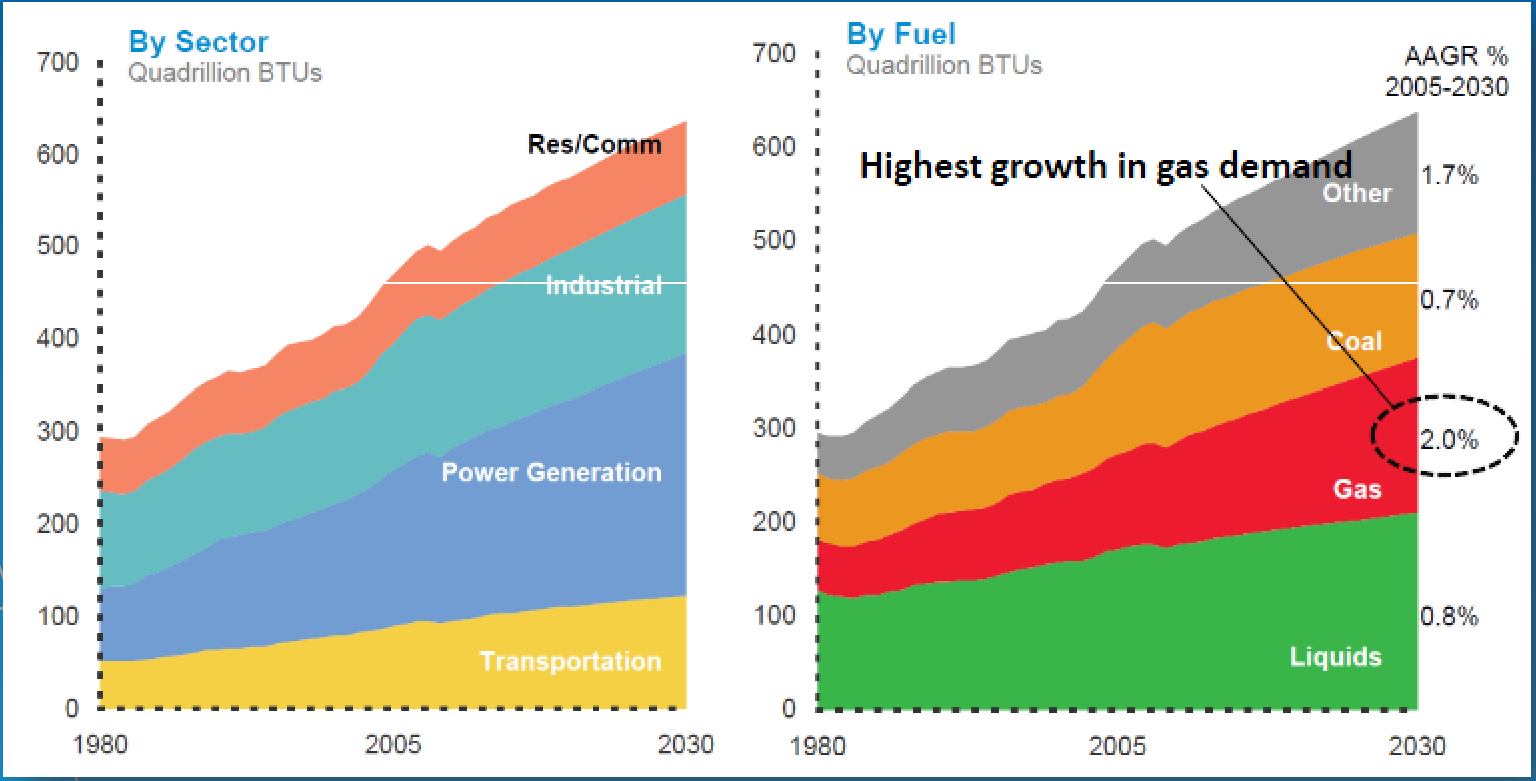
Presentation Outline

1) Summary of Shale Gas Resource
2) Horizontal Drilling and Hydraulic Fracturing
3) Water Management / Treatment

Growing Future Global Demand

- Global energy demand in 2030 will be about 35% higher than 2005, driven in large part by growth in power generation demand



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U.S. Reliance On Imports

Source: TrendMacro

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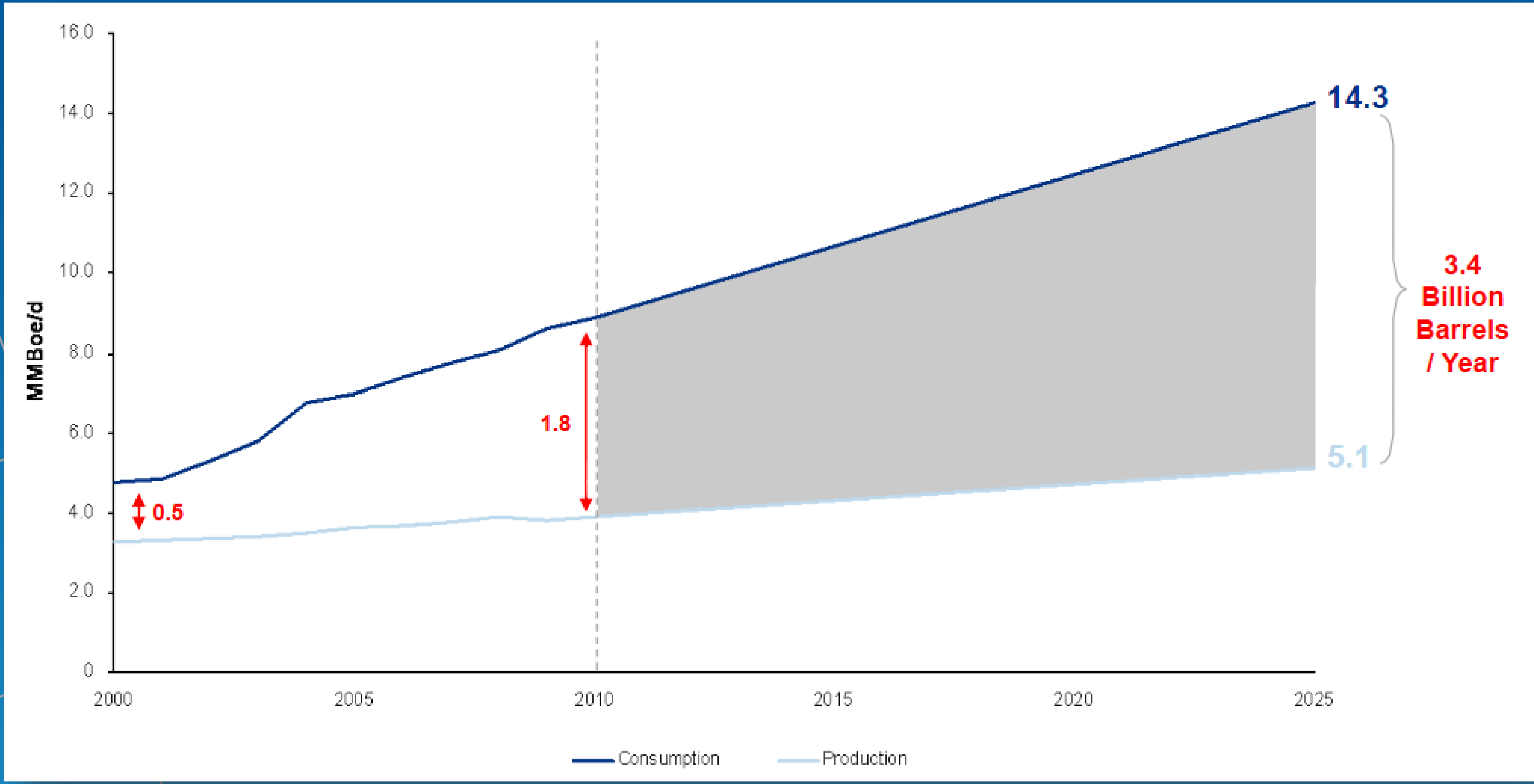
It's Not Going To Get Any Easier

(e.g., *Chinese Oil Production and Consumption)*



Source: EIA and BP Statistical Review

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We Can All Agree

- Increase U.S. energy efficiency
- Reduce reliance on foreign sources
- Transition to renewable energy as quickly as possible

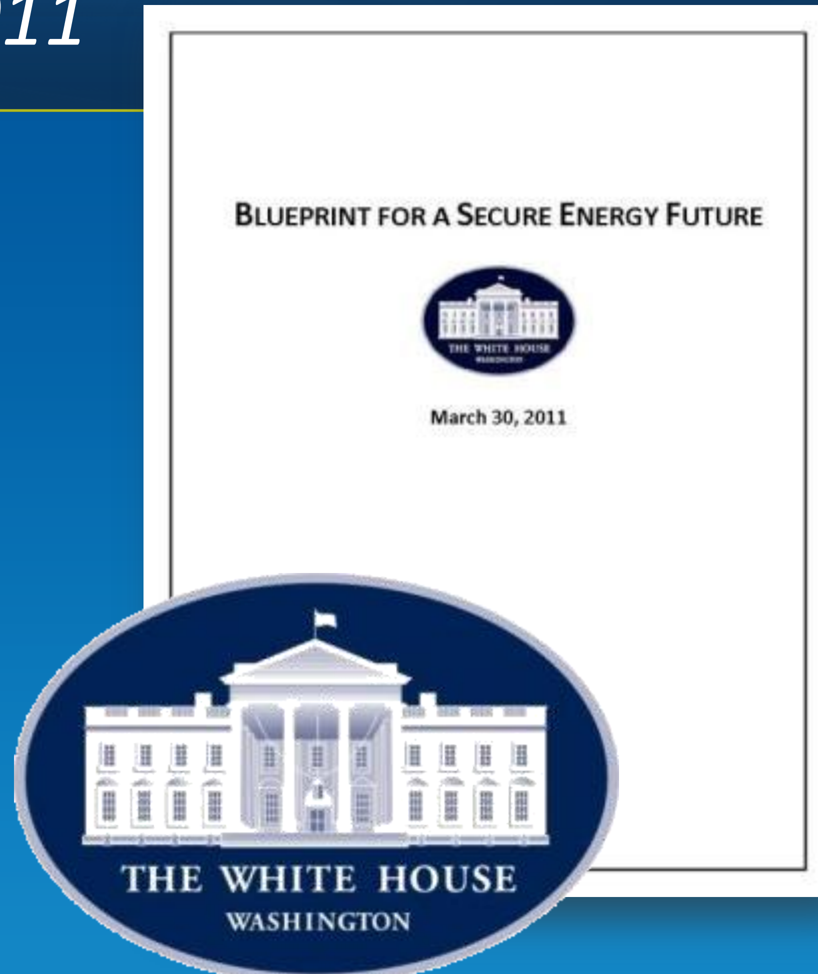
Where It Gets Sticky

- What do we do in the mean time while renewable energy development is a drop in the bucket compared to our total energy needs?

Blueprint for a Secure Energy Future
White House, March 30, 2011

- Three Point Plan
  - Develop and secure America's energy supplies
  - Energy reduction
  - Innovate clean energy

"Natural gas and oil from shale formations…will play a critical role in domestic energy production in the coming decades."


BLUEPRINT FOR A SECURE ENERGY FUTURE

March 30, 2011

Pertinent Quotes

"We've discovered the equivalent of two Saudi Arabia's in the last two years. The **greatest wealth transfer in human history** "$1B / day" takes place everyday and it doesn't have to."
- Aubrey McLindon, CEO of Chesapeake Energy

"One group says natural gas is the solution to America's energy problems and another group says it's our biggest environmental nightmare. **Their both right**."
- Michael Brune, Executive Direction of the Sierra Club

"Given the global demand growth, concerns about nuclear power, constraints on carbon emissions, and current limitations of renewable energy, natural gas is the **fuel of no choice**."
- Société Générale Bank

