The American Shale Revolution

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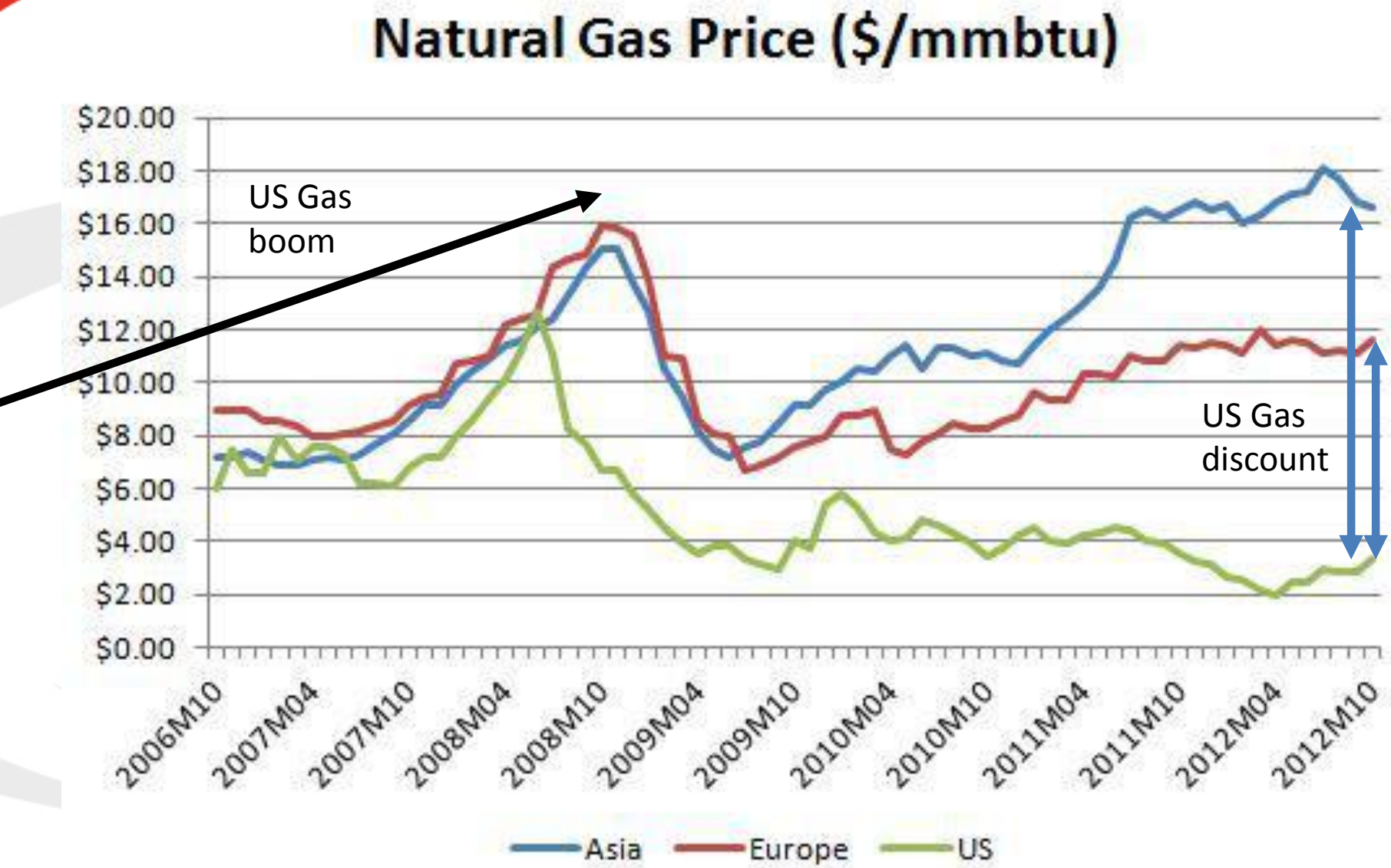
October 2, 2014

The House that Frac'ing built

Georgia instead of China

Cheap energy in the US more than offsets cheaper labor costs in emerging market economies

Gas Prices by Region



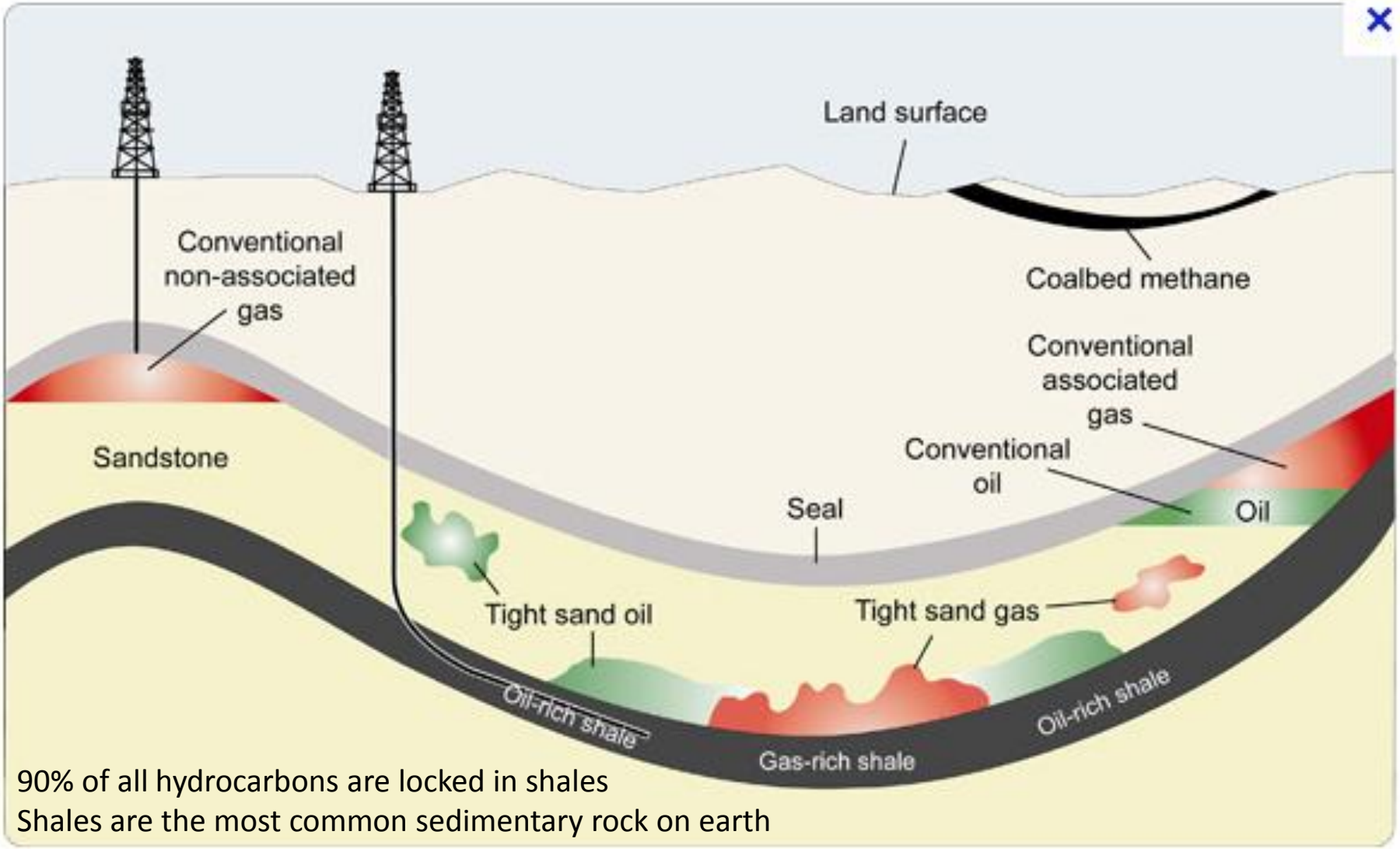
Shale Revolution – What Is It?

- Two technological innovations have unlocked vast natural gas and oil reserves from previously unproductive shale rocks
  - High-rate, low-viscosity network hydraulic fractures
  - horizontal drilling w/ multi-zone isolation fracturing
- Or, we are now able to create our own plumbing in very low-permeability shale
- Shales are the source rocks & contain the **vast** majority of the world's oil & gas

Shale Revolution – What Does It Mean?

- US Energy production has soared
- US energy prices have plummeted, saving average US households $1,500/year
- US is #1 natural gas producer – 50% from shale
- US now #3 oil producer – 40% from shale
- All with private capital, market forces (winners & losers), smaller "footprint" than older production
- Dominant Driver of reduction of US per capita CO2 emissions to 1964 level!
- Greater than 2X energy cost advantage over all industrialized nations
- Launching an Industrial renaissance in US

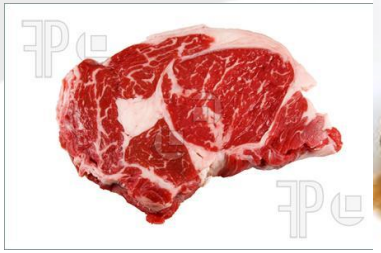
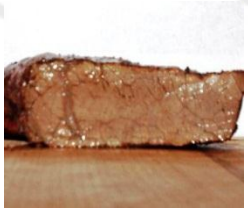
Conventional vs Unconventional Reservoirs



90% of all hydrocarbons are locked in shales
Shales are the most common sedimentary rock on earth

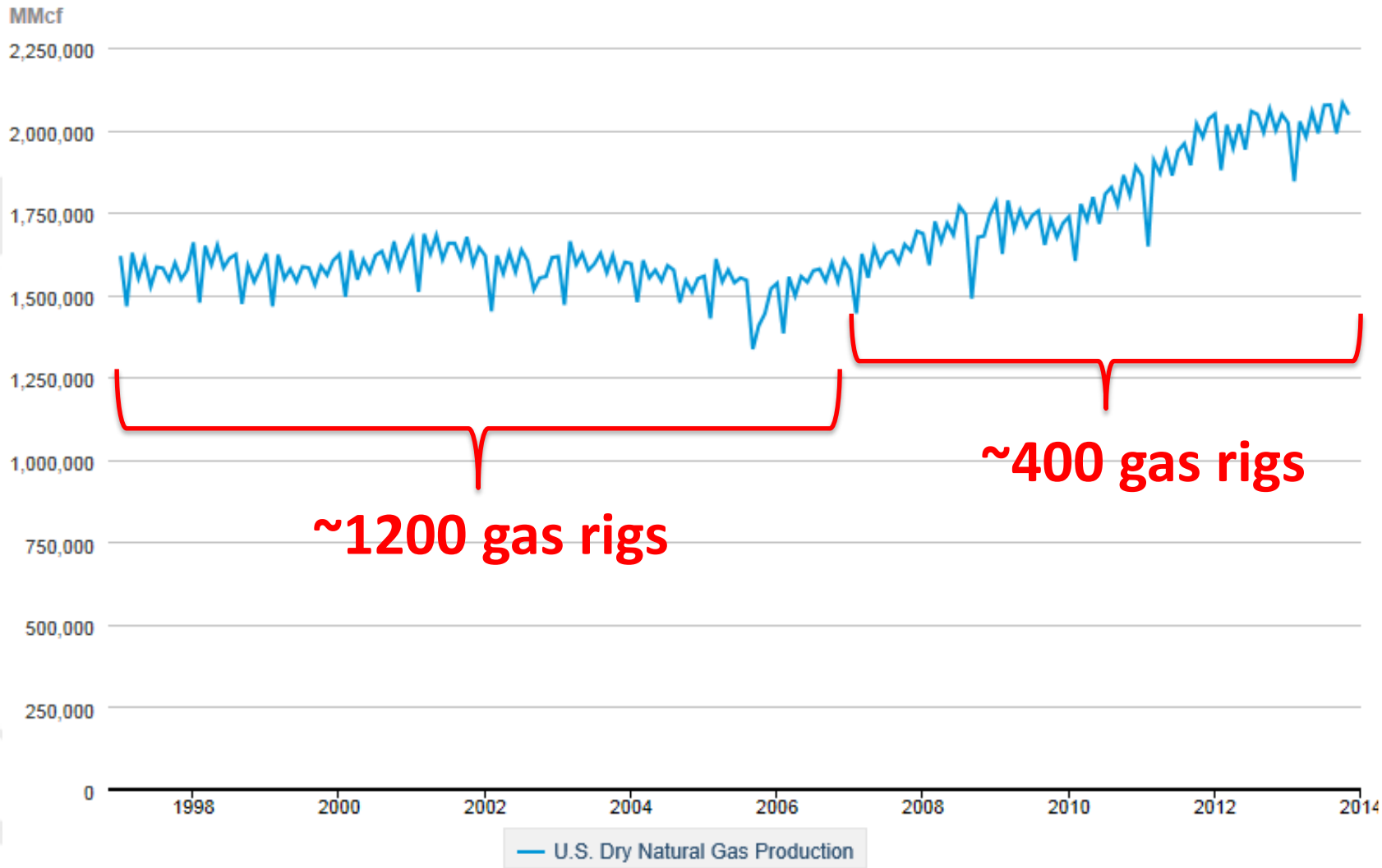
Gas is More Plentiful & Easier to Produce than Oil

