North American Shale Gas Development – *Regional and Global Implications*

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Research

Down Hole Technical Issues

- Water quality
- induced seismicity
- NORM

– Methane migration

- Well design
- Abandoned wells

– Emerging geology

– Well yield trends

– Decline curve analysis

– Regulatory

Above Ground Risk

– Fugitive methane

– Community impact(s)

- Socio-economic
  - – Agriculture --Tourism
- Environmental
- Water –lifecycle impacts
- Workforce
- Business Development
- Regulatory
- Governance
- Social license

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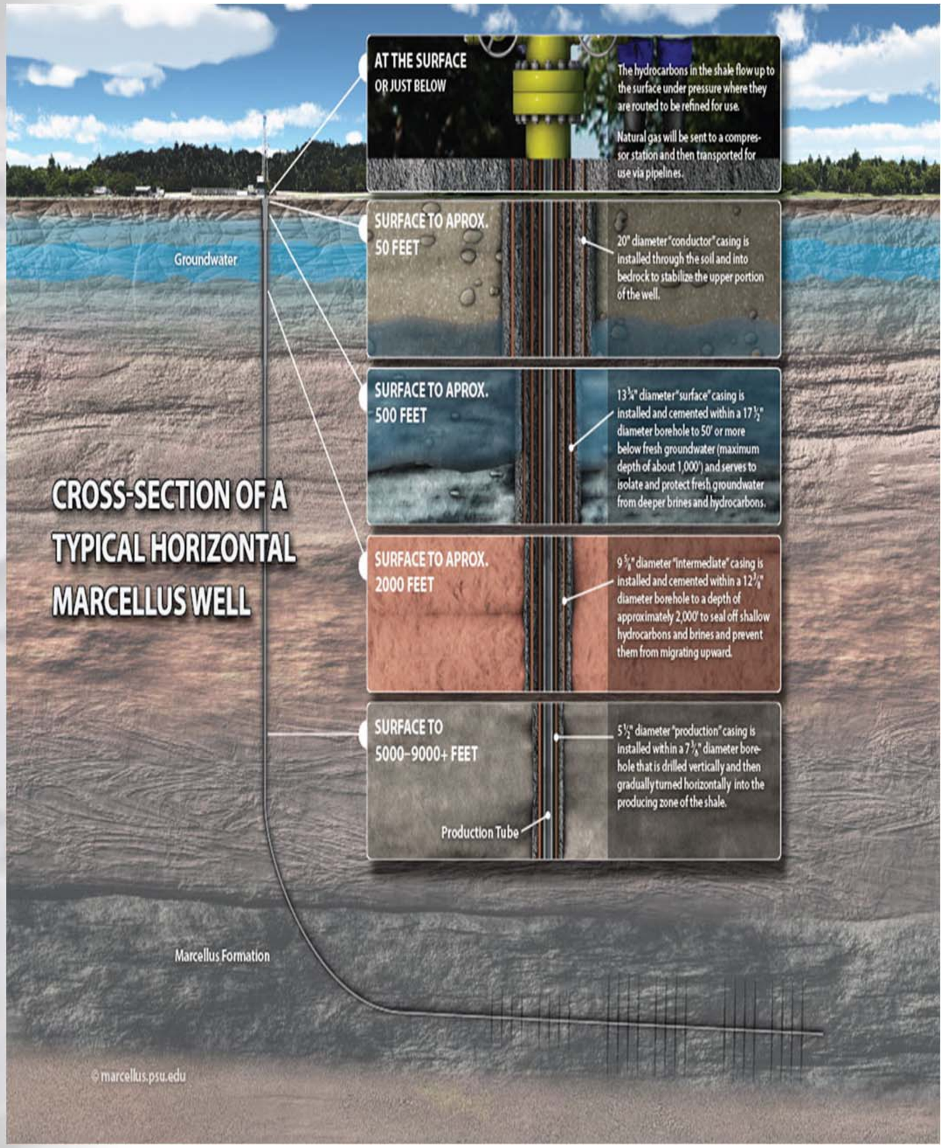
Water Quality Research



- 15,000+ shale wells
- Pre-existing issues
- Few cases of well bore integrity
- No fluid migration
- Limited methane migration
- Primary concern
  - Surface spillage
  - Offsite spills w/trucks