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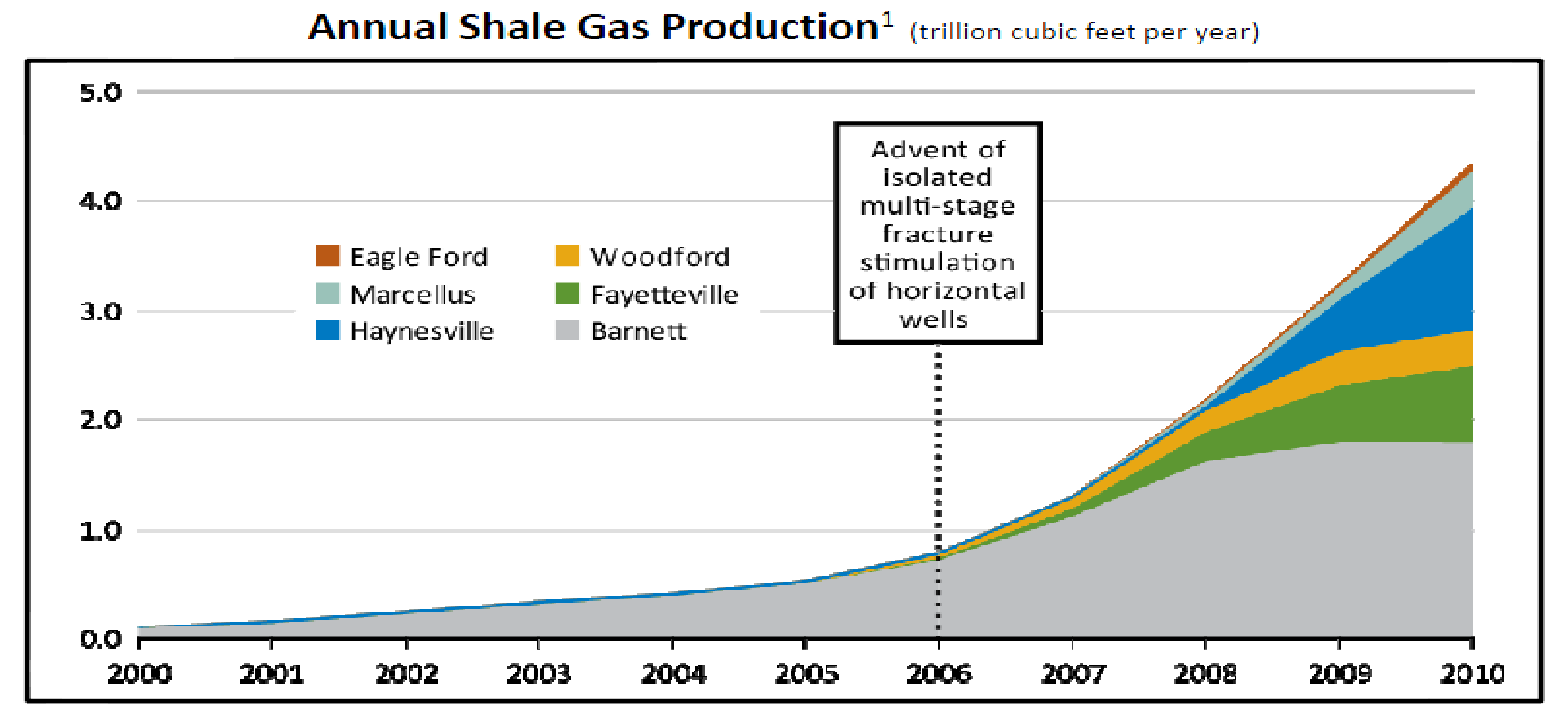
Shale Revolution Timeline

U.S. Shale Gas Production Has Increased Six-Fold Since 2006



Shale gas has grown to over 15% of U.S. gas production[2]

[1]*Source: EIA, Annual Energy Outlook 2011 Reference Case*
[2]*Source: EIA*

Shale

- Sedimentary rock
- Consolidated clay-sized particles
- Concurrent deposition of organics (algae, plant matter, and animal matter)
- Laminated layers with limited horizontal and extremely limited vertical permeability (hence need for hydraulic fracturing)

Marcellus Shale Outcrop

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U.S. Shale and Tight Gas Basins

Source: Energy Information Administration based on data from various published studies.

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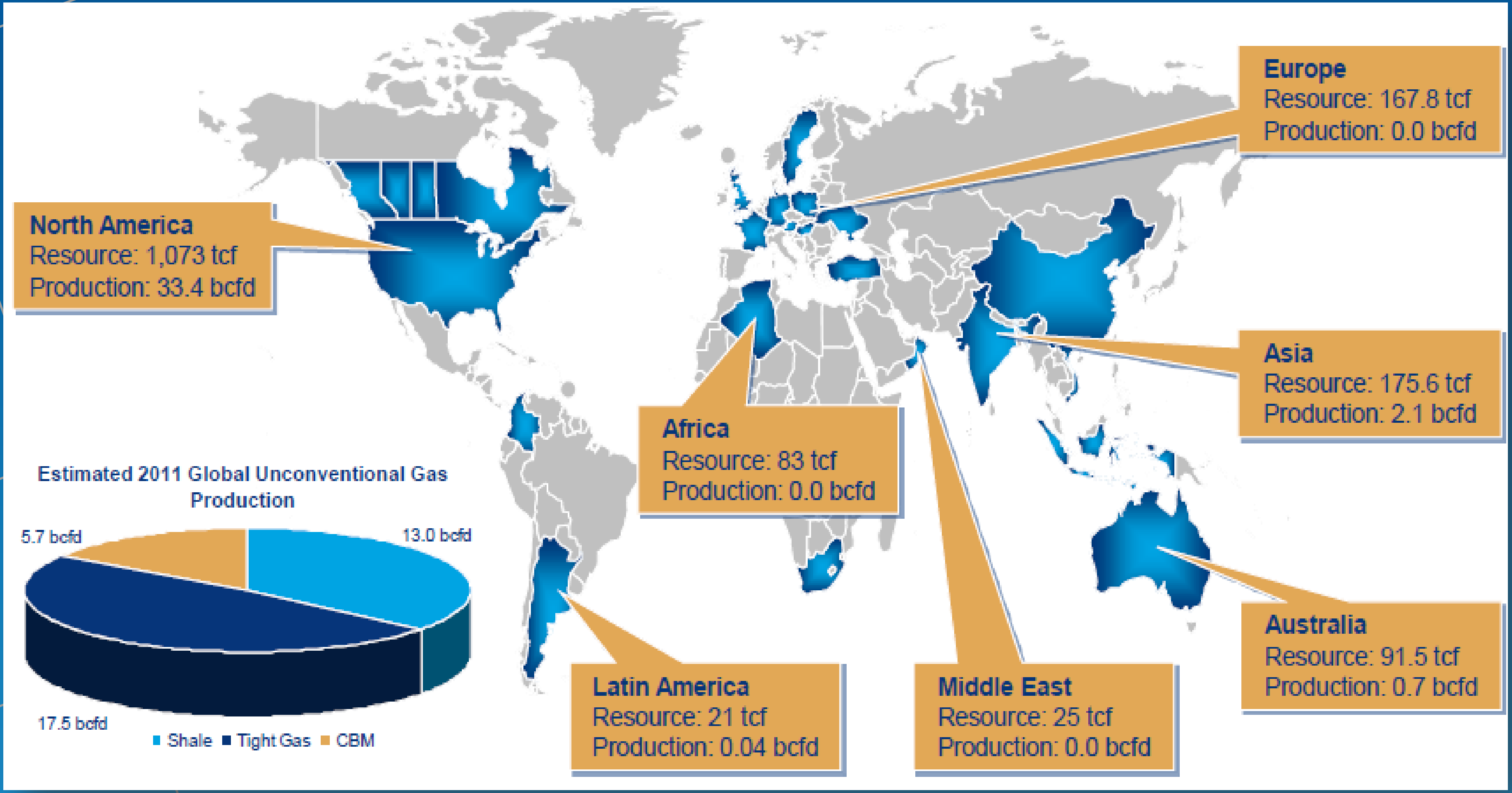
Natural Gas is Efficient and Clean Burning, and It's **OURS!**

- ~ ½ CO_2 as coal
- Emits mostly CO_2 and H_2O (very small SO_2 and NOx, no ash)
- Central component of greenhouse gas strategies
- Extensive availability and transmission / distribution network
- Obvious best choice for leveling supply variability of renewable sources of wind and solar
- Massive U.S. Shale Gas Plays now available due to horizontal drilling and hydraulic fracturing
- Best available "bridge" fuel for future transition to renewable energy

Shale Gas is Global with Production and Reserves Both Concentrated in North America



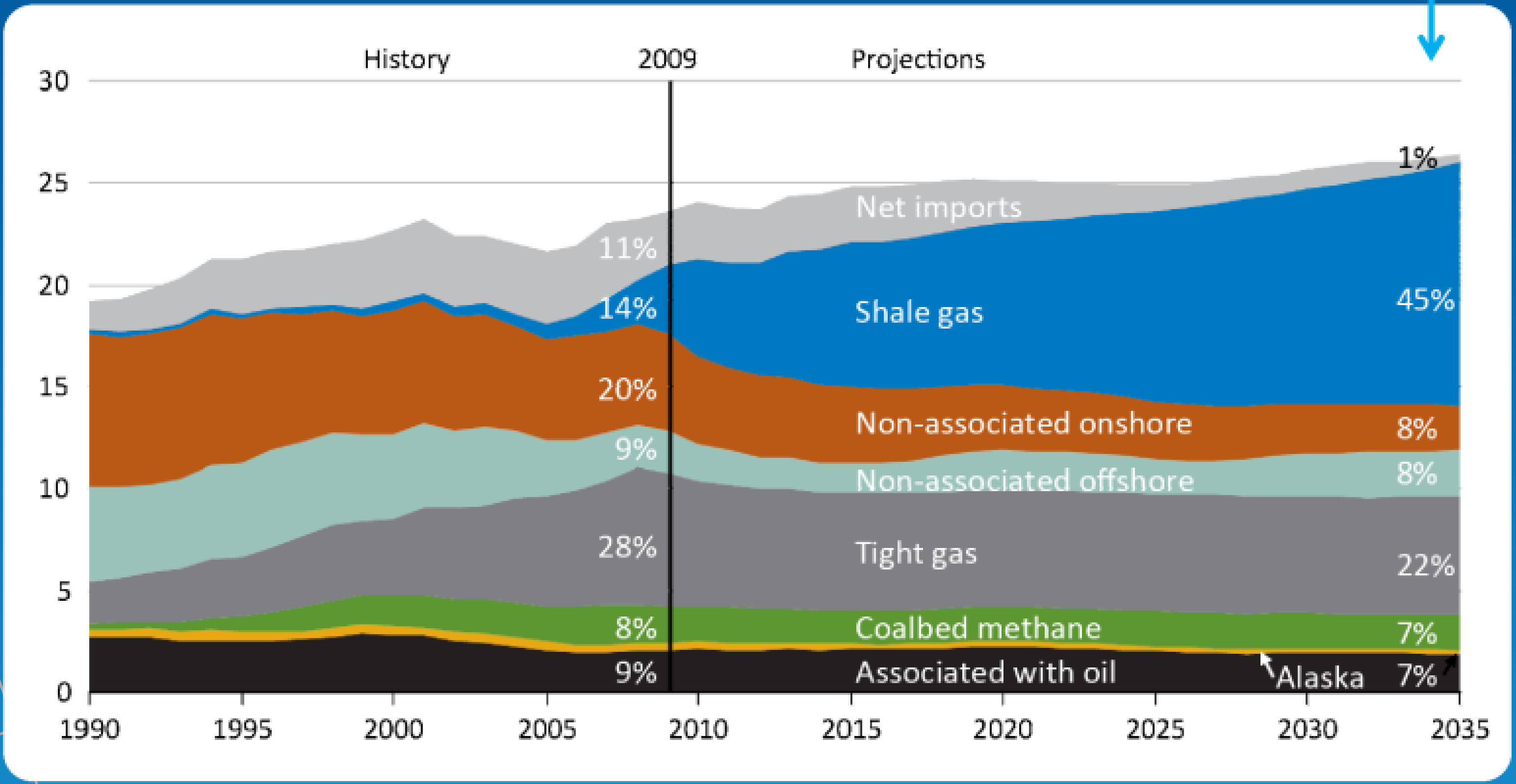
Source: Wood Mackenzie

Shale Revolution

U.S. Dry Gas Supply – History and Projections

trillion cubic feet per day

Imports practically eliminated



Shale gas in 2009 made up 14% of total U.S. natural gas supply. Production of shale gas is expected to continue to increase, and constitute 45% of U.S. total natural gas supply in 2035.