- A lot of reservoirs are overcooked

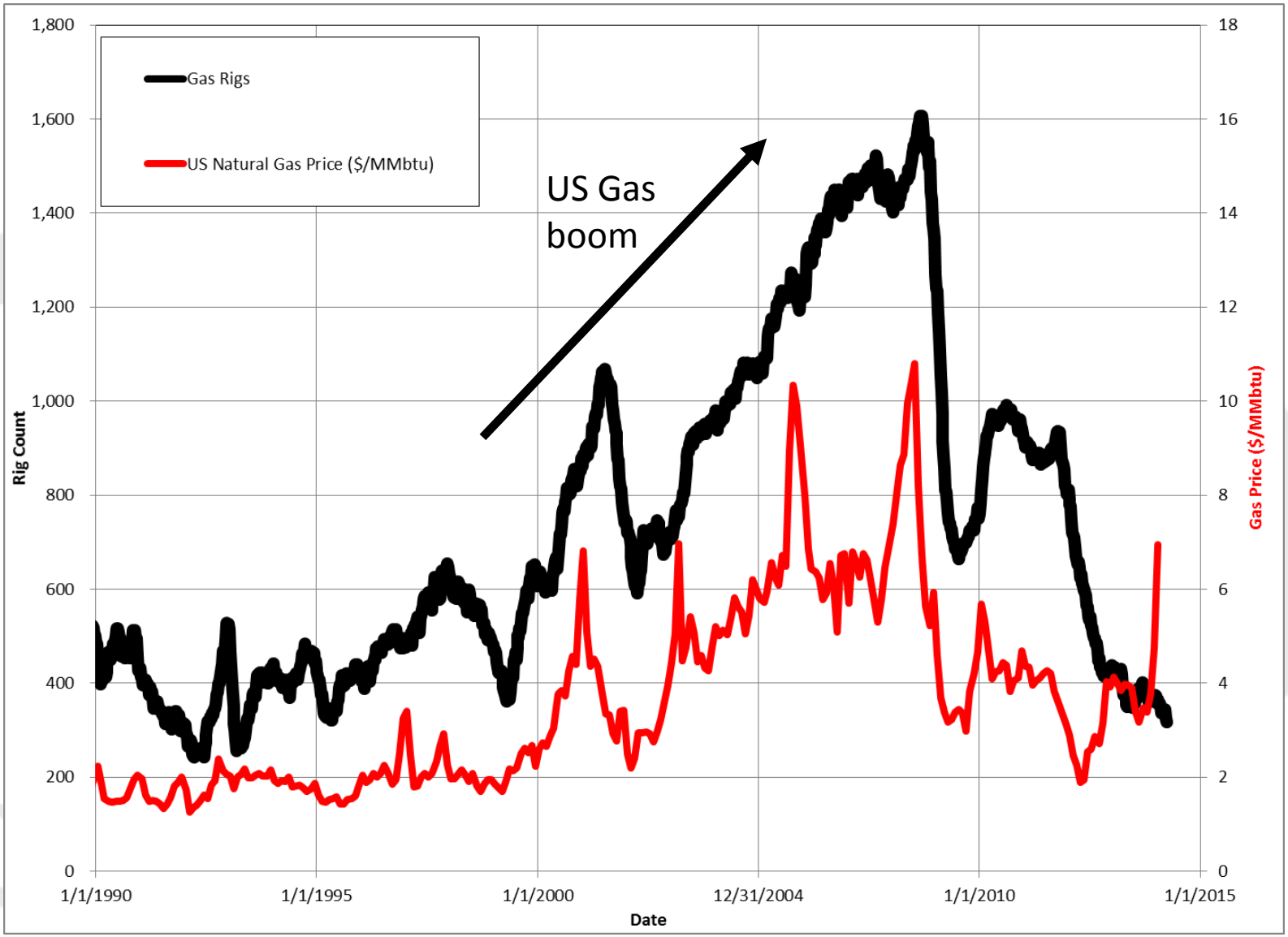
Raw	Rare	Medium rare	Medium	Well-done
				
Kerogen	Heavy / Dead Oil	Light Oil	NGLs	Gas

Cooking time / temperature

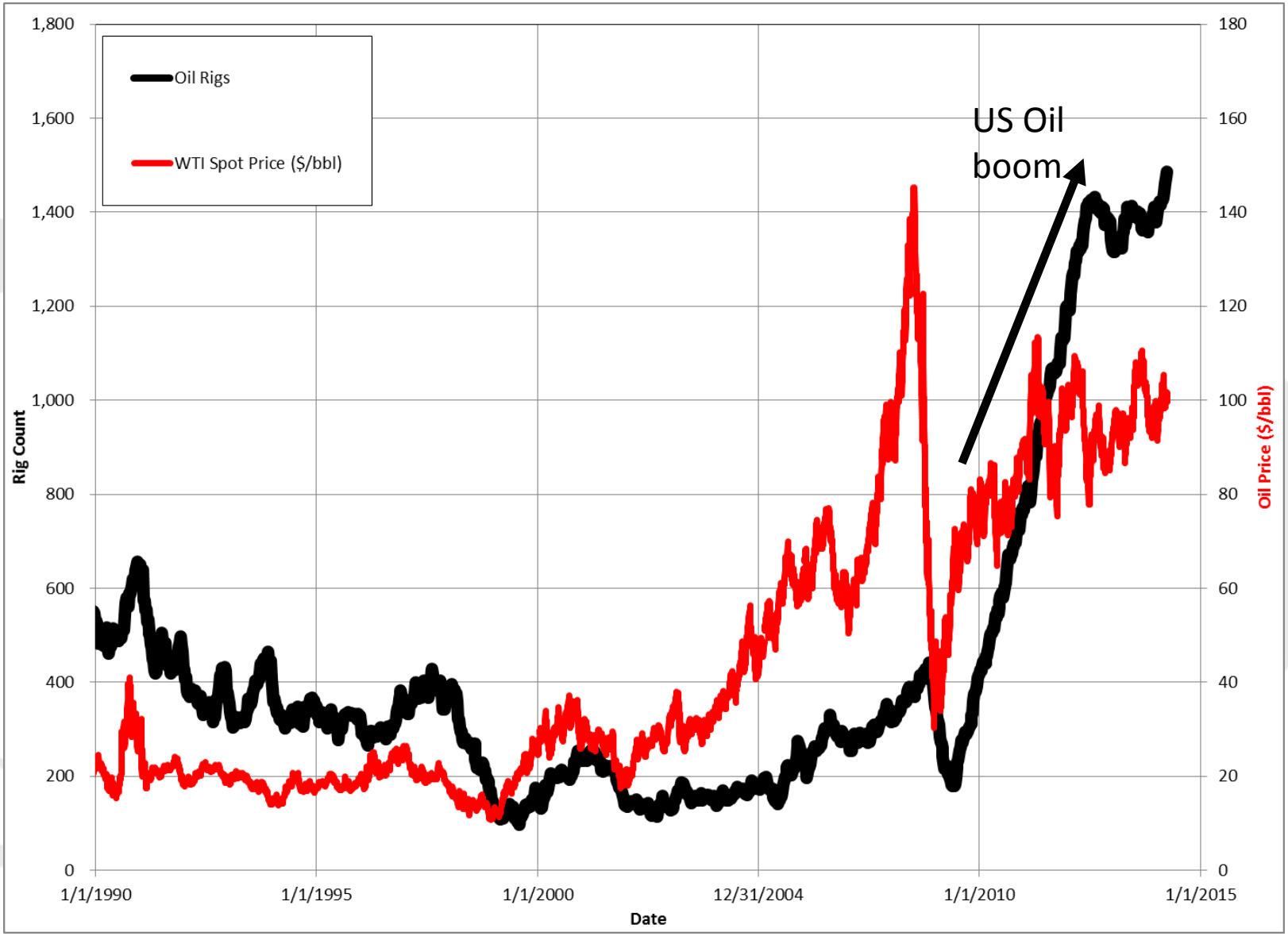
17 Years of US Gas Production
Significant Efficiency Improvements



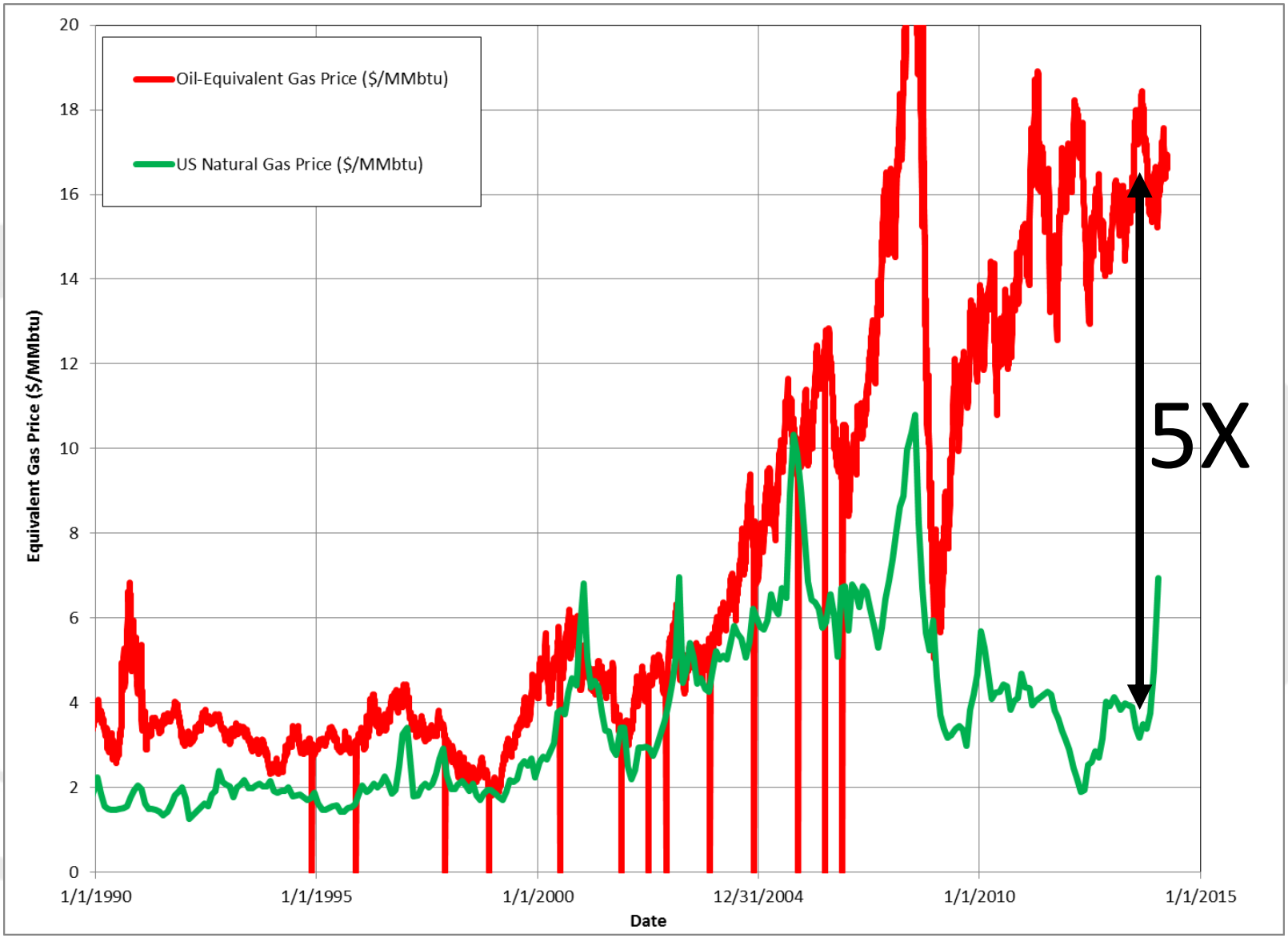
Gas Price/Rig Count History



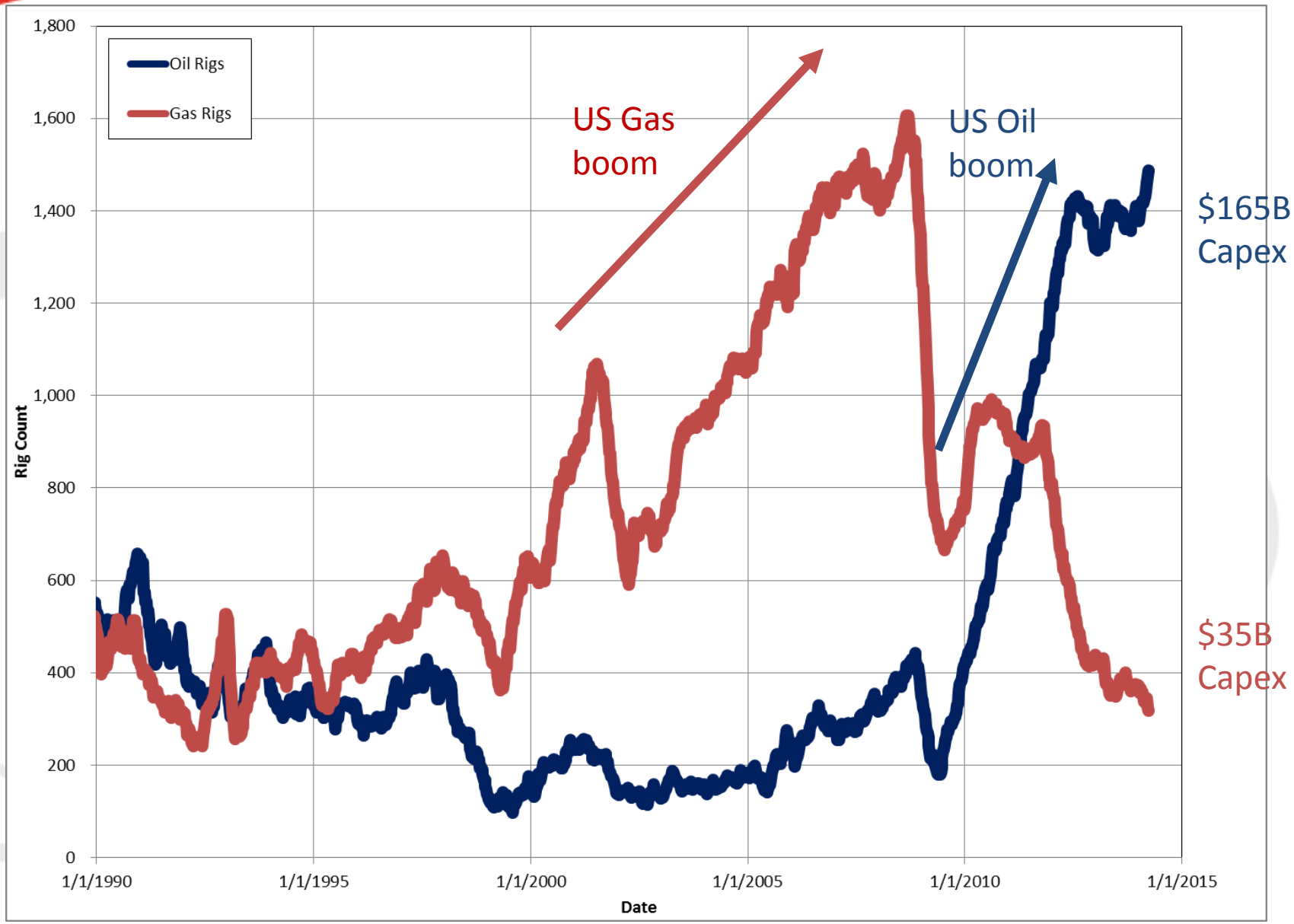
Oil Price/Rig Count History



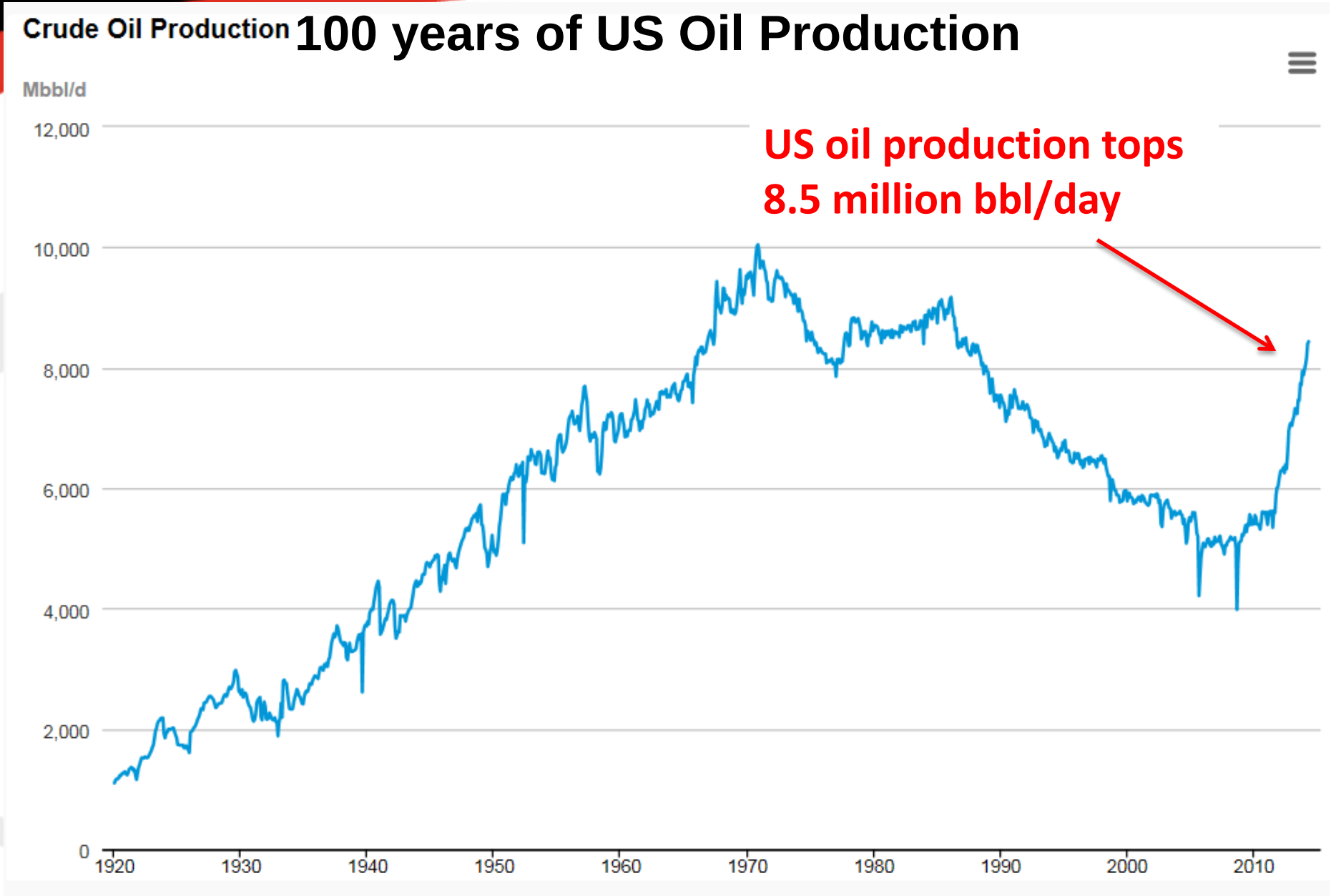
Gas / Oil Prices History



Gas / Oil Rig Count History



100 years of US Oil Production



Cheap Energy Builds US Businesses

U.S. PetChems: Retooling and Expanding

Announced Incremental C_2 Demand Ranges from 600–750 MBPD

ExxonMobil

Filed permits to expand Baytown ethylene complex by ≈1.5 MM mt/yr as soon as 2016

Source: Company statement June 2012

CP Chemical

CEO announced permits filed for 1.5 MM mt/yr ethylene plant at Cedar Bayou, TX to be completed in 2017