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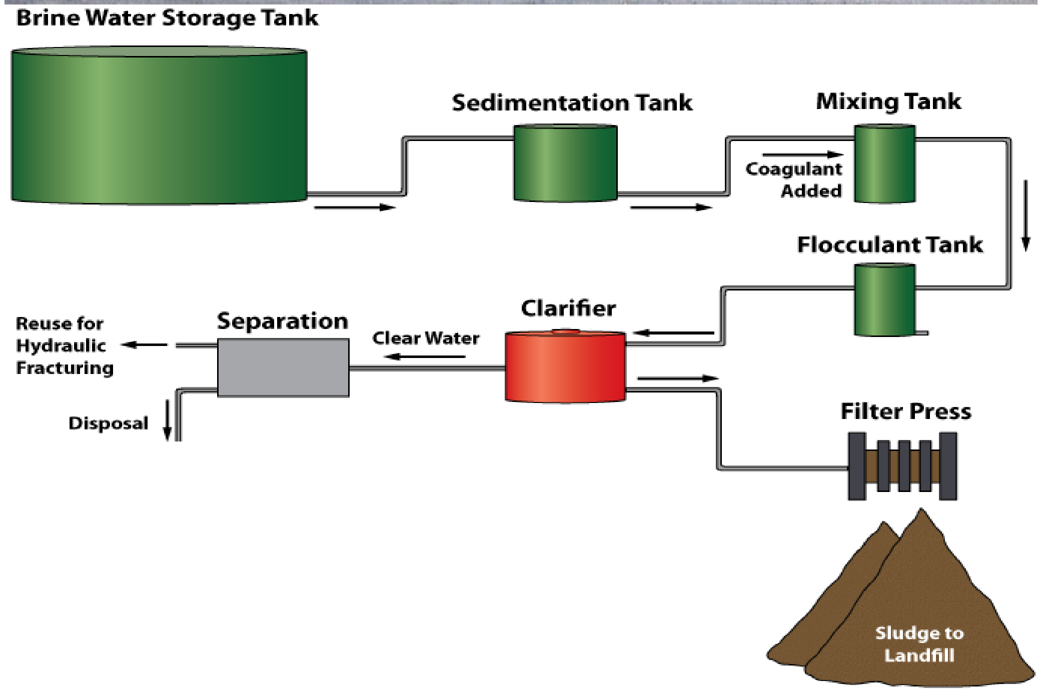
Produced Water Management Options



Produced water management options

- Direct reuse (blending)
- On-site treatment w/reuse
- Off-site treatment w/reuse
- UIC well disposal

Treatment technologies include

- Bag filters
- Chemical precipitation
- Electrocoagulation
- Evaporation (MVR)
- Filtration
- Costs of <$2 to >$10/bbl

During 2016 in PA ~85%+ of shale gas produced water was recycled and ~13% disposed of via injection wells

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Evolution of BMP Technologies

--Redundant systems for fluid control
--New storm water and erosion controls

--Transparent evolution of regulatory protocols
--Trend towards "closed loop" on fluids and drilling wastes
--Greater use of vertical equipment reducing pad footprint
--New sound and light mitigation

