INFUSE

INTERNATIONAL FORUM ON UNCONVENTIONAL GAS SUSTAINABILITY AND THE ENVIRONMENT

Department of Geology and Geography

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Overview and Unconventional Resources Parameters for Successful Shale Plays

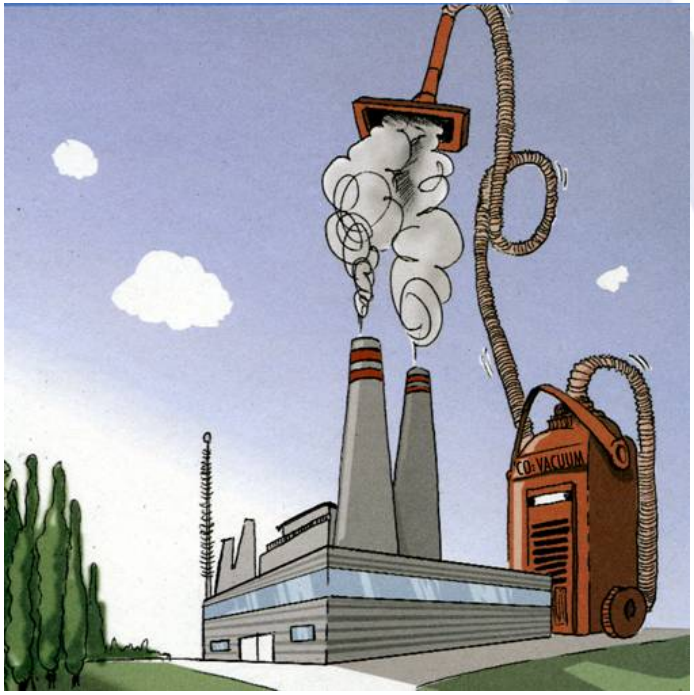
- Energy Challenges
- Units and Molecules
- Shale Energy Disruptive Technology
  - Resource is Adequate
  - Fossil Fuel (Required)
  - Non-Fossil (Needed)
    - Nuclear & Alternative
- Keys to Successful Shale Production

Promethean Energy Technology Basis of Civilization

- Fire
  - Warmth, Cooking,
  - Forge Metals, Long Life
- Heat Engine
  - Power, Speed, Flight
- Chemistry
  - Fertilizer
  - Plastics, etc., etc.
- Emissions Management
  - Particulates
  - SO_x, NO_x, Hg
  - CO_2

Pieter Paul Rubens: "Prometheus Bound"

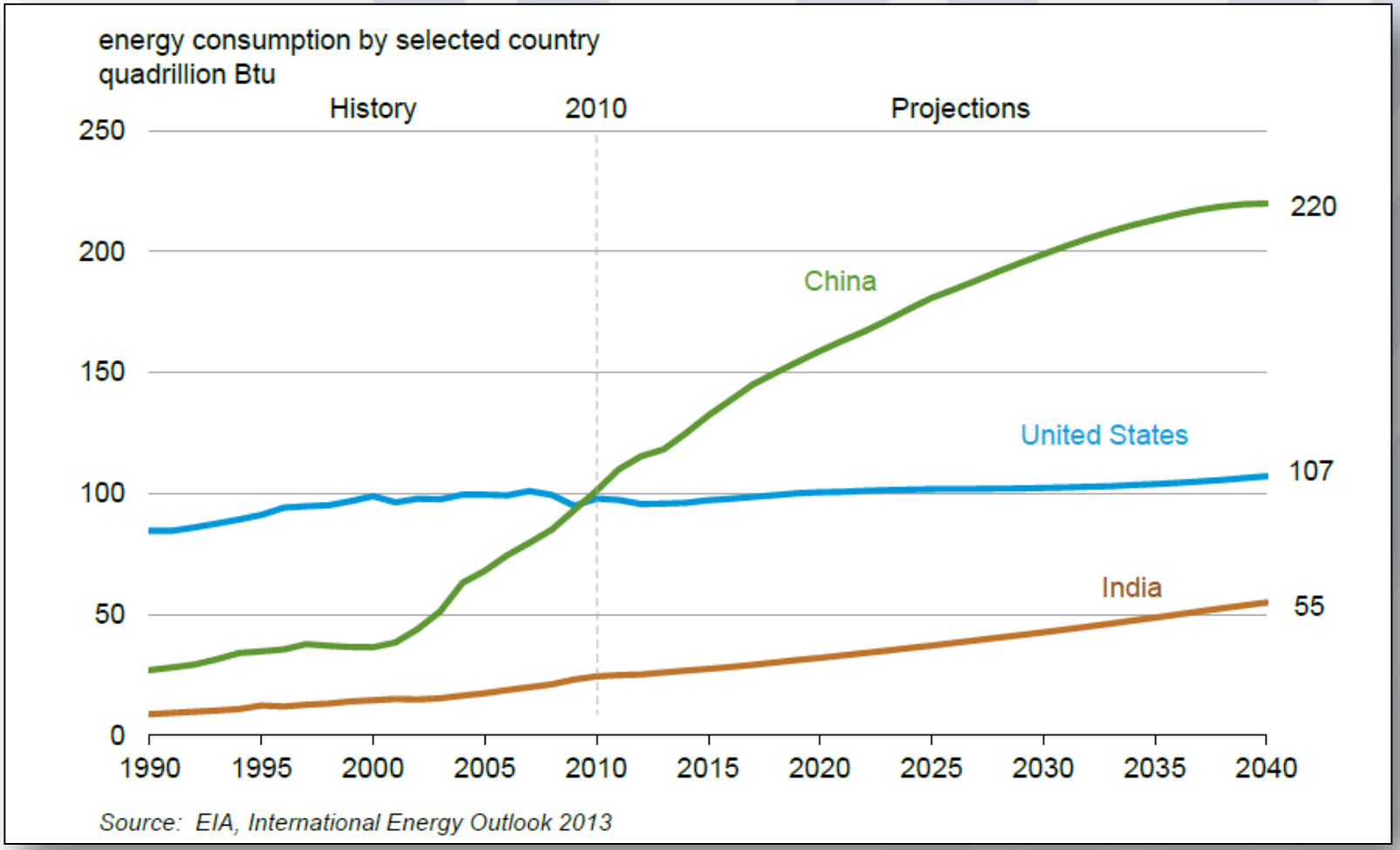
Our Energy Challenges



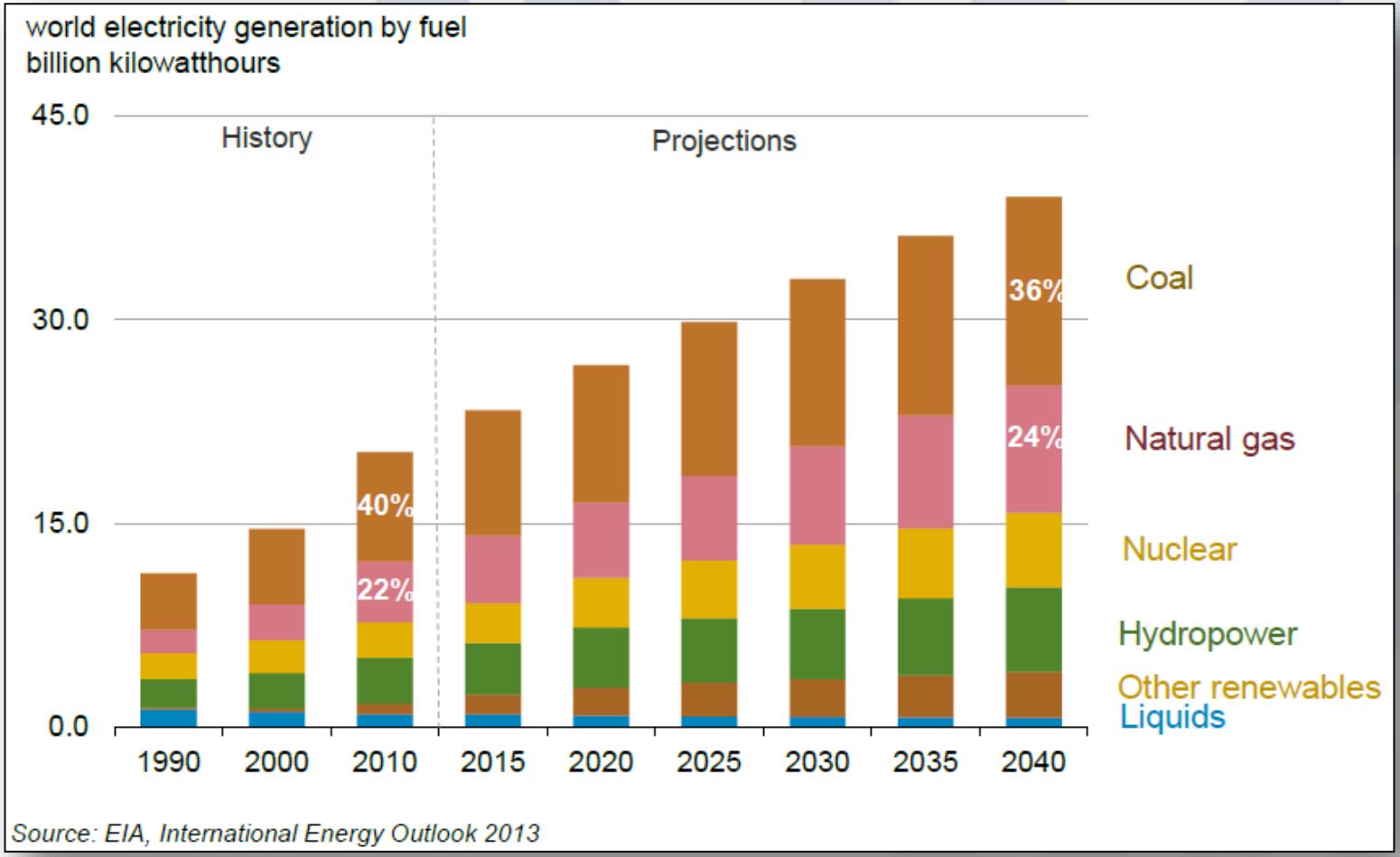
CO_2 Capture and Storage: Not This Simple

- Demographic Challenge
- Supply Challenge
  - Resource is Adequate
  - Fossil Fuel (Required)
  - Non-Fossil (Needed)
    - Nuclear & Alternative
- Environmental Challenge
- Technology Challenge
- Energy Transitions/Revolutions
  - Centuries to Decades
  - Disruptive

World Energy Consumption



Fossil Fuels Dominate



"suggesting that renewables will let us phase rapidly off fossil fuels in the United States, China, India, or the world as a whole is almost the equivalent of believing in the Easter Bunny and Tooth Fairy." *James Hansen* (grandfather of climate change)

Measurement Units

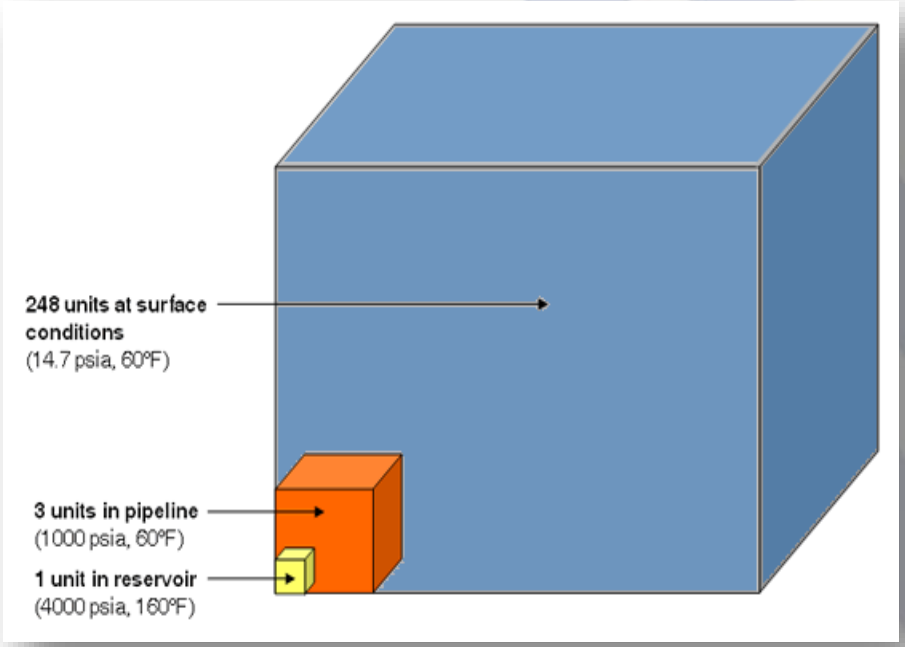
- Volume
- Weight
- Thermal Energy

Crude Oil

1 Barrel of Crude Oil

42 gallons
10,000 B/D equals 500,000 tonnes/year (7.2 - 7.35 bbls per metric ton)
1 barrel #6 Oil = 6.287 Million BTU
300 lbs
6.33×10^9 Joules (6.33 Gigajoules)

Natural Gas



Unit of Gas Volume Measurement	Standard Conditions	Area of Common Usage
Standard Cubic Foot (SCF)	14.73 psi (one atmosphere), 60°F	US, Latin America, Africa, Middle East.
Normal Cubic Meter (Nm^3)	One atmosphere, 0°C	Europe, Canada, Russia.
Conversions: 1 m^3 = 35.31 ft^3; 1 ft^3 = 0.0283 m^3		

Natural Gas

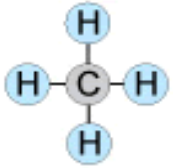
Units	Quantity	Symbol ft^3	Symbol m^3	Application
Thousand	1000	MCF	Mm^3	Basic unit of sale
Million	1,000,000	MMCF	MMm^3	Daily well production
Billion	1,000,000,000	BCF	bm^3	Annual field production
Trillion	1,000,000,000,000	TCF	tm^3	Field reserves

If gas volume is measured in m^3, simply replace CF with m^3 within the above symbols. Some companies use K, M°, Giga ("G") and Tera ("T") in place of thousand, million, billion and trillion.

Hydrocarbon Molecules

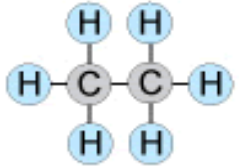
Natural Gas

Methane, CH_4



Heating Value: 1010 BTU/ft^3
(1.06 million Joules)
Boiling Point: -259^{o}F (-162^{o}C)

Ethane, C_2H_6

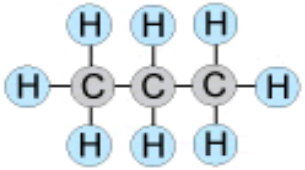


Heating Value: 1770 BTU/ft^3
(1.87 million Joules)
Boiling Point: -127^{o}F (-89^{o}C)

Retain in Natural Gas or Convert to Ethylene

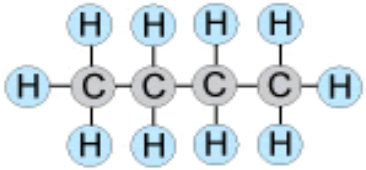
LPG's

Propane, C_3H_8



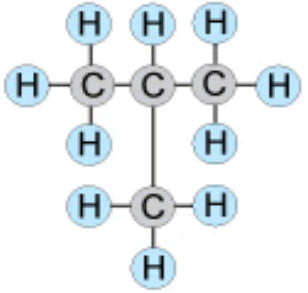
Heating Value: 2516 BTU/ft^3
(2.65 million Joules)
Boiling Point: -44^{o}F (-42^{o}C)

Normal Butane, C_4H_{10} (nC_4)



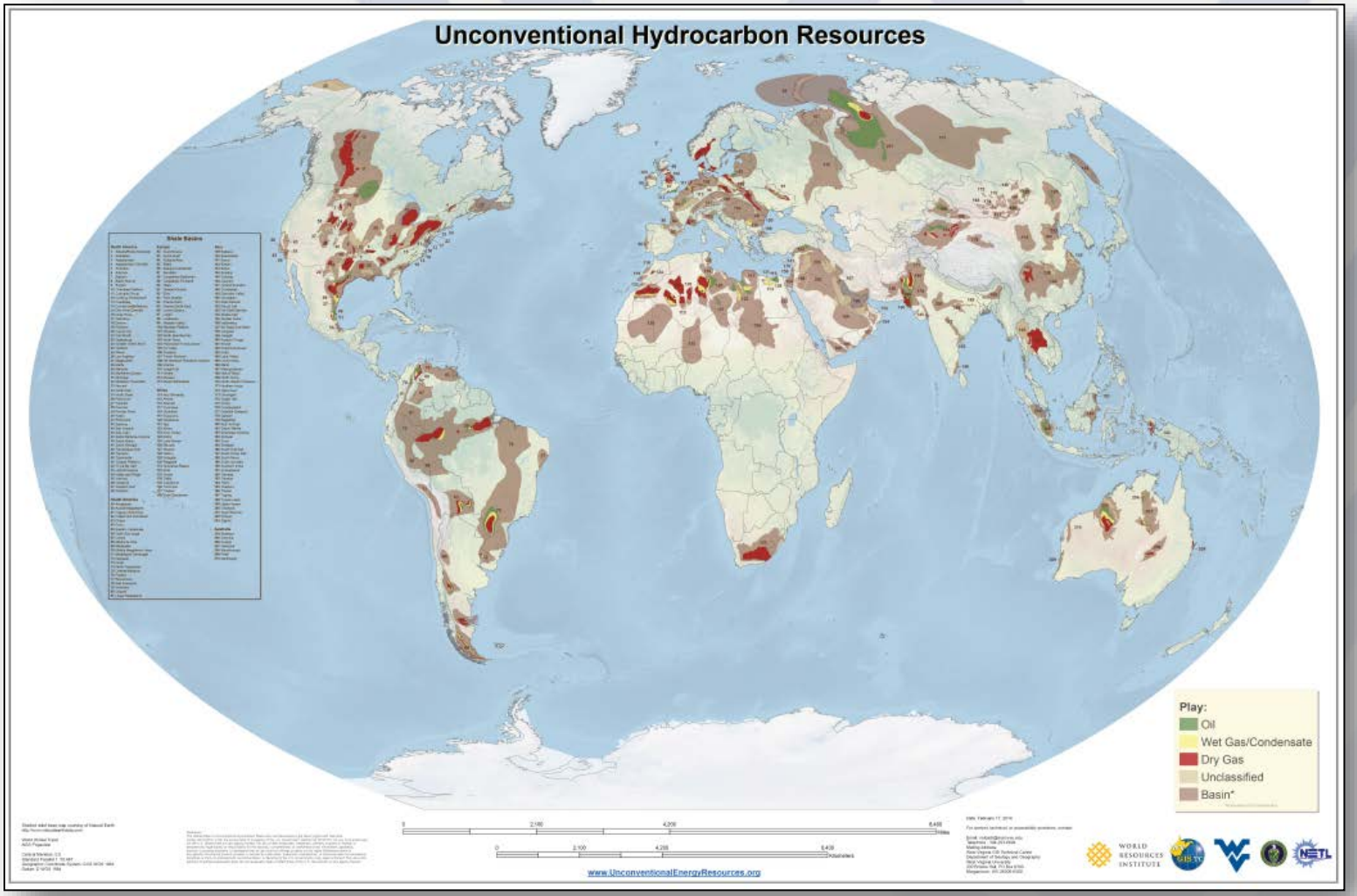
Heating Value: 3263 BTU/ft^3
(3.44 million Joules)
Boiling Point: -31^{o}F (-51^{o}C)

Isobutane, C_4H_{10} (iC_4)



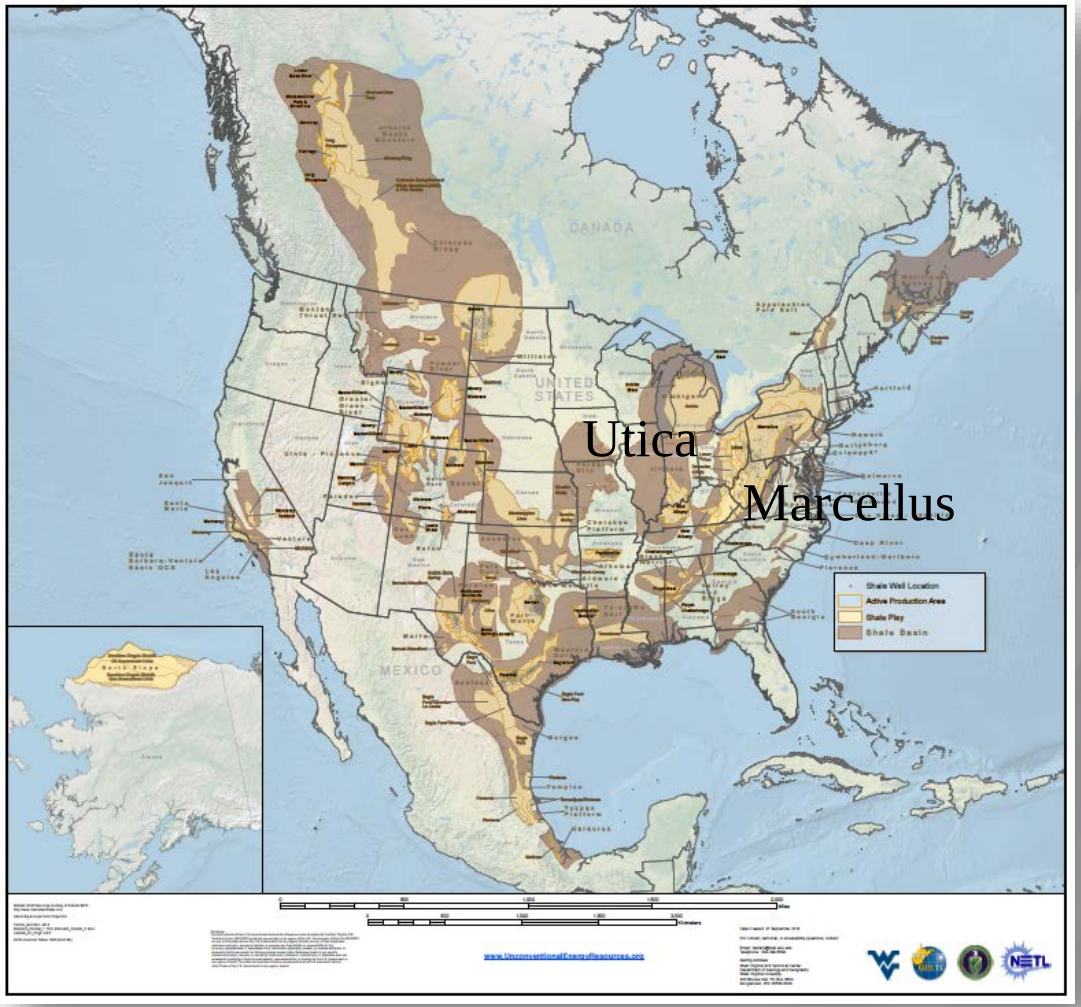
Heating Value: 3252 BTU/ft^3
(3.43 million Joules)
Boiling Point: -11^{o}F (-12^{o}C)