Source: Company statement December 2011

Dow Chemical

$4 billion investment to build 1.5 MM mt/yr ethylene plant plus 1–2 on purpose propylene plants in USGC in 2017

Source: Company announcement April 2012

Lyondell Basell

Over $1 billion in projects to expand ethylene capacity by 18%, EBITDA impact of $600–$700 million per year

Source: Company Investor Day March 2013

Formosa Plastics

$1.7 billion investment to build 800K mt/yr ethylene plant, 600K mt/yr PDH and 300K mt/yr polyolefin plant in USGC to be completed in 2016–2017

Source: Company announcement March 2012

Sasol

Announces front-end engineering / design for an integrated 96 MBPD GTL plant in 2018 / 2019 and in 2017 a 1.5 MM mt/yr ethylene plant in Lake Charles, LA

Source: Company statement December 2012

American Chemistry Council estimates that over 50 new chemical projects (valued at over $40 billion) have been announced

Source: Individual Company Press Releases

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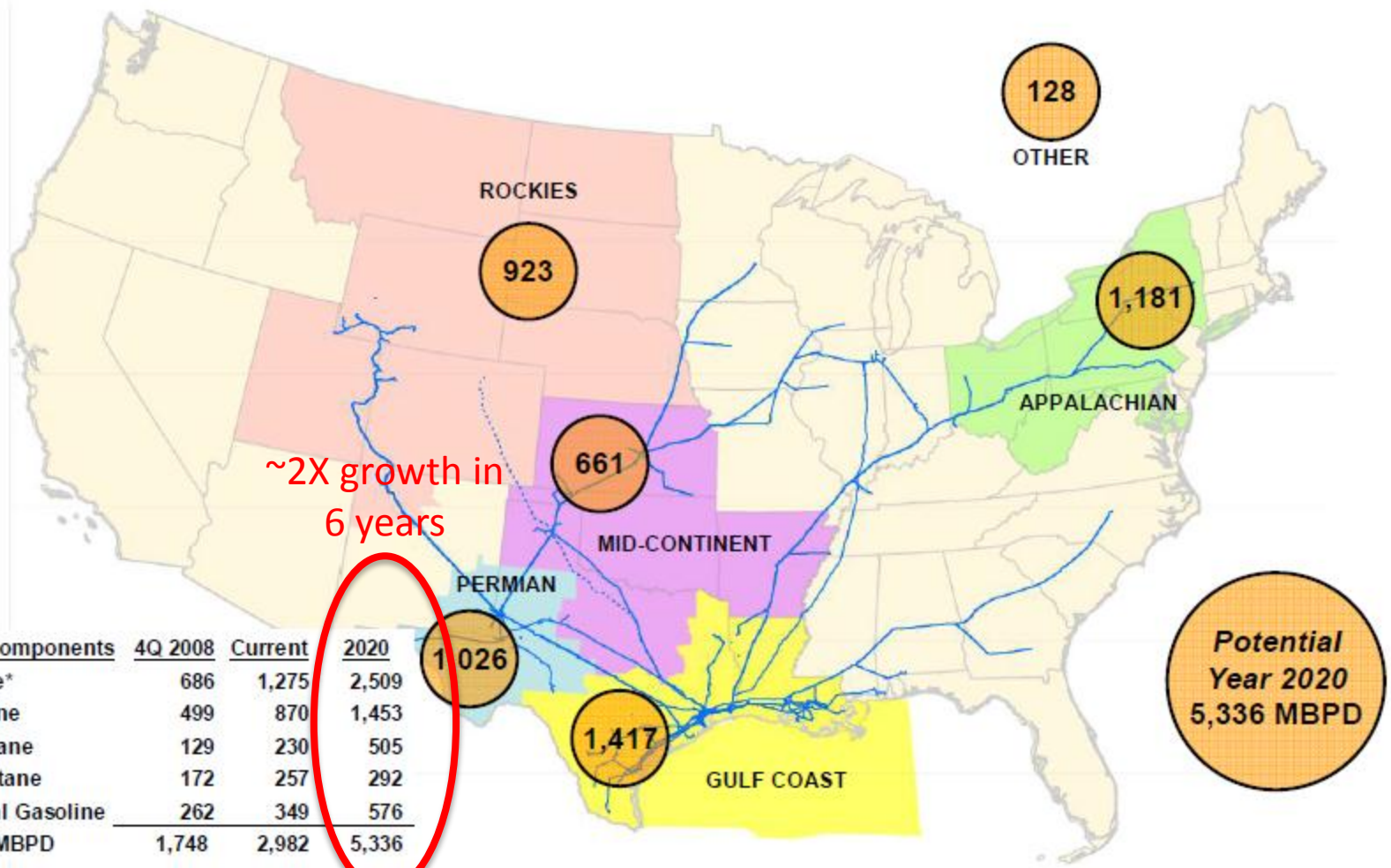
U.S. NGL Supply ***Potential*** Assuming Sufficient Markets (MBPD)



NGL Components	4Q 2008	Current	2020
Ethane*	686	1,275	2,509
Propane	499	870	1,453
N. Butane	129	230	505
Iso Butane	172	257	292
Natural Gasoline	262	349	576
MBPD	1,748	2,982	5,336

** Current is increased by 200–250 MBPD for estimated ethane rejection*

Source: EPD Fundamentals

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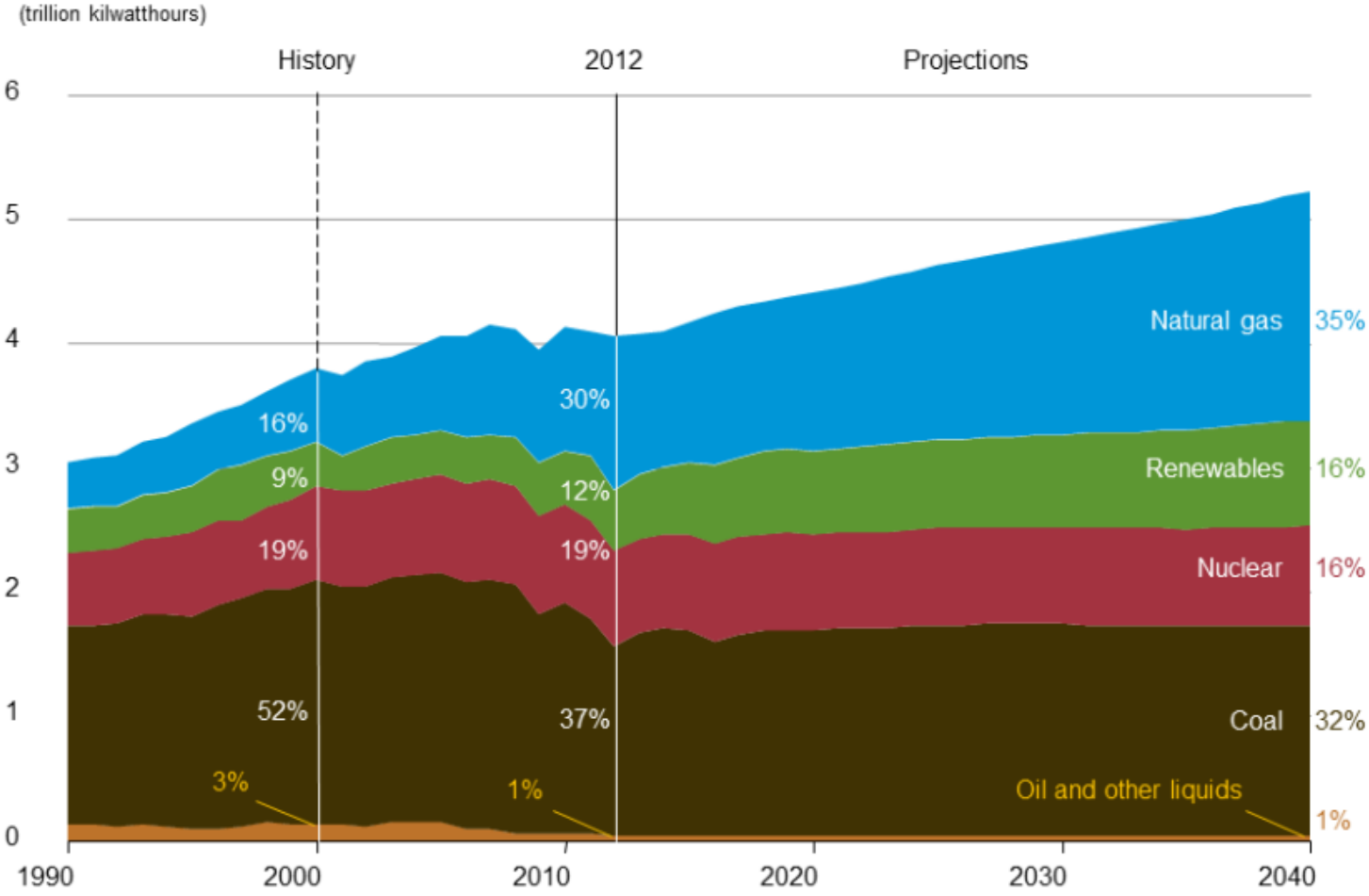
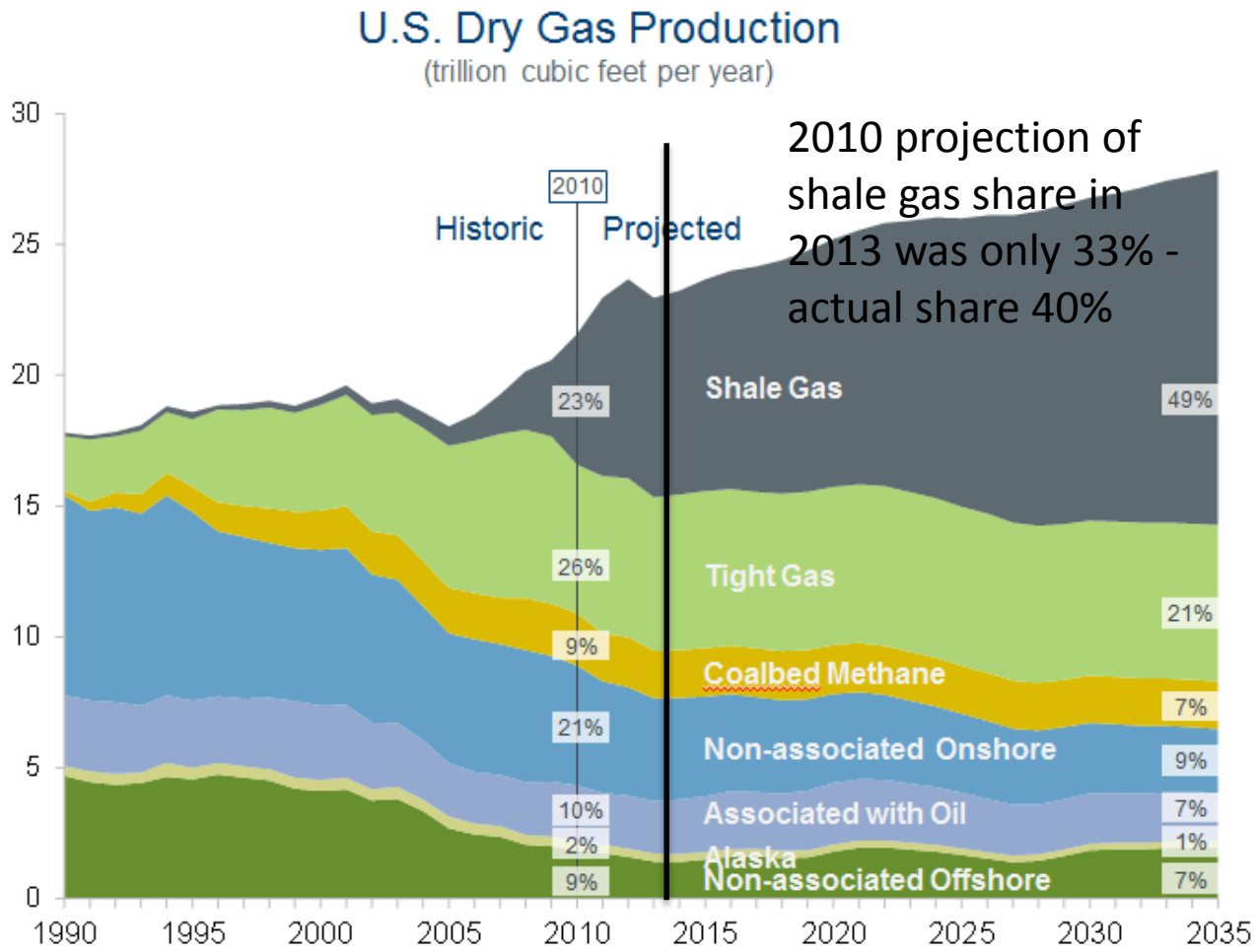
Natural Gas Share of US Electricity Generation

Figure 13. Electricity generation by fuel, 1990-2040



Shale Gas Share of US Gas Production

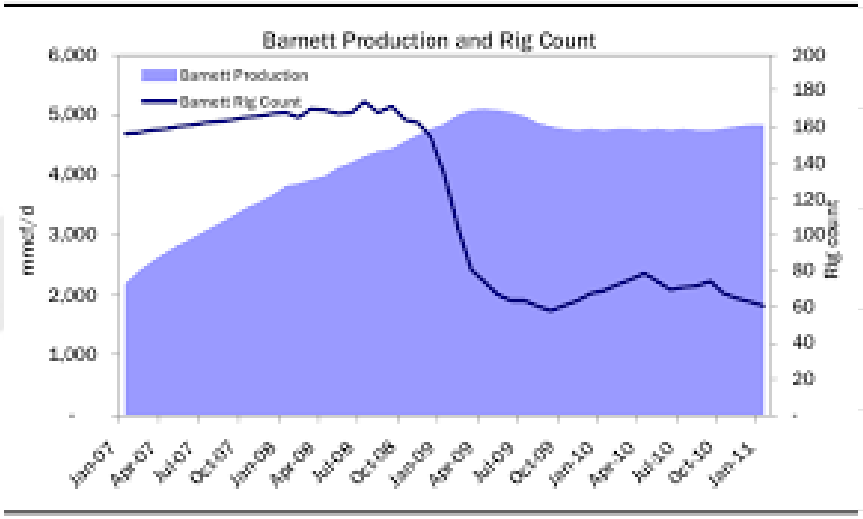


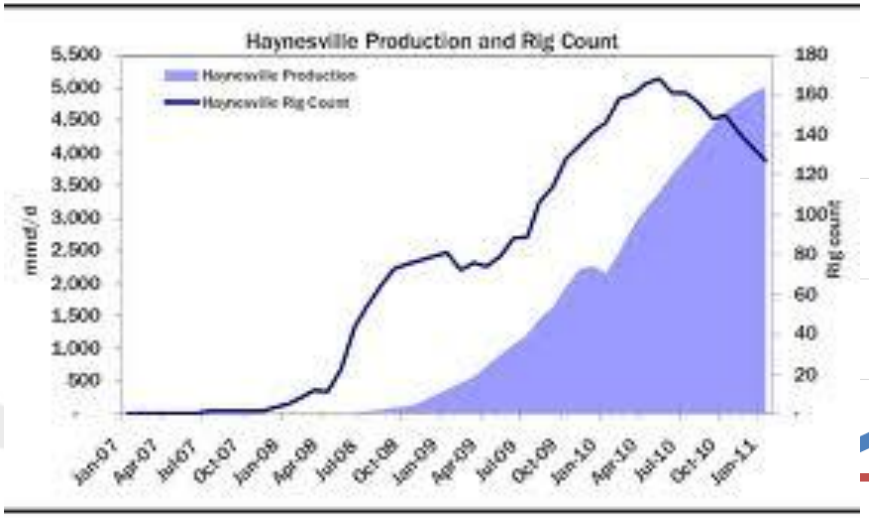
Source: EIA Annual Energy Outlook: 2012 (Early Release)