Source: EIA, 2011 Energy Outlook

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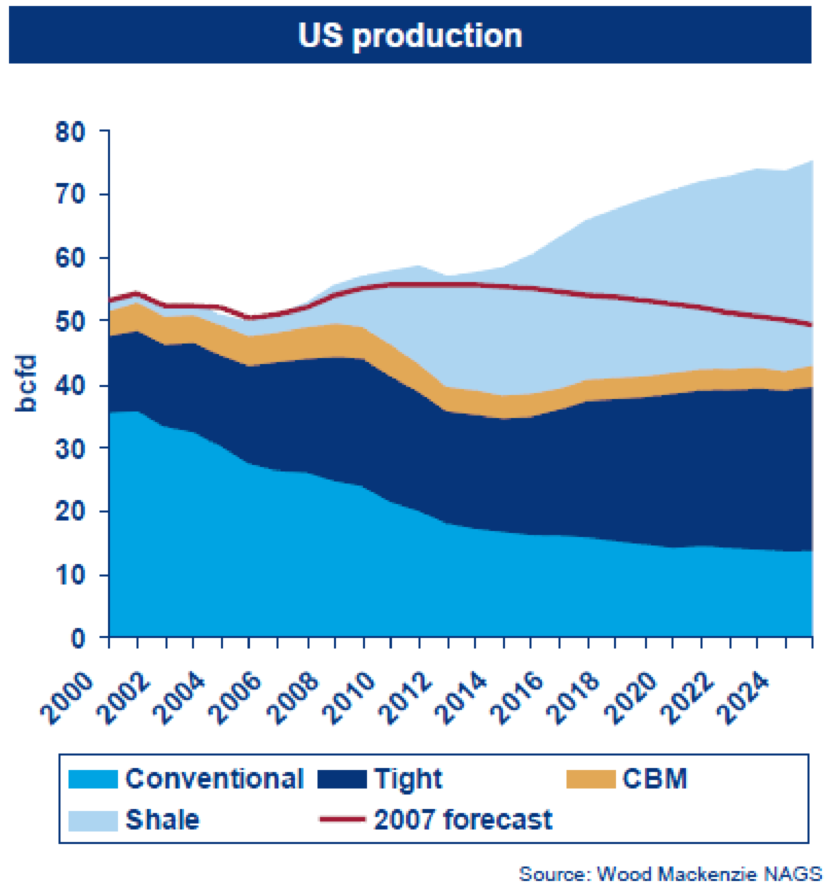
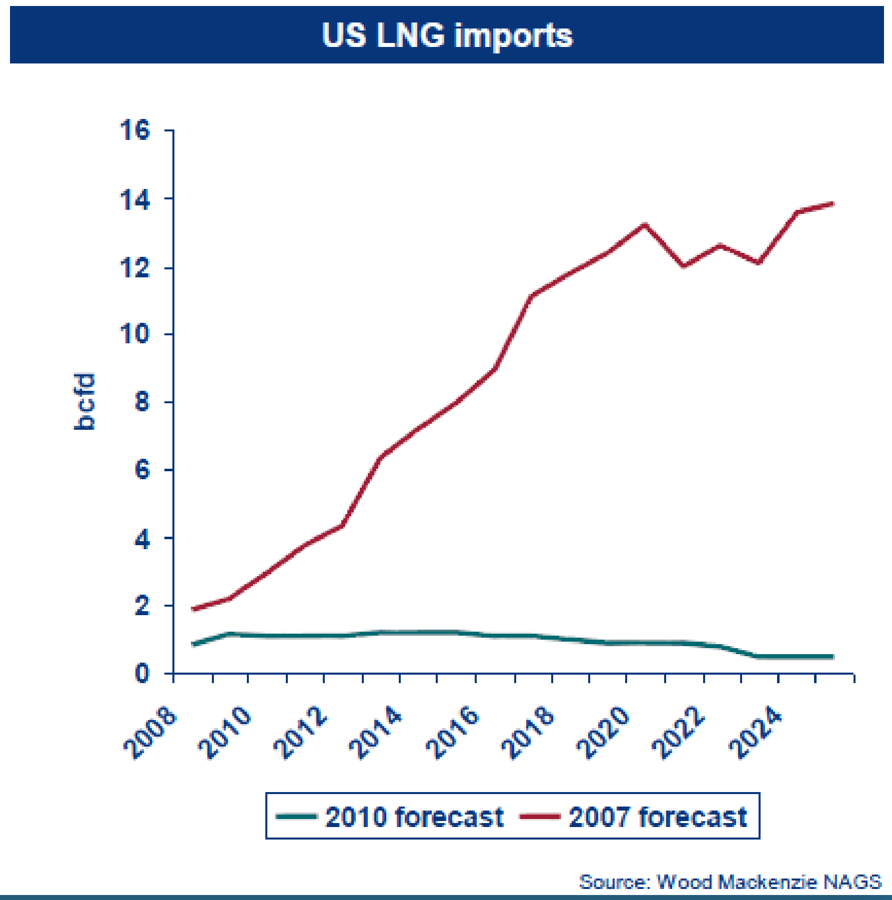
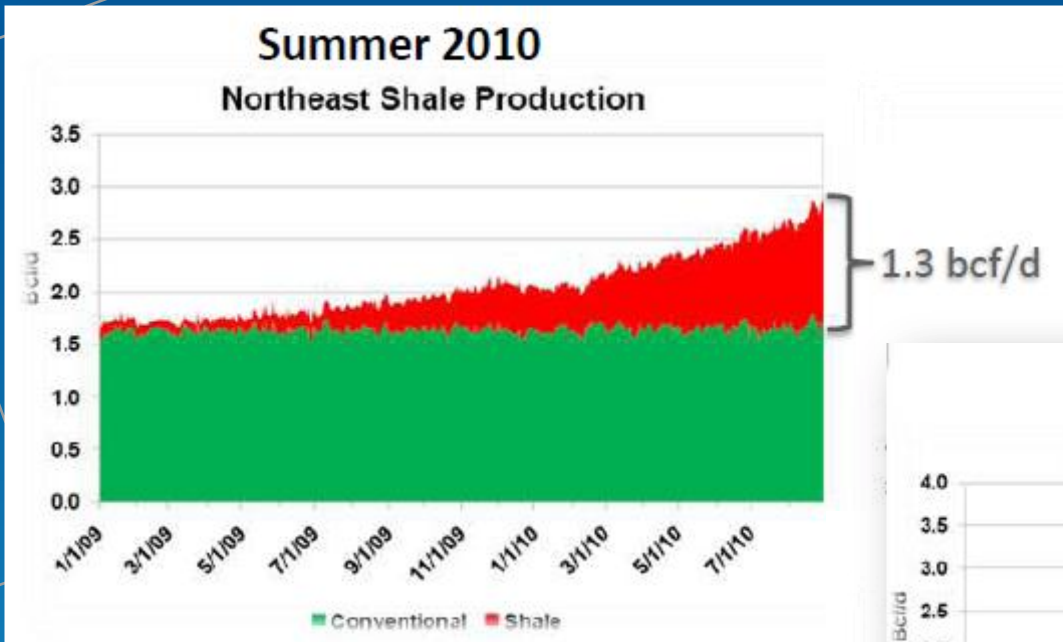
Availability of Shale Gas Has Dramatically Changed U.S. Supply Projections



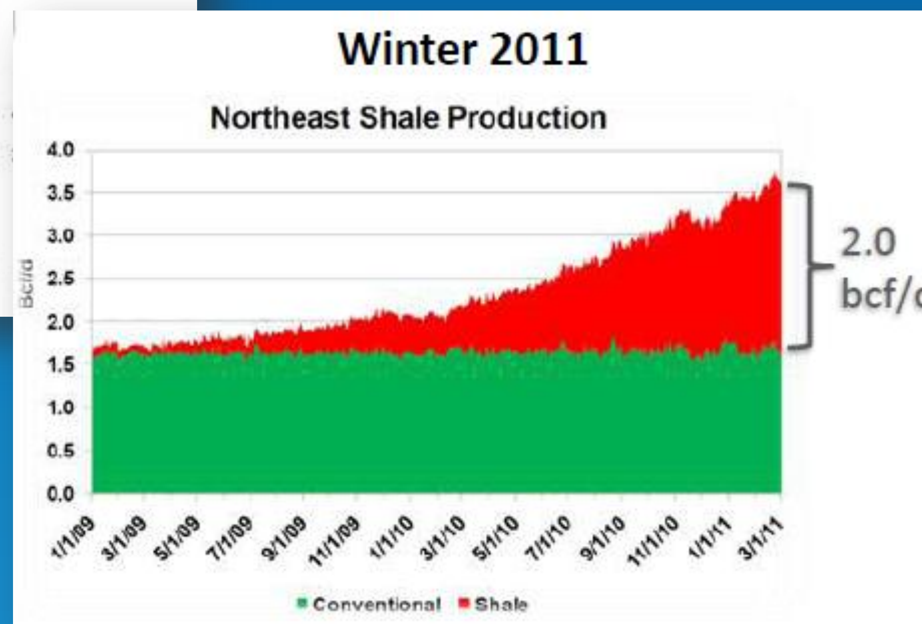


Source: Wood Mackenzie NAGS

Changing Supply Dynamics
NE Shale vs. Traditional Appalachian

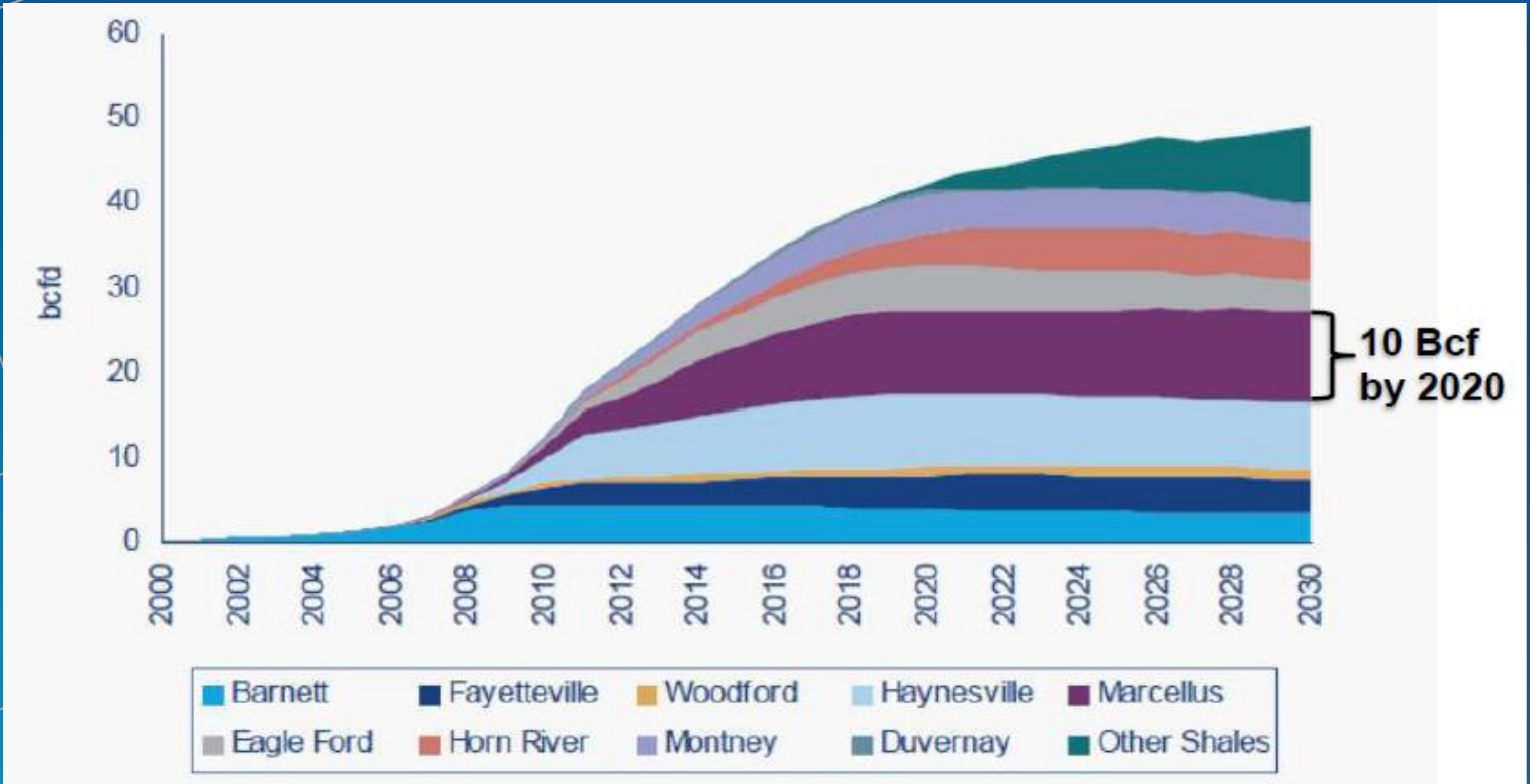


Shale production in the Northeast grew 0.6 bcf/d in 6 months



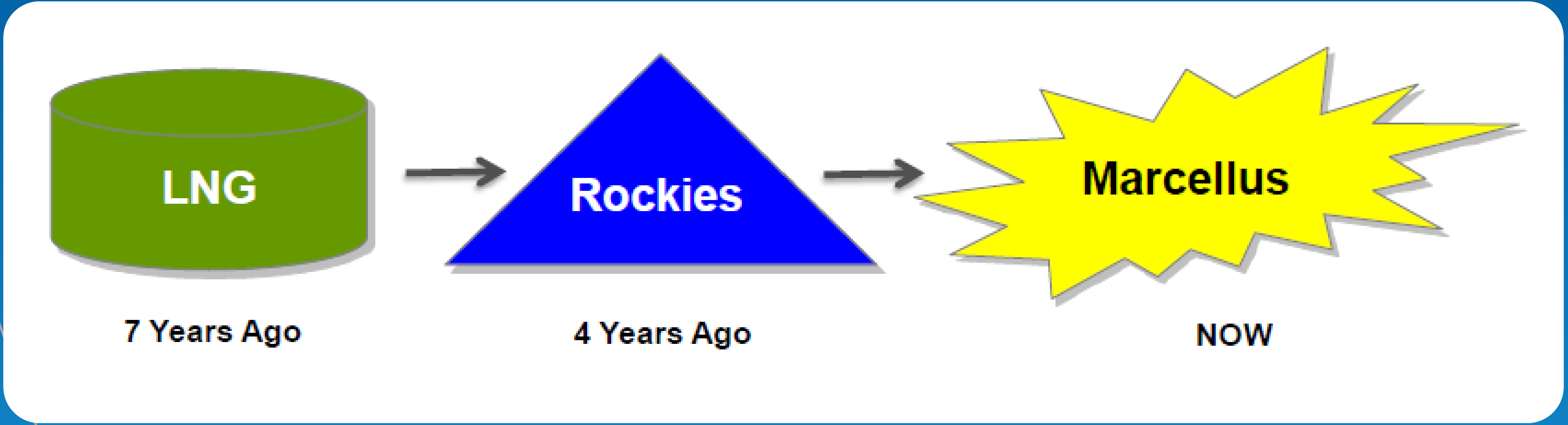
Source: Bentek Energy, LLC

Domestic Shale Production Projections



Source: Wood Mackenzie (North America Gas Service)

Natural Gas Supply Trends



Source: Dominion Transmission Inc.