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Reuse Trends of Waste

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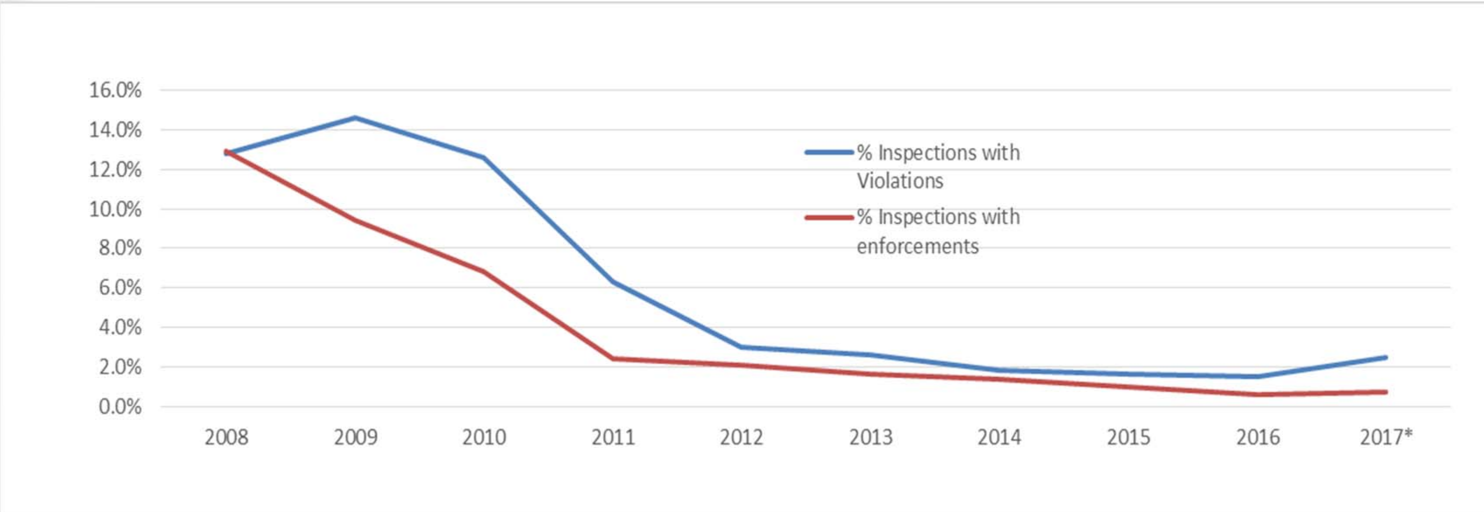
PA Well Site Inspections

Year	Inspections	Wells inspected	Inspections with Violations	Total Violations	Enforcements	% Inspections with violations	% Inspections with enforcements
2017*	11,793	6,113	289	572	83	2.5%	0.7%
2016	15,198	6,627	235	456	94	1.5%	0.6%
2015	13,254	5,949	210	405	130	1.6%	1.0%
2014	11,530	5,130	210	423	161	1.8%	1.4%
2013	12,472	5,594	319	528	201	2.6%	1.6%
2012	12,704	4,861	380	711	271	3.0%	2.1%
2011	10,569	3,939	663	1,221	256	6.3%	2.4%
2010	5,248	2,006	659	1,280	357	12.6%	6.8%
2009	2,352	926	343	684	221	14.6%	9.4%
2008	1,254	376	161	234	162	12.8%	12.9%



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Outreach

- Science-based information
- Rapid response
- Localized outreach
- Current materials
- Rapid evolution of info
- Broad range of views
- Access to regulators
- Positive link between stakeholders, researchers, industry, and elected officials

"Translational Outreach"