Global Shale (Mudrock) Basins



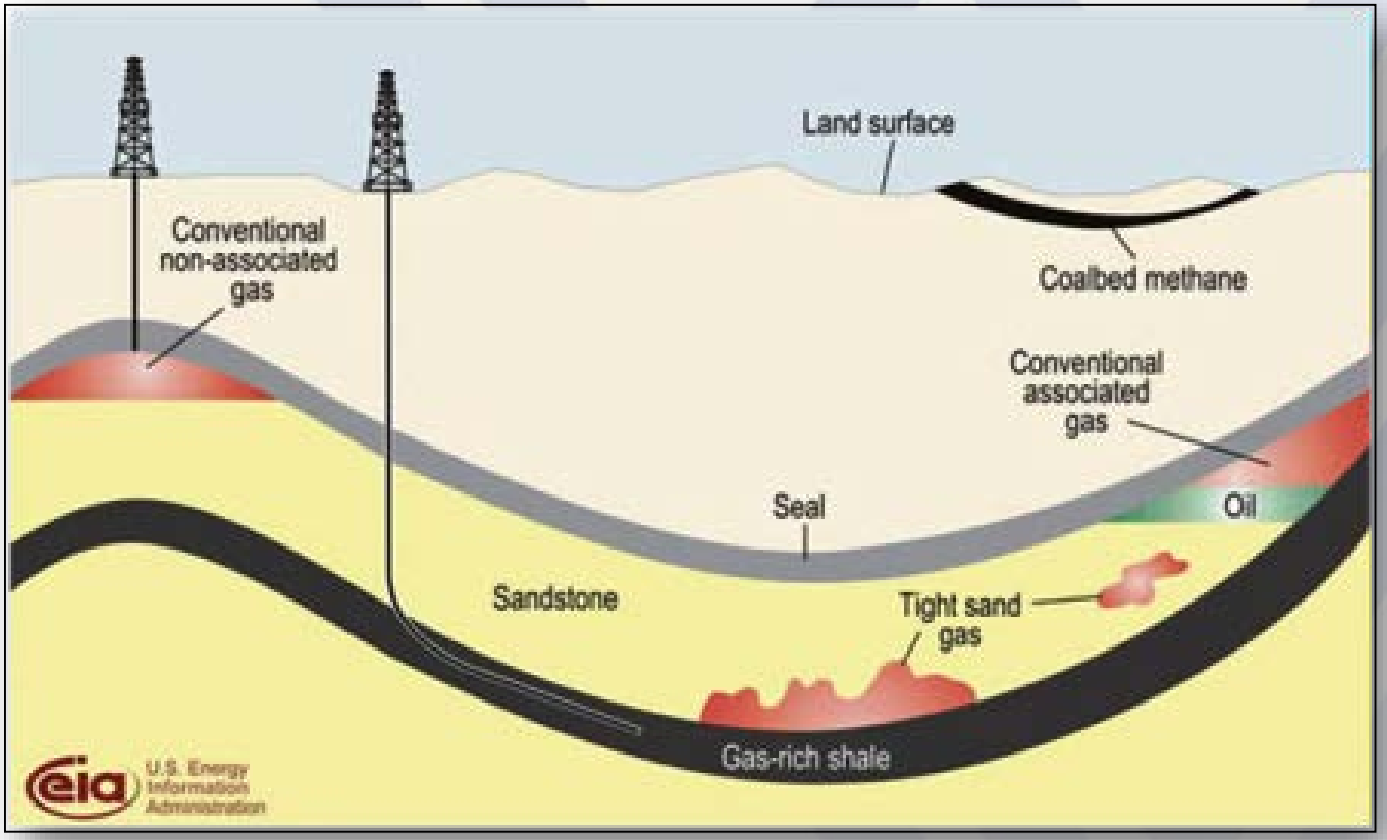
http://www.unconventionalenergyresources.com/

North America Mudrock Basins



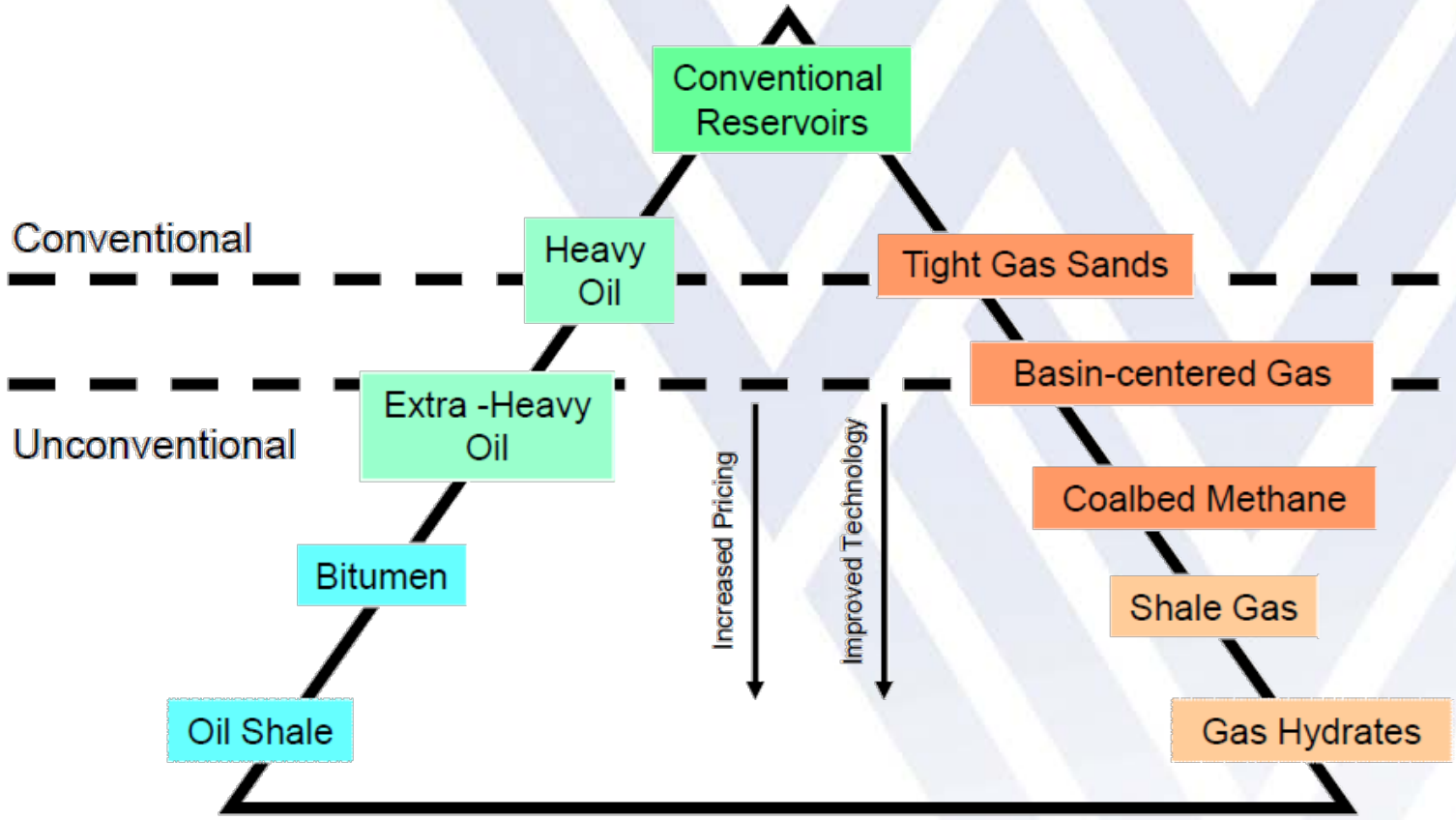
http://www.unconventionalenergyresources.com/

Unconventional Reservoirs



- Conventional gas: Source ≠ Reservoir
- Unconventional gas: Source = Reservoir

Petroleum Resource Triangle

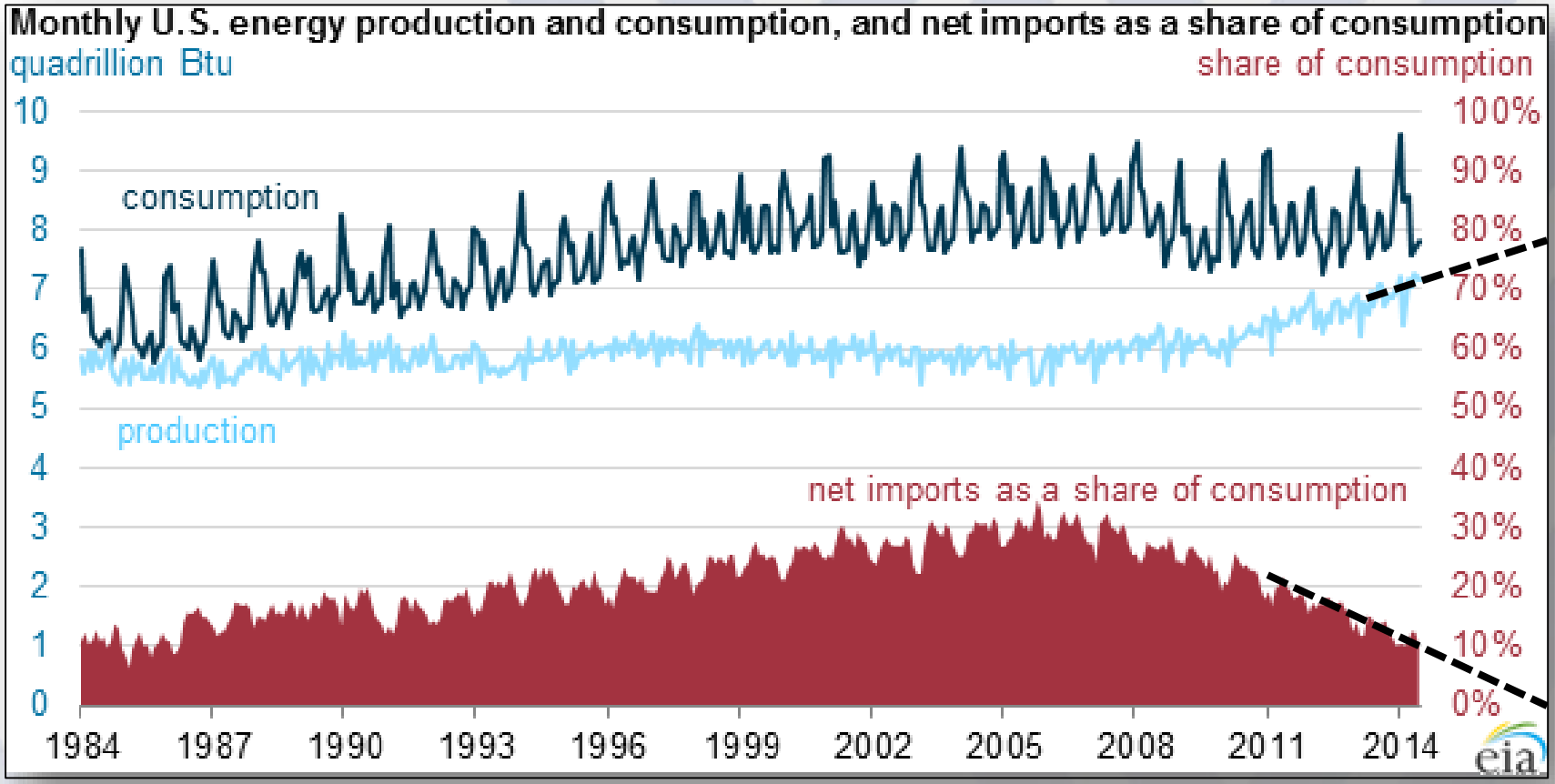


(modified from Holditch, JPT Nov. 2002)

Shale Revolution Affects Everything Disruptive Technology

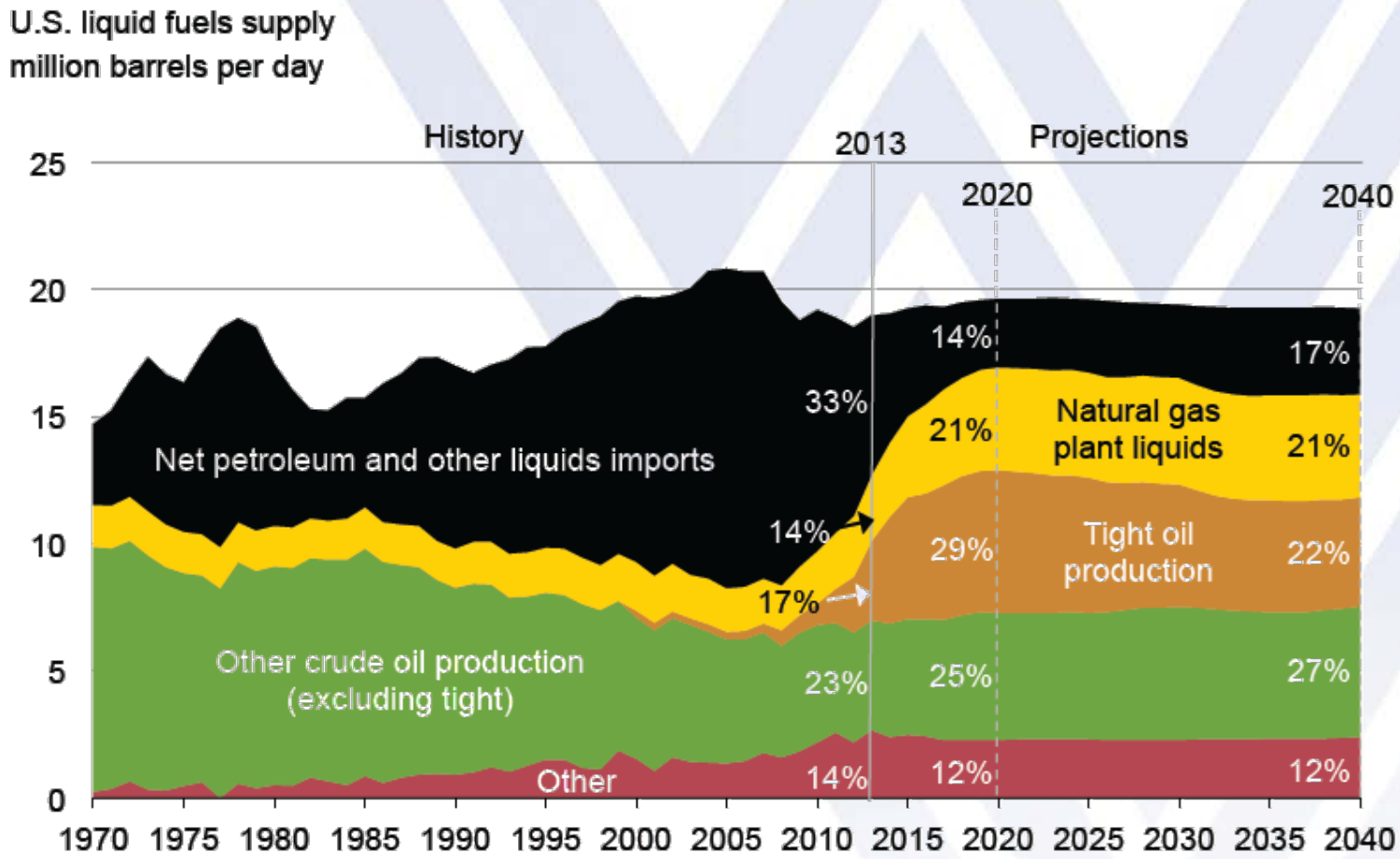
- Technology has Made Quadrillions of BTU's of New Energy Available to Humanity
- Benefits
  - Largest Increase in Hydrocarbon Production in the World
  - Decreased Energy Prices
  - Increased Economic Activity
  - Increased Government Revenues
  - Reduced Emissions (Particulates and CO_2)
- Challenges
  - Local Air Pollution
  - Water – Supply and Quality Impacts
  - Noise and Increased Activity
  - Boom and the Bust
- Goal – Minimize Costs While Maximizing Benefits

US Energy Forecast



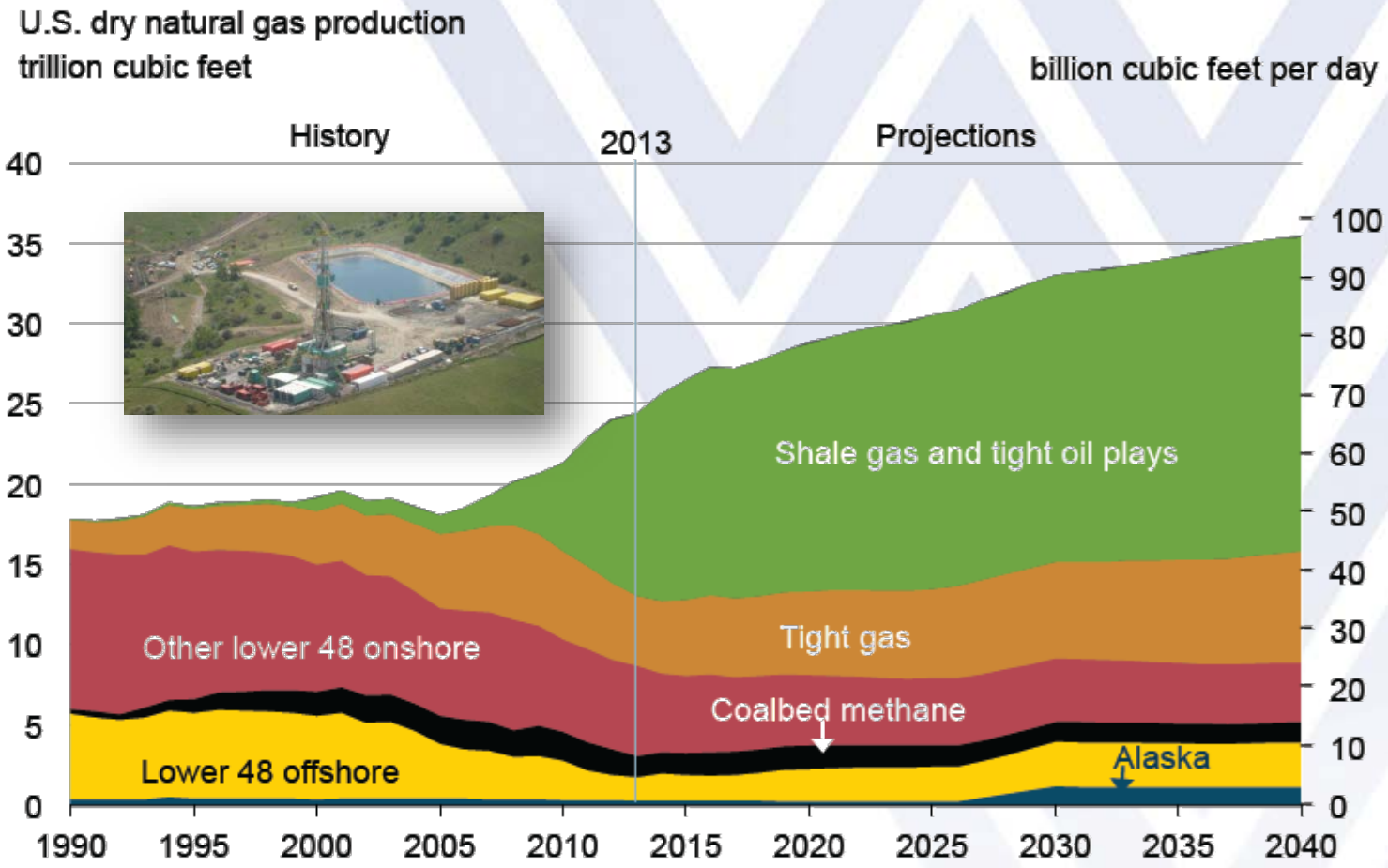
Source: EIA

U.S. Oil Production



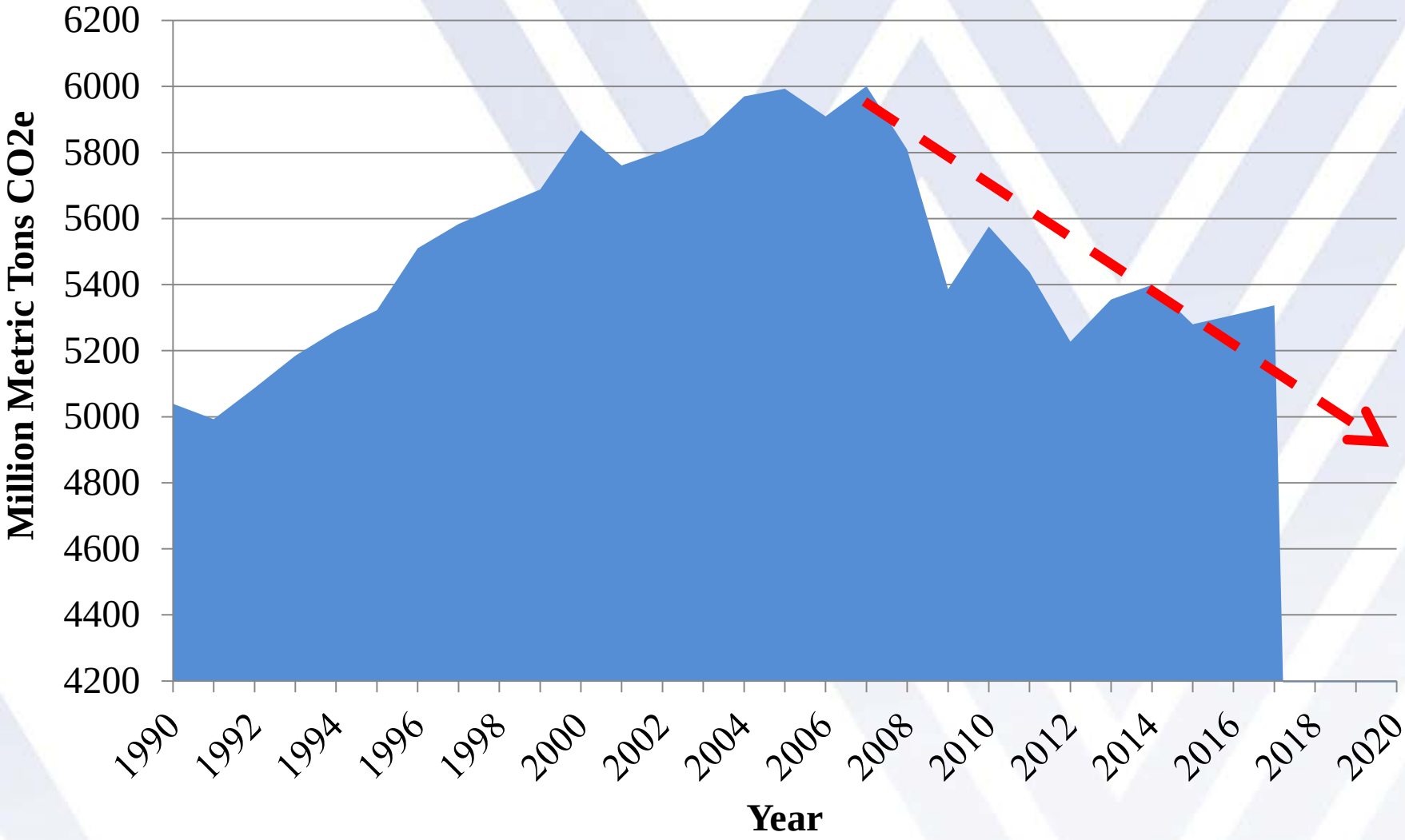
Note: "Other" includes refinery gain, biofuels production, all stock withdrawals, and other domestic sources of liquid fuels
Source: EIA, Annual Energy Outlook 2015 Reference case