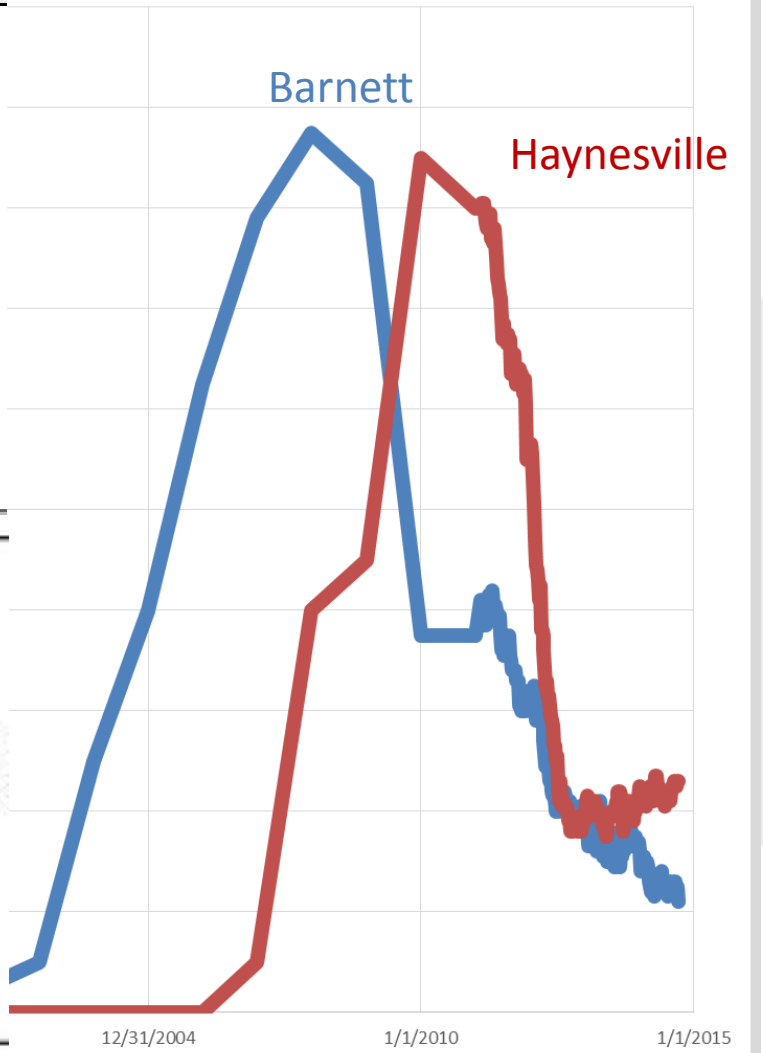
anga America's Natural Gas Alliance

Haynesville & Barnett Rig Count

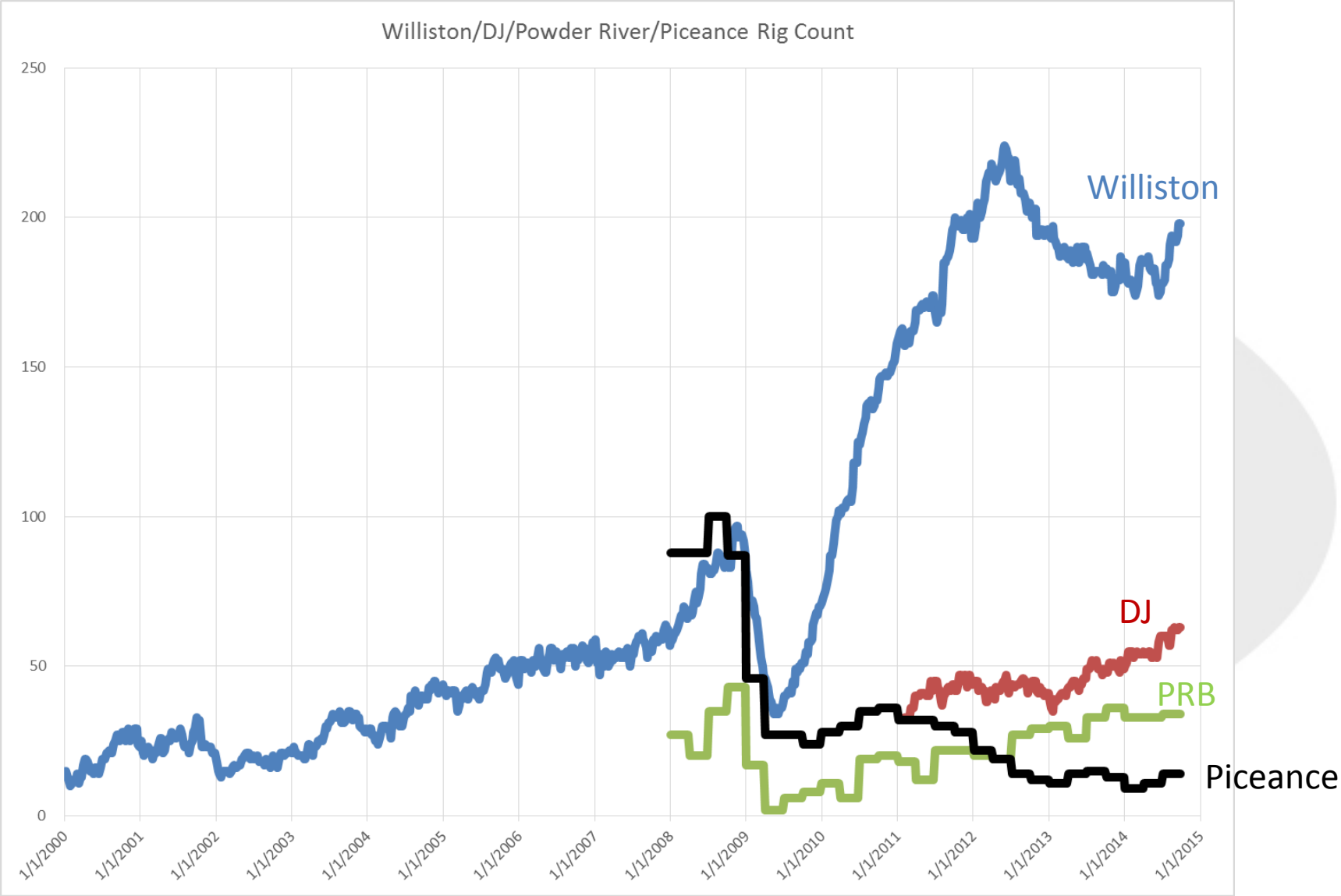
Efficiencies Lead to Reduction in Rig Count while Maintaining/Growing Production







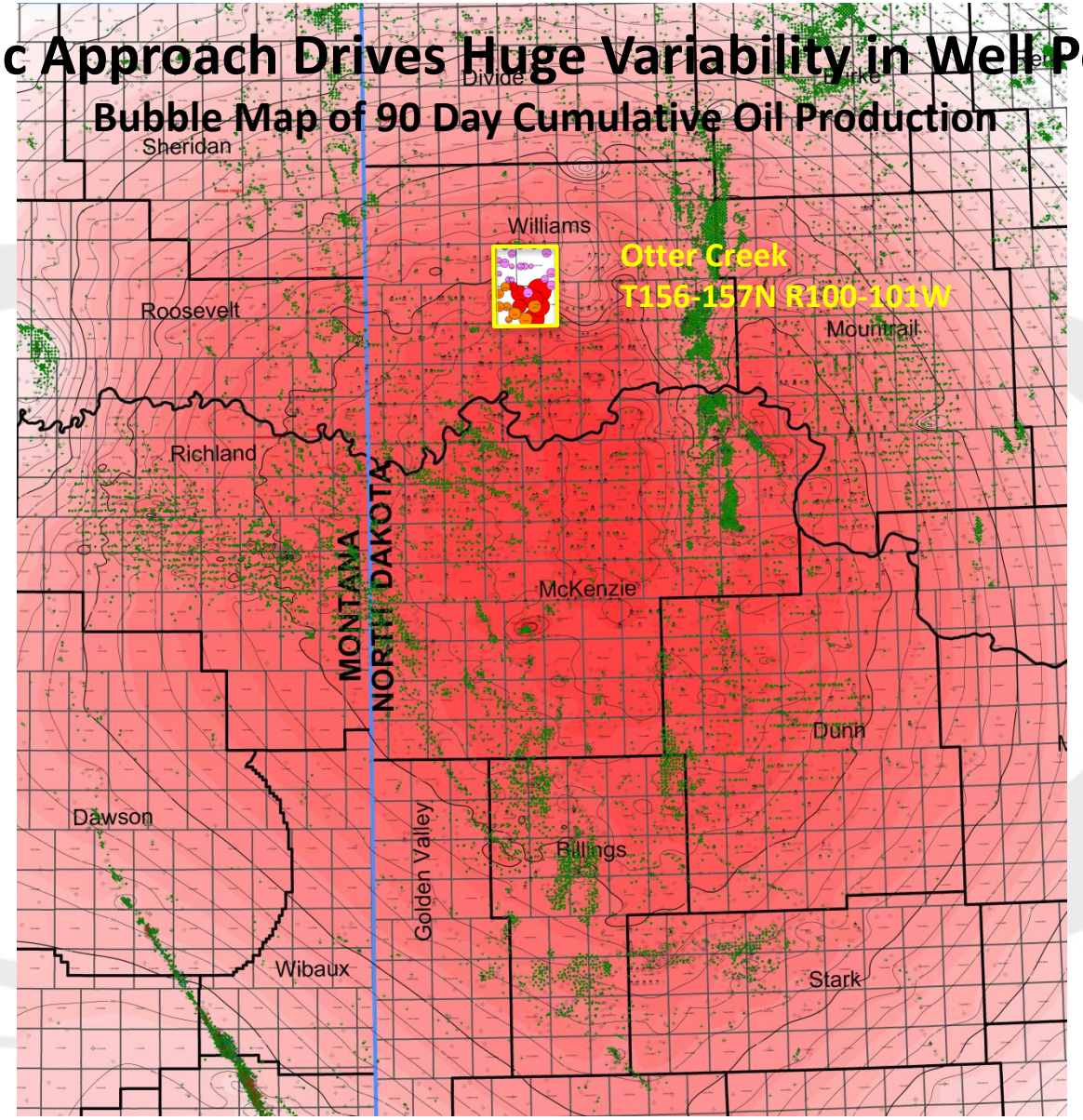
Rockies Rig Count – Focus on Oil



A Frac Is Not a Frac – Central Williams Cty

Specific Frac Approach Drives Huge Variability in Well Performance

Bubble Map of 90 Day Cumulative Oil Production



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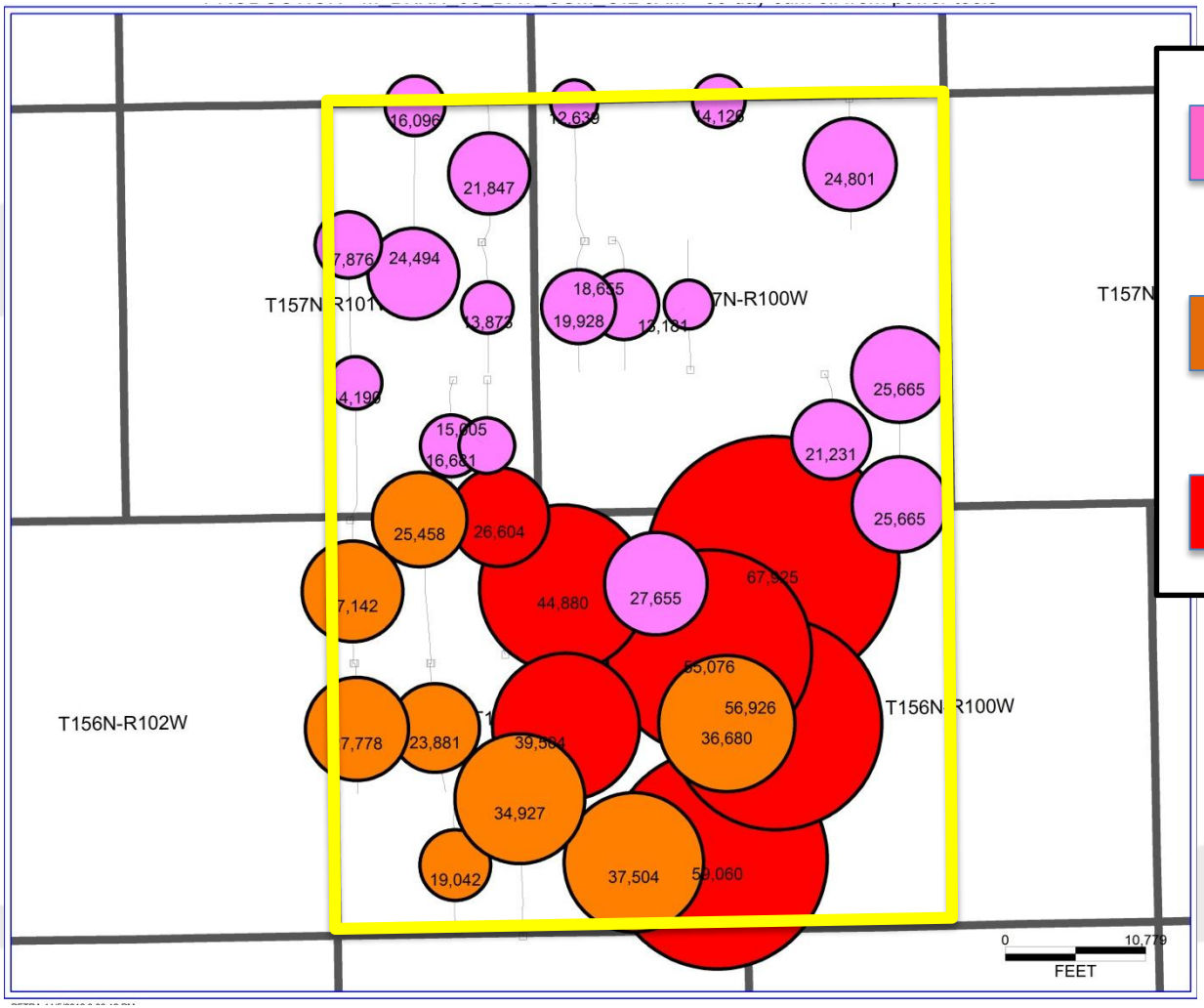


35# X-link gel, sliding sleeves, w/ sand or ceramic

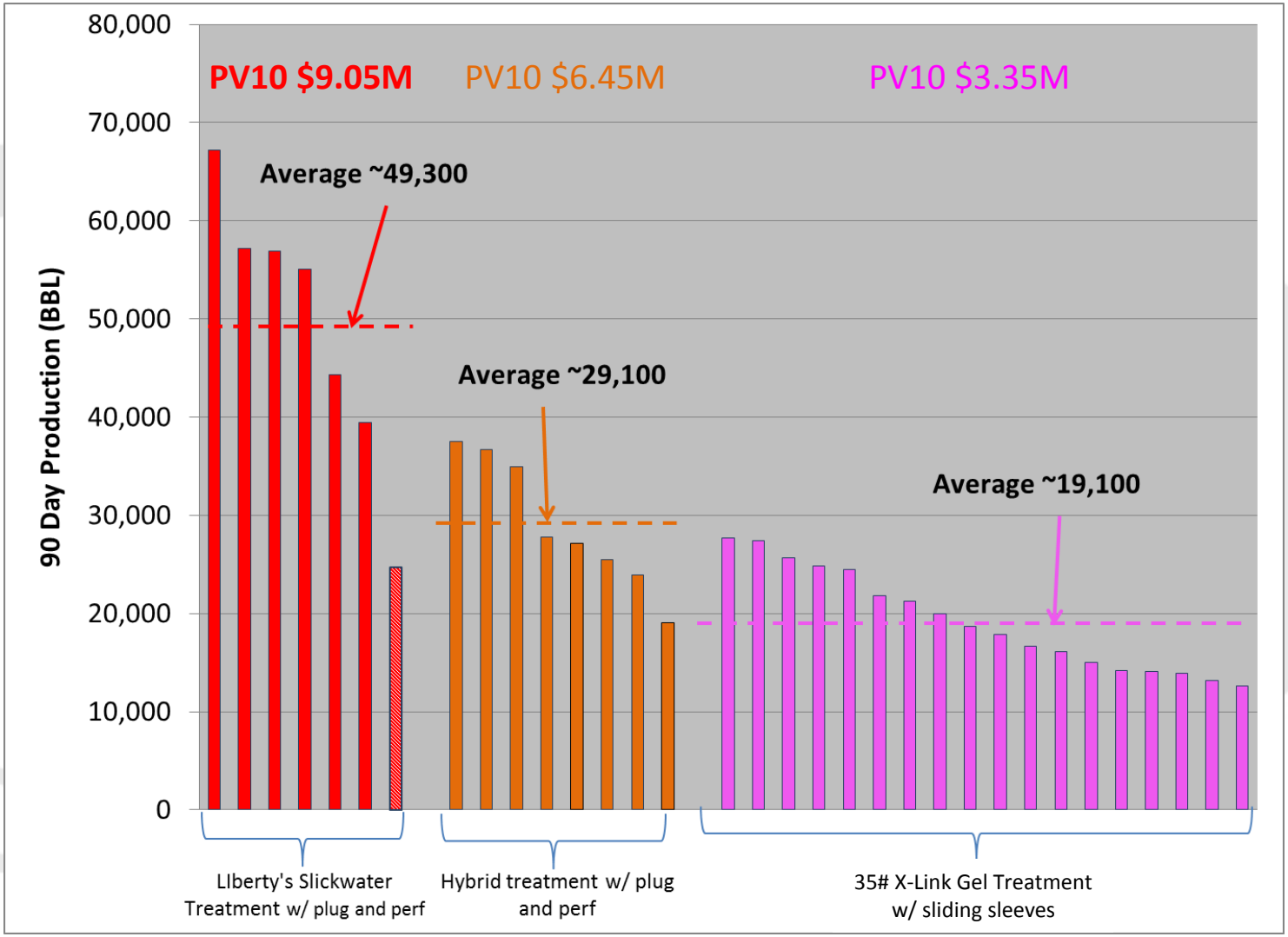
Hybrid, plug & perf, w/ sand and ceramic

Slickwater, plug & perf, w/ ceramic

A Frac Is Not a Frac

Specific Frac Approach Drives Huge Variability in Well Performance

Bar Graph of 90 Day Cumulative Oil Production



What Does It Mean for Garfield County?