--Creating advocates of science

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Global Energy Trends

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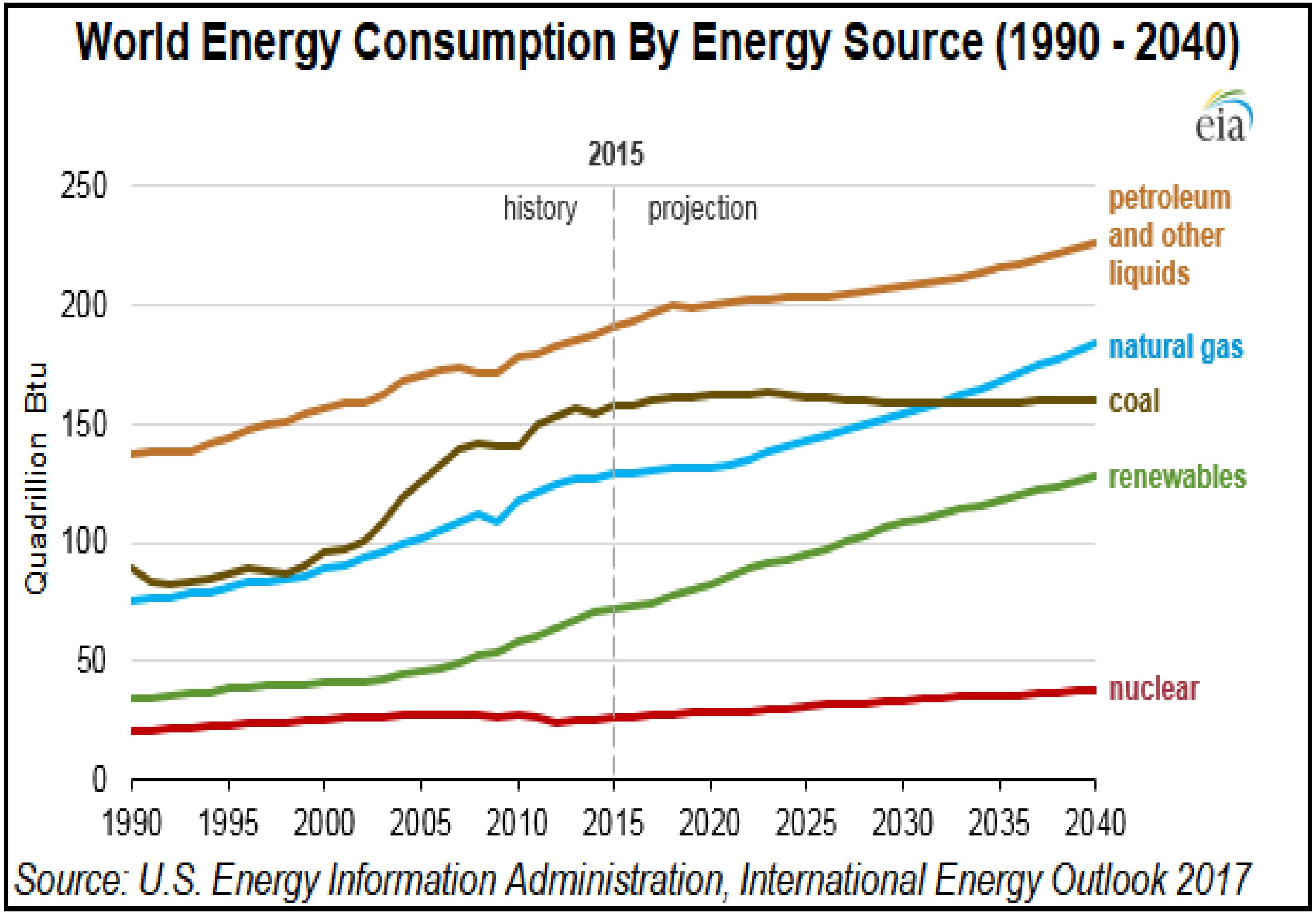