U.S. Natural Gas Production



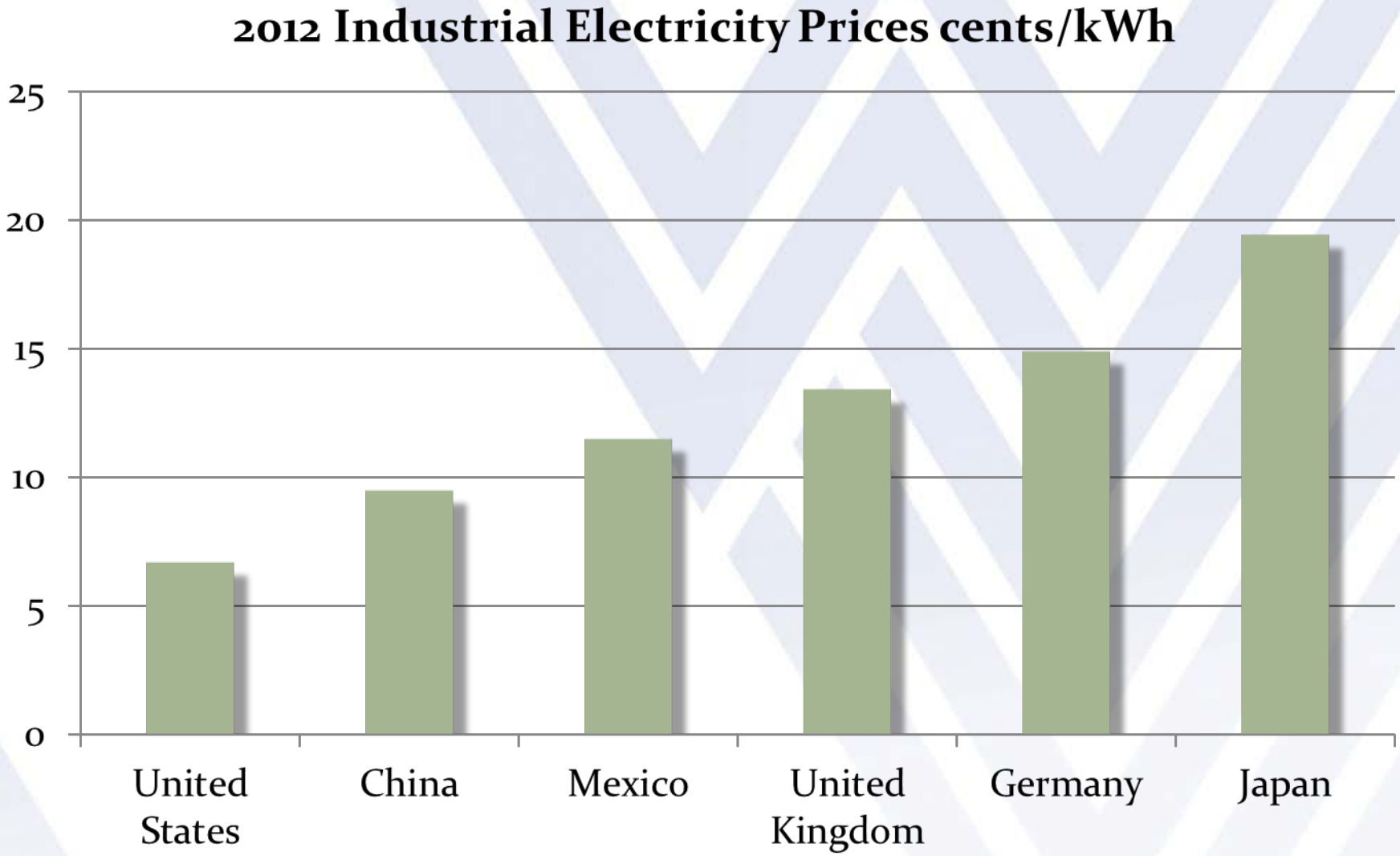
Source: EIA, Annual Energy Outlook 2015 Reference case

U.S. CO_2 Emissions



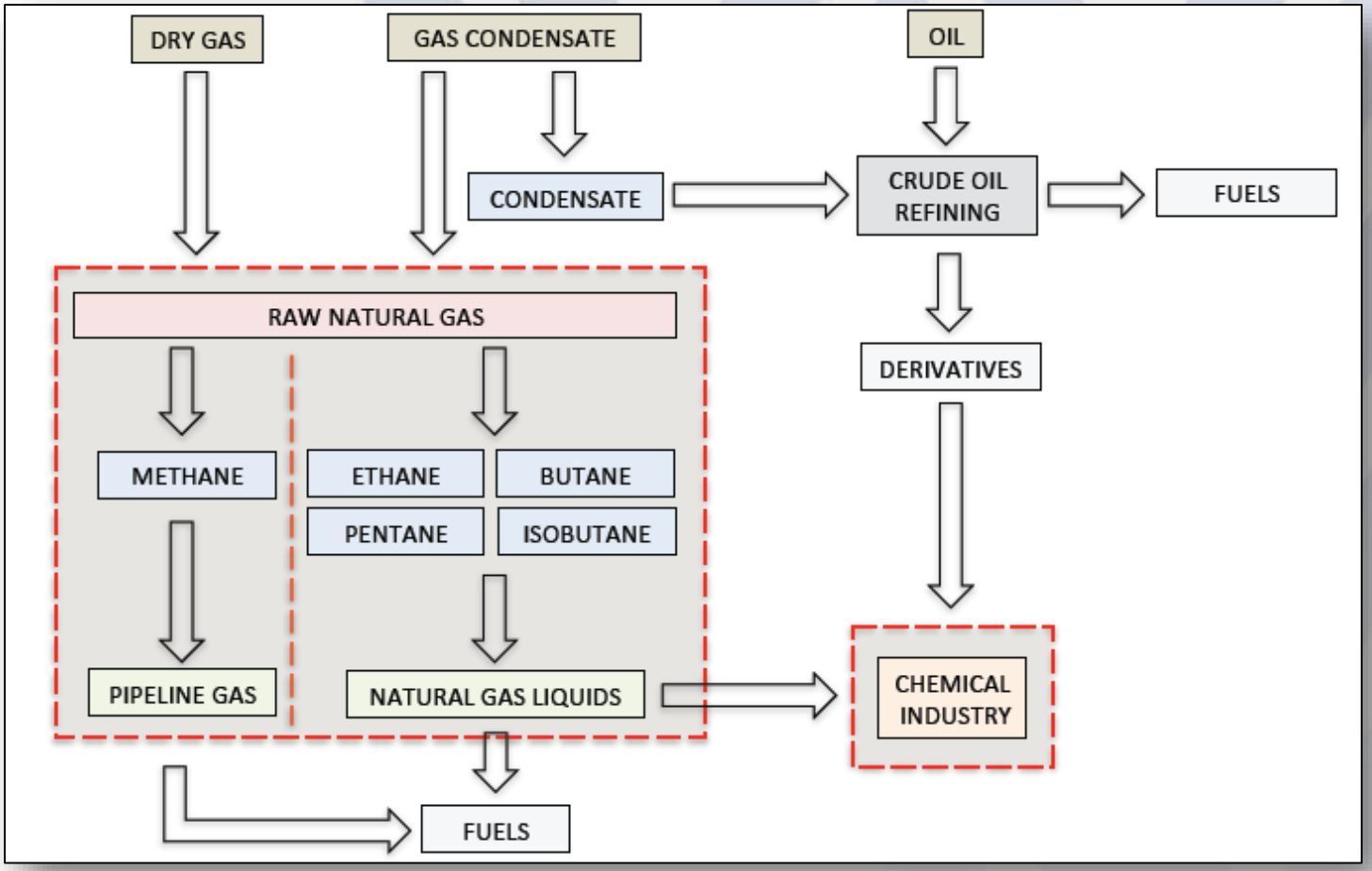
Source US-DOE, EIA, February 2016

Electricity Price Impact



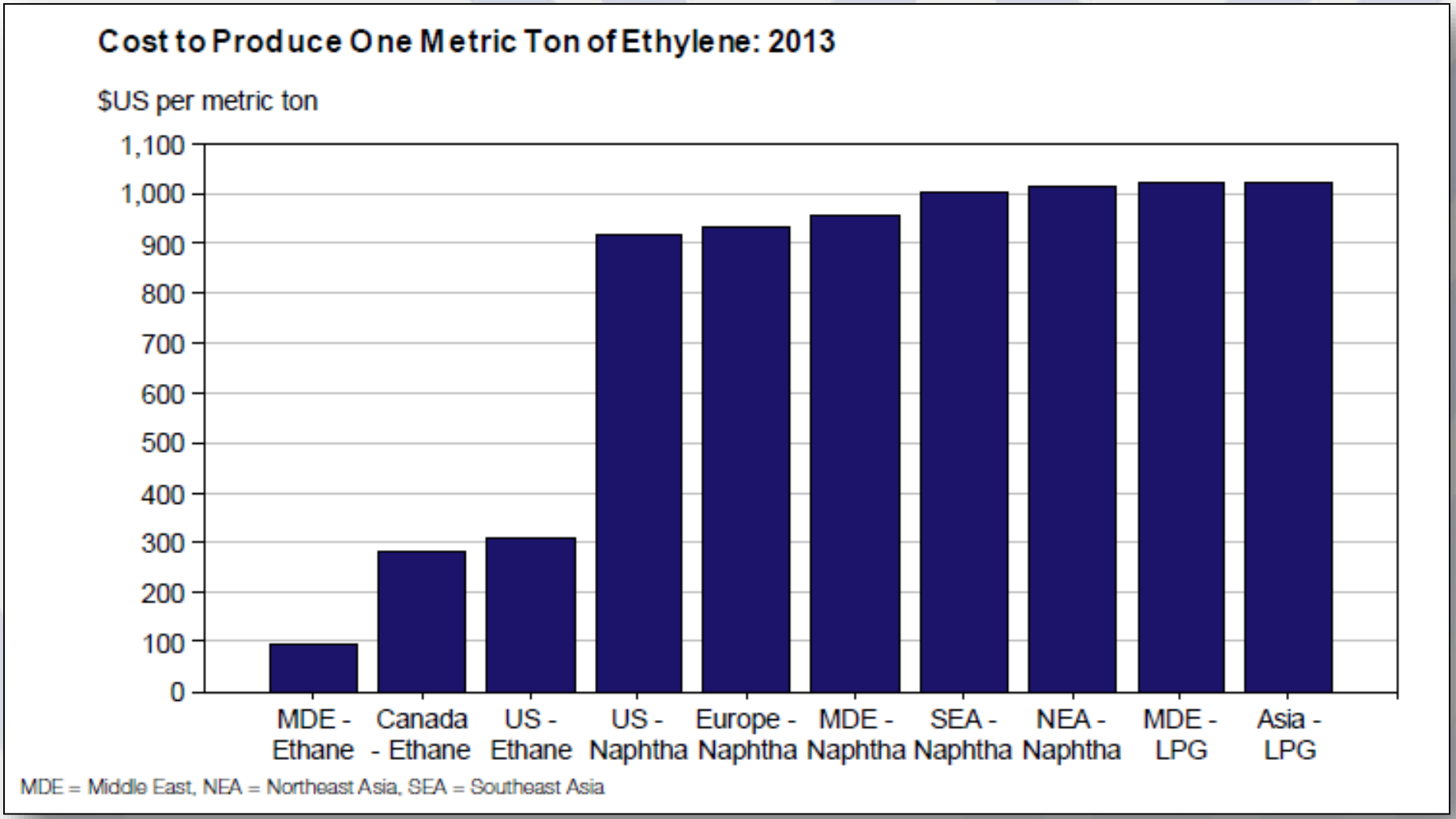
Source: International Energy Agency, 2013 Key World Energy Statistics

Revolution in the Hydrocarbon Market

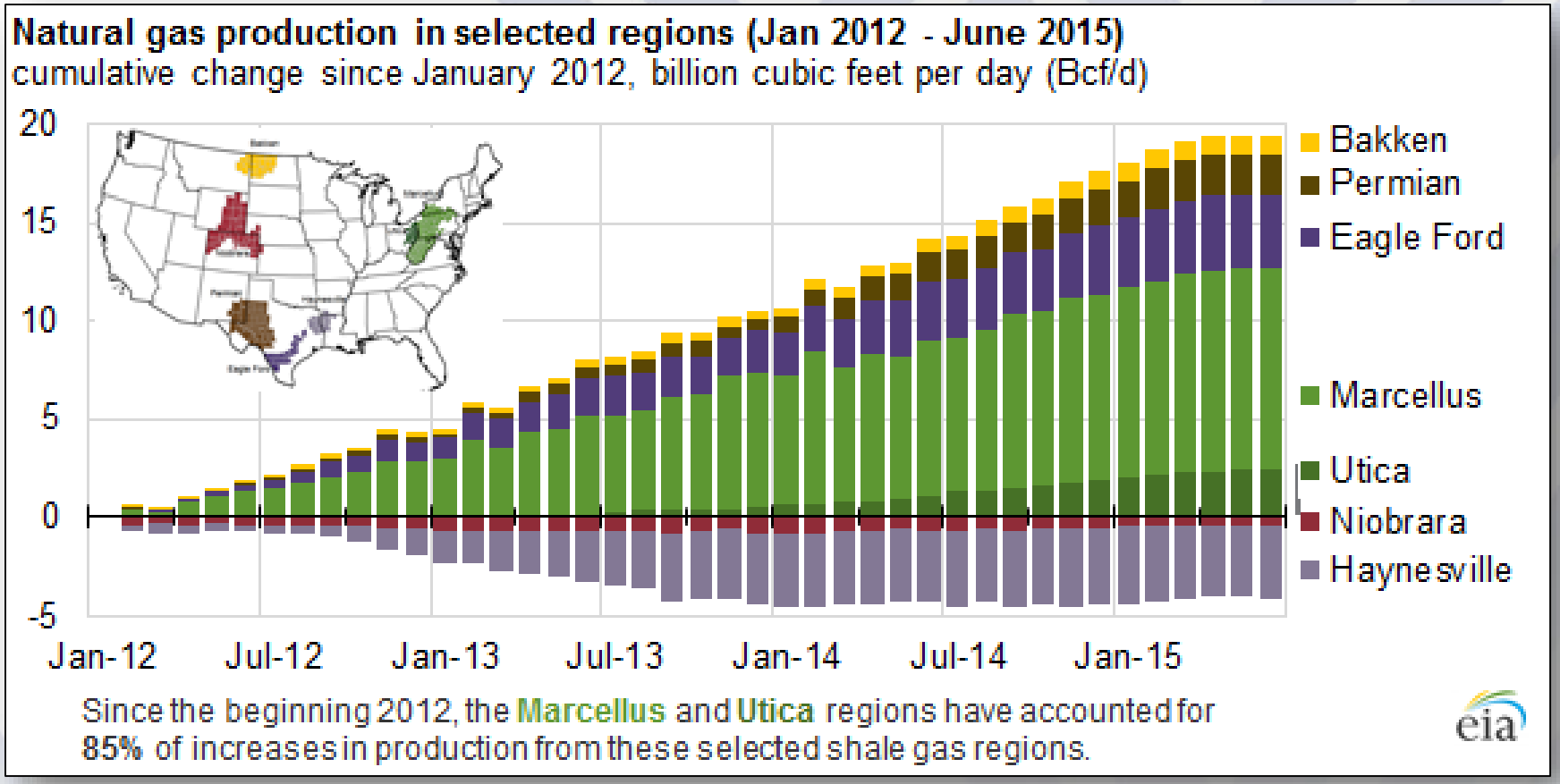


Dutton, 2012

Shale NGL's as Feedstock

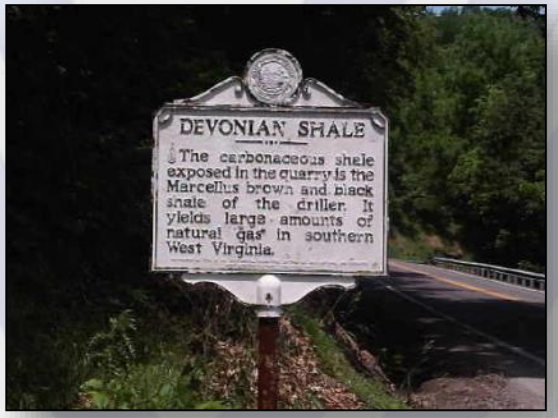


U.S. Natural Gas Production



Shale-Gas in the Appalachian Basin

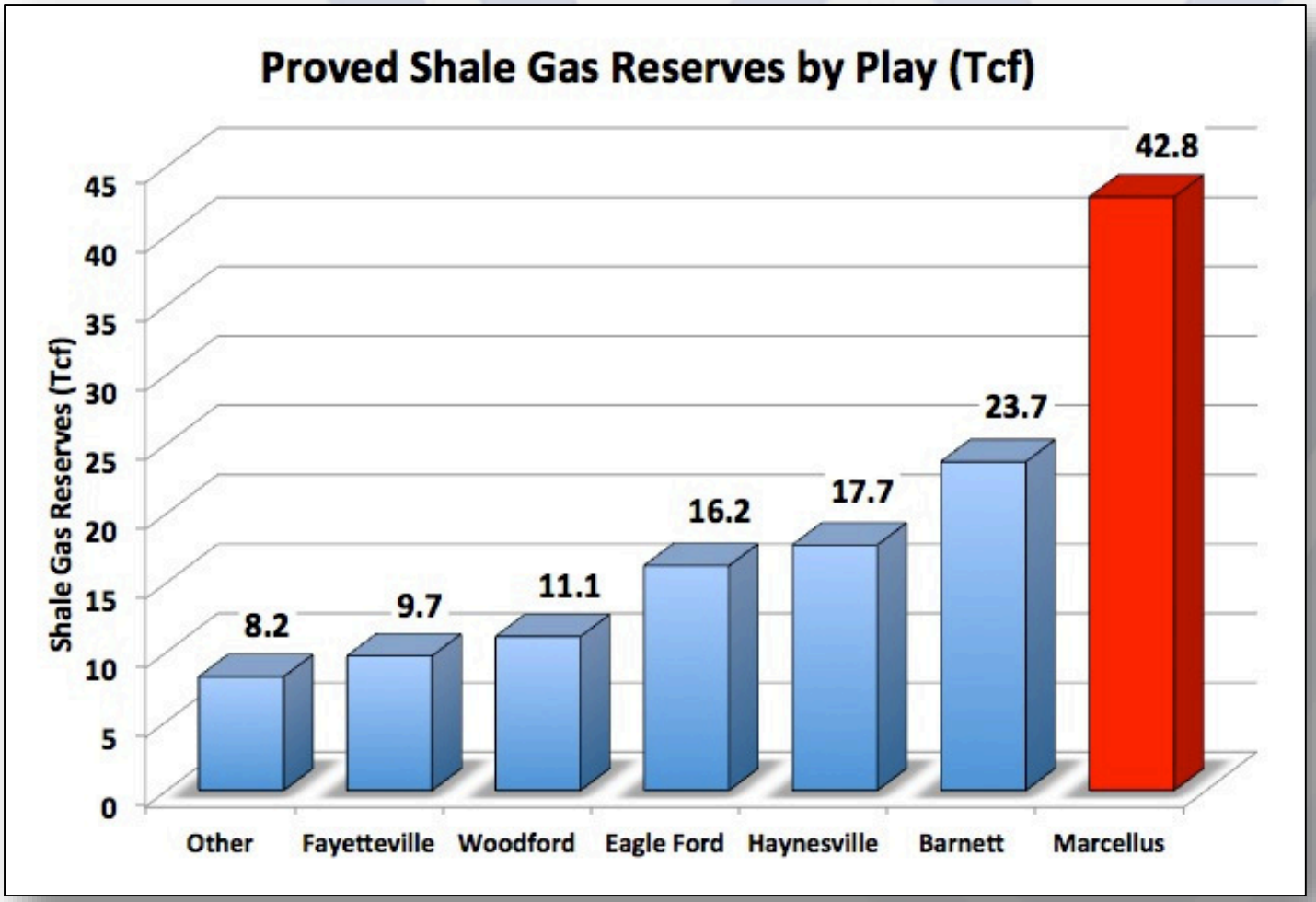
- Extremely Large Resource
  - 1.6 TCF in 2002 ➔ 500-1,300 Tcf, today
  - Large Area – 16-32 Million Acres in the Core Area
  - Adjacent to the Market
- Challenges
  - Terrain
  - Infrastructure
  - Societal/Environmental Impact
  - Public Perception-Tension / Outdated Regulations and Management Systems
- History
  - 1821, Fredonia, New York
  - 1970's – 1990's Research & Demonstration
    USDOE & Mitchell
  - 2003 Well - Range Resources
  - Approx. 13,079 Wells in Marcellus (96 Plugged)
    ~7,500 Wells in Process
  - Approximately 693 Wells in Utica
    ~554 Wells in Process



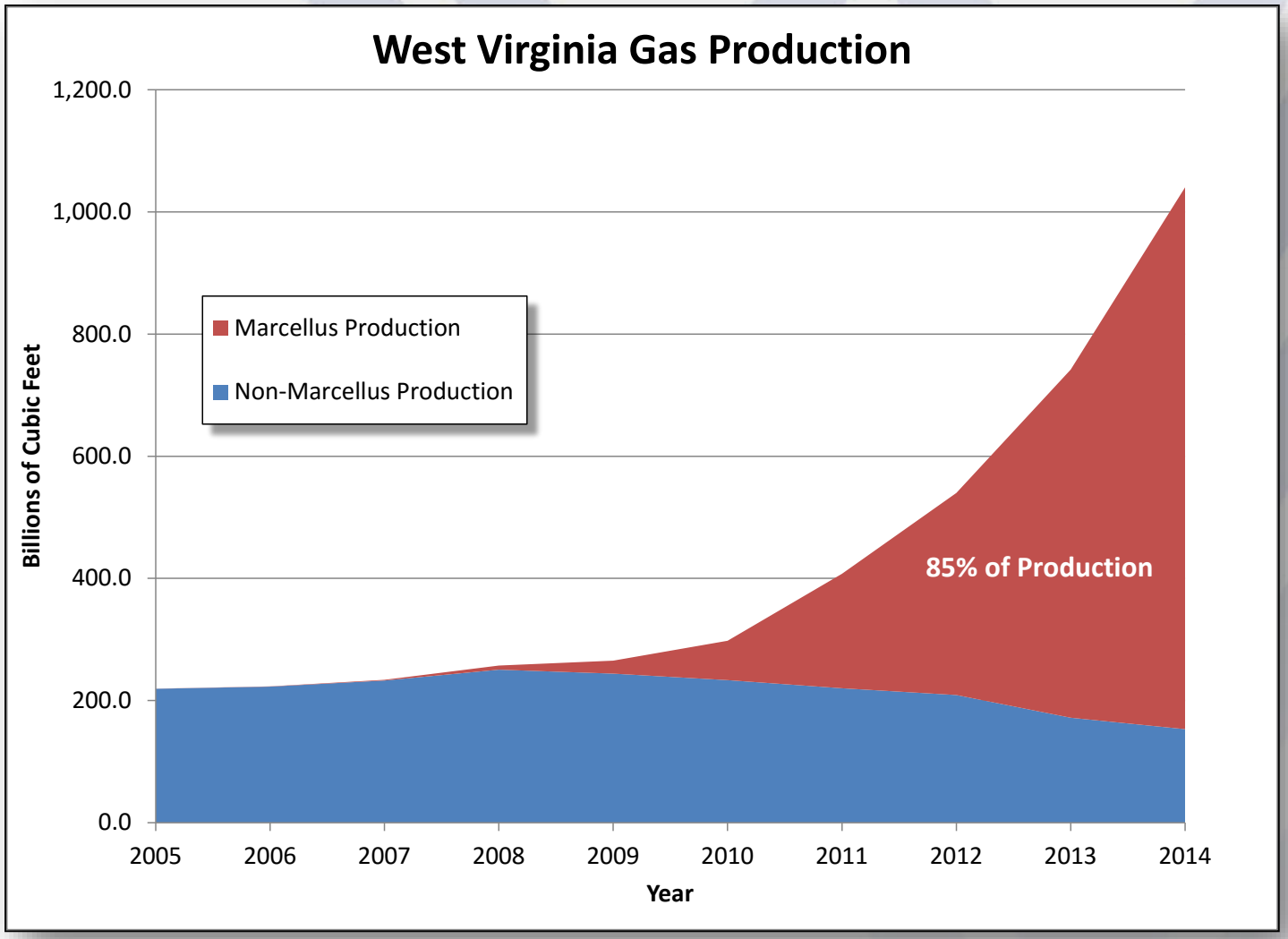
Located in downtown Fredonia, the boulder proudly displays the site of the first commercial gas well in the US, dedicated in 1925 on the 100th anniversary by the Daughters of the American Revolution.