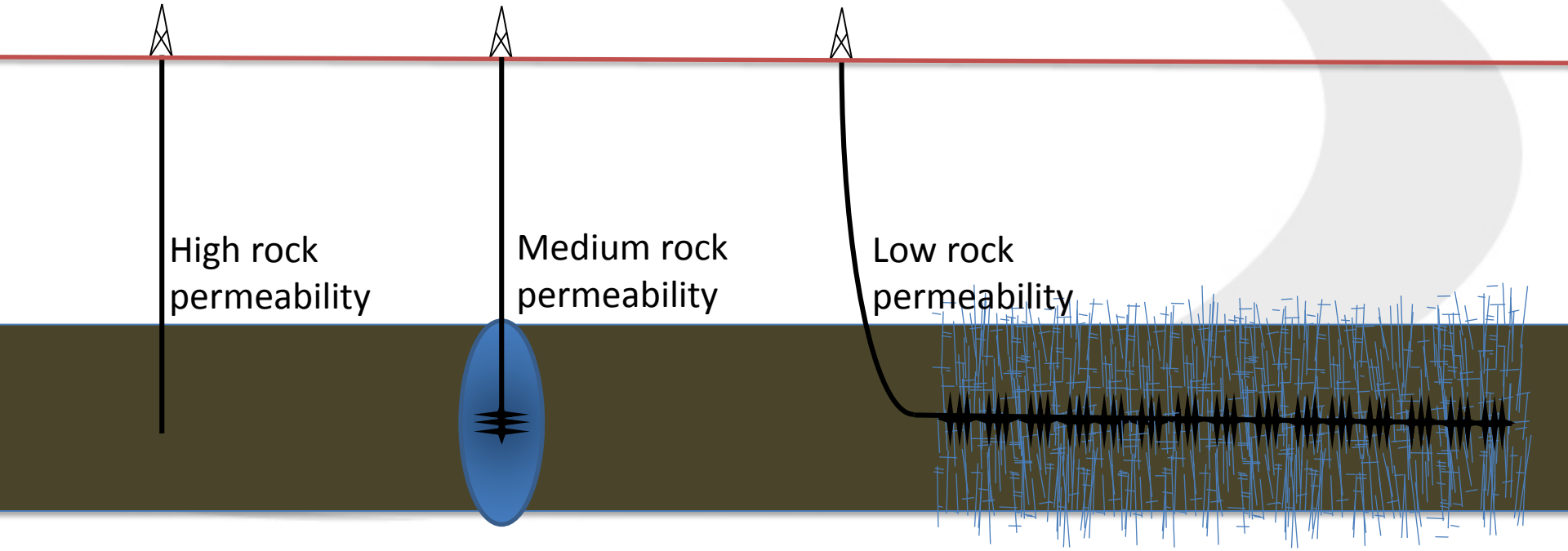
- Natural gas more abundant than ever
  - Natural gas prices have been low through the shale revolution
  - Oil and gas industry has focused on oil
- US gas demand is on the rise
  - Partnership with GTL manufacturers
    - (COVOS clear diesel sample)
    - WPX JV with G2X for methanol and gasoline generation
  - More natural gas for electricity generation
  - Higher US manufacturing needs
  - Increasing exports
- Operators are responsible partners in innovation and oil and gas development
  - Voluntary development of dual liners with leak detection for produced water ponds
  - Championing remote frac'ing operations – reducing truck trips
  - Multi-well pads to reduced "footprint"
- Innovation may hold promise: Early and promising horizontal well development in Niobrara, which is present underneath the entire basin (>1 Bcf in 100 days)

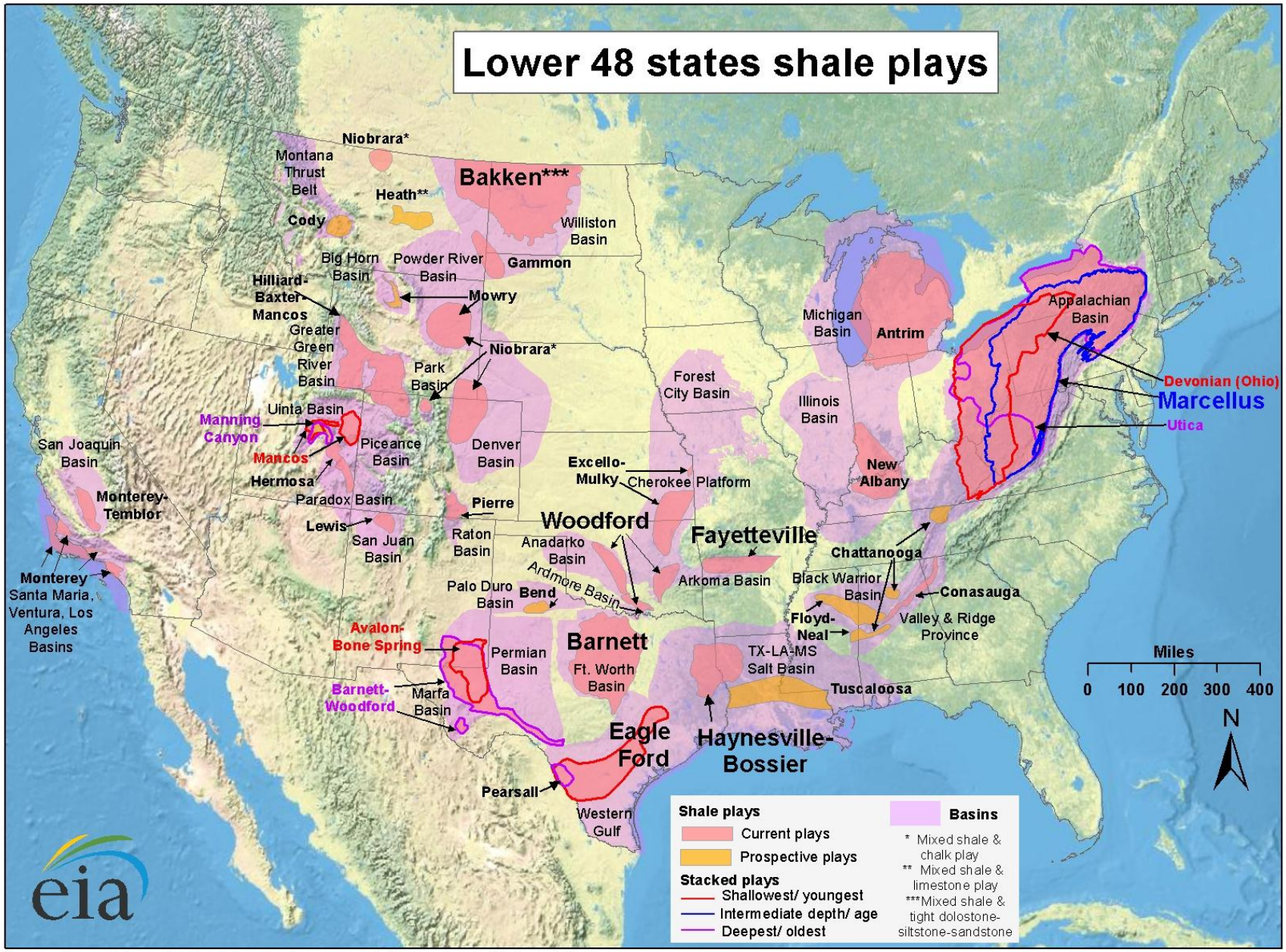
Conclusions

- US Shale Revolution has transformed US and World Energy
- Economic benefit is massive – Biggest benefit is for lower income Americans!
- Environmental footprint of oil & gas production is shrinking and will continue to do so

Installing Plumbing 2 miles Underground

- Oil and gas is formed in shale rocks and most still remains there
- By installing better plumbing we can produce oil & gas from the shales where it was originally created
- No longer need to wait for it to naturally leak out and get trapped in more permeable rocks

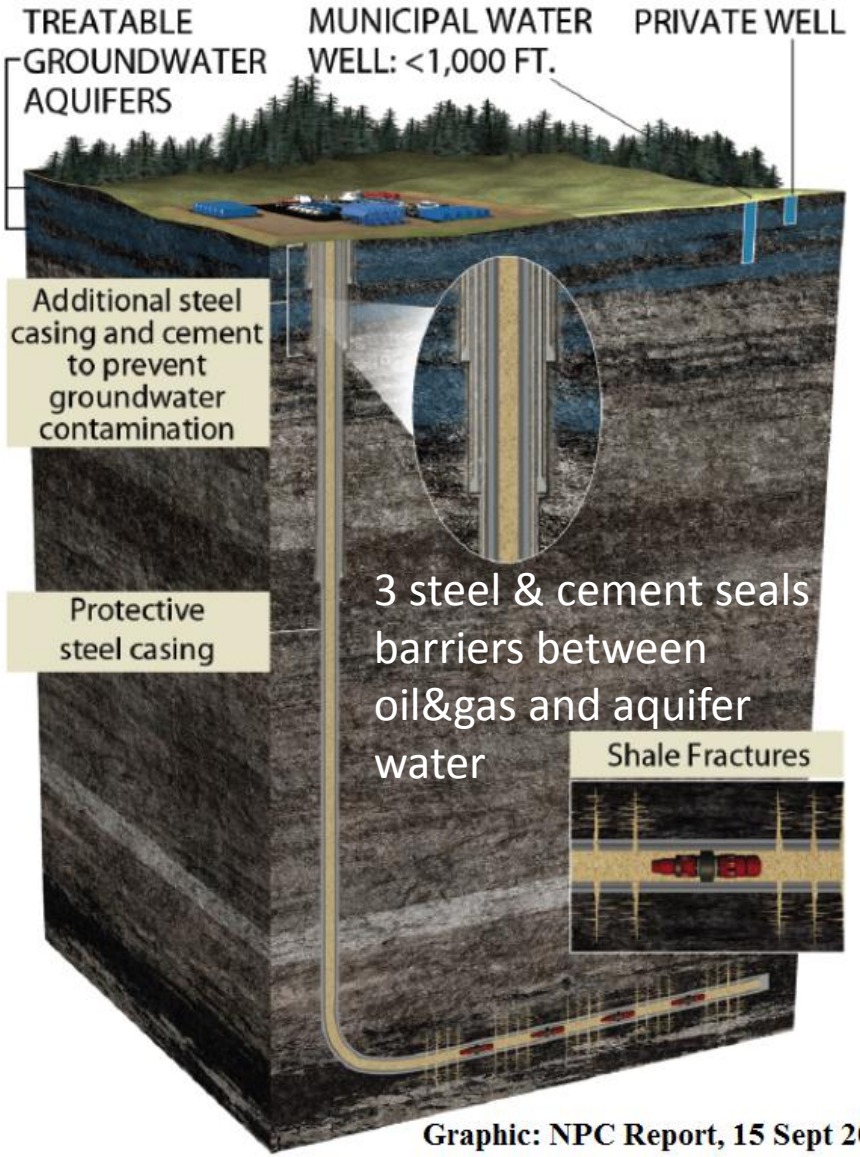




Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Horizontals Drilling and Completions

- Site selection, pad preparation and installation of production facilities
- Set surface conductor and drill and cement surface casing through shallow aquifers
- Drill vertical section and bend, set casing and cement
- Drill horizontal lateral and set liner
- Pressure test and cement bond log for casing integrity test
- Frac, set plug, perforate, frac, set plug, perforate, frac set plug, perforate, frac, set plug, perforate, frac ….
- Initial flow back free flow period (overpressured reservoirs)
- Set production string
- Install wellhead production pump
- Produce for 30+ years



Graphic: NPC Report, 15 Sept 2011

First Commercial Hydraulic Fracture In 1949 near Duncan, OK

Frac'ing in Beverly Hills 90210

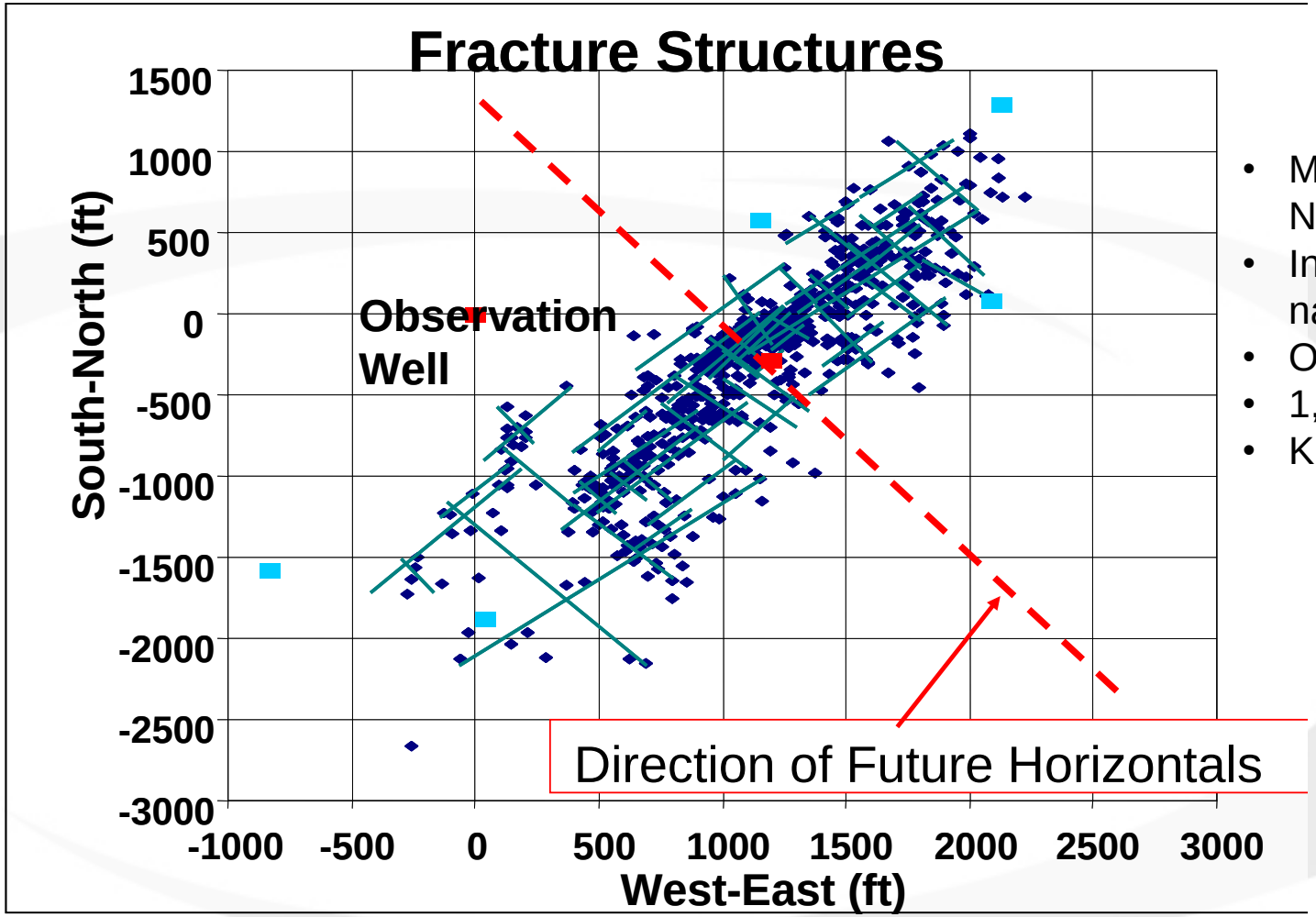
Shale Revolution begins late 1990's in Barnett Shale on north side of Fort Worth, Texas