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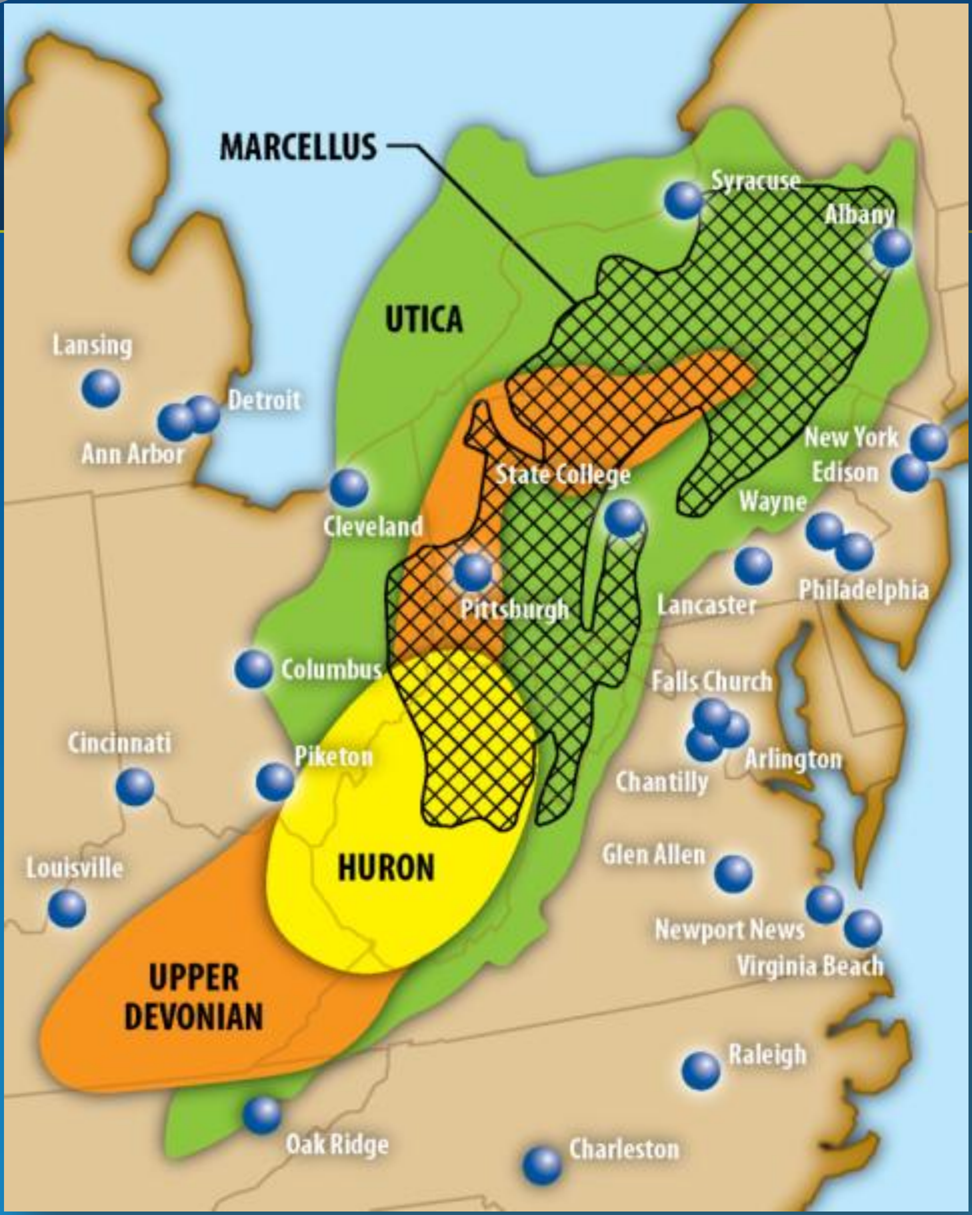
Marcellus Shale and Other Appalachian Formations

500 – 1,500 trillion cubic feet (tcf) in place (50 - 500 tcf recoverable) in the Marcellus.

First gas well in U.S. – 1821, Devonian Shale, Fredonia, NY.



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A Trillion Cubic Feet is Enough Gas to:

- Heat 15 million homes for 1 year
- Generate 100 billion kilowatt-hours of electricity
- Fuel 12 million natural gas vehicles for one year
- Marcellus ≃ 50 – 500 x above

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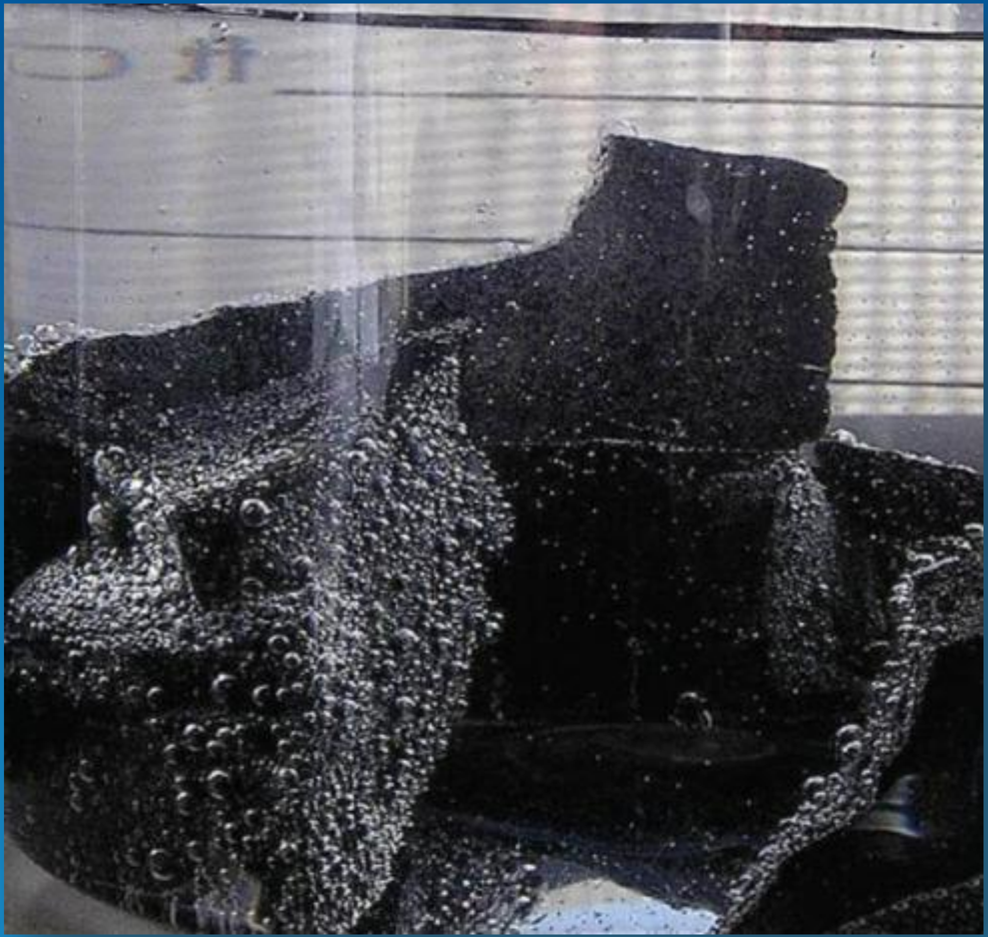
Release of Natural Gas from Shale Rock



Source: BNK Petroleum

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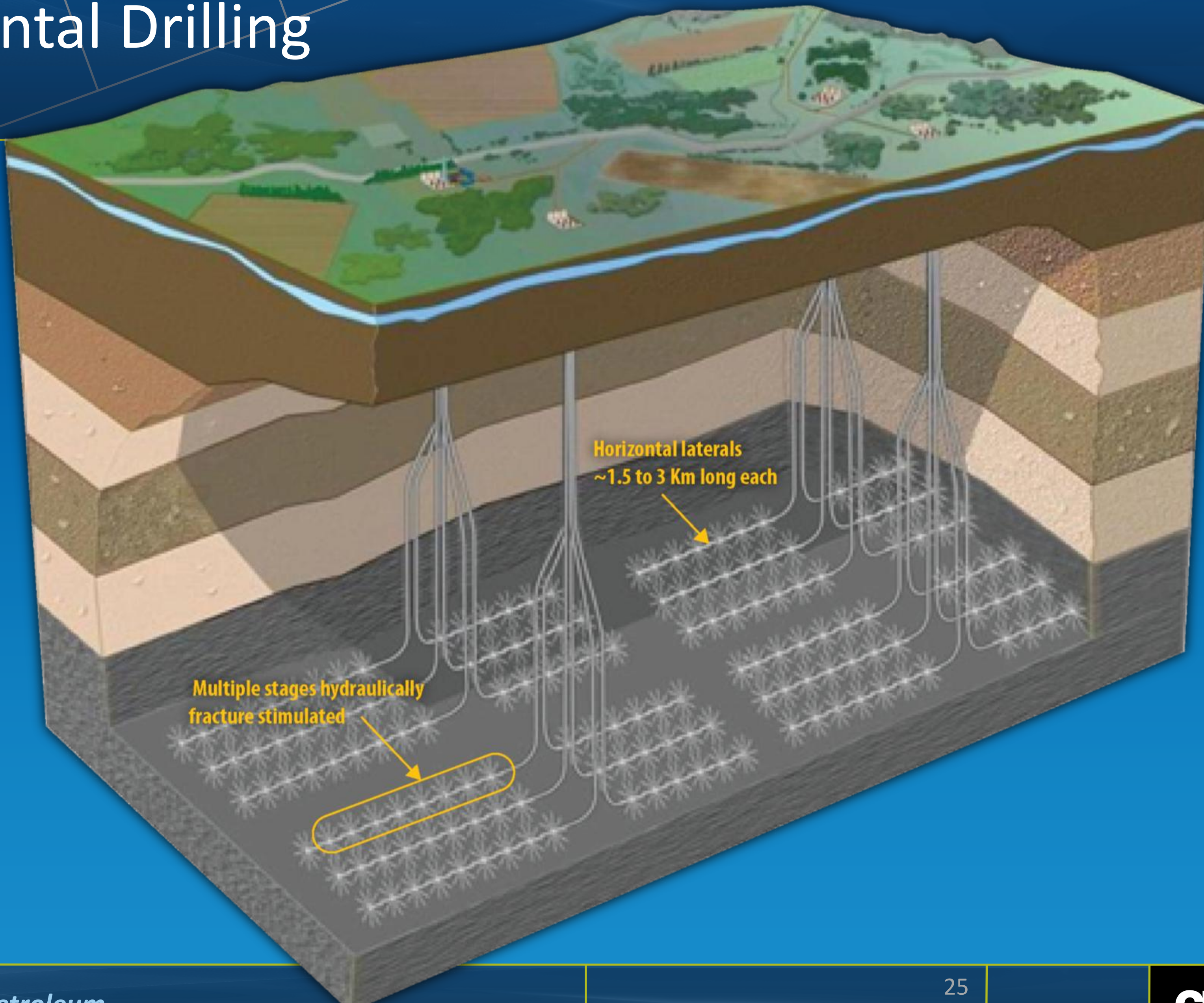
HORIZONTAL DRILLING
AND HYDRAULIC FRACTURING

Horizontal Drilling



Source: BNK Petroleum

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Horizontal Drilling

- Six to eight wells at a single site versus approximately 16 separate wells for typical vertical well spacing
- ~1/10 surface impact
- 2,000 – 6,000 feet of formation exposure per well versus only formation thickness (50 – 300 feet typical) for vertical wells