Picture source - http://www.fredonia.edu/shaleinstitute/facts.asp

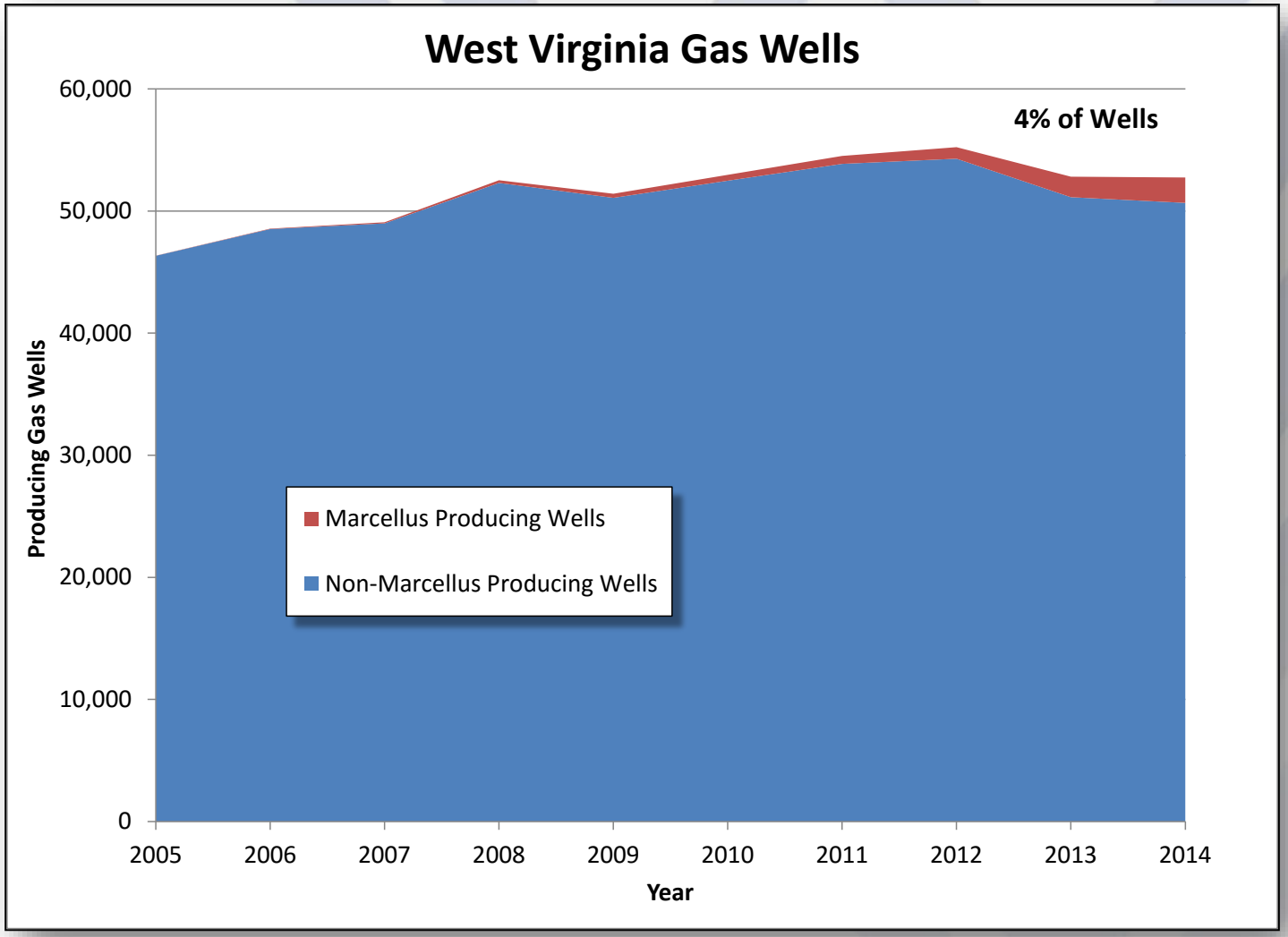
Shale Gas Plays



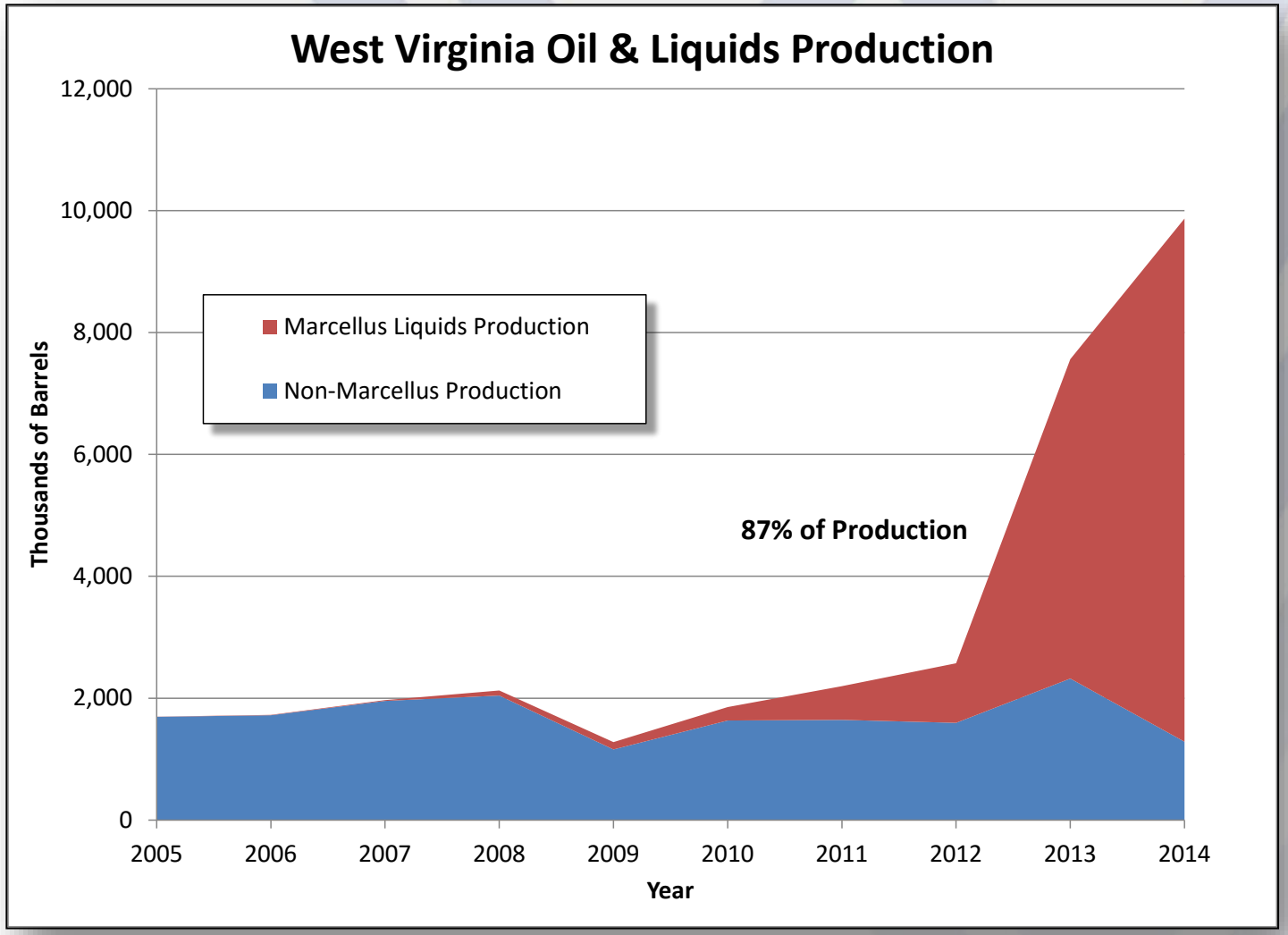
West Virginia Gas Production



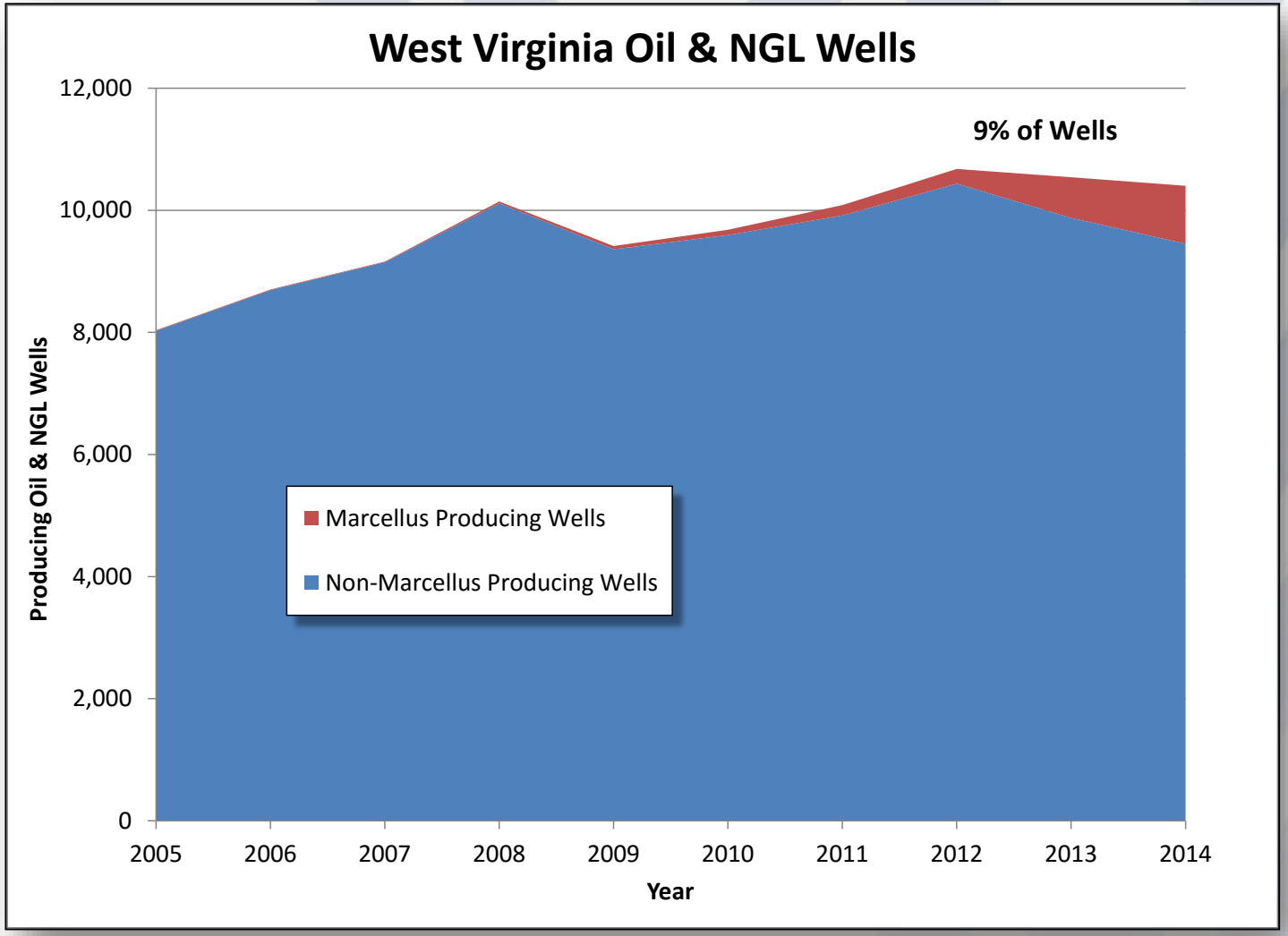
West Virginia Gas Production



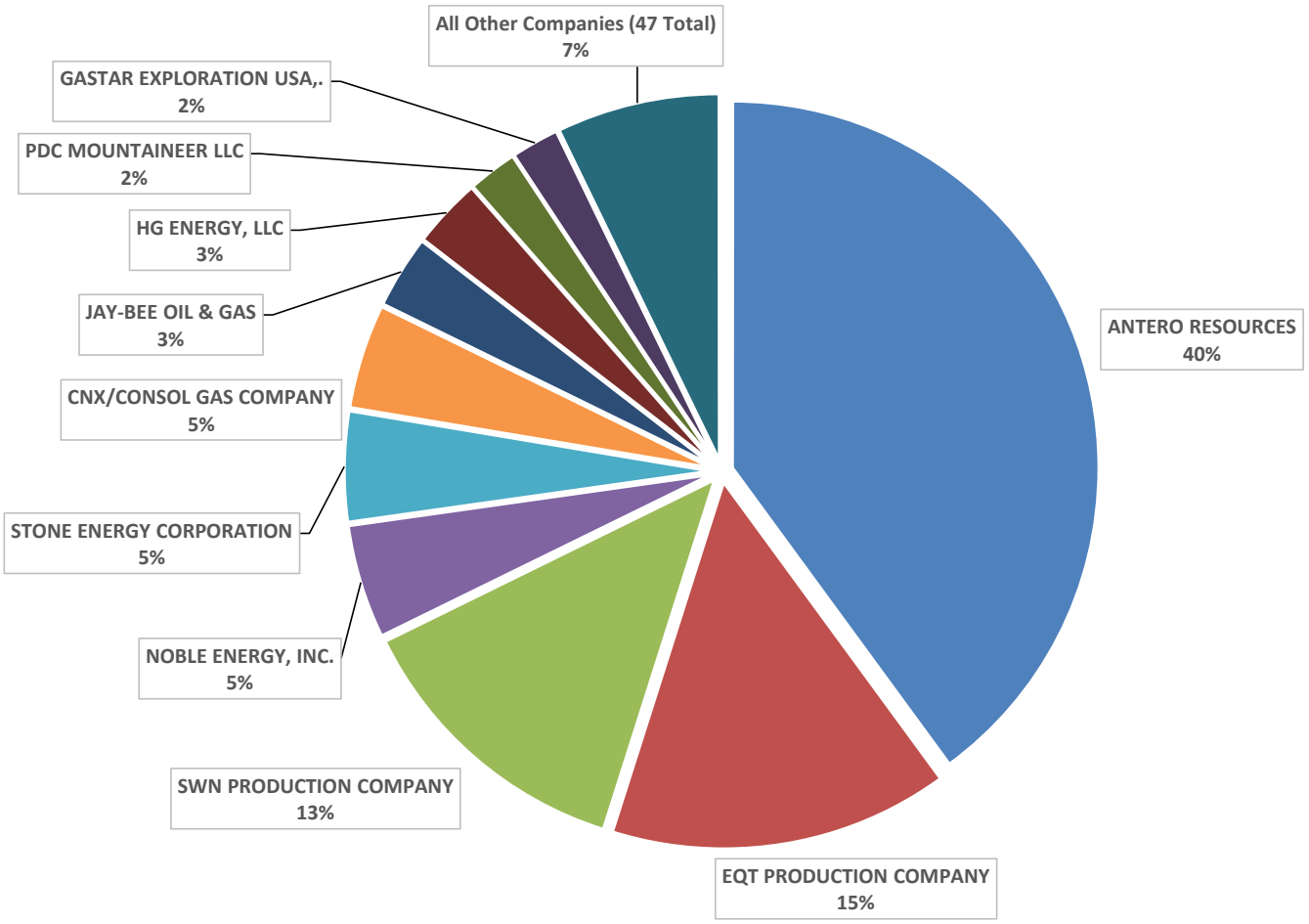
West Virginia Liquids Production



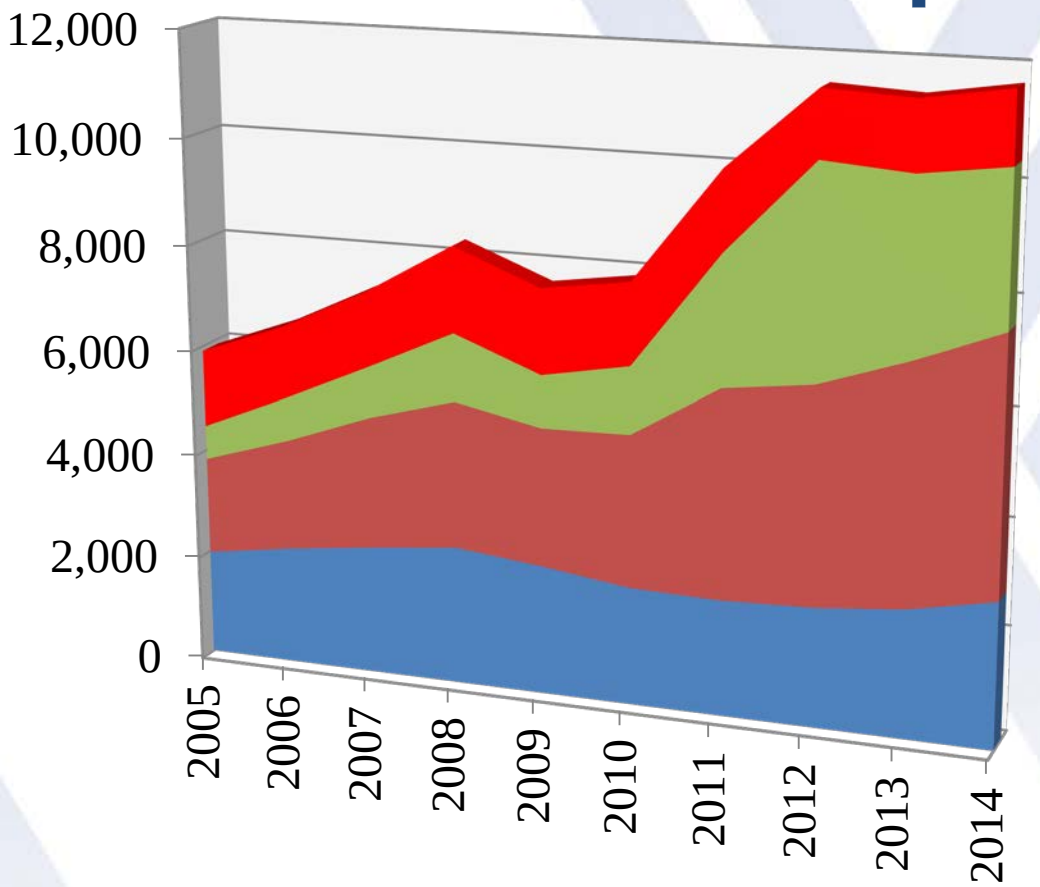
West Virginia Liquids Production



West Virginia 2014 Marcellus Gas Production by Operator



West Virginia Direct Oil & Gas Industrial Sector Employment



Industrial Sector
Avg. Wage $39,833.04/yr.

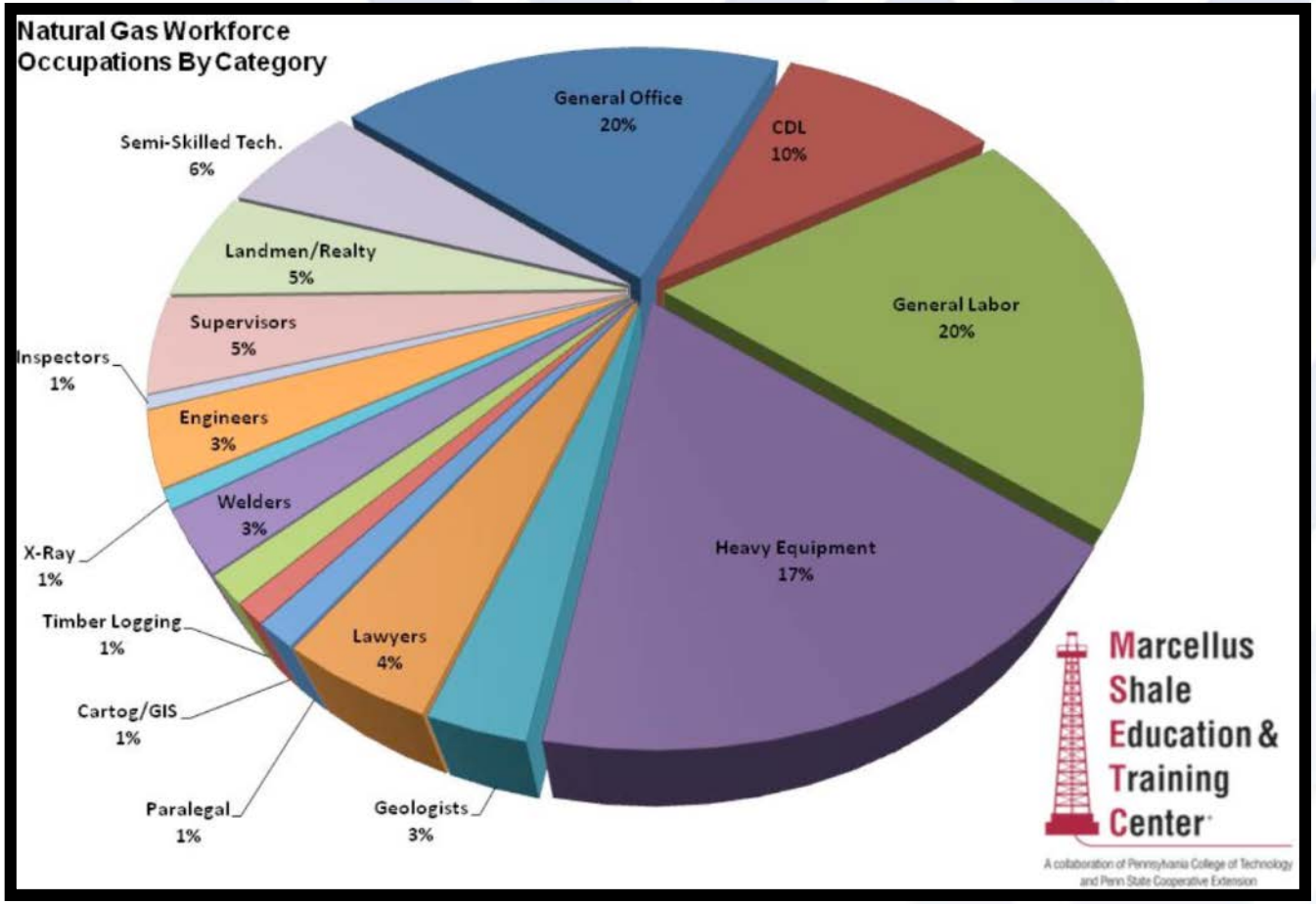
Oil & Gas Sector
Avg. Wage $81,542.37/yr.