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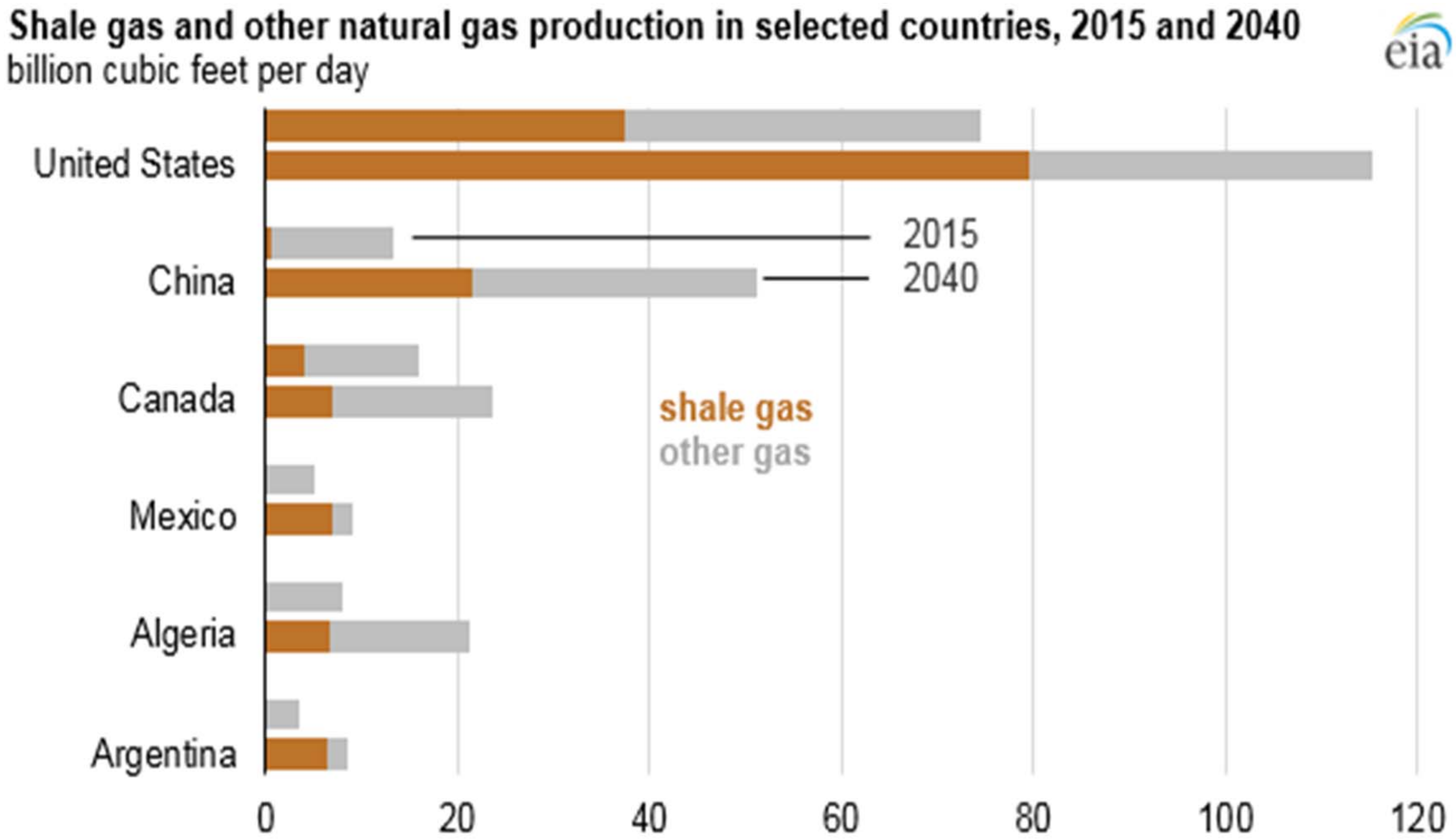