Barnett Shale rock

Courtesy Dan B. Steward

The Frac that Changed Everything

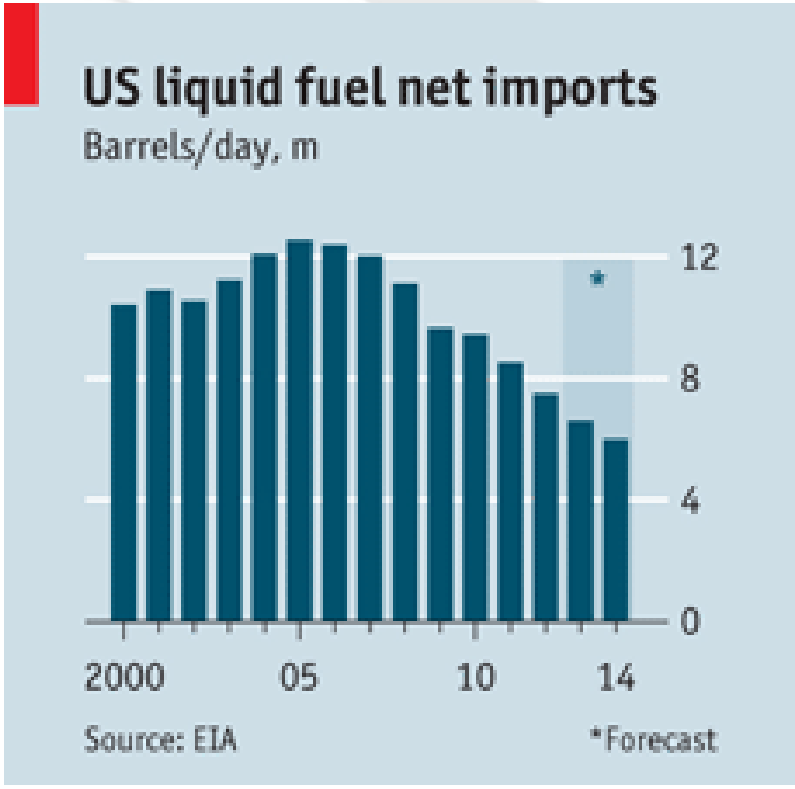
2001 Barnett Shale Vertical (SPE 77441 & 90051)



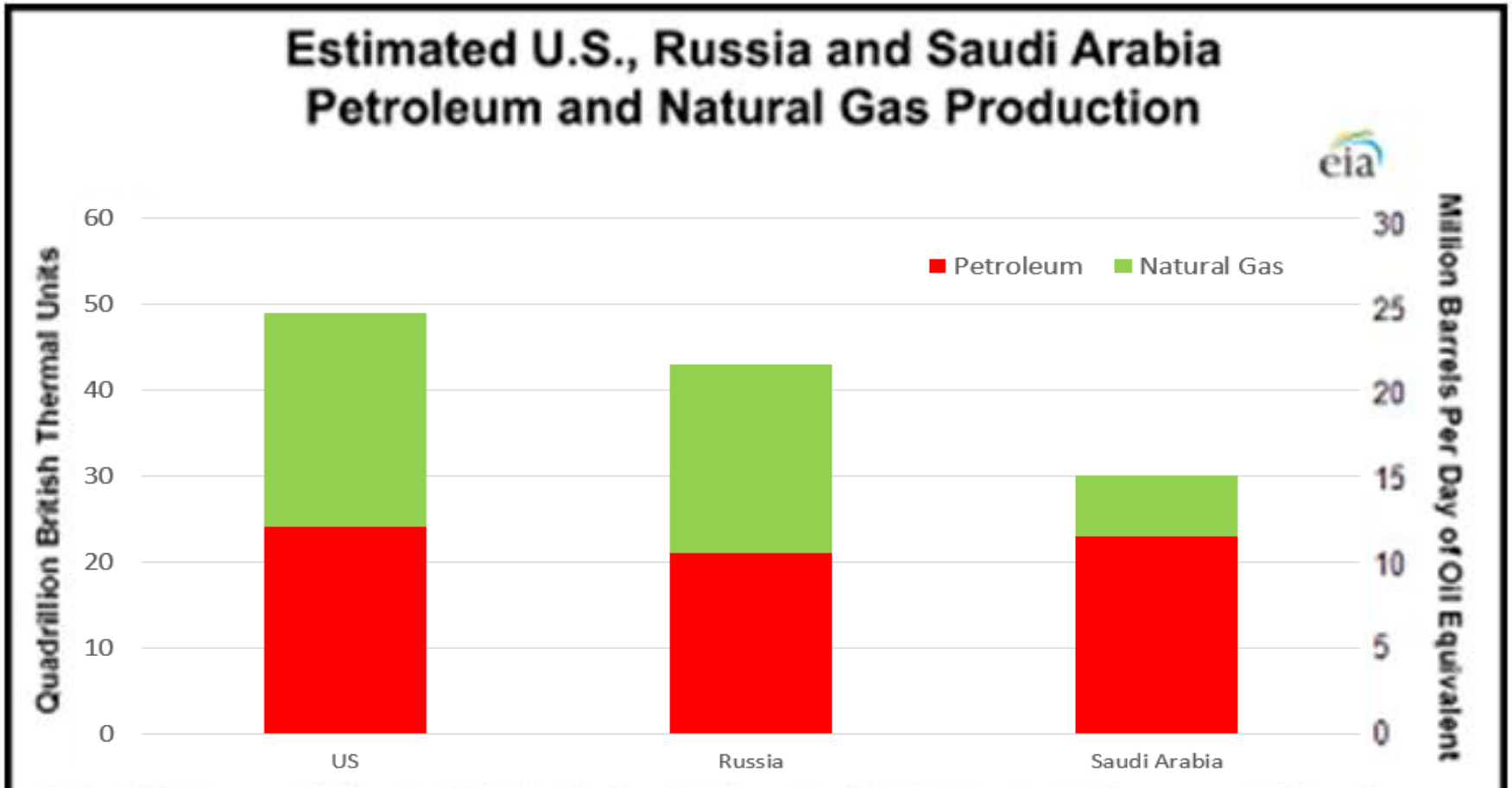
- Multi-Directional Networks
- Interaction w/ natural fracs
- One mile long
- 1,200 ft wide
- Killed offset wells

Shale Oil Revolution

- Shale / tight oil revolution driven by two things
  - Price of oil
  - Technology made available by shale gas revolution
- Both are required to continue driving US oil production growth
- Capital and technology are now focused on growing US oil / liquid production
  - After 34 years of declining US oil production (1971 -2005) we are now seeing dramatic growth
  - US imported 60% of our oil in 2005; 35% in 2014



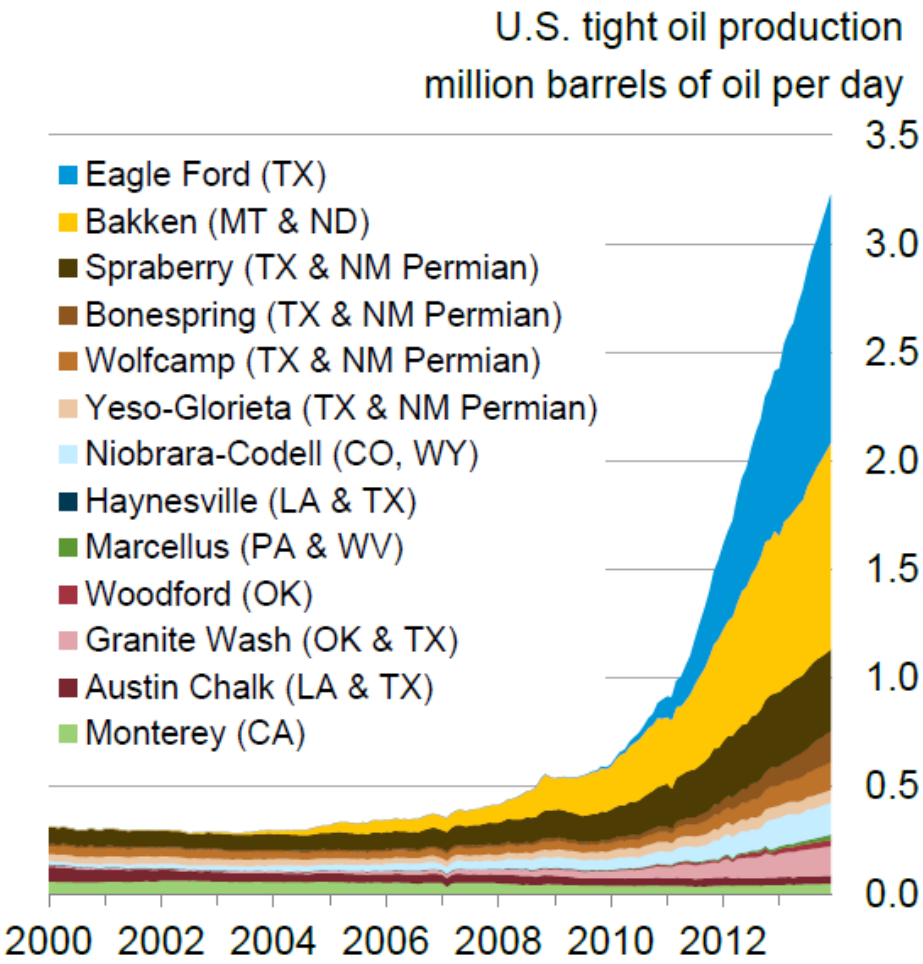
US Surpassing Russia in Energy

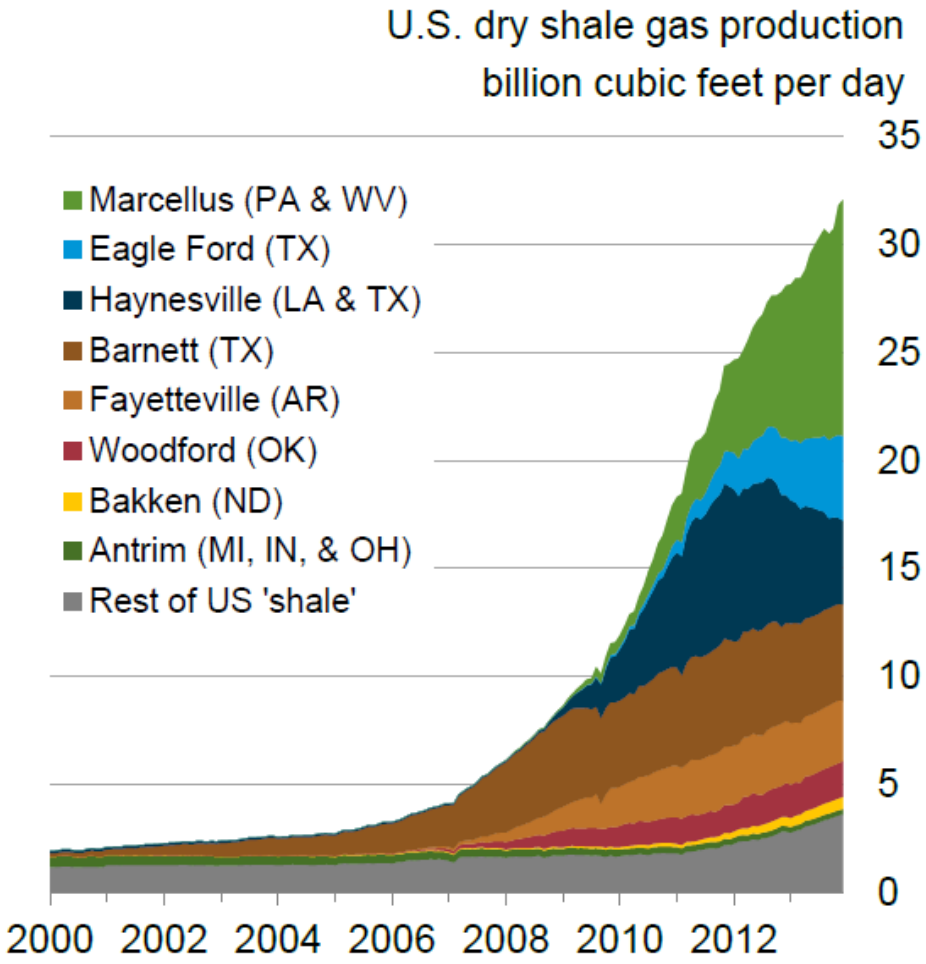


Note: Petroleum production includes crude oil, natural gas liquids, condensates, refinery processing gain, and other liquids, including biofuels. Barrels per day oil equivalent were calculated using a conversion factor of 1 barrel oil equivalent = 5.55 million British thermal units (Btu).

Source: U.S. Energy Information Administration

US Shale Production Boom





Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through December 2013 and represent EIA's official tight oil & shale gas estimates, but are not survey data. State abbreviations indicate primary state(s).

Old-Style “tight” Oil Production
Belridge Field Near Bakersfield, CA

Footprint

New Oil Production
Williston Basin, ND

Northwestern North Dakota

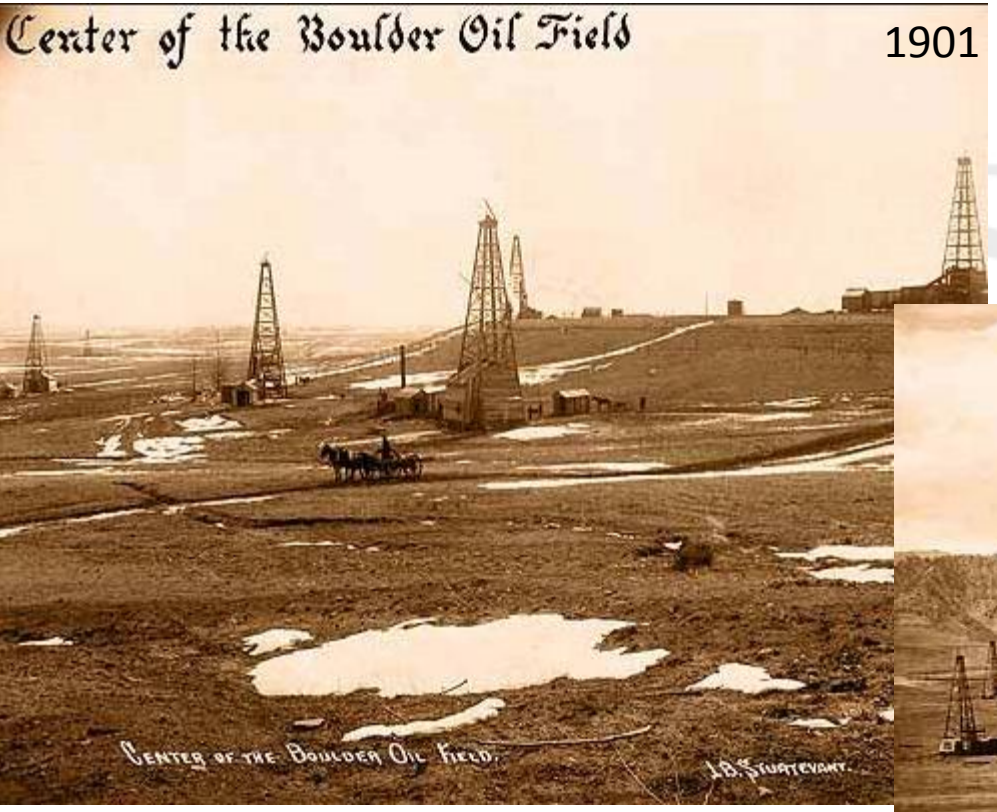
- 2006
  - Farm and Ranch Lands
- 2012
  - Farm and Ranch Lands and…… largest oilfield in the United States with 1,000,000 BOPD production, greater than Iranian exports
  - Surpassed three OPEC nations: Ecuador, Qatar, Libya and soon Algeria!