Since 2005: Increase 5,516 jobs in Oil & Gas to 11,428

90% of the total increase in private sector employment

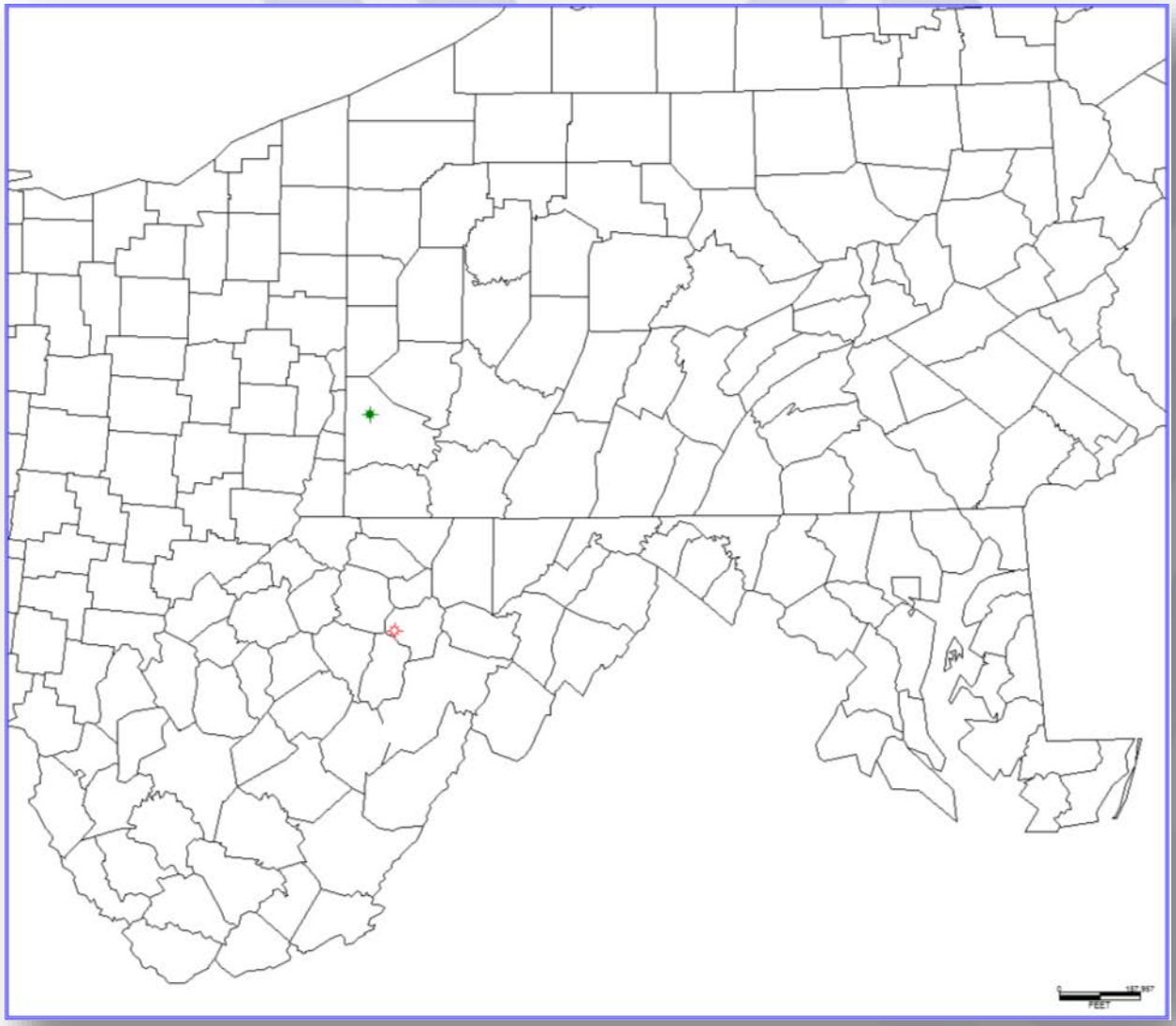
Source: Workforce West Virginia, http://www.workforcewv.org through 2nd quarter 2014. Average wages and employment changes computed form annual data 2005 to 2013.

West Virginia Direct Oil & Gas Industrial Sector Employment



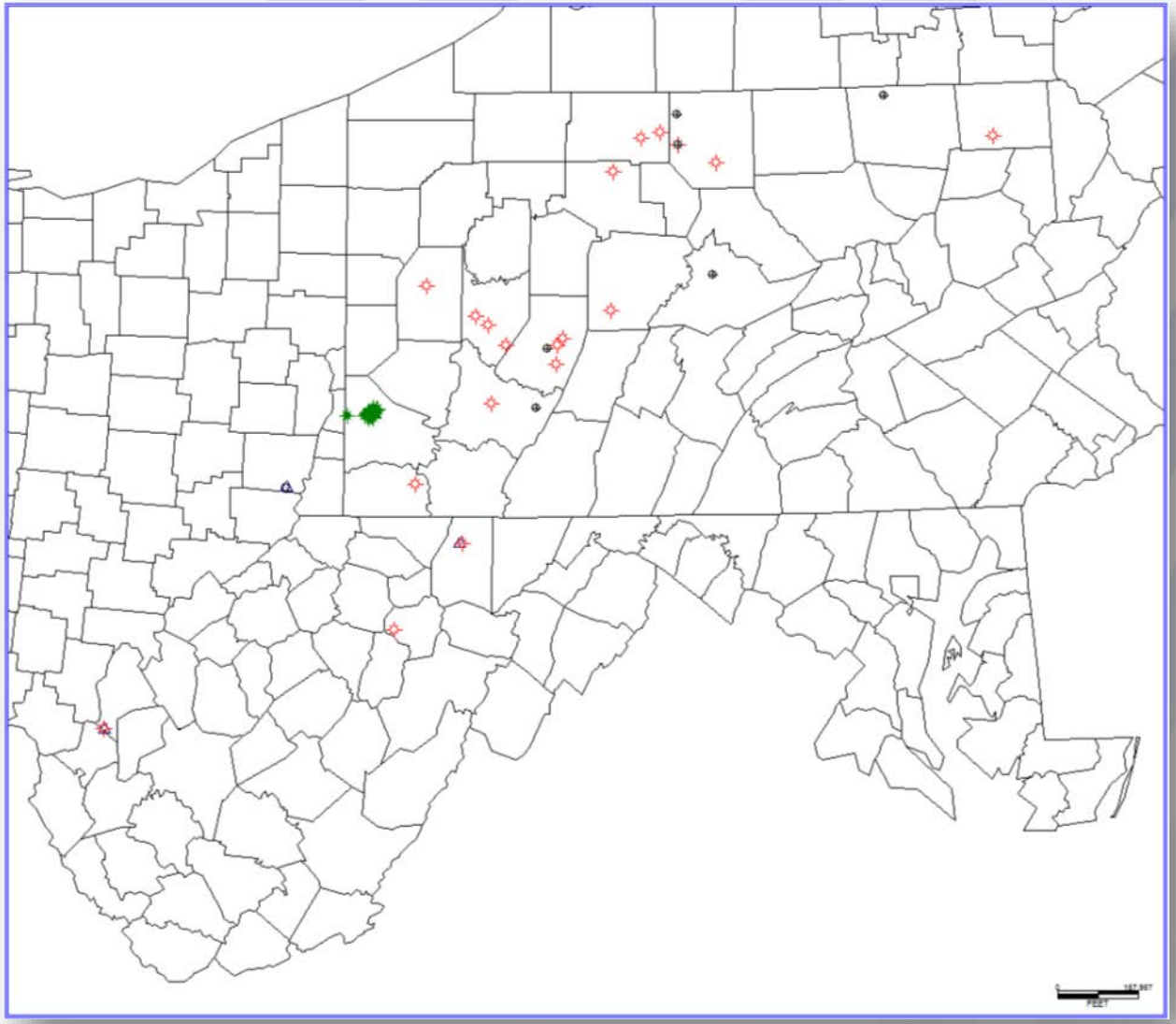
J. Jacquet, Marcellus Shale Education and Training Center