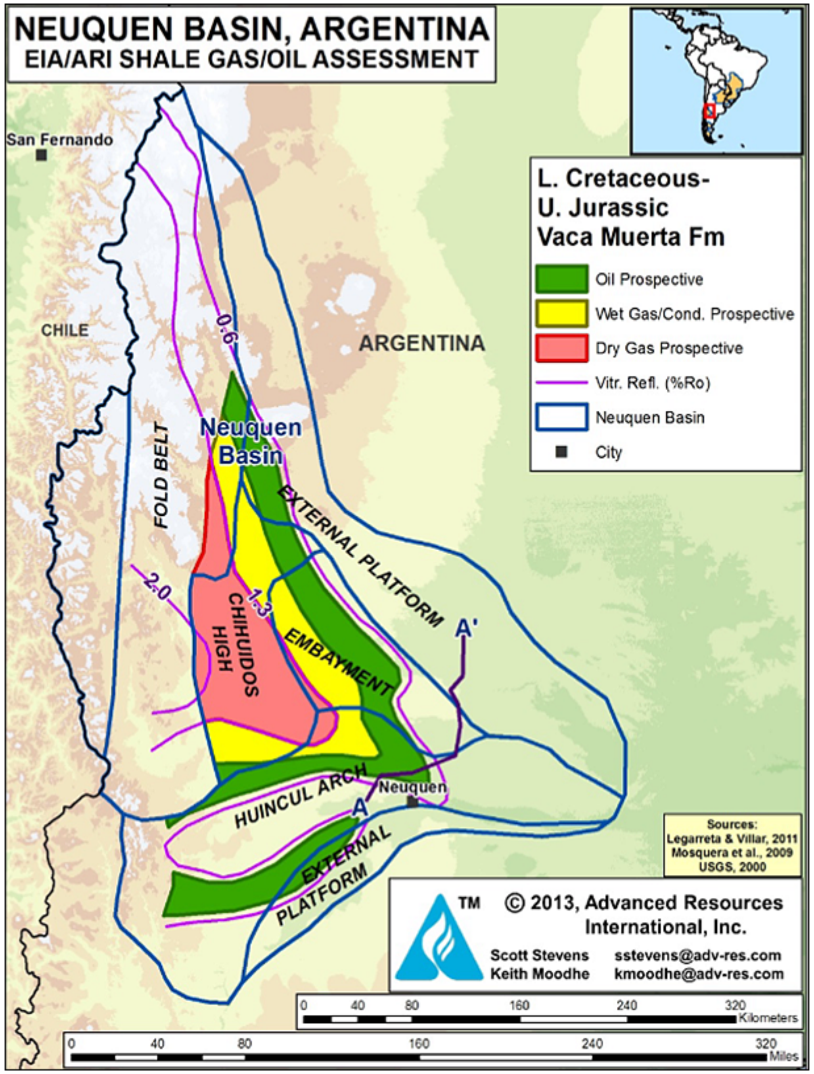
Global Shale Gas Trends