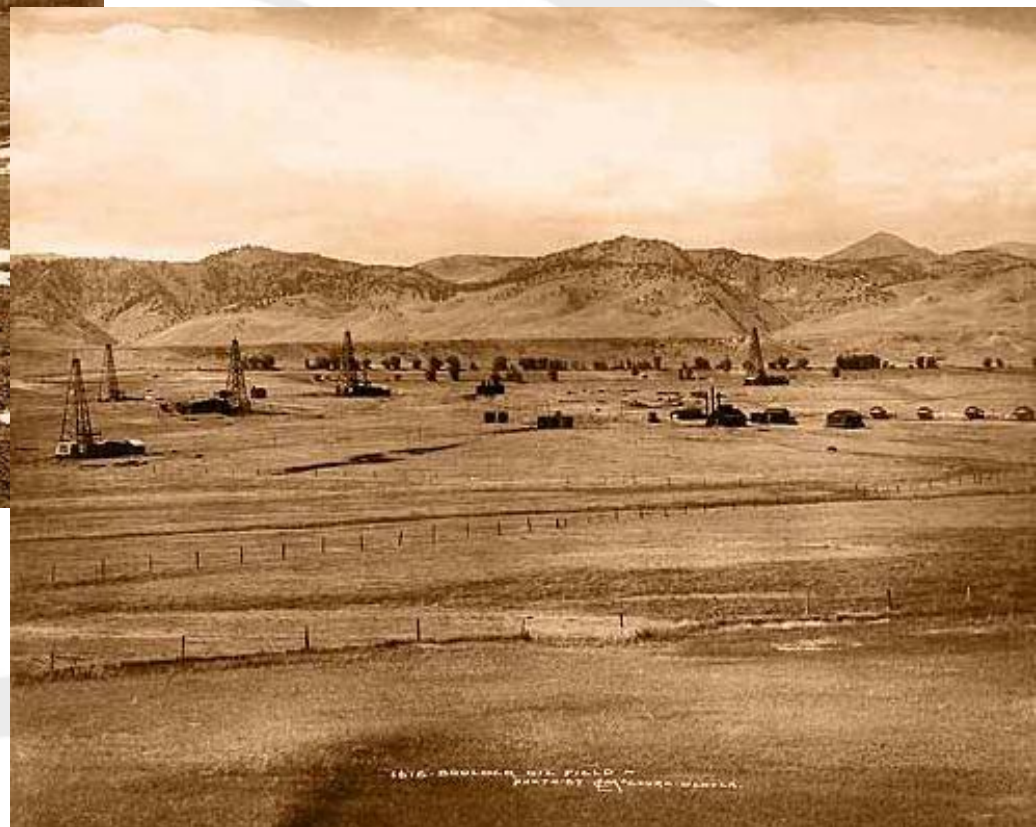
North Dakota Benefits

	State	2006 GDP per capita			State	2012 GDP per capita
1	Dist. of Col.	$60,957		1	Dist. of Col.	$74,710
2	Connecticut	$52,324		2	Connecticut	$58,908
3	Massachusetts	$47,559		3	Massachusetts	$54,687
4	New Jersey	$47,500		4	New Jersey	$53,628
5	Maryland	$44,858		5	New York	$52,095
6	New York	$44,567		6	Maryland	$51,971
7	Wyoming	$43,836		7	ND	$51,893
8	CA	$41,518		8	Wyoming	$48,670
9	Virginia	$41,218		9	Virginia	$47,082
10	Colorado	$41,181		10	New Hampshire	$47,058
11	New Hampshire	$41,092		11	Alaska	$46,778
12	Illinois	$39,900		12	Minnesota	$46,227
13	Minnesota	$39,867		13	Washington	$45,413
14	Washington	$39,570		14	Colorado	$45,135
15	Alaska	$38,951		15	Rhode Island	$44,990
16	Delaware	$38,812		16	CA	$44,980
17	Nevada	$38,786		17	Illinois	$44,815
18	Rhode Island	$38,251		18	Hawaii	$44,024
19	Florida	$37,996		19	South Dakota	$43,659
20	Hawaii	$37,507		20	Pennsylvania	$43,616
21	Pennsylvania	$36,984		21	Nebraska	$43,143
22	Vermont	$35,867		22	Vermont	$42,994
23	Kansas	$35,678		23	Iowa	$42,126
24	Wisconsin	$35,598		24	Delaware	$41,940
25	Nebraska	$35,432		25	Kansas	$41,835
26	Texas	$35,287		26	Texas	$41,471
27	Oregon	$34,706		27	Wisconsin	$40,537
28	Arizona	$34,326		28	Florida	$40,344
29	Georgia	$34,061		29	Maine	$39,481
30	Missouri	$34,013		30	Louisiana	$39,413
31	Ohio	$34,008		31	Ohio	$39,289
32	South Dakota	$33,948		32	Missouri	$39,049
33	Iowa	$33,719		33	Oklahoma	$39,006
34	Maine	$33,474		34	Oregon	$38,786
35	North Carolina	$33,373		35	Tennessee	$37,678
36	Michigan	$33,365		36	Michigan	$37,497
37	Louisiana	$33,287		37	Montana	$37,370
38	Oklahoma	$33,040		38	Nevada	$37,361
39	ND	$32,914		39	North Carolina	$37,049
40	Tennessee	$32,885		40	Indiana	$36,902
41	Indiana	$32,667		41	Georgia	$36,869
42	Montana	$31,959		42	Arizona	$35,979
43	Idaho	$31,493		43	Alabama	$35,625
44	Alabama	$31,208		44	**New Mexico**	**$35,079**
45	Utah	$31,035		45	Kentucky	$35,041
46	South Carolina	$30,794		46	Arkansas	$34,723
47	**New Mexico**	**$30,209**		47	Utah	$34,601
48	Kentucky	$30,034		48	West Virginia	$34,477
49	Arkansas	$29,385		49	South Carolina	$34,266
50	West Virginia	$28,372		50	Idaho	$33,749
51	Mississippi	$27,917		51	Mississippi	$33,073

Williston Basin Near Williston, ND

Boulder Oilfield in 1901



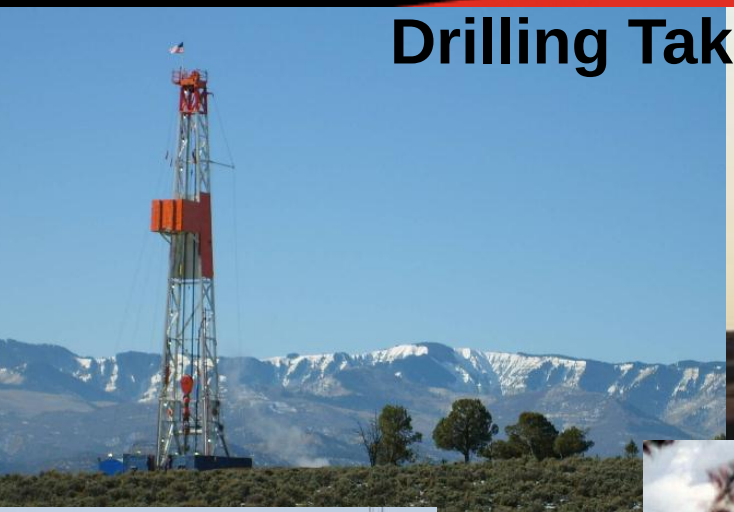


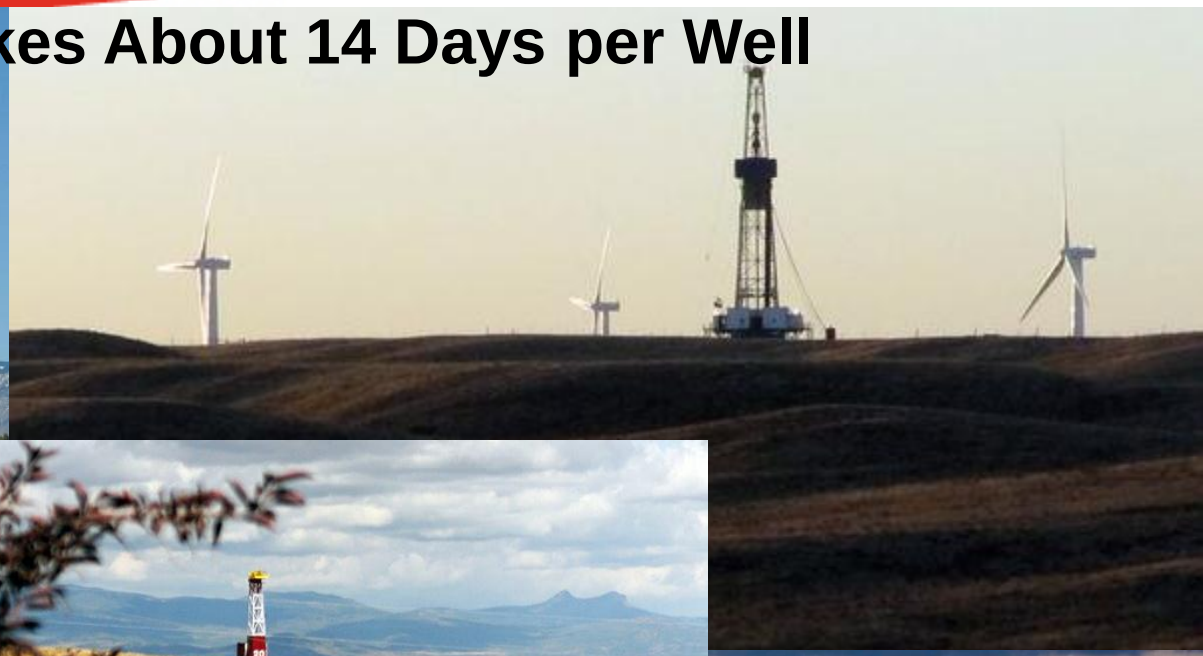
Boulder Oilfield Lands in 2013

Oil and gas development leaves a small and temporary impact that is compatible with the western vistas and wide-open spaces we love. – Matt Silverman, Boulder Petroleum Geologist

Did drilling permanently scar Boulder? Hardly – Matt Silverman

Drilling Takes About 14 Days per Well





Frac'ing Takes 1-7 Days per Well

What remains after drilling & fracturing?

What if the US Shale Revolution Had Not Happened?

- Your natural gas and power bills would be 2x to 3x higher
- Your annual household disposable income would be $1,500 less
- US would import 14-16 Bcfd gas, cost ~$12/Mcf or $70 billion/year
- US would import >10.5 Mmbod, cost ~140/bbl or $127 billion/year
- Gasoline would cost ~$5/gallon
- 2.1 million additional Americans might not have jobs
- Loss of $2.4 trillion in O&G capital investment through 2025
- The emerging renaissance in US manufacturing would not happen
- The 12% drop in 2012 US GHG emissions would not have happened
- Biggest impact is on the Poor
- Blue Collar jobs tend to be energy intensive

These estimates are derived from the September 2013 HIS Report "America's New Energy Future: The Unconventional Oil and Gas Revolution and the U.S. Economy", Volume 3, "A Manufacturing Renaissance – Main Report."

Colorado Oil & Gas Industry…

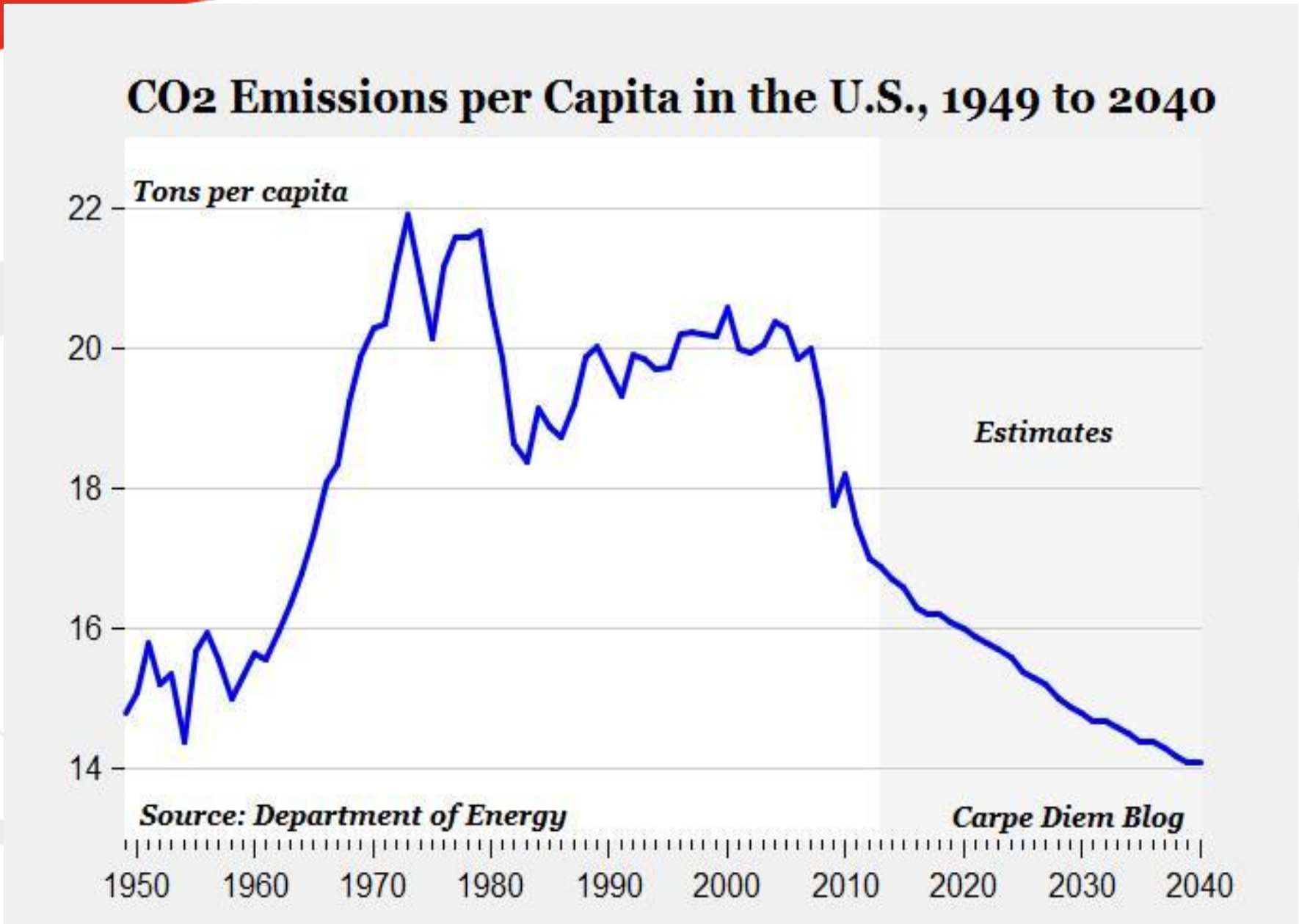
- Generates 11% of CO GDP ($29.6 billion/year)
- Furnishes 110,000 direct and indirect jobs
- Provides royalties for 600,000 landowners
- Accounts for 1/12 of CO property taxes ($6.9 billion)
- Generates $1.6 billion in public revenue
- Provides $682 million for schools and other public entities
- Produces enough natural gas for all of CO (25% of production) and enough to export the remaining 75%
- Lowers energy cost to heat CO homes (43% lower heating bill than New England)
- Produces enough oil for yearly use by 2.2 million people and growing rapidly – Colorado will soon be a net oil exporter
- Experienced 40% nationwide job growth during 2007-2012 recession
- "Footprint" on land (and steel, cement, water, etc.) of energy production is dramatically shrinking