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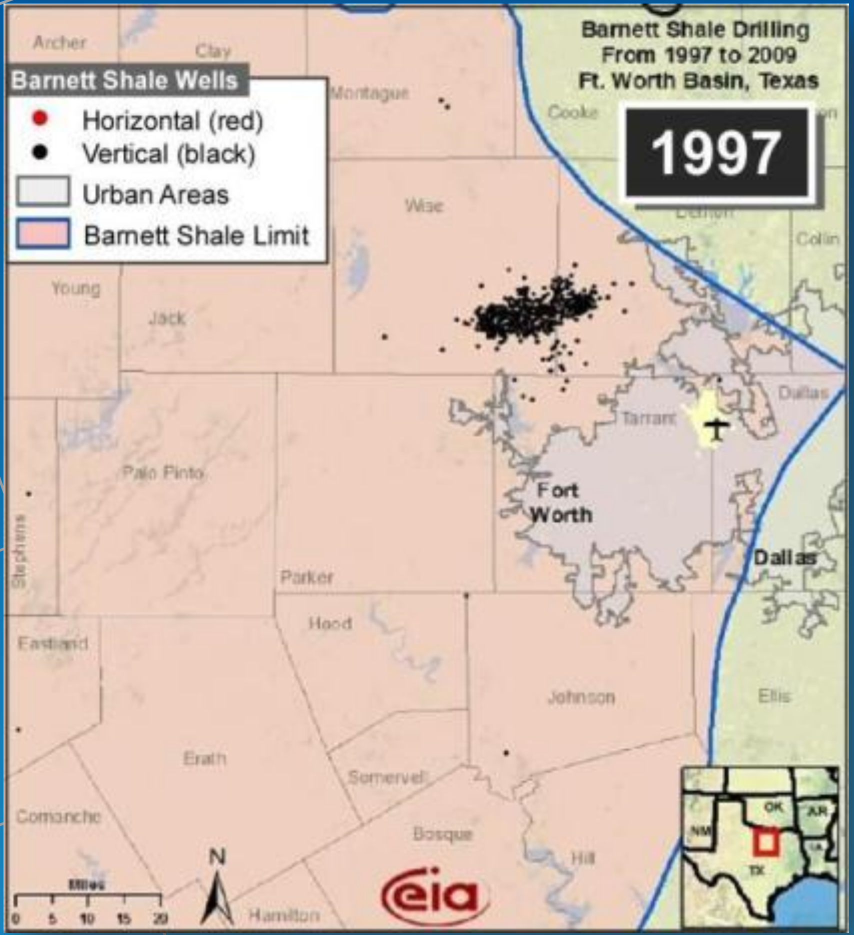
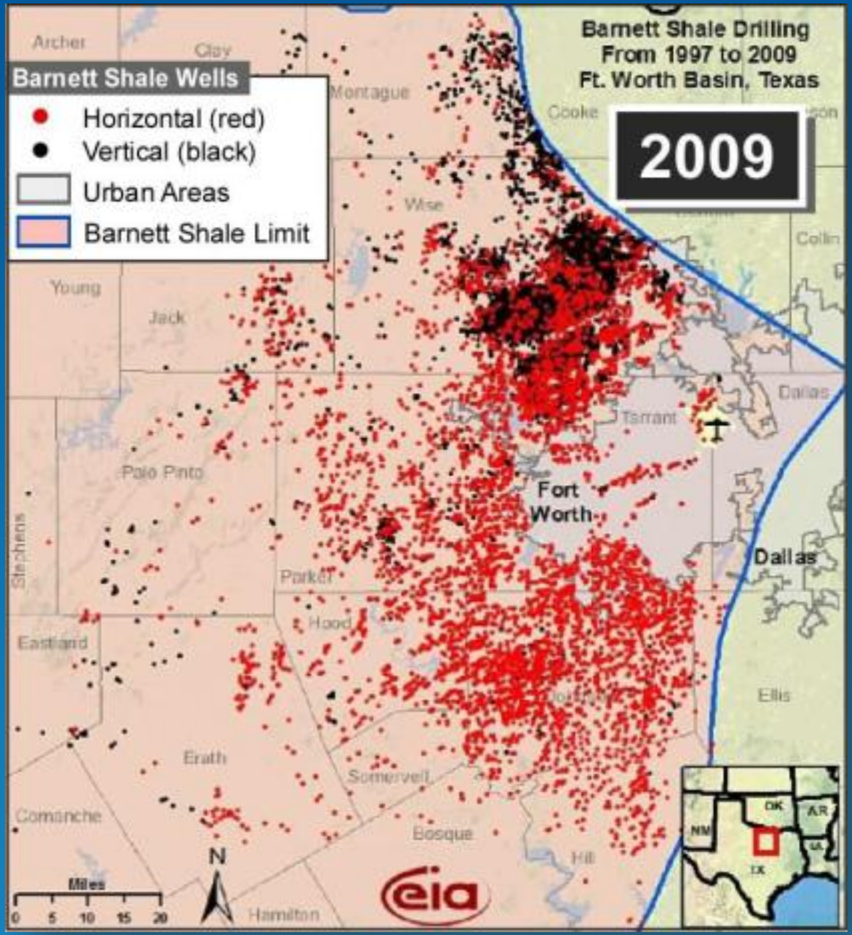
Barnett Shale:
Intensive Drilling Activity 1997 - Present





Source: EIA

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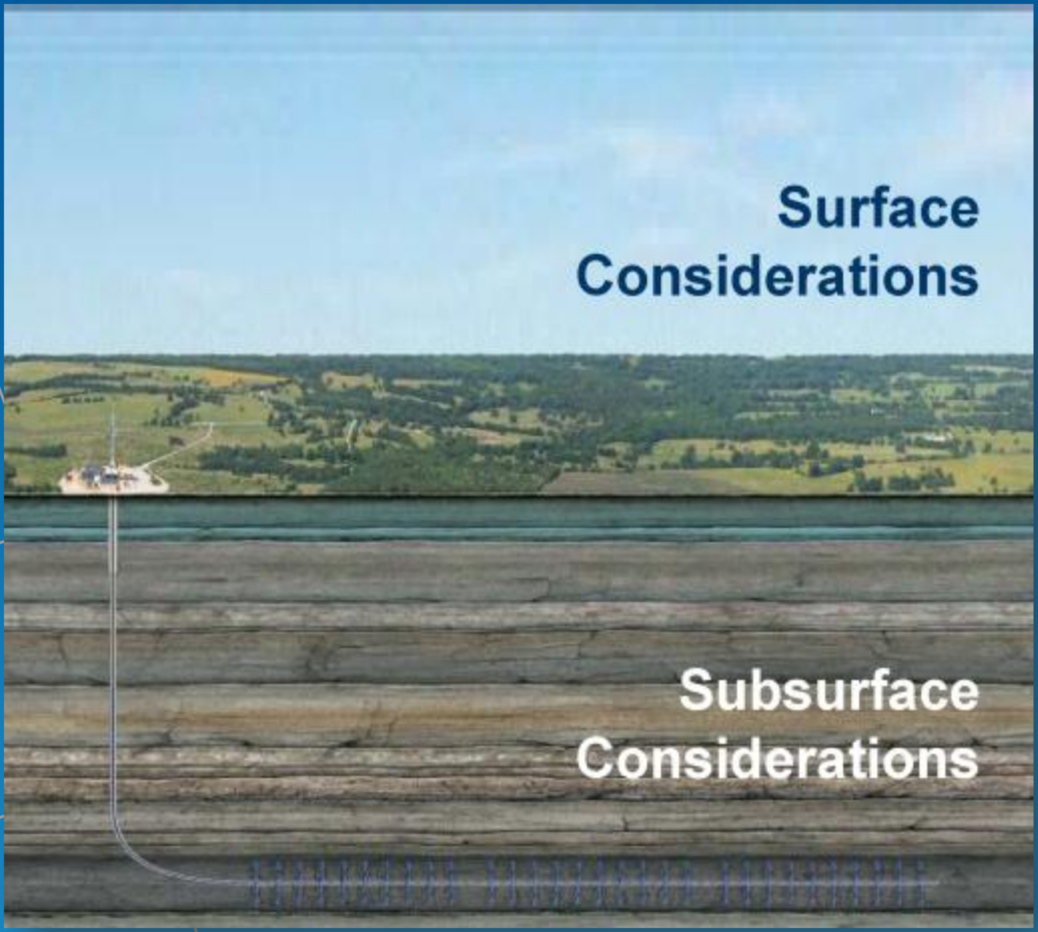
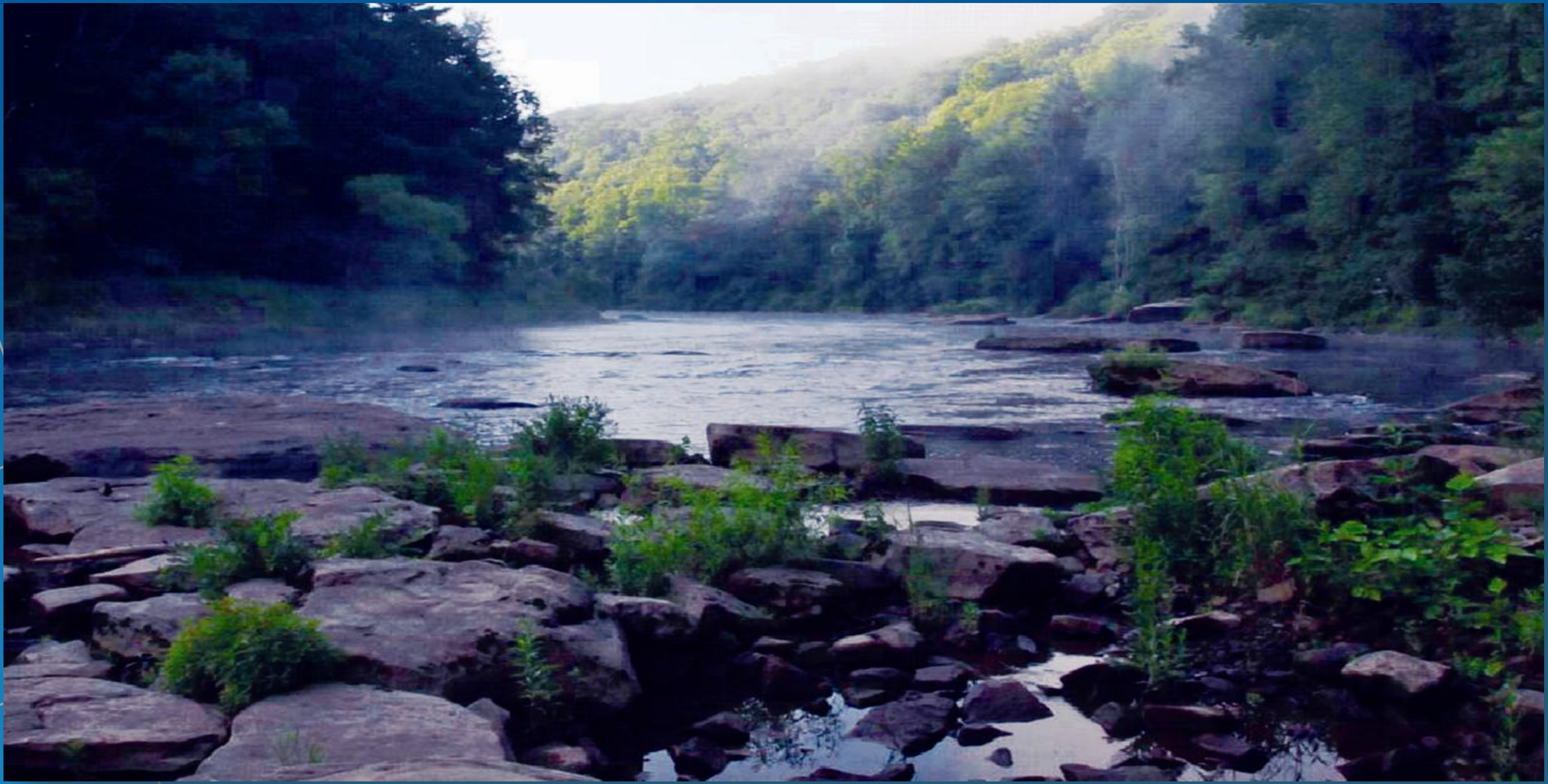
Environmental Concerns



- Air Emissions
- Water Supply / Water Handling / Water Disposal
- Surface Impact
  - Drilling Locations (Pit Construction; Chemical Storage; Erosion Control)
  - Infrastructure (Roads; Compressors; Pipelines; Water Treatment Facilities)
  - Truck Traffic and Road Damage
- Protecting Underground Water Resources
- Frac Fluid Disclosure

Source: Southwestern Energy

Marcellus Basin Surface Waters



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The Shale Development Solution and Environmental Controversy

- Frac Water Volume: 2 to 6 M gallons
- Additional components include biocides, corrosion inhibitors, O2 scavengers, proppant, etc.
- 20 -30% frac "flowback" water recovery requires collection, handling, and disposal / treatment / reuse

Source: ALL Consulting. *Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives,* July 2003.

Shale Gas and Water

- Source it
- Transport it
- Store it
- Treat it
- Re-use it
- Dispose of it
- Protect it
  - Surface Water
  - Ground Water

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Key Water Management Concerns

- Water “wasting” and general water resource concern
- Surface water quality impacts
- Shallow groundwater quality impacts
- Long-term soil damage from salinity and sodicity (SAR)
- Transport – 1 MG = 200 trucks

BOTTOM LINE:

- Huge unconventional gas resources are driving development; and water solutions are key
- Water quality concerns leading to more treatment and reuse
- Solutions can be simple to very complex – ***Reduce, Reuse, Recycle*** are key goals

Total Water Use – 4 Major Shale Plays

Shale Gas Play	Public Supply	Industrial and Mining	Power Generation	Irrigation	Livestock	Shale Gas	Total Water Use (Bbbl/yr)
Barnett Shale	82.70%	4.50%	3.70%	6.30%	2.30%	0.40%	11.15
Fayetteville Shale	2.30%	1.10%	33.30%	62.90%	0.30%	0.10%	31.9
Haynesville Shale	45.90%	27.20%	13.50%	8.50%	4.00%	0.80%	2.15
Marcellus Shale	11.97%	16.13%	71.70%	0.12%	0.01%	0.06%	85