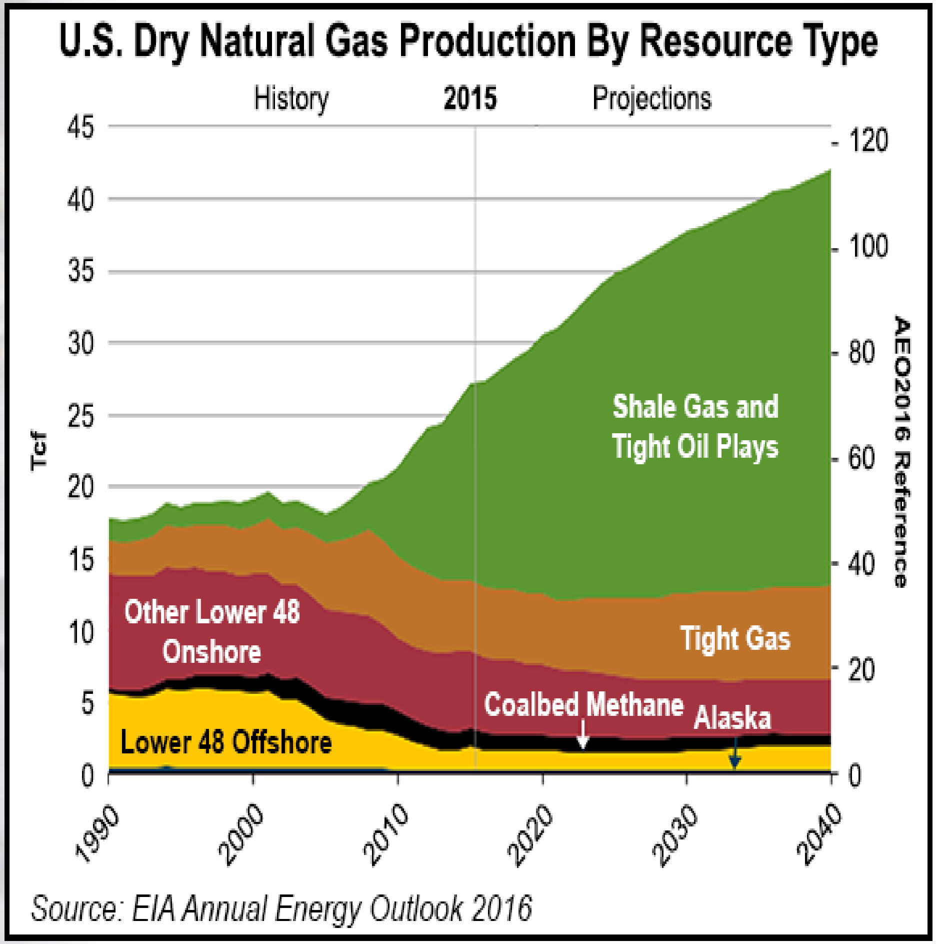
Strong Global Shale Interest

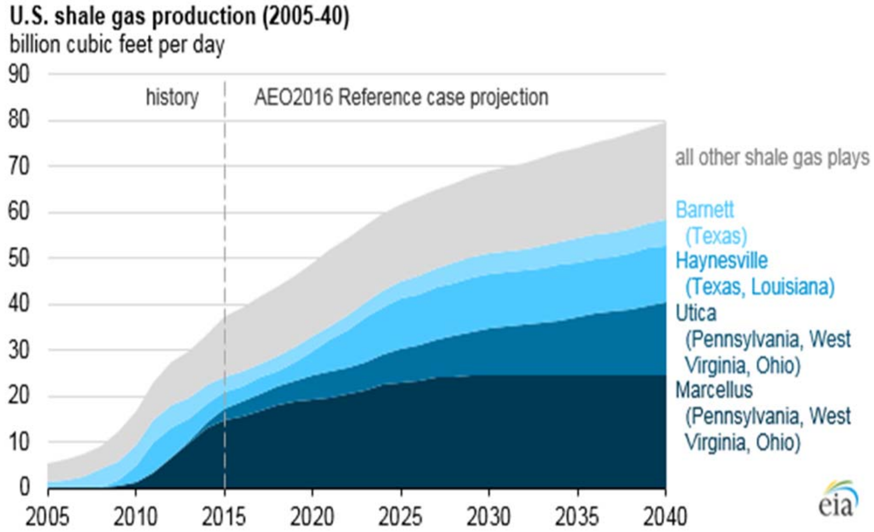


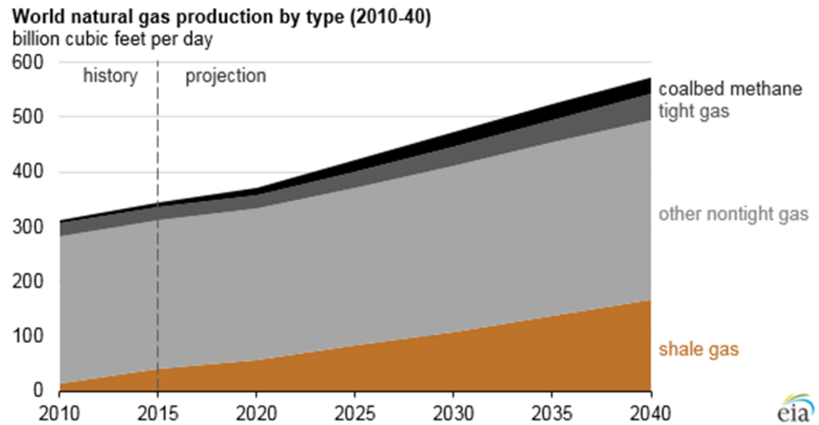
Source: EIA, Advanced Resources International

- Expanding interest in repeating North America shale energy
- New global energy paradigm emphasis since Paris. Gas??
- New markets for gas – pipeline & ship
- Greater pairing with renewable technologies

Shale Gas Trends







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Drilling Trends in North America

- Shorter time to drill a well
  – Months to weeks to days(currently) -30 to 50% increase in efficiencies
- Costs decreasing
- Move to “walking” rigs built for purpose
- Longer wellbores -- 6000+ meter lateral in OH
- More frac stages and move to target best rock(40% yields 80%)
  – More proppant –almost doubled from recent past
  – Every frac is a unique effort –matching pressures to rock
  – Upgrades to subsurface technical expertise/technology
- Increased gas volumes per lateral
- Increased IPs/EURs/ROR –flatter declines