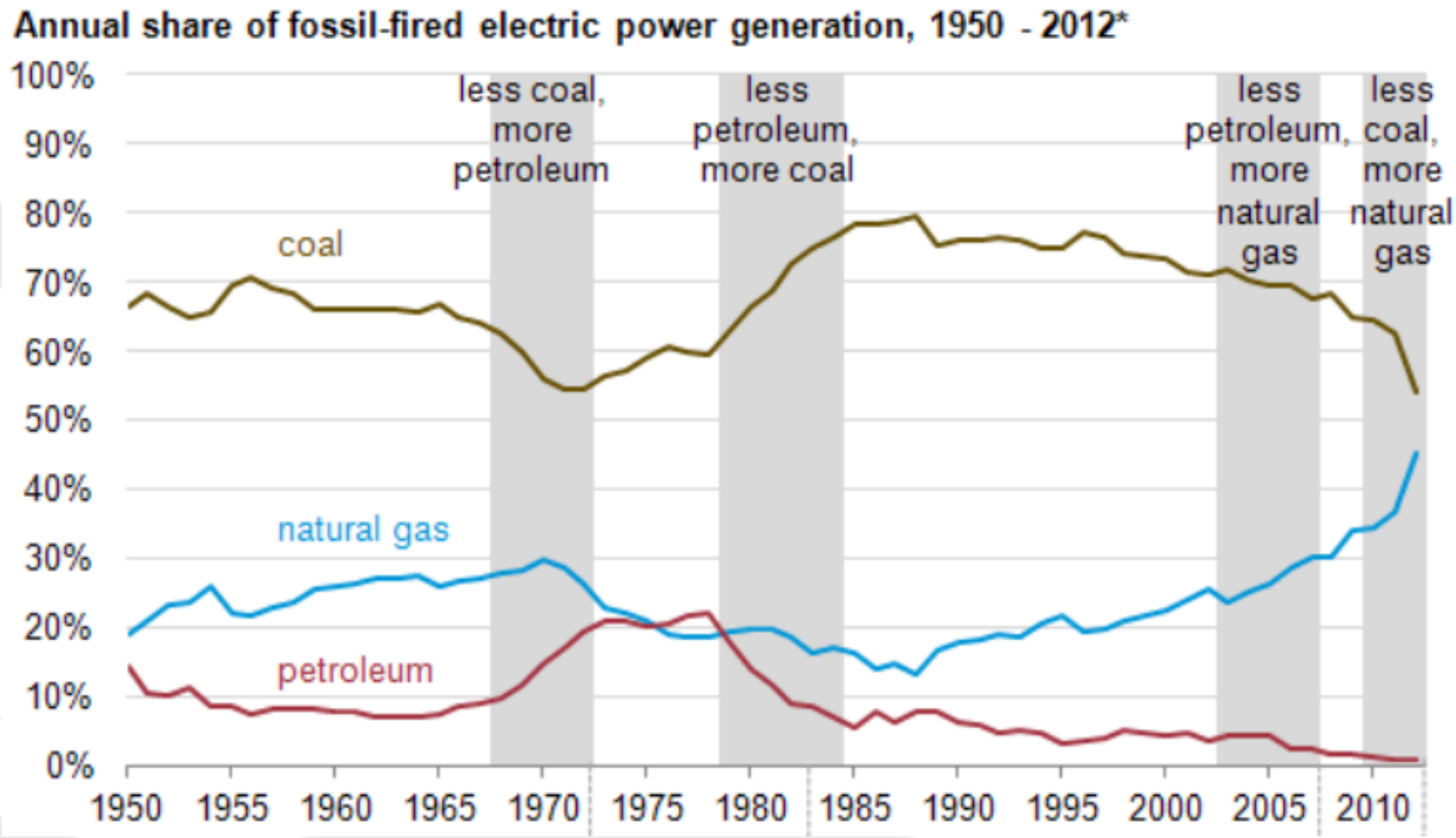
What About All the Bad Stuff?

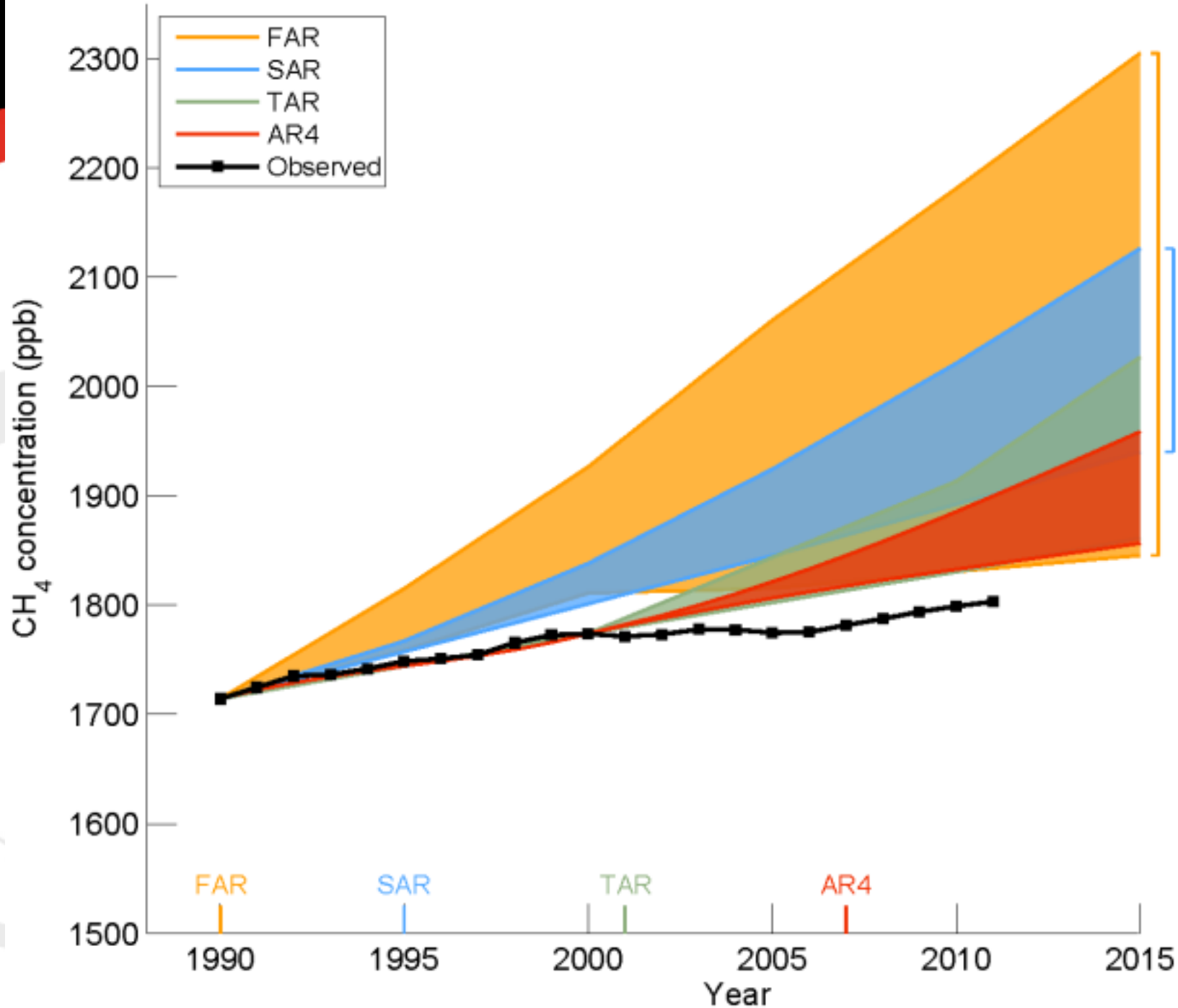
- “GasLand showed frac’ing caused a faucet to be lit on fire” – Aquifer water well contained natural gas before frac’ing
- “Frac’ing uses millions of gallons of water” – Only 0.13% of Colorado water to produce 11% of Colorado GDP
- “Frac’ing causes earthquakes” – Only very small ones and much less than hydropower, geothermal or mining – Waste water injection is the real issue and is being solved with lower injection per well and seismic monitoring
- “Frac’ing causes groundwater contamination” – Over 2,000,000 frac jobs and not a single case of confirmed cases of groundwater contamination!
- “Frac’ing causes greenhouse emissions” – Gas revolution has helped lower per capita CO2 emissions to 1964 levels by displacing coal

Colorado Water Use

Sector	2010 Use (Acre-Feet/Yr)[4]	Percent of State Total
Total	**16,359,700**	
Agriculture	13,981,100	85.5%
Municipal and Industrial	1,218,600	7.4%
Total All Others	1,160,000	7.1%
Breakdown of "All Others"		
Total All Others	**1,160,000**	
Recreation	923,100	5.64%
Large Industry	136,000	0.83%
Thermoelectric Power Generation	76,600	0.47%
Hydraulic Fracturing	13,900	0.08%
Snowmaking	5,300	0.03%
Coal, Natural Gas, Uranium, and Solar Development	5,100	0.03%
Oil Shale Development	0	0.00%


CO2 Emissions per Capita in the U.S., 1949 to 2040
Tons per capita
22
20
18
16
14
Estimates
Source: Department of Energy
Carpe Diem Blog
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040


Annual share of fossil-fired electric power generation, 1950 - 2012*
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
less coal, more petroleum
less petroleum, more coal
less petroleum, more natural gas
less coal, more natural gas
coal
natural gas
petroleum
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


FAR
SAR
TAR
AR4
Observed
2300
2200
2100
2000
1900
1800
1700
1600
1500
CH_4 concentration (ppb)
FAR
SAR
TAR
AR4
1990
1995
2000
2005
2010
2015
Year

Fracturing: Main Issues

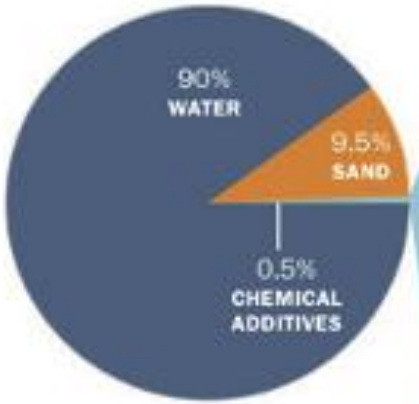
- **Community / Landowner issues**
  - Different communities evaluate tradeoffs differently
    - Jobs, boost to community businesses and tax revenues vs. disturbance from activity
    - Natural partnership with land / mineral owners
    - Tougher when mineral and surface rights are separated
  - NIMBY – we all chose to consume oil & gas. Issue is where does it come from?
- **Well integrity**
  - Multiple concentric pipes with cement sheets in between to protect groundwater
- **Surface Handling of drilling and fracturing chemicals and produced fluids**
  - Strict surface spill rules and reporting are in place.
  - Well site frac equipment containment is becoming common.
  - Industry constantly evaluating & adopting greener chemicals
- **Produced Water Disposal**
  - Oil, gas, and water all produced together
  - This “produced” water is not “fresh” and must be safely disposed of
  - Typically via reinjection back where it came from
- **Air pollution**
  - Frac fleets mostly use diesel, but ongoing movement to switch over to natural gas
  - Dust from sand trucks and storage bins. Move to dust control or encased sand storage
  - Leakage of methane from surface pipe. Drive to wellsite monitoring and leak detection by various DJ operators
  - Gas flaring is temporary activity associated with exploratory drilling until pipeline infrastructure is in place
- **Traffic and Noise**
  - Temporary industrial activity on site (frac’ing a well takes 1-7 days; producing the well ~30 years).
  - Move to fewer but bigger pads (multiple wells) enclosed by sound walls in urban areas

LIBERTY OILFIELD SERVICES

HF Fluids

Additive	Main Compound	Common Use
Diluted Acid	Hydrochloricor, Muriatic Acid	Swimming Pools
Biocide	Glutaraldehyde	Dental Disinfectant
Breaker	Ammonium Persulfate	Bleaching Hair
Crosslinker	Borate Salts	Laundry Detergents
Iron Control	Citric Acid	Food Additive
Gelling Agent	Guar Gum	Biscuits
Scale Inhibitor	Ethylene Glycol	Antifreeze
Surfactant	Isopropanol	Glass Cleaner
Friction Reducer	Polyacrylamide	Water and Soil Treatment

Common Chemicals in Frac Fluids

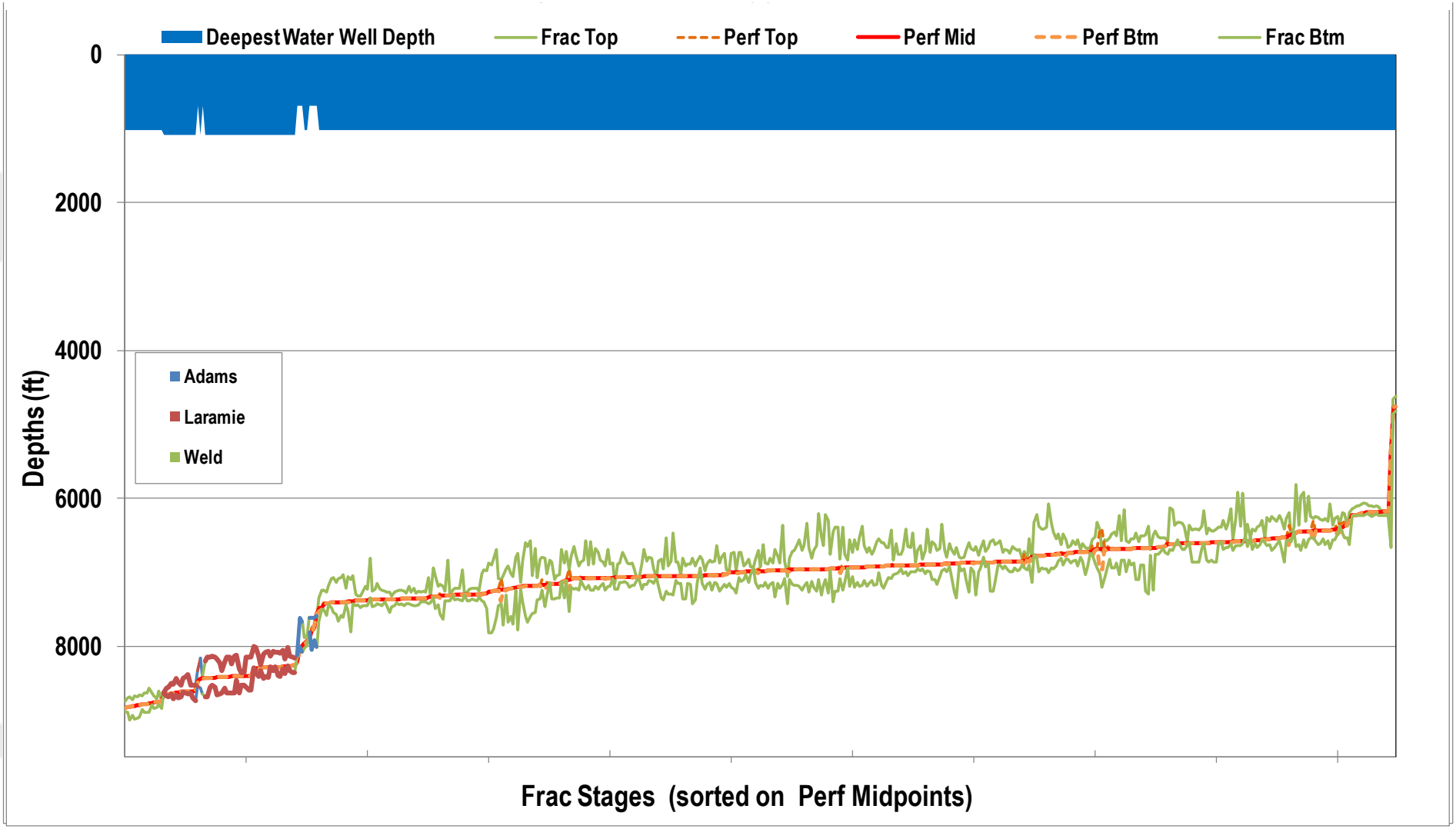


"Slickwater frac'ing" generally only uses 4 additives at less than 0.2% of total volume

Typical Chemical Additives Used in Frac Water

Compound	Purpose	Common application
Acids	Helps dissolve minerals and initiate fissure in rock (pre-fracture)	Swimming pool cleaner
Sodium Chloride	Allows a delayed breakdown of the gel polymer chains	Table salt
Polyacrylamide	Minimizes the friction between fluid and pipe	Water treatment, soil conditioner
Ethylene Glycol	Prevents scale deposits in the pipe	Automotive anti-freeze, deicing agent, household cleaners
Borate Salts	Maintains fluid viscosity as temperature increases	Laundry detergent, hand soap, cosmetics
Sodium/Potassium Carbonate	Maintains effectiveness of other components, such as crosslinkers	Washing soda, detergent, soap, water softener, glass, ceramics
Glutaraldehyde	Eliminates bacteria in the water	Disinfectant, sterilization of medical and dental equipment
Guar Gum	Thickens the water to suspend the sand	Thickener in cosmetics, baked goods, ice cream, toothpaste, sauces
Citric Acid	Prevents precipitation of metal oxides	Food additive; food and beverages; lemon juice
Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, hair coloring

Source: DOE, GWPC: Modern Gas Shale Development in the United States: A Primer (2009).

Microseismic height for Niobrara

- Top: shallowest microseism; Bottom: deepest microseism
- Aquifers: USGS deepest water wells by county