Source: Gas Technology Institute

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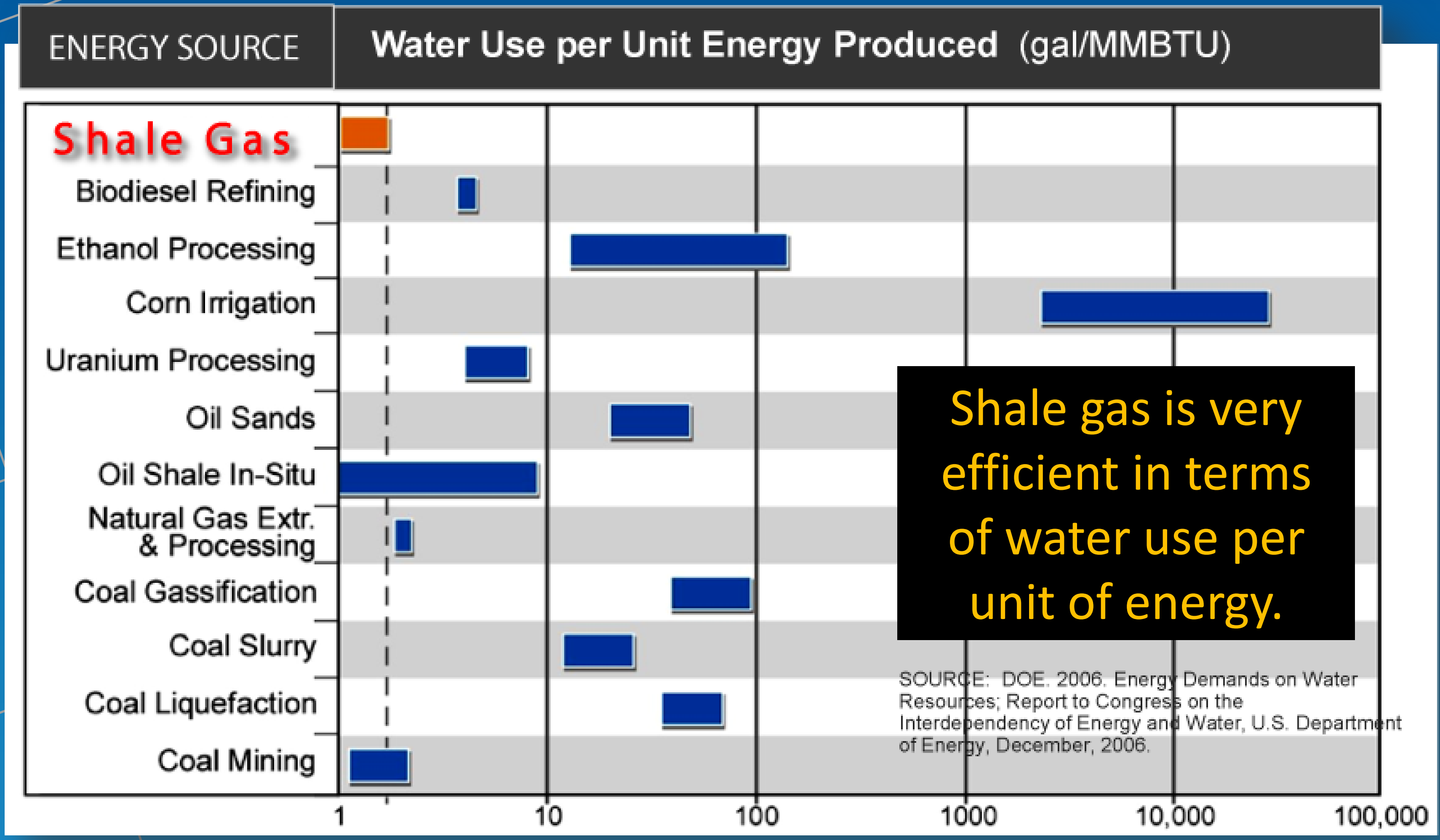
Shale Gas:
Water Use Efficiency vs. Other Energy Sources



Source: GSI Environmental, Houston, Texas, 2010

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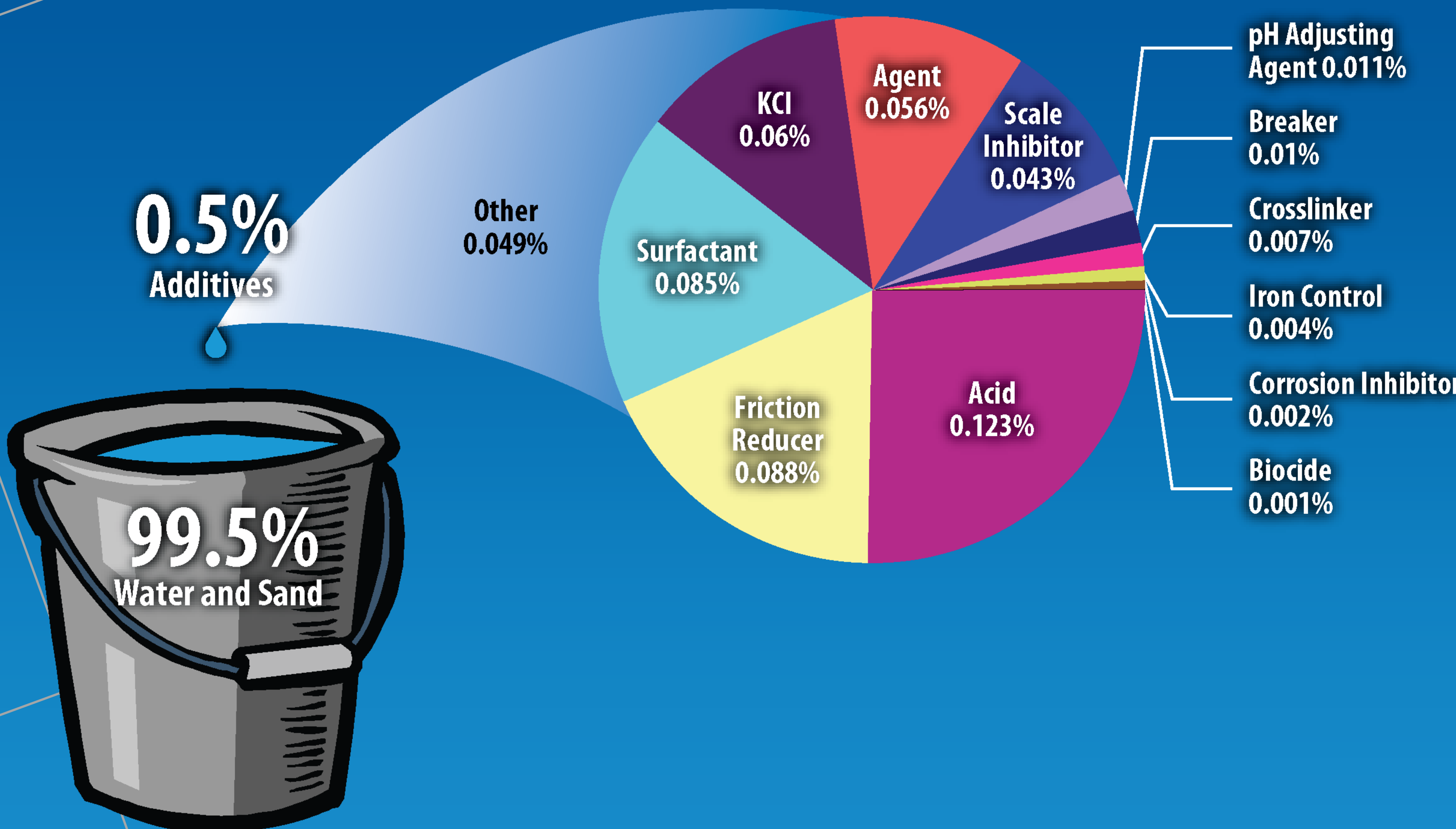
Composition of a Fracturing Fluid



Reference: All Consulting 2009

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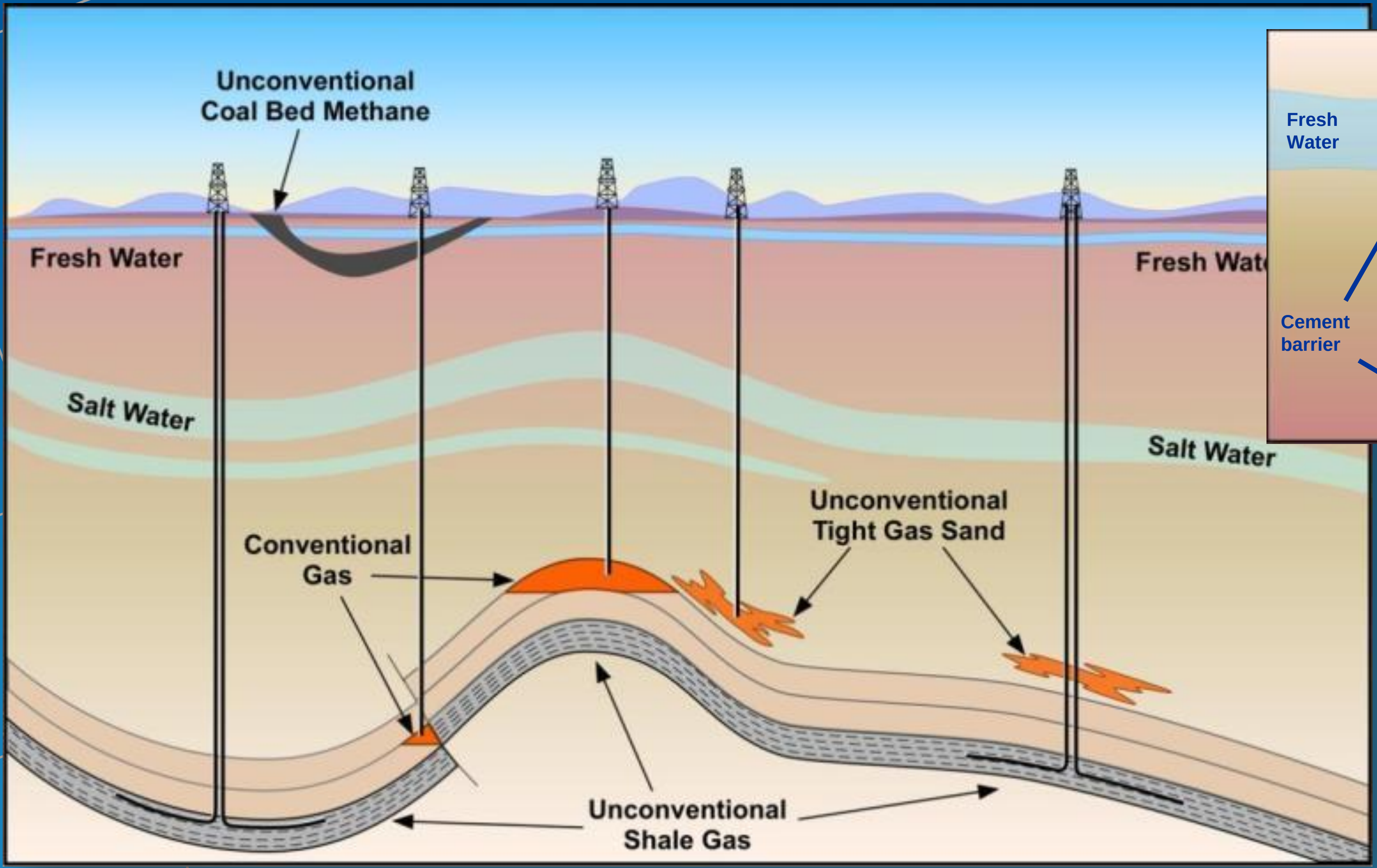
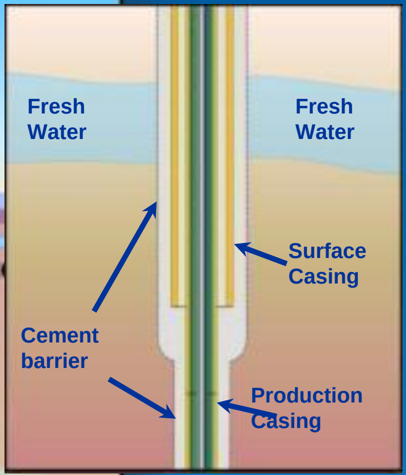
Protection of Groundwater and Surface Water

This is a Critically Important Consideration





Source: BNK Petroleum

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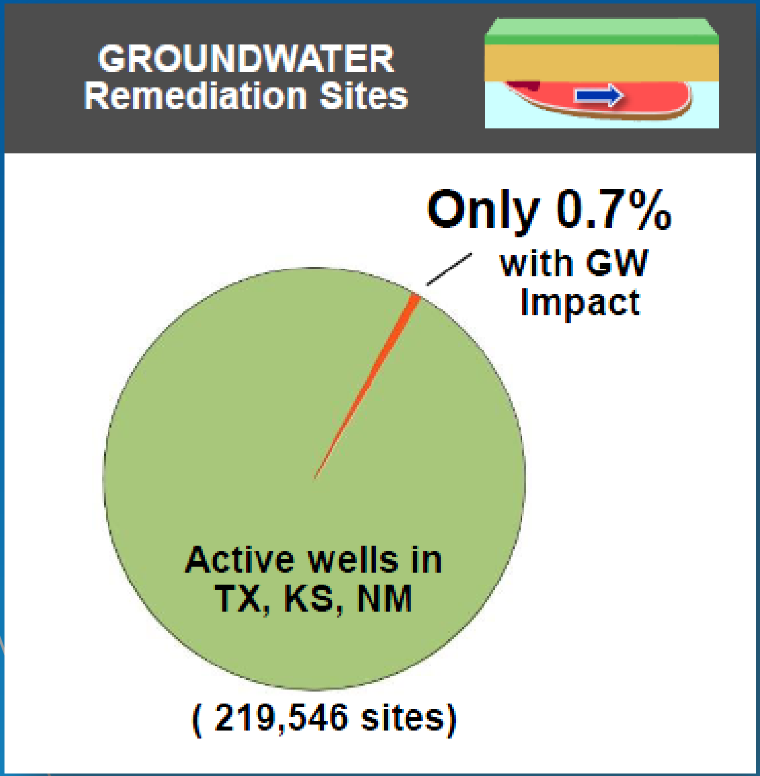
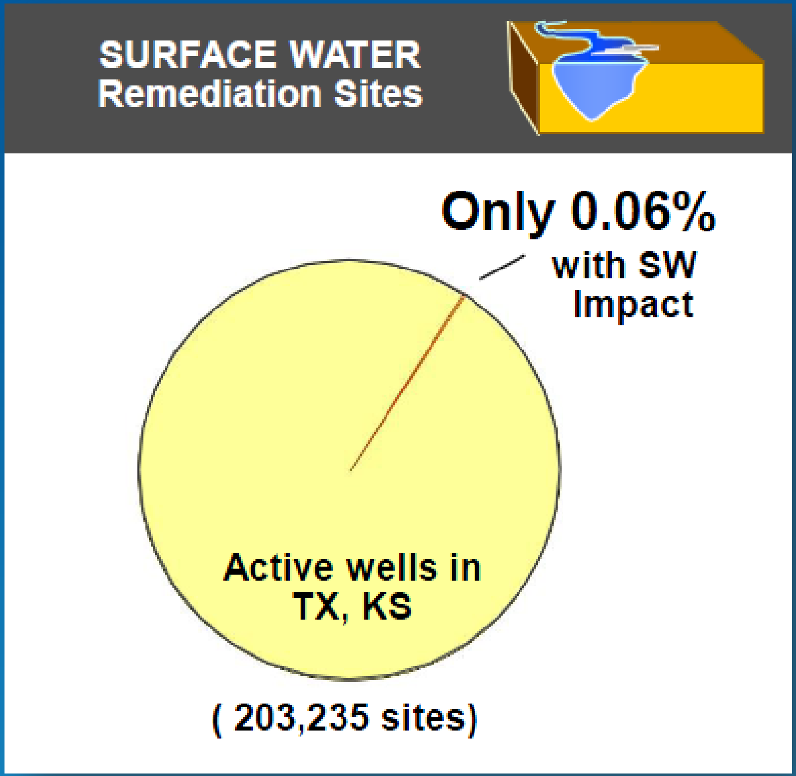
Oil & Gas Sites:
Environmental Impacts in Regulatory Agency Records