Marcellus Horizontal Wells Through 2005



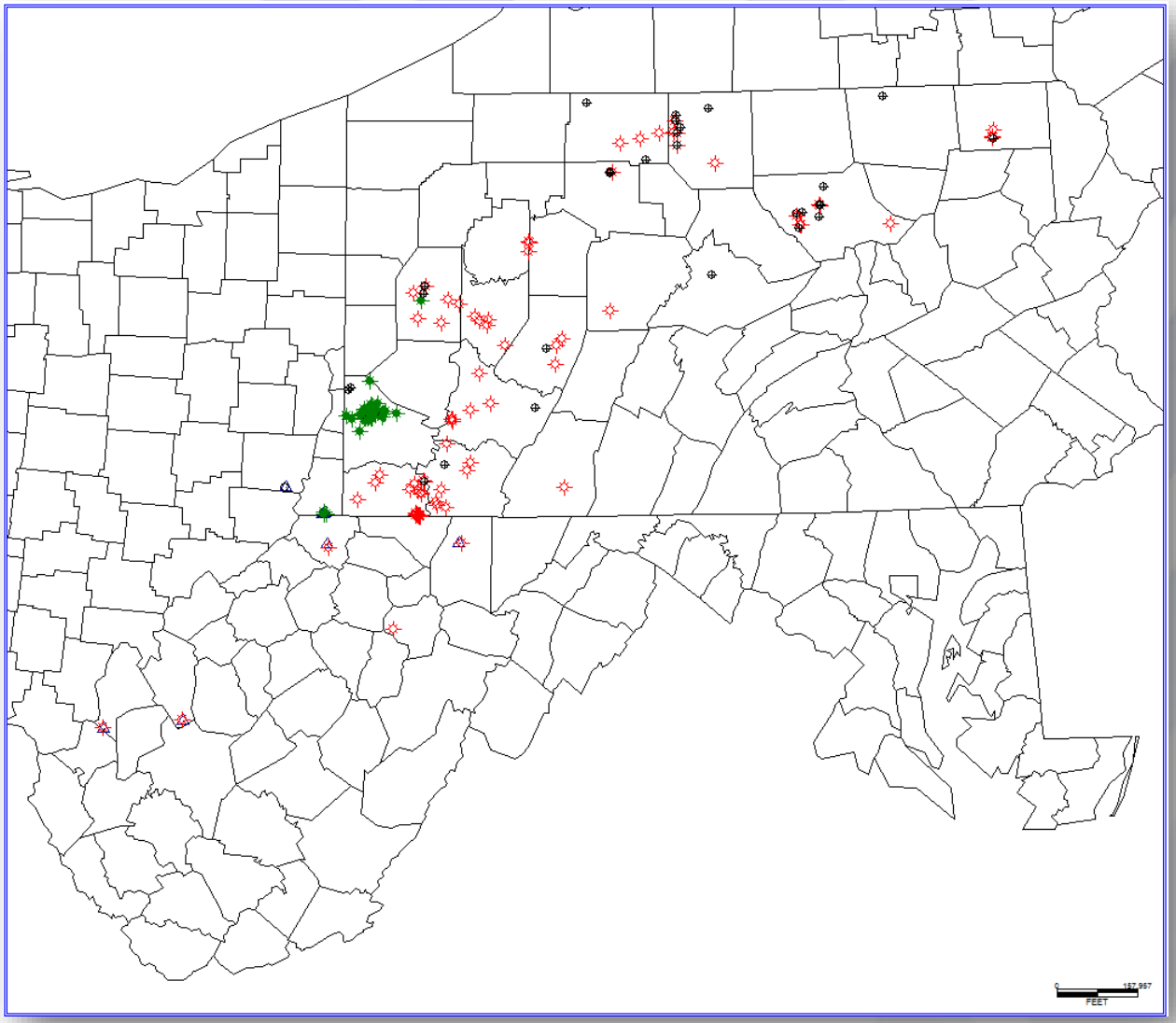
1 Well

Marcellus Horizontal Wells Through 2006



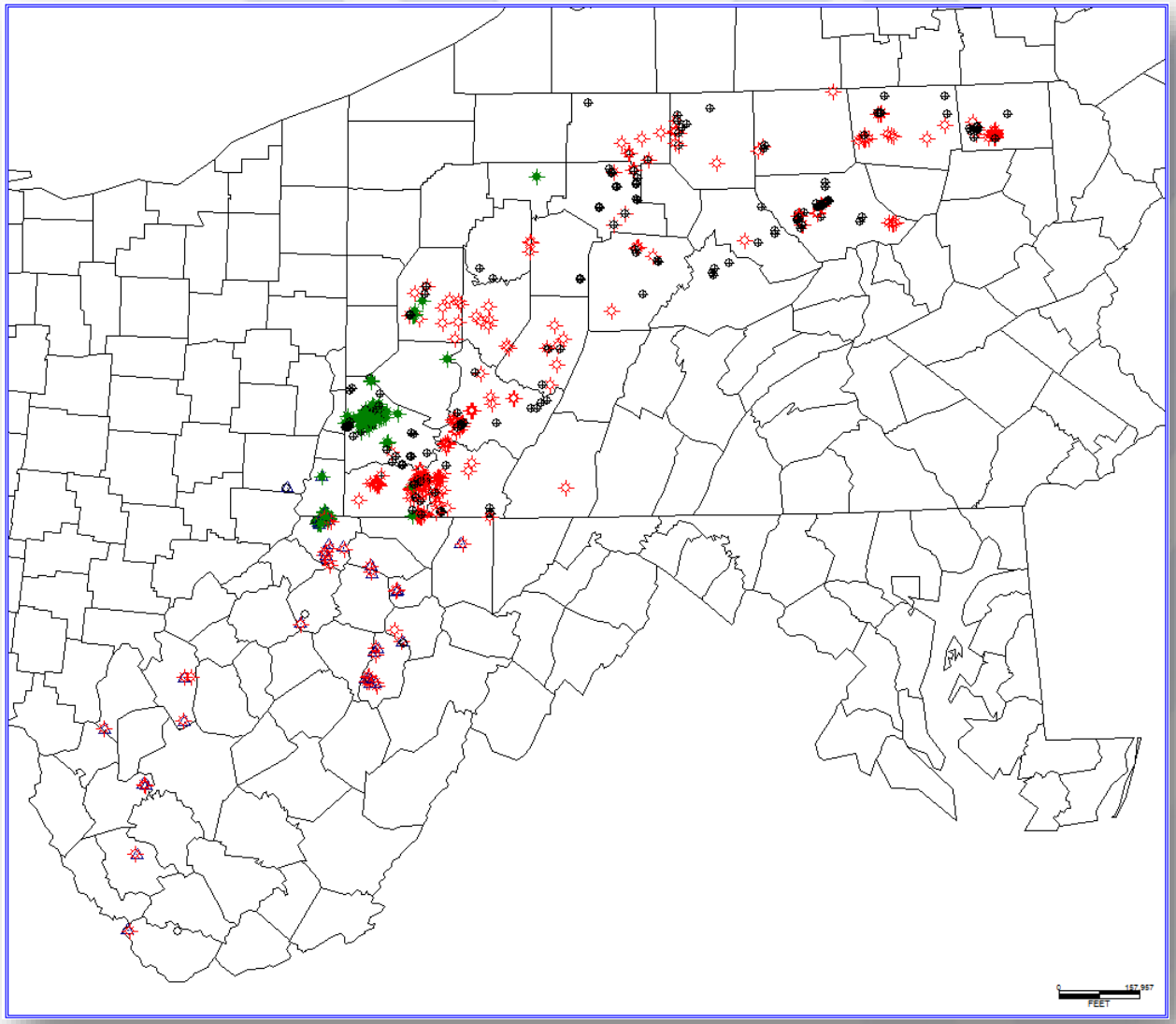
51 Wells

Marcellus Horizontal Wells Through 2007



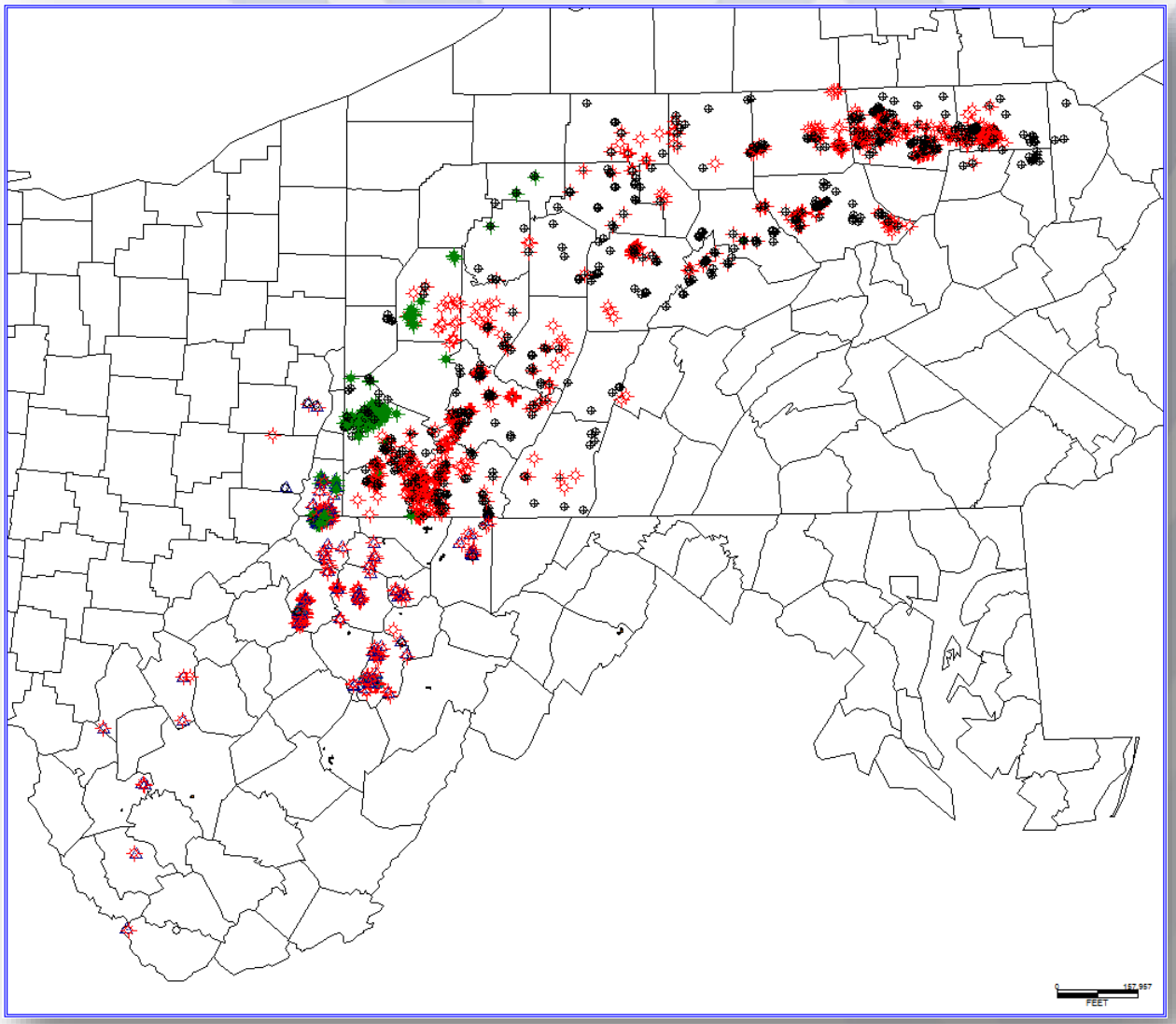
187 Wells

Marcellus Horizontal Wells Through 2008



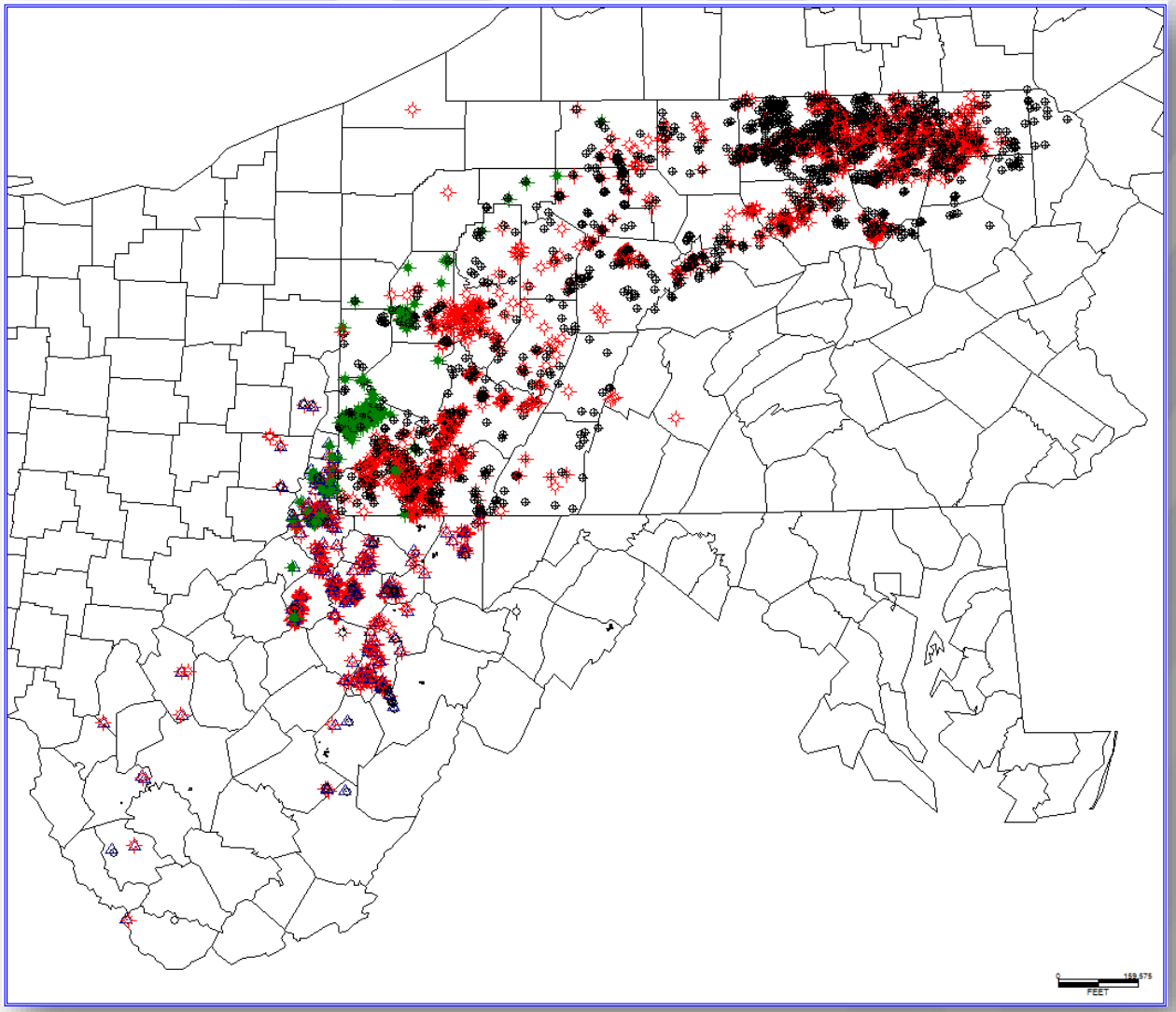
637 Wells

Marcellus Horizontal Wells Through 2009



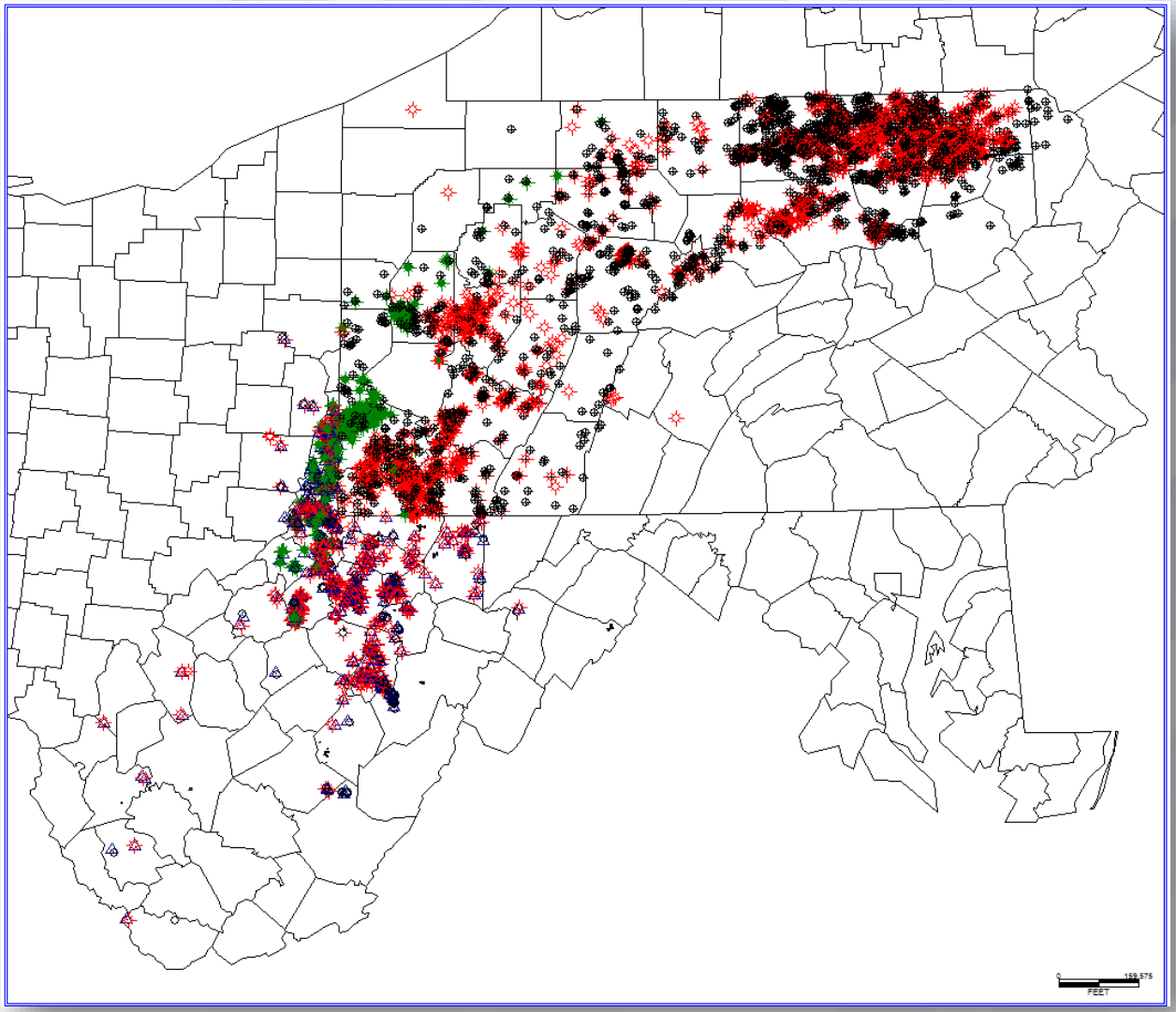
2,594 Wells

Marcellus Horizontal Wells Through 2010



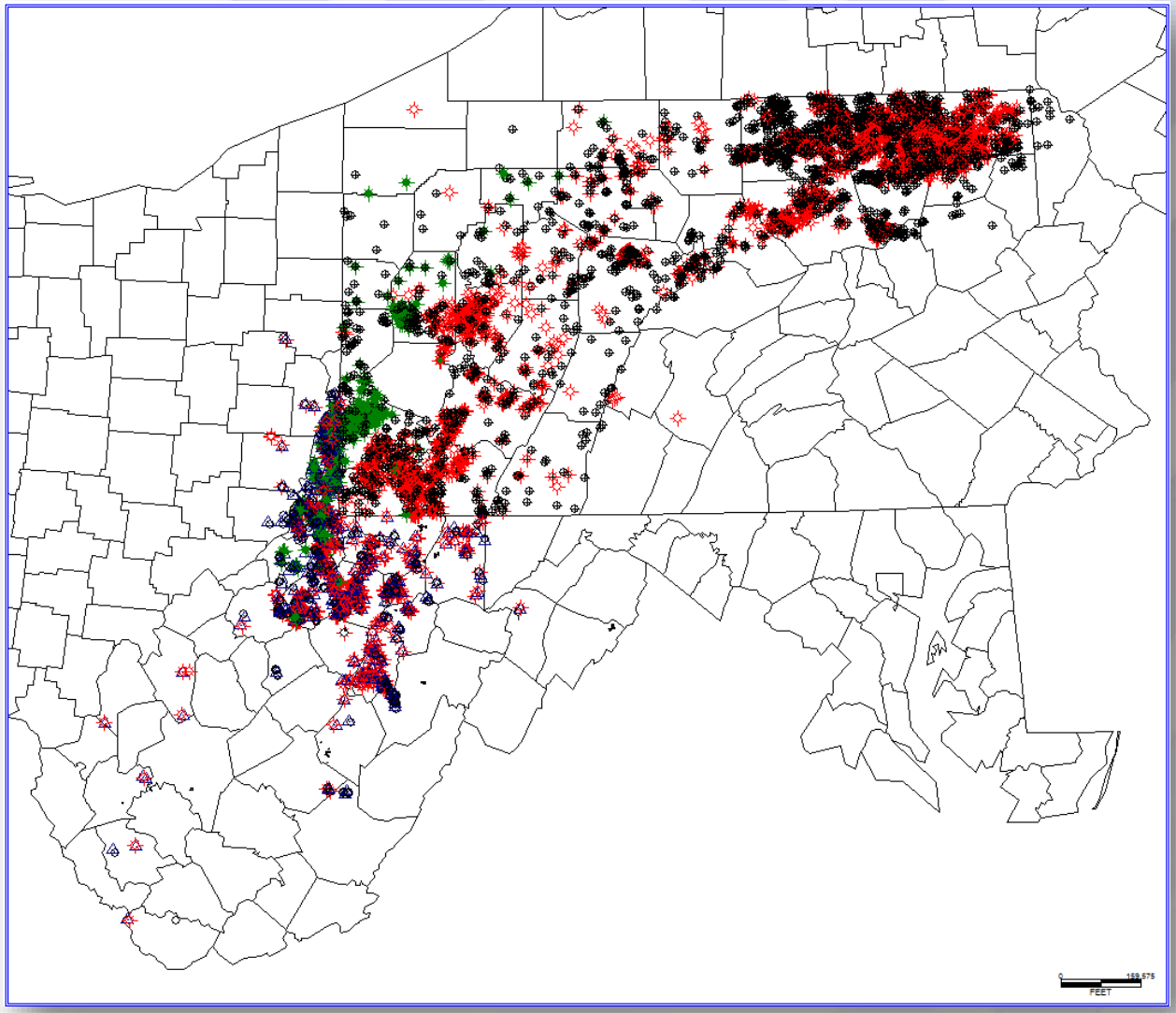
6,936 Wells

Marcellus Horizontal Wells Through 2011



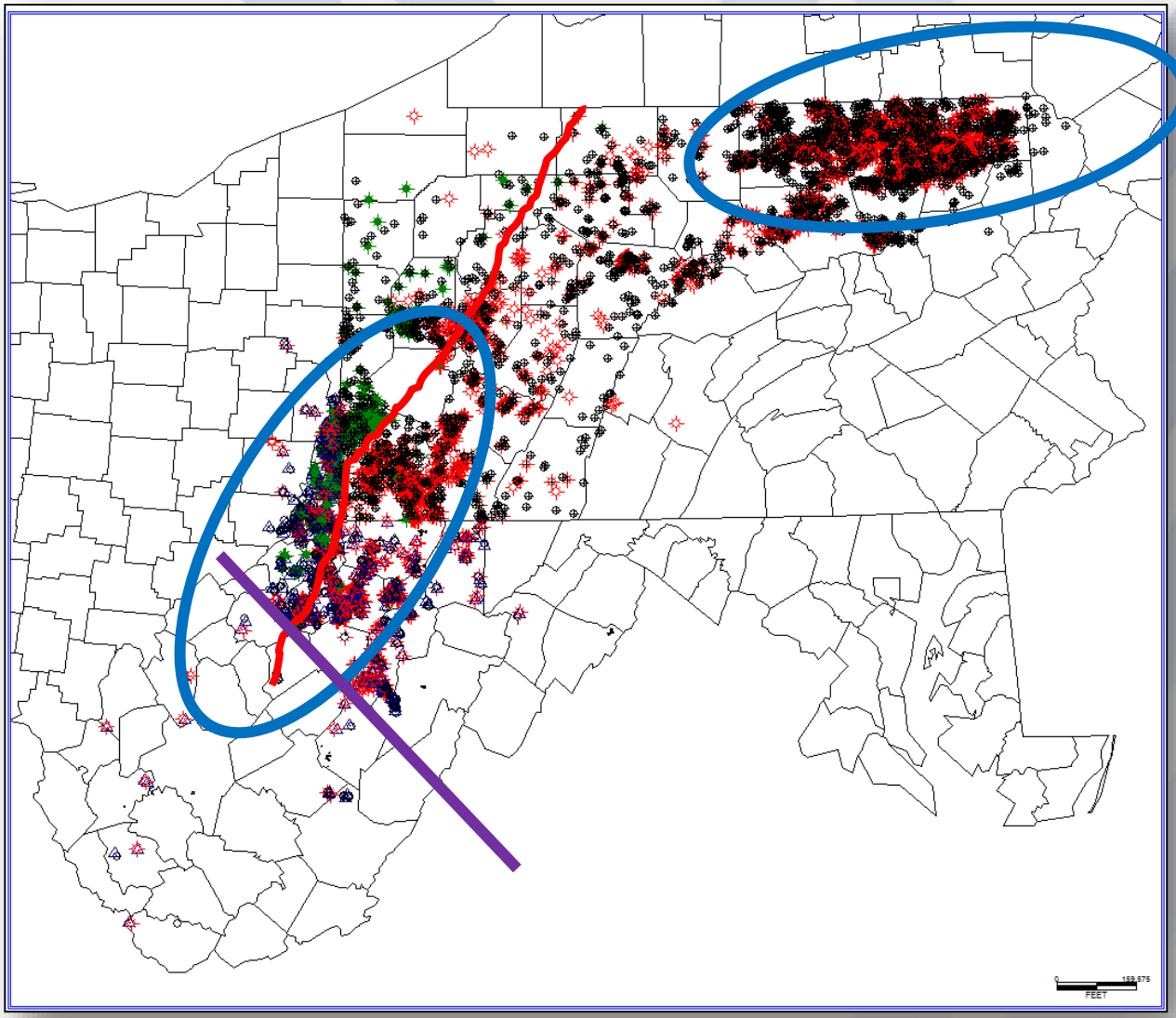
9,856 Wells

Marcellus Horizontal Wells Through 2012



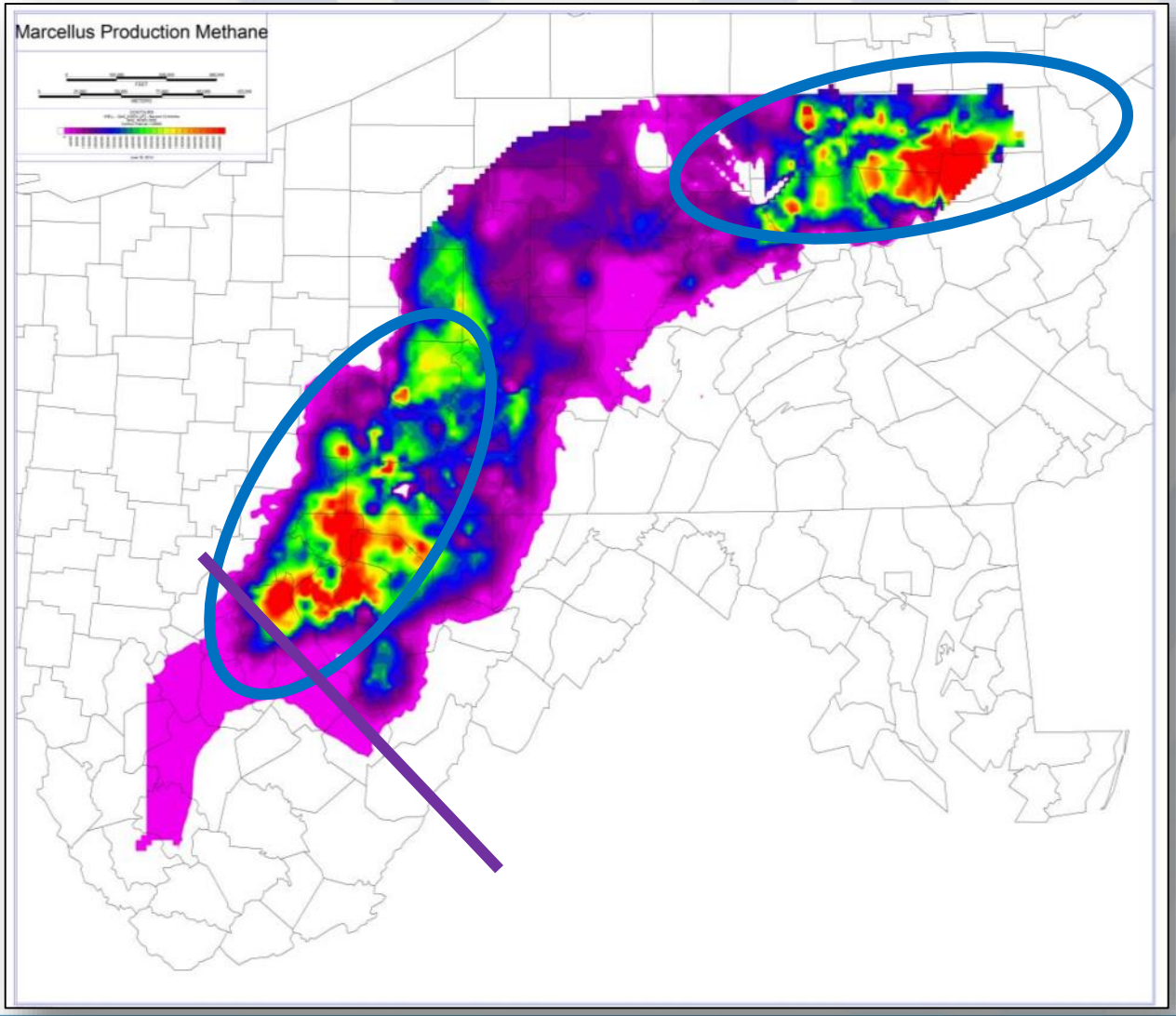
11,789 Wells

Marcellus Horizontal Wells Through 2013



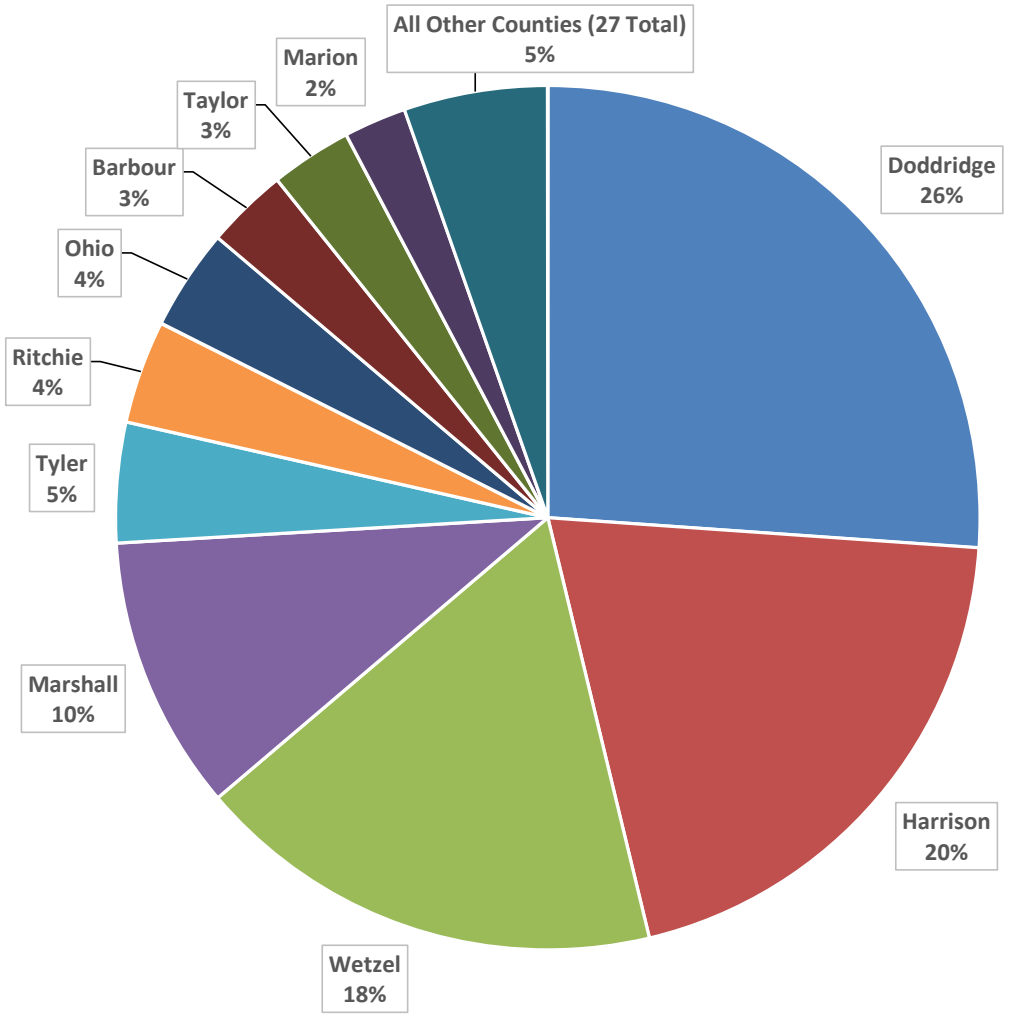
13,079 Wells

Marcellus Annual Production Normalized

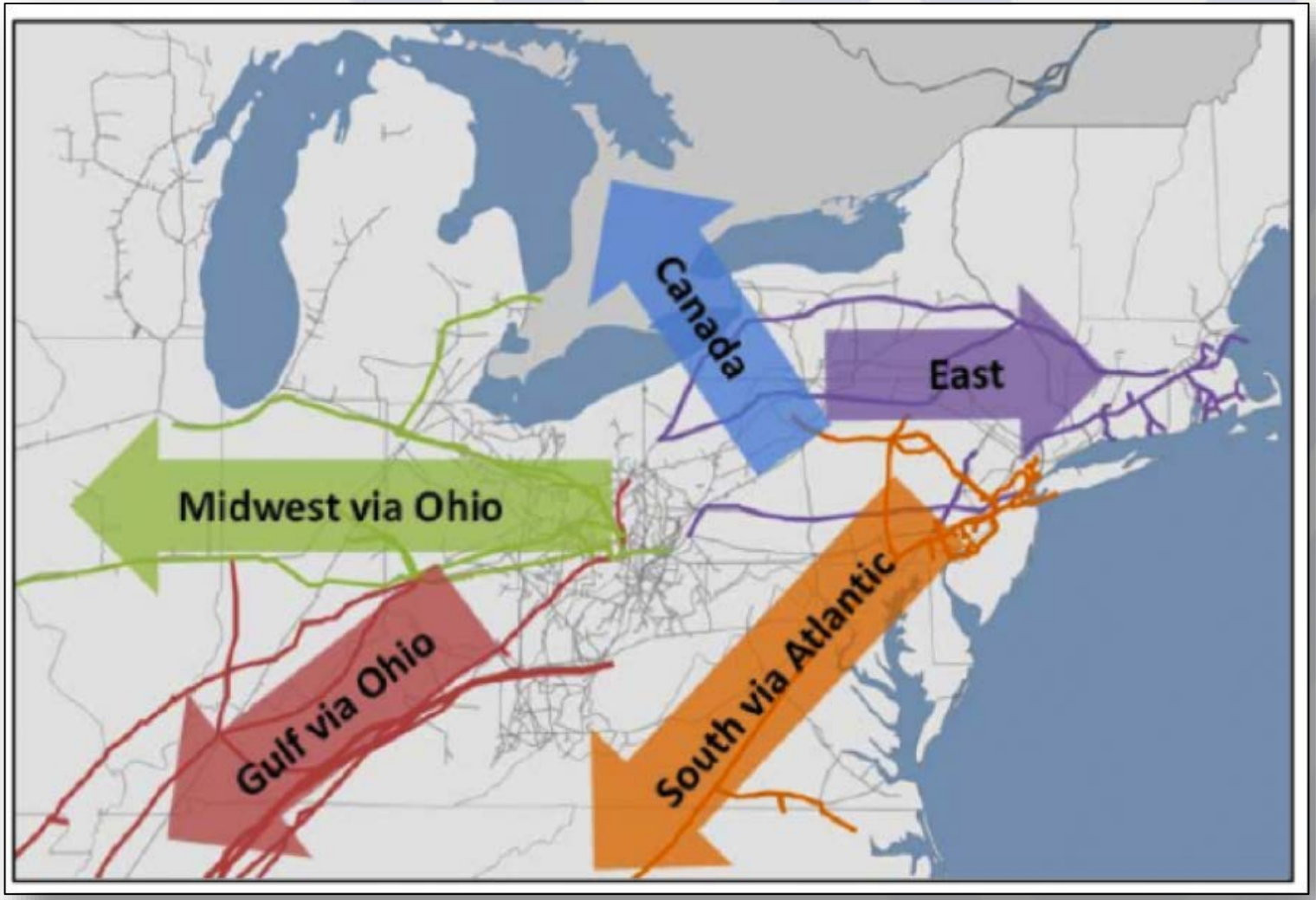


2nd and 3rd Six Month Production

West Virginia 2014 Marcellus Gas Production by County

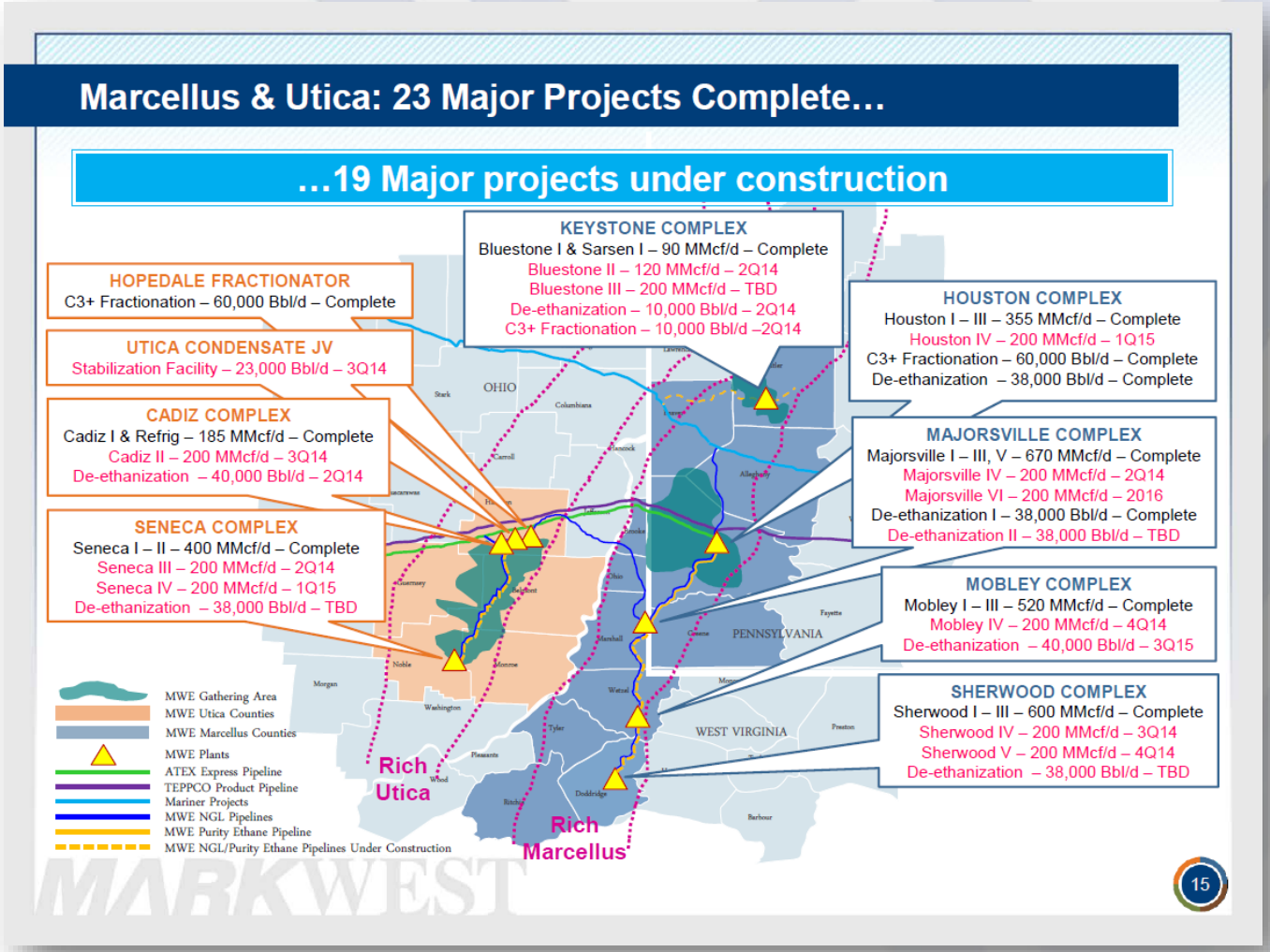


Shale Gas – Pipeline Construction

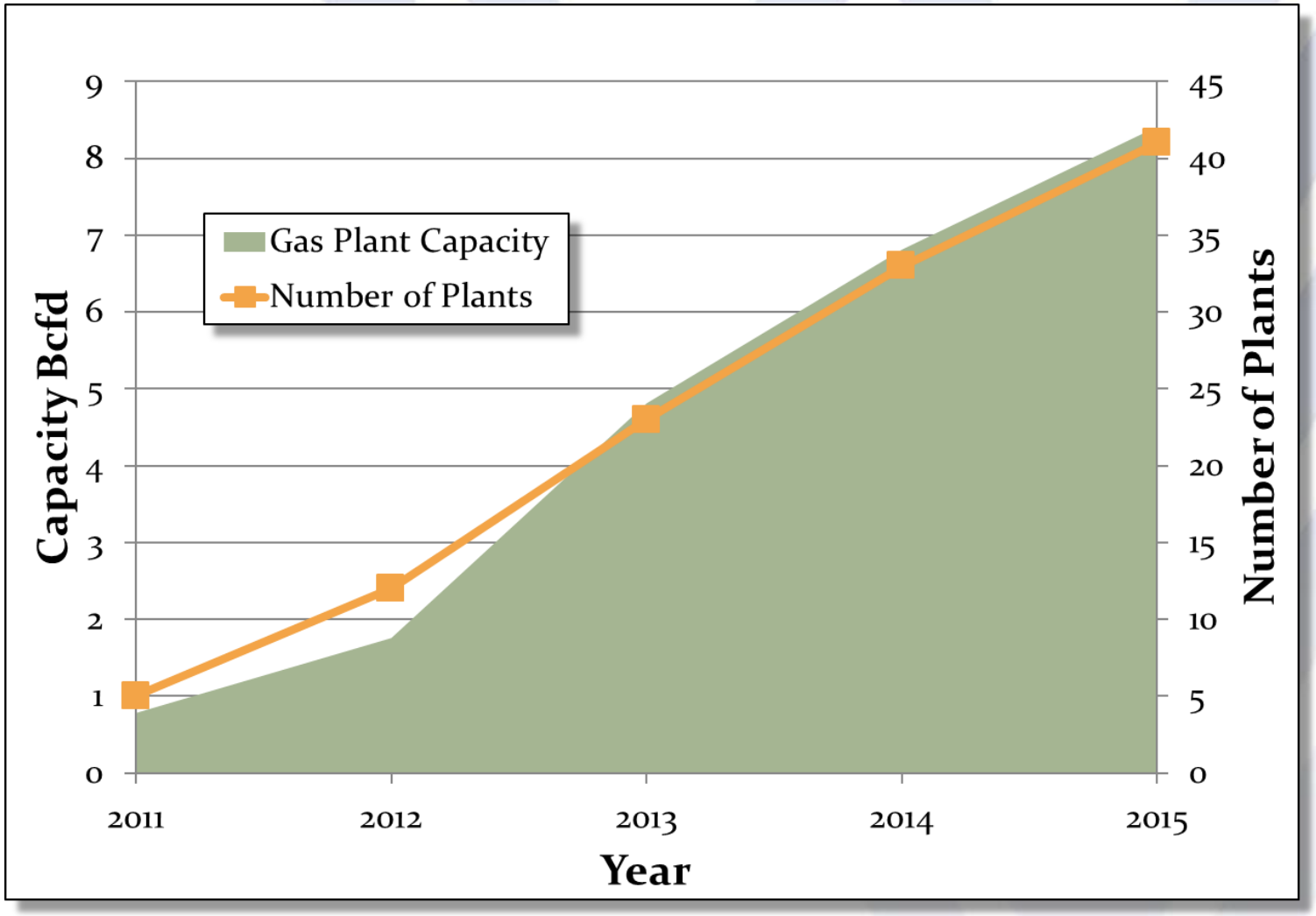


Source: RBN Energy

Marcellus-Utica Gas Processing

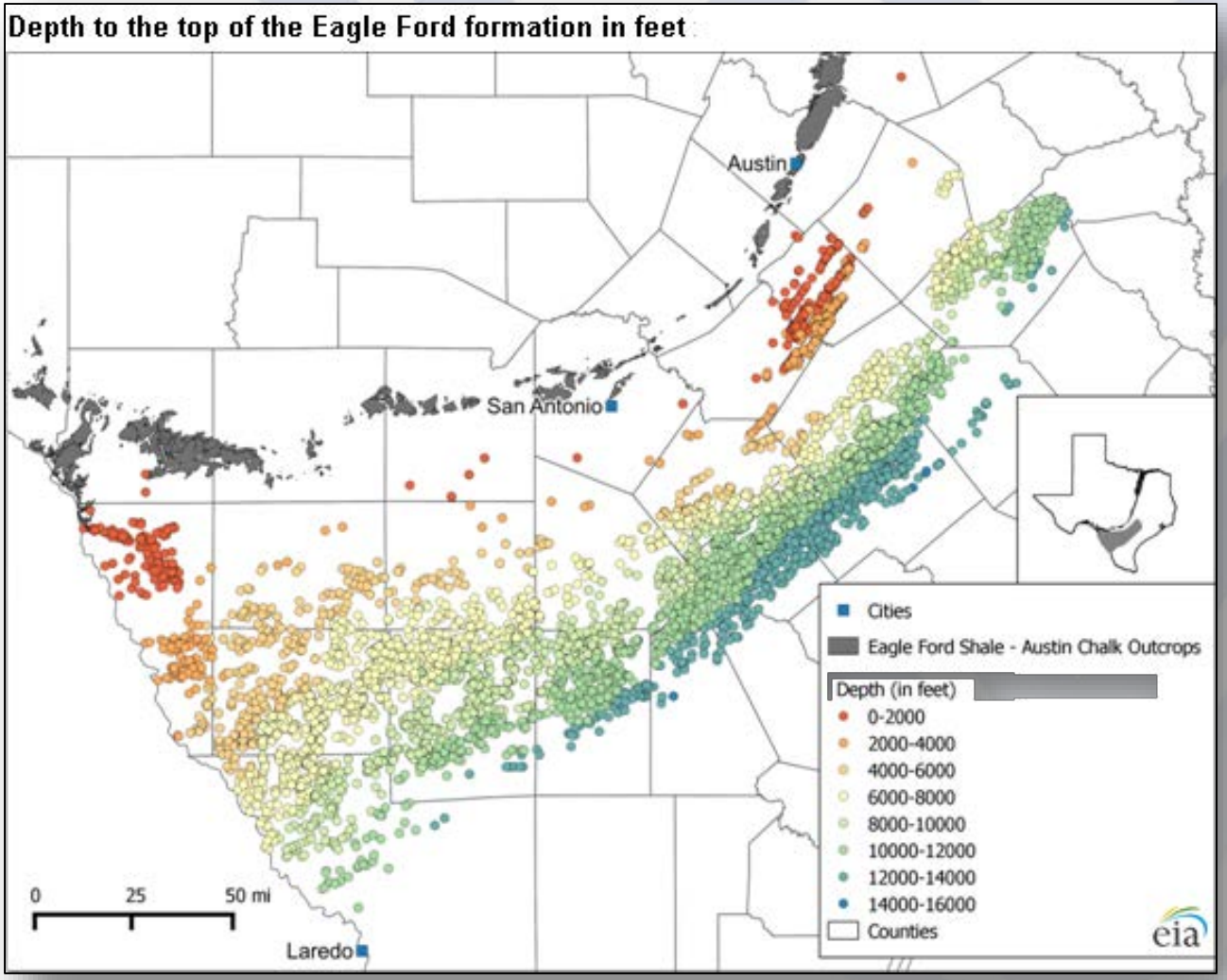


Appalachian Basin New Gas Facilities

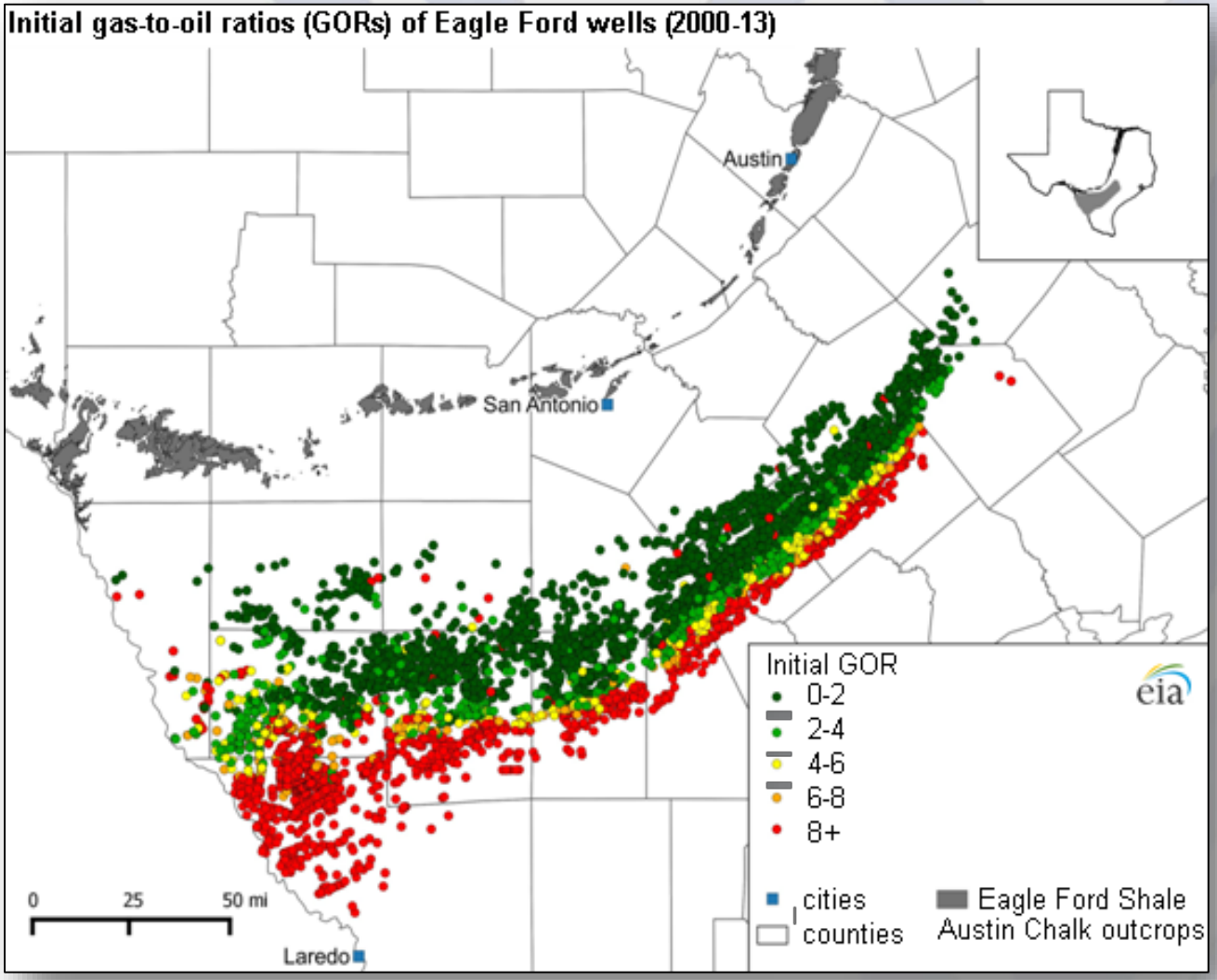


Source Oil & Gas Journal 06/02/2014

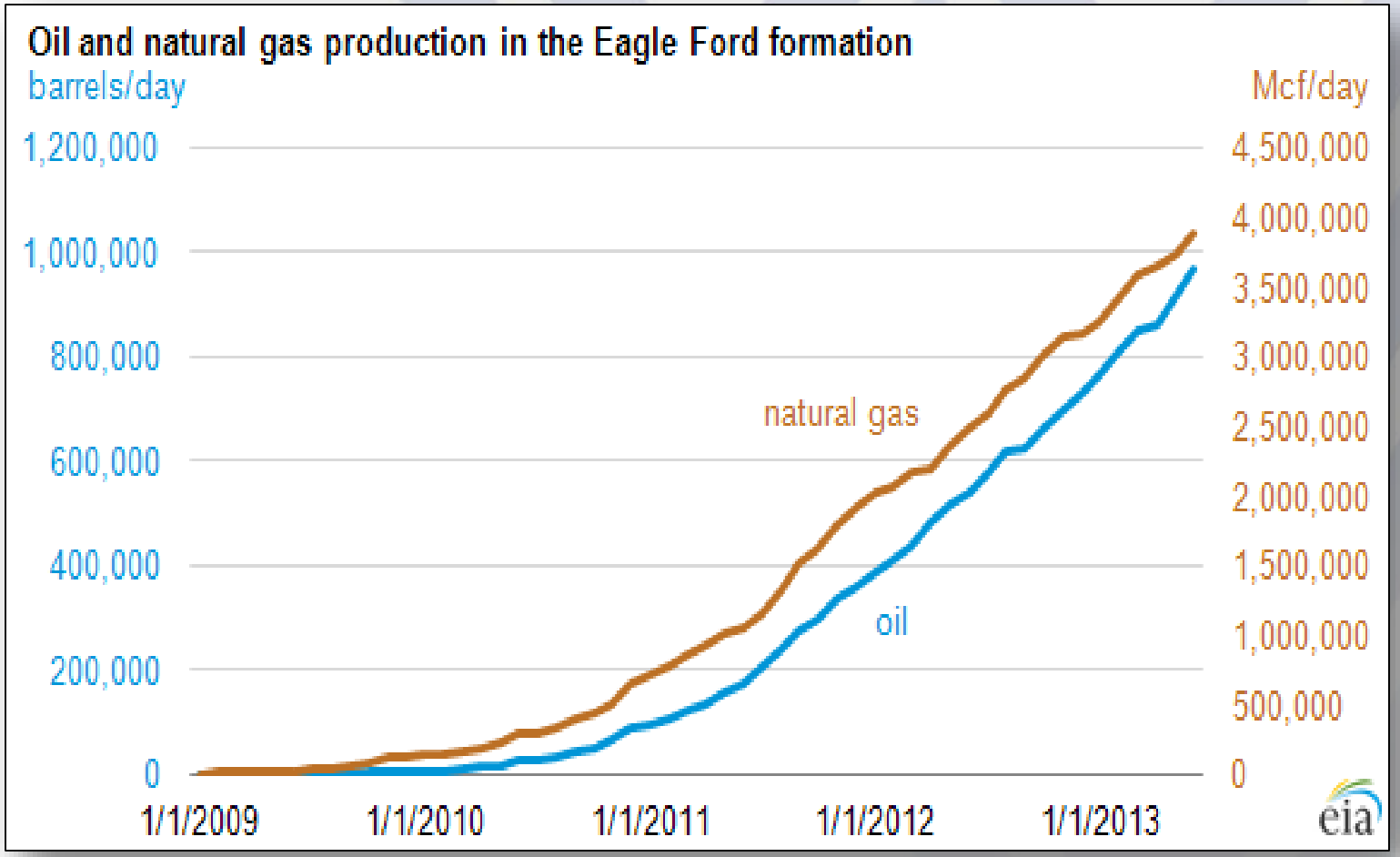
Eagle Ford Shale



Eagle Ford Shale



Eagle Ford Shale



International Opportunities

Shale oil

rank	country	billion barrels
1	Russia	75
2	United States	58
3	China	32
4	Argentina	27
5	Libya	26
6	Venezuela	13
7	Mexico	13
8	Pakistan	9
9	Canada	9
10	Indonesia	8
	World total	**345**

Shale gas

rank	country	trillion cubic feet
1	China	1,115
2	Argentina	802
3	Algeria	707
4	United States	665
5	Canada	573
6	Mexico	545
7	Australia	437
8	South Africa	390
9	Russia	285
10	Brazil	245
	World total	**7,299**

Note: ARI estimates U.S. shale oil resources at 48 billion barrels and U.S. shale gas resources at 1,161 trillion cubic feet.