- **KEY POINT: Impacts to GW and SW by oil and gas wells are rare, with NO impacts recorded by shale gas wells**

Source: GSI Environmental, Houston, Texas, 2010

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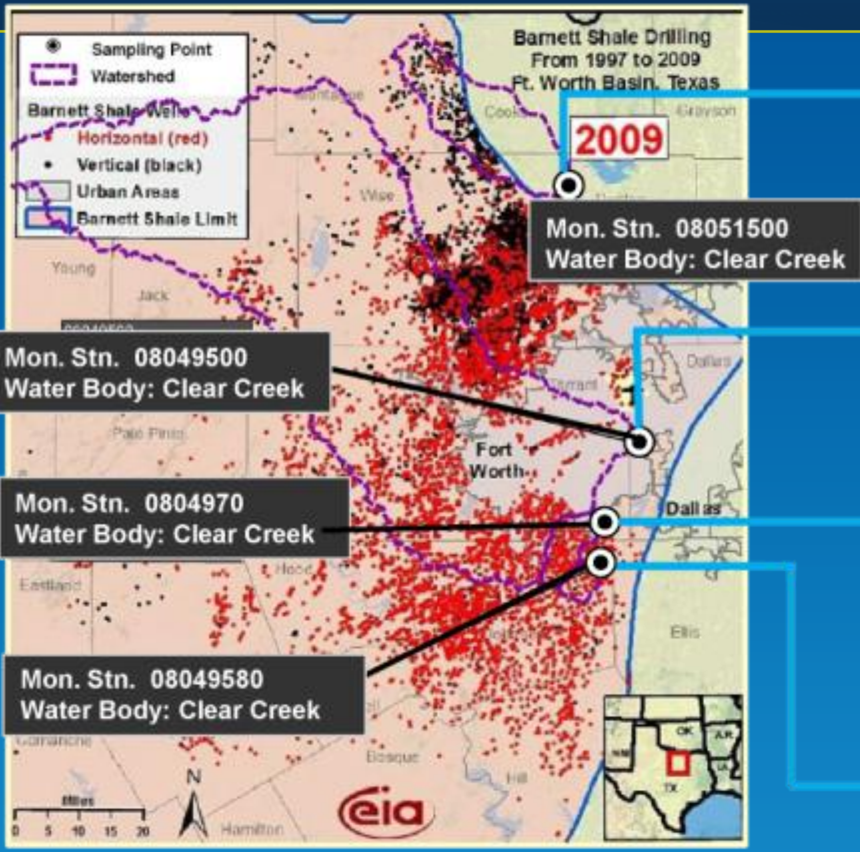
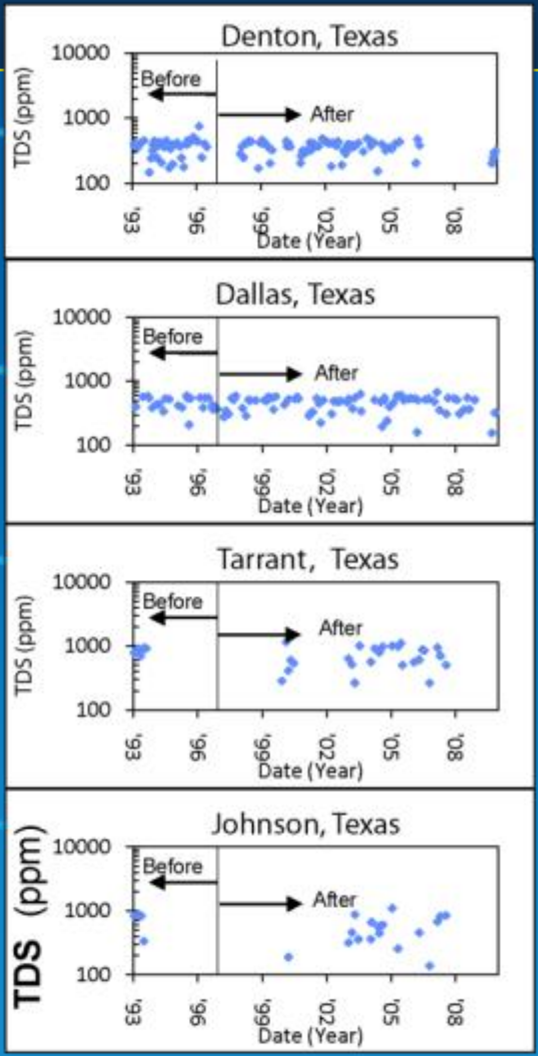
Barnett Shale: Surface Water Quality, 1990's - Today





TDS = Total Dissolved Solids

- **KEY POINT: Actual monitoring records show no change in surface water TDS before and after shale gas development.**

Source: EIA, GSI Environmental, Houston, Texas, 2010

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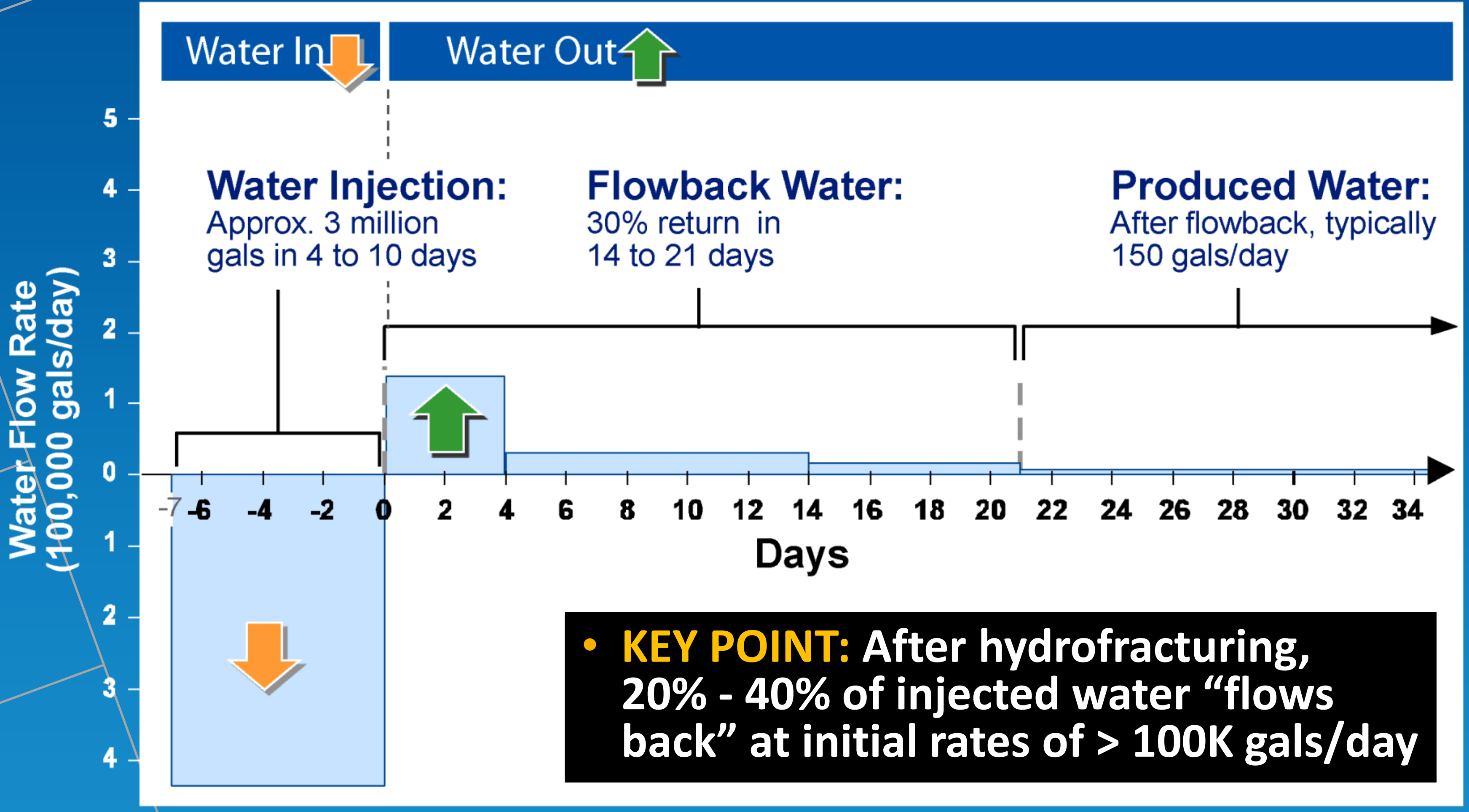
Shale Gas: Fast Rate of Water "Flowback"



- **KEY POINT:** After hydrofracturing, 20% - 40% of injected water "flows back" at initial rates of > 100K gals/day

Source: GSI Environmental, Houston, Texas, 2010

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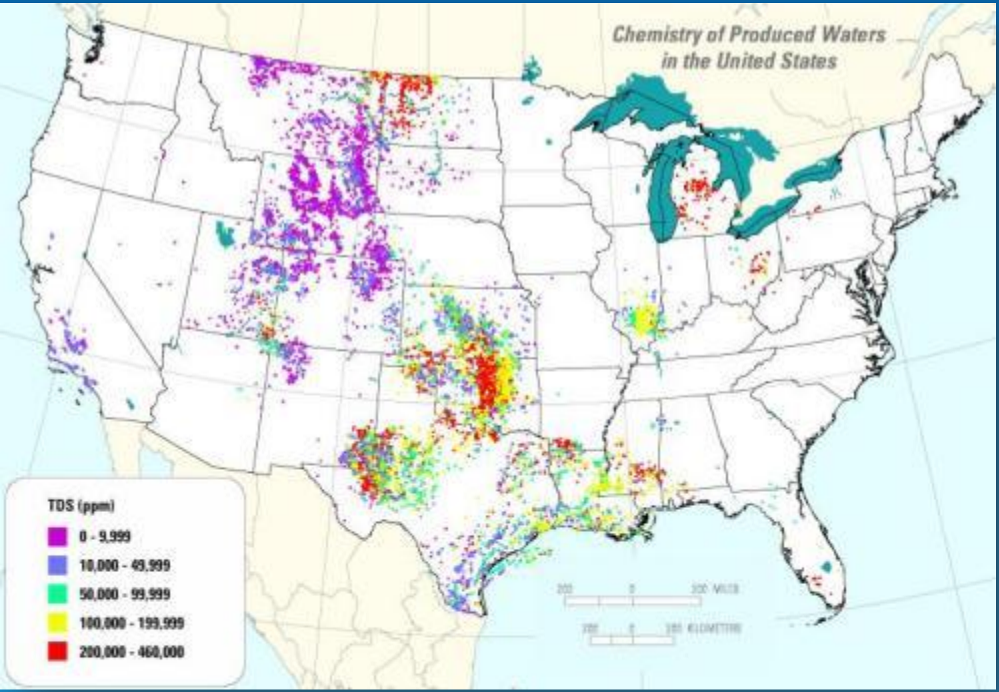
Total Dissolved Solids from the Produced Water Database in the United States

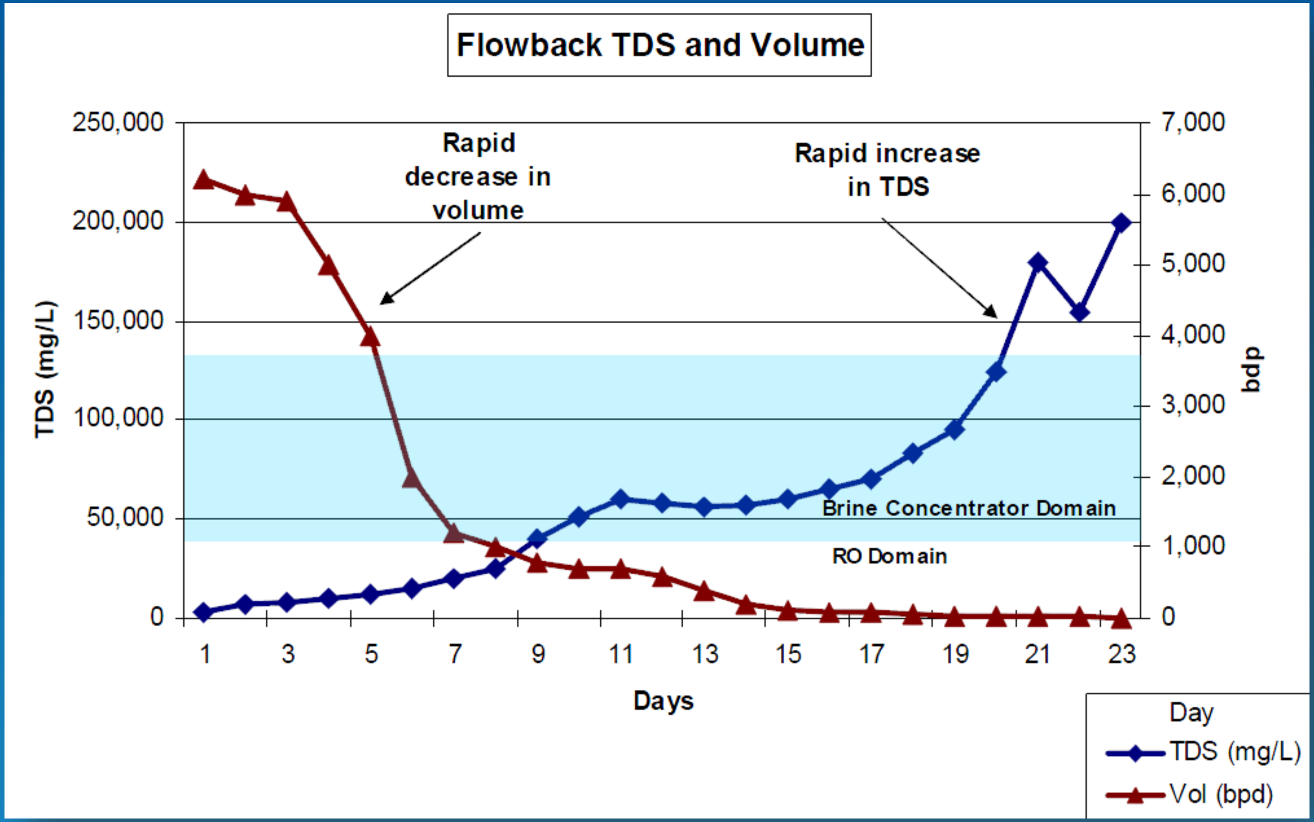
- Typical Produced Water TDS Levels – Selected Areas
  - Powder River CBM – 1200 mg/l
  - San Juan CBM – 4500 mg/l
  - Greater Green River – 8000 mg/l
  - Fayetteville Shale – 25,000 mg/l
  - Barnett Shale – 60,000 mg/l
  - Woodford Shale – 110,000 mg/l
  - Haynesville Shale – 120,000 mg/l
  - Permian Basin – 140,000 mg/l
  - Marcellus Shale – 180,000 mg/l



Source: USGS

Marcellus Flowback Characteristics

As frac water spends an increasing amount of time in the ground it transitions from fresh water to salty brine, dissolving salt compounds in the earth. Over time, volume decreases and TDS increases.



Source: Siemens AG 2009

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Current Produced Water Management by Shale Gas Basin

Shale Gas Basin	Water Management Technology	Availability	Comments
Barnett Shale	Class II injection wells[303]	Commercial and non-commercial	Disposal into the Barnett and underlying Ellenberger Group[304]
	Recycling[305]	On-site treatment and recycling	For reuse in subsequent fracturing jobs [306]
Fayetteville Shale	Class II injection wells[307]	Non-commercial	Water is transported to two injection wells owned and operated by a single producing company [308]
	Recycling	On-site recycling	For reuse in subsequent fracturing jobs[309]
Haynesville Shale	Class II injection wells	Commercial and non-commercial	
Marcellus Shale	Class II injection wells	Commercial and non-commercial	Limited use of Class II injection wells[310,311]
	Treatment and discharge	Municipal waste water treatment facilities, commercial facilities reportedly contemplated[312]	Primarily in Pennsylvania
	Recycling	On-site recycling	For reuse in subsequent fracturing jobs[313]
Woodford Shale	Class II injection wells	Commercial	Disposal into multiple confining formations[314]
	Land Application		Permit required through the Oklahoma Corporation Commission[315]
	Recycling	Non-commercial	Water recycling and storage facilities at a central location[316]
Antrim Shale	Class II injection wells	Commercial and non-commercial	
New Albany Shale	Class II injection wells	Commercial and non-commercial	

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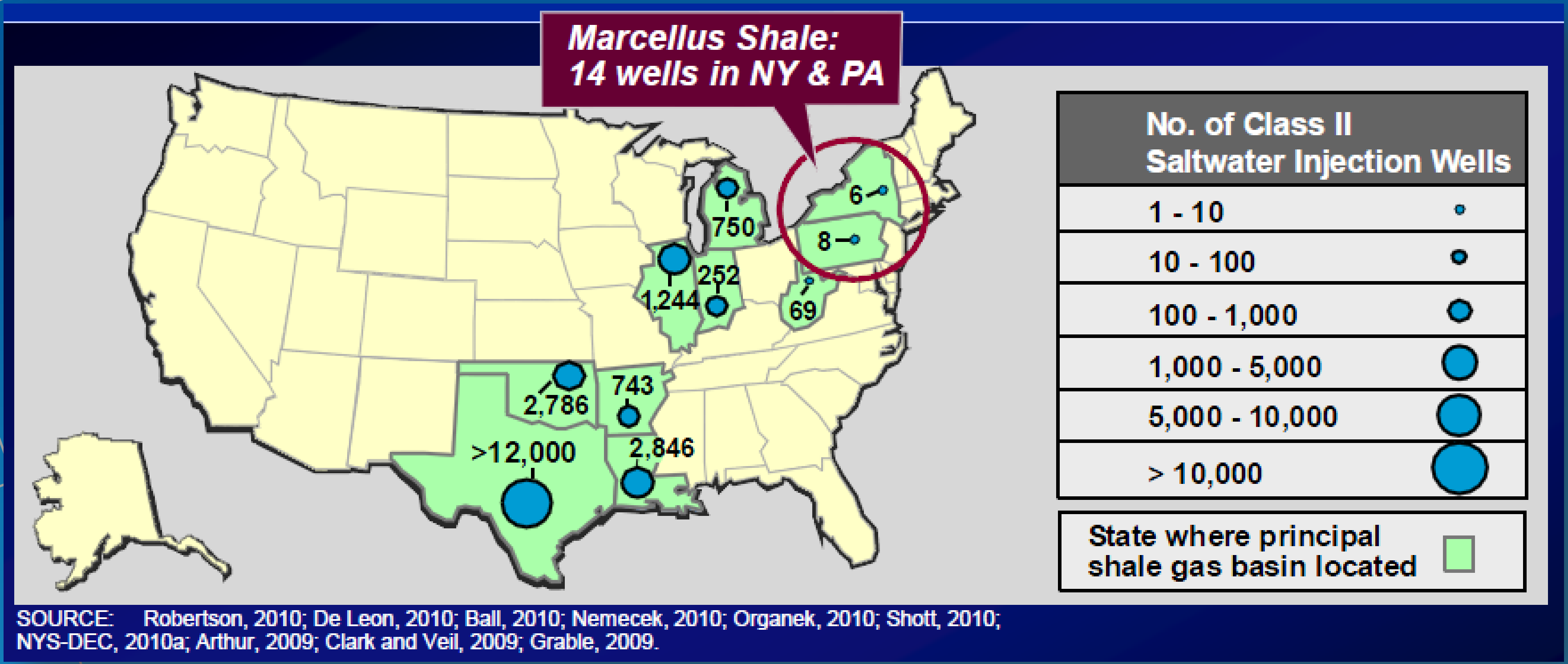
Shale Gas:
Insufficient Injection Well Capacity in Northeast



- **KEY POINT: Very few Class II injection wells in Marcellus, requiring alternative methods of water disposal**

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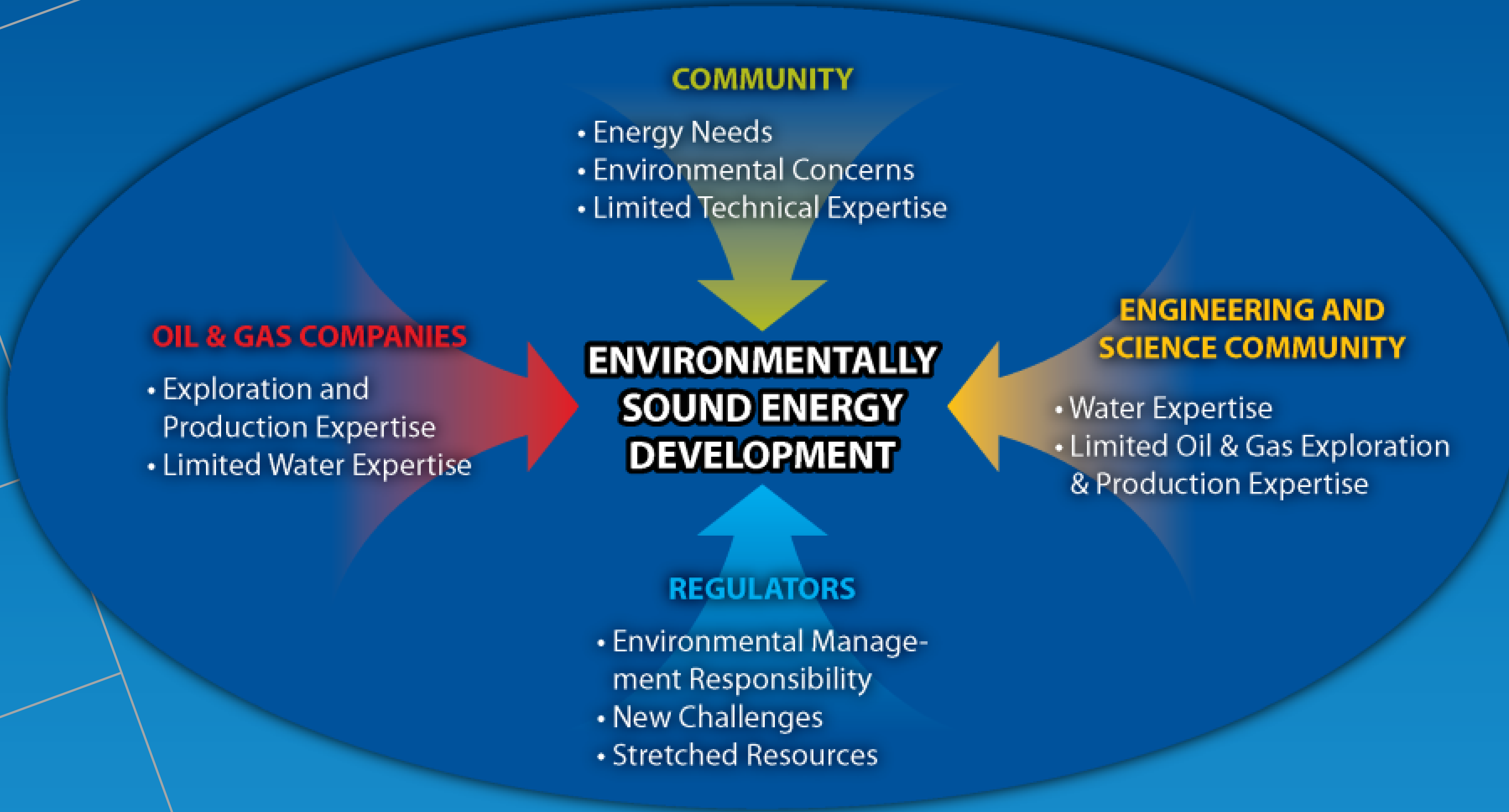
Treatment Technologies – Treatment Options

Technology	Bact.	CH3OH	O/G	DRO	GRO	TA	HCO3-	TH	Ca	Mg	Fe	Ba	St	SO4	Cl	TDS	TSS	Poly mers
API Separators			X															
Dissolved Gas Flotation				X	X													
Activated Carbon			X	X	X													X
Nut Shell Filters			X															
Organi-Clay Adsorbants			X															
Chemical Oxidation	X										X							X
UV Disinfection	X																	
Biological Processes			X	X	X													
Air Stripper					X	X	X											
Chemical Precipitation								X	X	X	X	X	X	X				
Lime/Soda Softening	X					X	X	X	X	X	X							
Clariifers																	X	
Settling Ponds																	X	
Ion Exchange								X	X	X	X	X	X	X	X	X		
Multi- Media Filtration																	X	
Membrane Filtration	X																X	
Greensand Filters	X										X							
Cartridge Filters																	X	
Reverse Osmosis						X	X	X	X	X				X	X	X		
Evaporation								X	X	X	X	X	X	X	X	X		
Steam Stipping		X		X	X													
Acidification						X	X											

Oil and Gas / Water Knowledge Convergence



Questions and Answers

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