Source: United States: EIA and USGS; Other basins: ARI.

Shale Revolution Affects Everything

- Horizontal Drilling and Hydraulic Fracture Stimulation have been Around for Decades
- The Shale Boom has Emerged from Smart Drilling
  - 3D Seismic - Map
  - Down Hole Sensors While Drilling - Headlights
  - Steerable Bits and Precision Guidance – Steering Wheel
  - Microseismic, Tiltmeters and Fiber-optics to Monitor Stimulation – Headlights
  - Computerized Punp and Blending Controls – Steering Wheel
- Real-Time Data Integration
  - Remote Access
  - Automated Rigs
  - Closed Loop Systems
  - Computer-Controlled Power - Bifuel, CNG and LNG
- A Drilling Rig is a Computer with a Drill Bit Attached to One End
  - Petabytes of Data Generated with Each Well

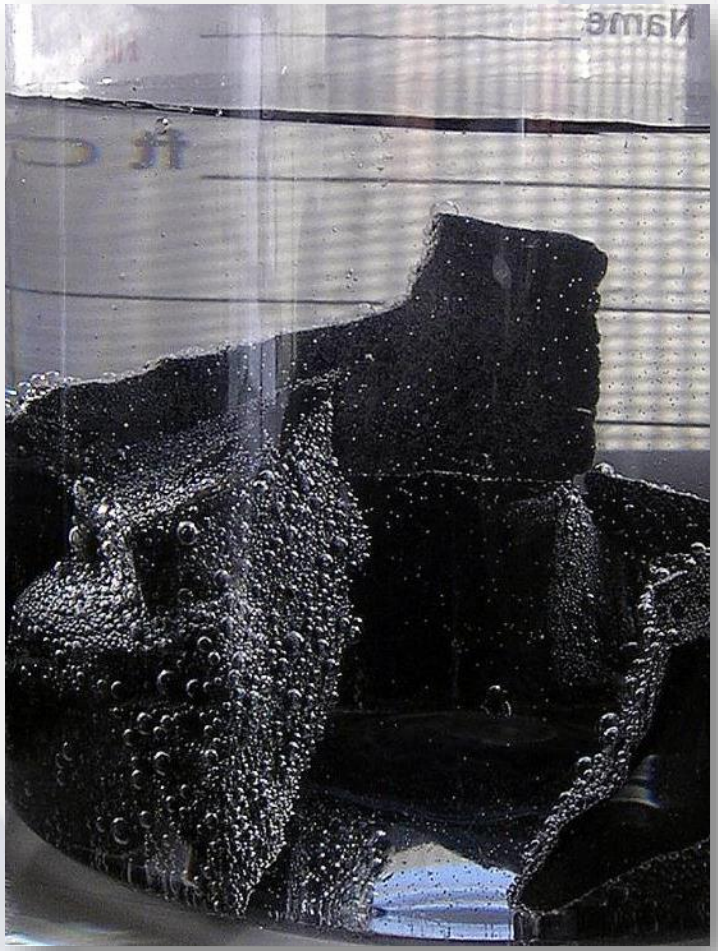
Successful Mudrock Plays

- Function of Drilling Intensity and Cost Reductions
- Technology can reduce cost and increase production
- Per Well Production Increased 200-300% in 5 years
  - Steerable Rotary Bits
  - Length and Optimal Placement of Wellbores Direction and Spacing
  - Number and Placement of Stages and Clusters
  - Concentrate Drilling Effort Then Push Beyond
  - Ability to Stay in Zone
- Production Disparities Among Wells
  - Better Definition of Most Productive Core Areas
  - Better Definition of Target Zones & Stage Locations

Successful Mudrock Plays Key Parameters

- Understanding Resource, Reserves & Productivity
  - Depth, Thickness, Pressure Gradient
  - Determining Geologic Position/Orientation
  - Geosteering
  - Placing Perforation Clusters
  - Selecting Staging Design and Stimulation Treatment
- Subtle Changes Mudrock Reservoir Properties
  - Distribution of Organic Content
  - Mineralogy – “Fracability”
  - Structural Discontinuities
    - Faulting and Geosteering
  - Present Stress Regime / Past Stress Regimes
    - Stimulated Reservoir Volume
  - Maturity
    - Fluid/Gas Type
    - Influence on Reservoir Porosity and Permeability

Marcellus Shale



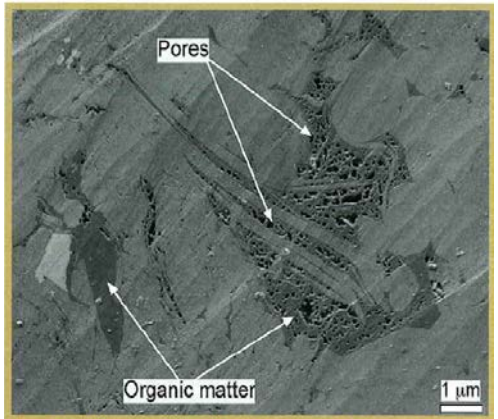
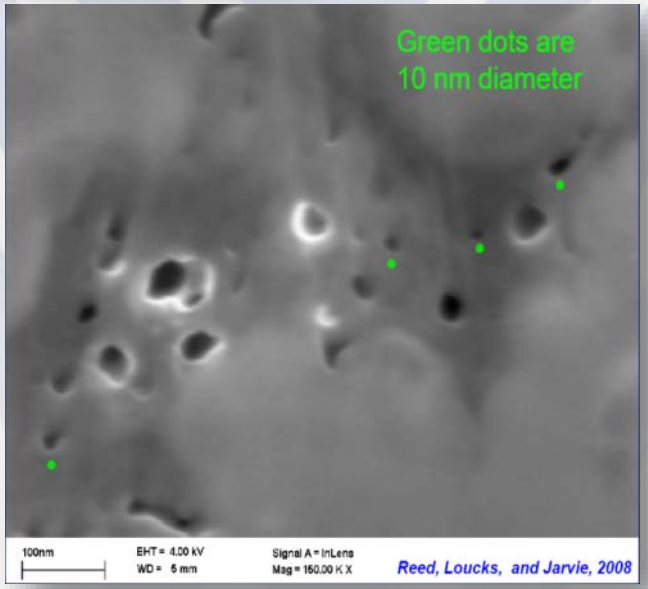
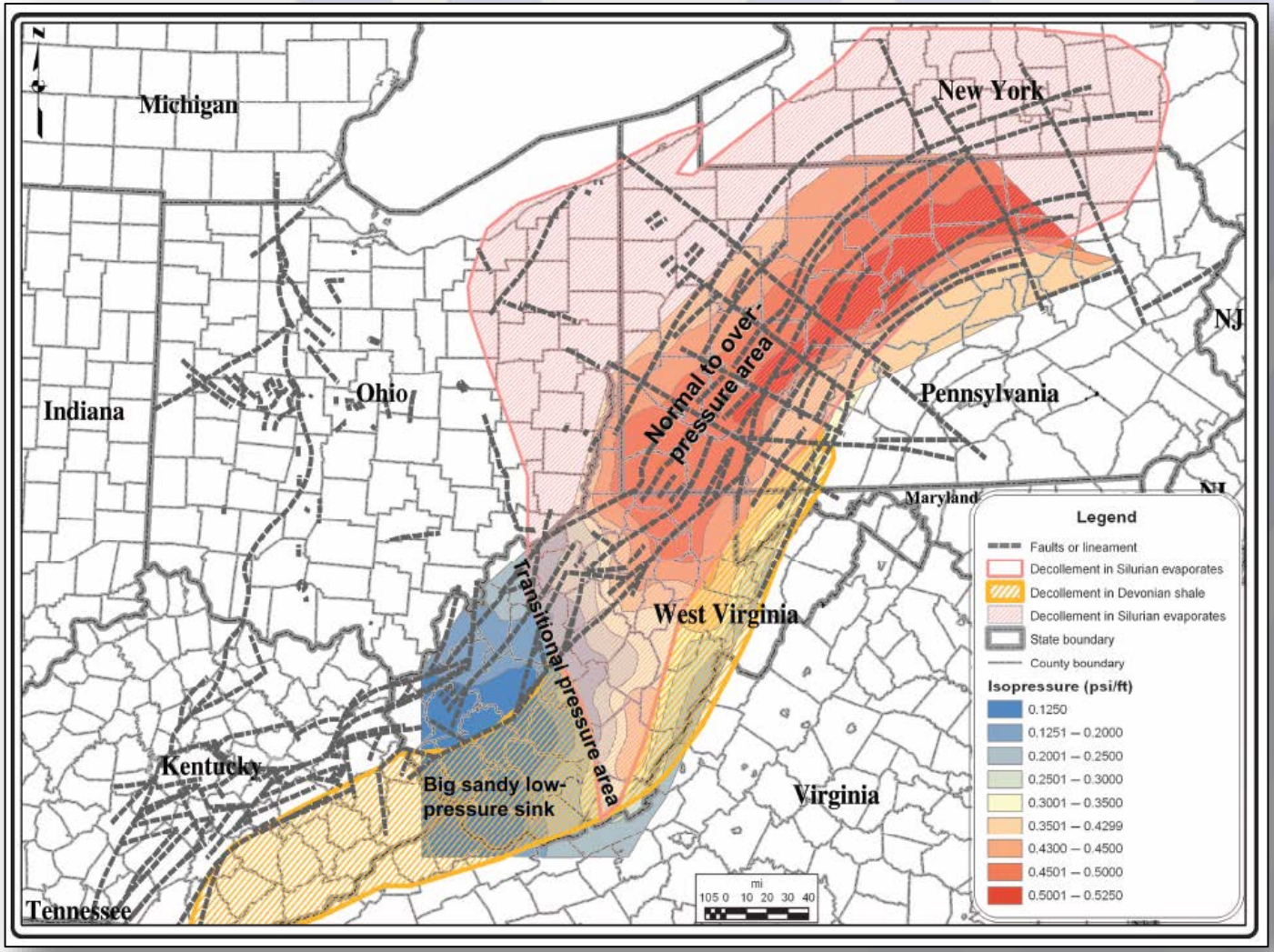


Figure 3. Field emission scanning electron photomicrograph of nanoscale pore architecture in the Barnett Formation. Image provided by R. Reed.

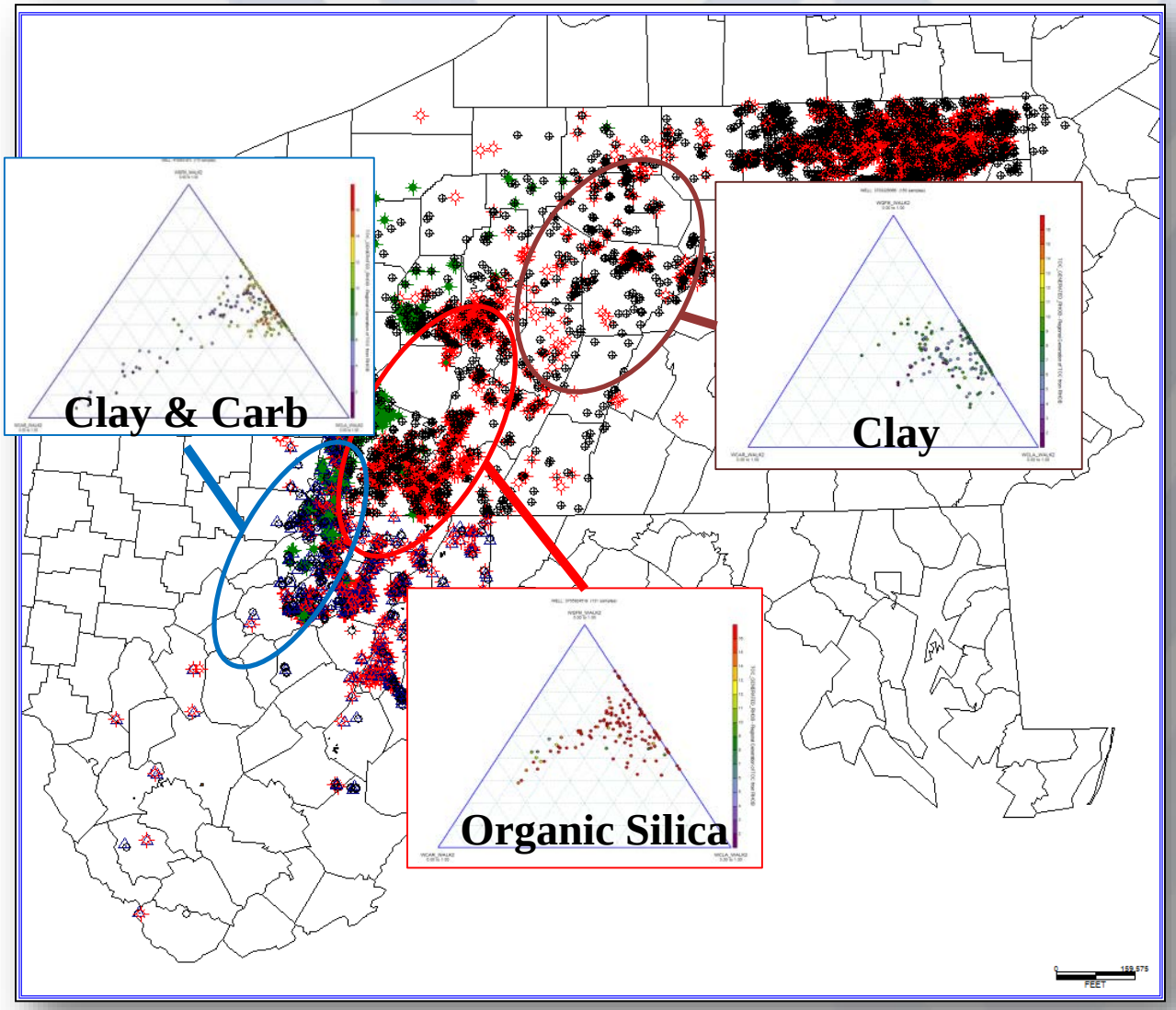


Pressure Gradient



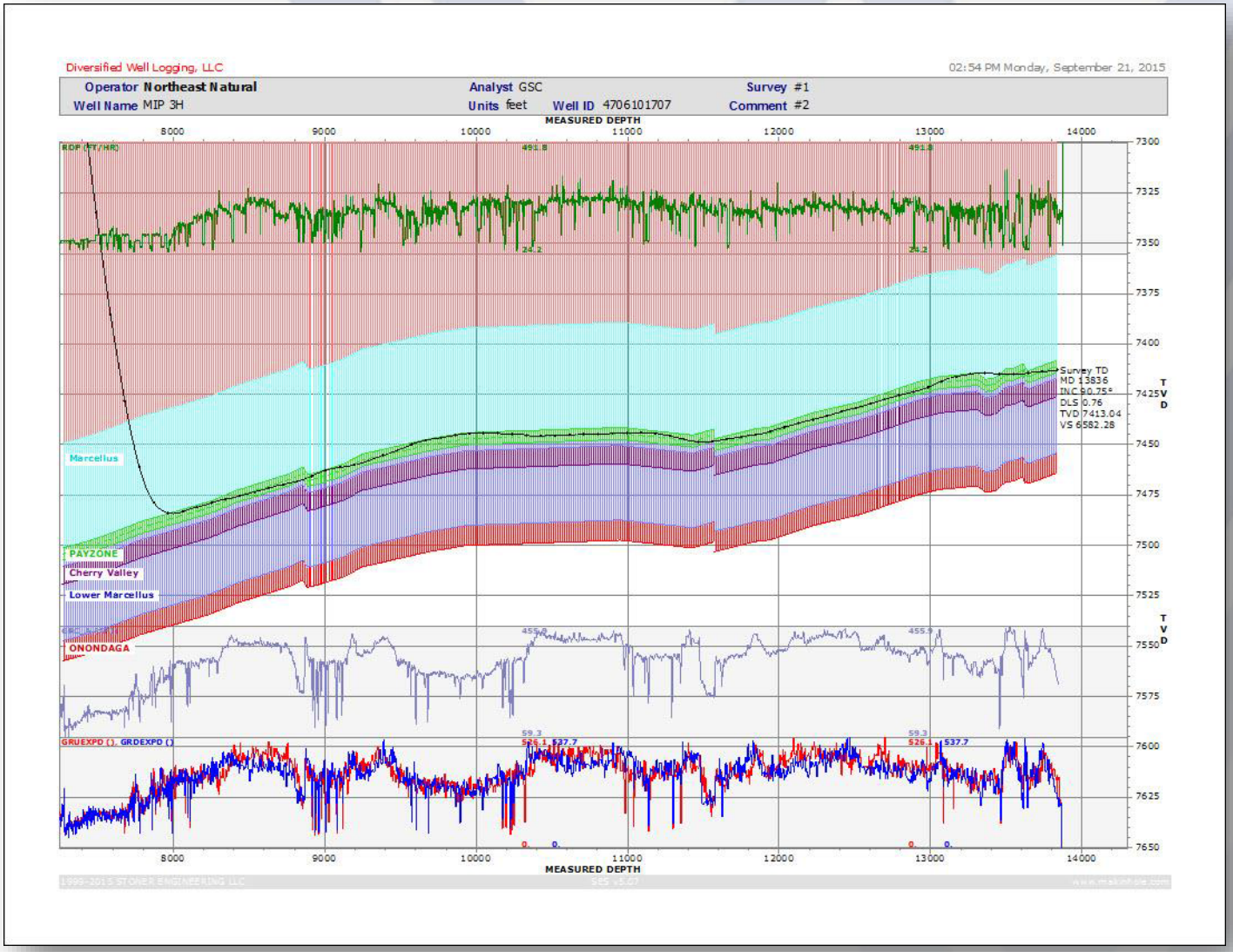
(Zagorski et al., 2012)

Marcellus Horizontal Wells

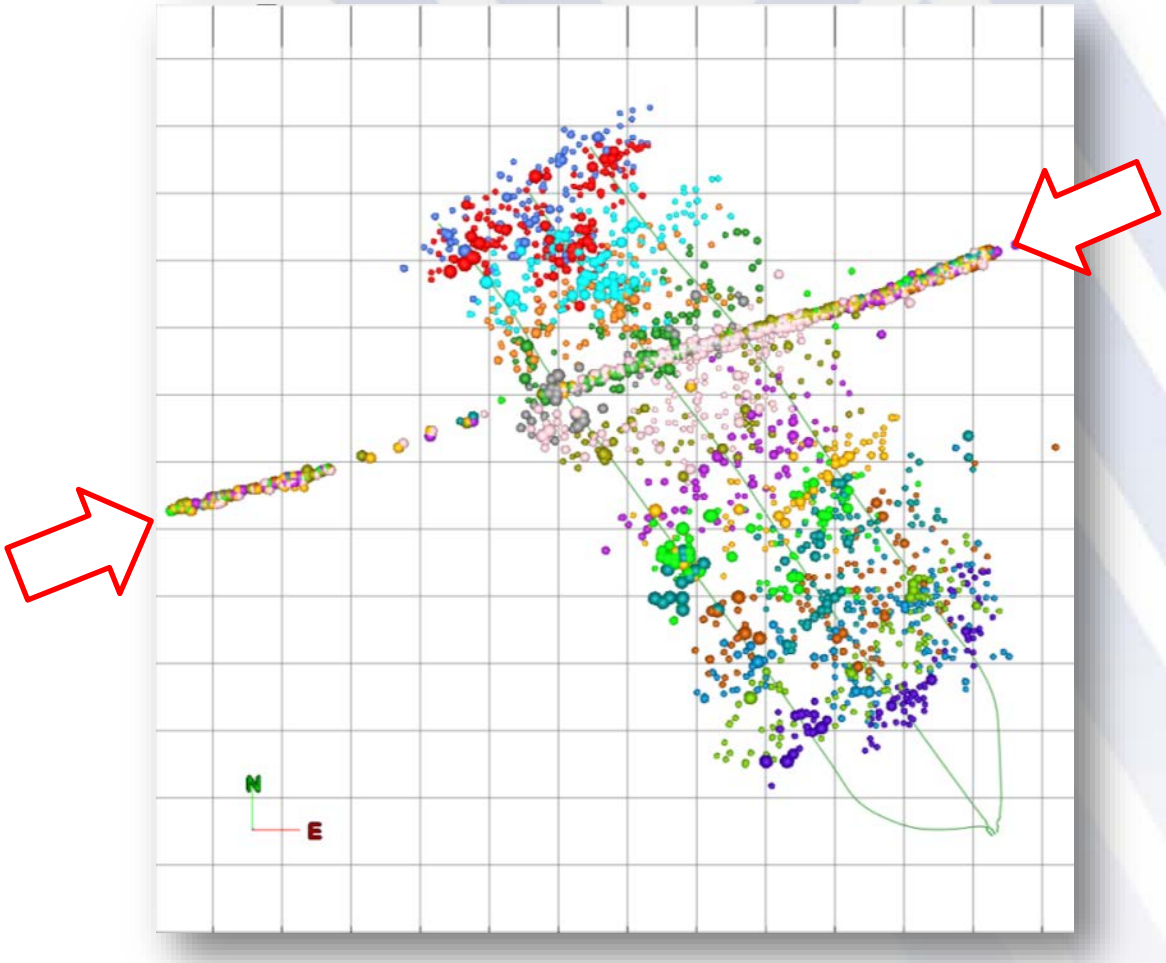


13,079 Wells

Geosteering MIP-3H



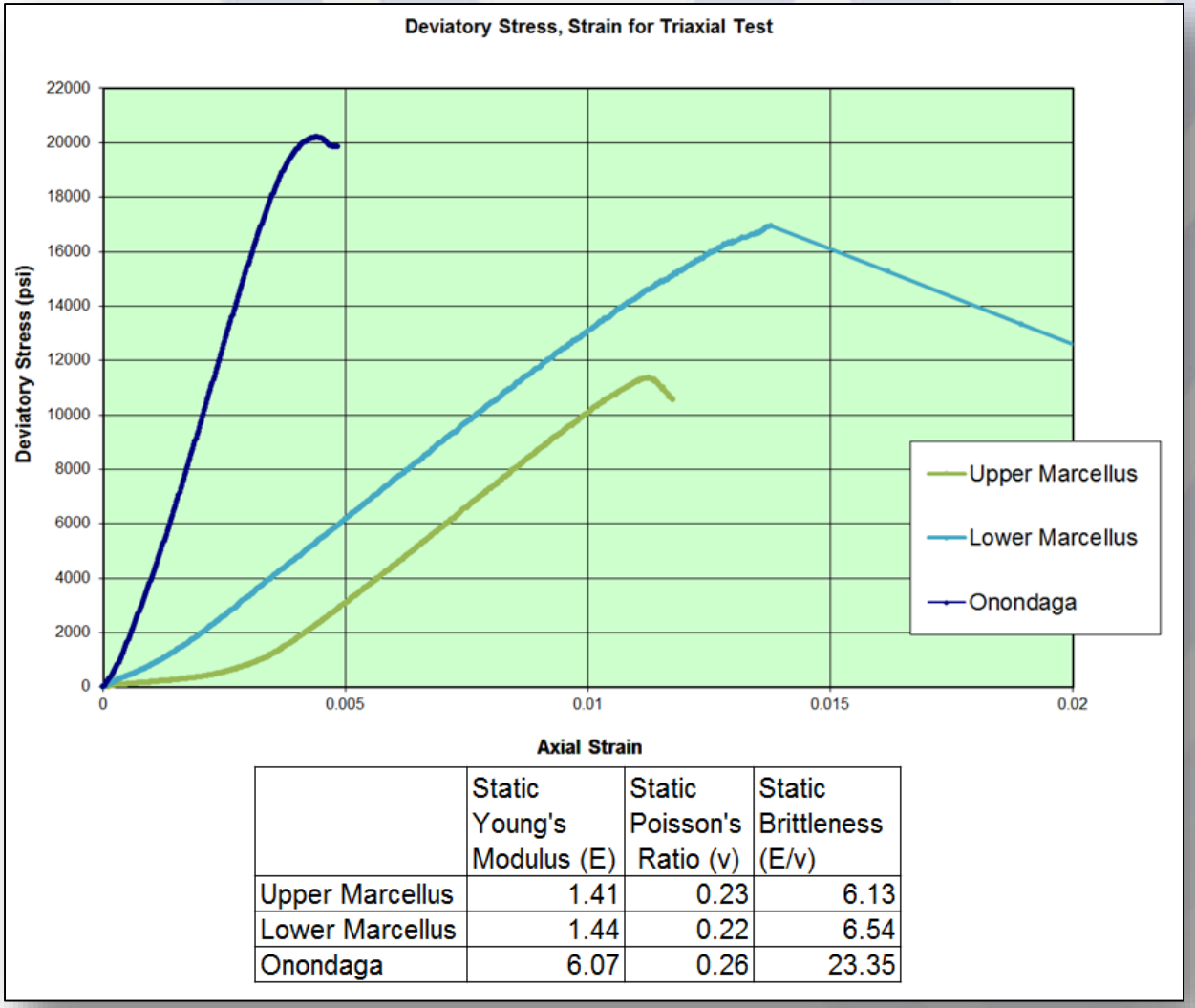
FRACTURE STIMULATION CONTAINMENT



Each square 500 x 500 feet

Microseismic, Inc.

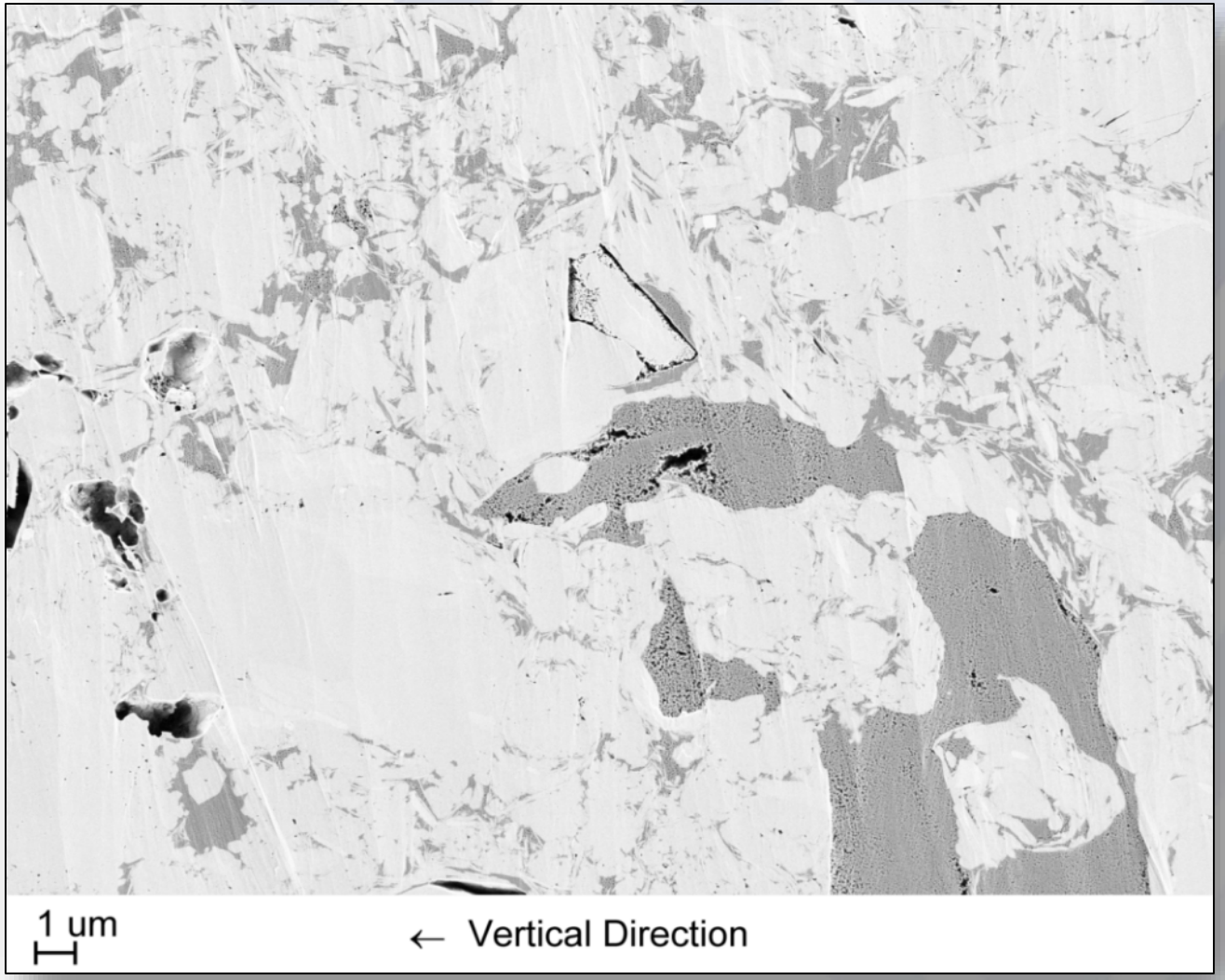
Mechanical Stratigraphy



	Static Young's Modulus (E)	Static Poisson's Ratio (v)	Static Brittleness (E/v)
Upper Marcellus	1.41	0.23	6.13
Lower Marcellus	1.44	0.22	6.54
Onondaga	6.07	0.26	23.35

(Bowers, 2014)

Marcellus Shale



Building Partnerships for Research, Education, and Outreach

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