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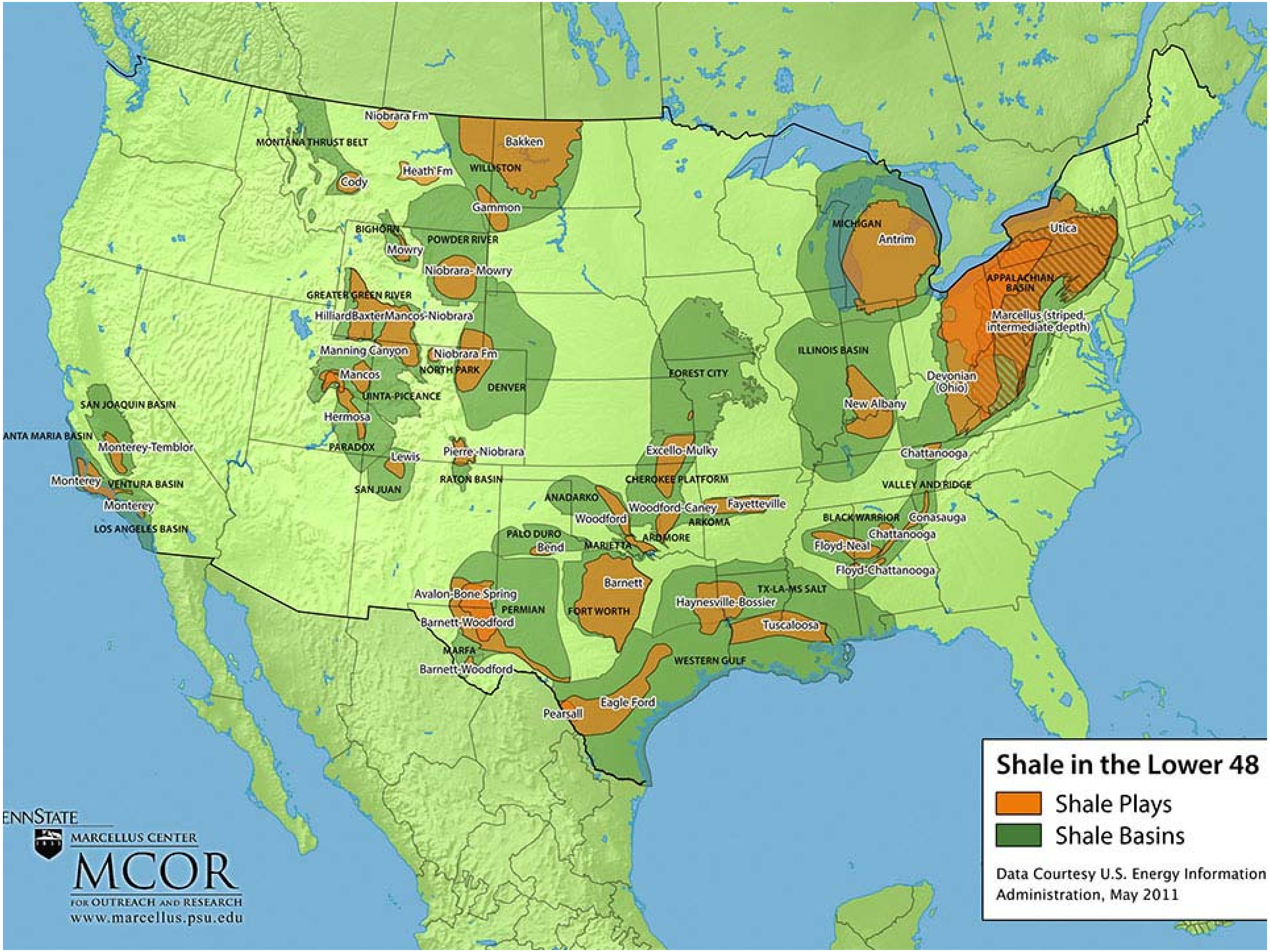
Shale Energy Developments

- Geopolitical -- 80% of shale gas is in locations with 30% of conventional gas resources
  - EU diversification –shale development(UK), LNG
  - Commercial production in Argentina and China
- In U.S., increasing quantities of NGLs and "dry" nat gas
  - Substantial increase in reserves and utilization
  - New exports of NGLs --Propane/Ethane
  - 74 Bcf/d --27+ Tcf/yr
  - Currently approx. 50% of dry gas production from shale
- Large need for infrastructure–midstream/roads/people
- U.S. -commercially predictable regulatory environment



Shale in the Lower 48
Shale Plays
Shale Basins
Data Courtesy U.S. Energy Information Administration, May 2011
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Niobrara Fm
MONTANA THRUST BELT
Bakken
WILLISTON
Heath Fm
Cody
Gammon
BIGHORN
POWDER RIVER
Mowry
Niobrara- Mowry
GREATER GREEN RIVER
HilliardBaxterMancos-Niobrara
Manning Canyon
Niobrara Fm
NORTH PARK
Mancos
UINTA-PICEANCE
DENVER
Hermosa
PARADOX
Lewis
SAN JUAN
Pierre-Niobrara
RATON BASIN
SAN JOAQUIN BASIN
SANTA MARIA BASIN
Monterey-Temblor
Monterey
VENTURA BASIN
Monterey
LOS ANGELES BASIN
MICHIGAN
Antrim
Utica
APPALACHIAN BASIN
Marcellus (striped, intermediate depth)
ILLINOIS BASIN
FOREST CITY
Devonian (Ohio)
New Albany
Chattanooga
Excello-Mulky
CHEROKEE PLATFORM
VALLEY AND RIDGE
ANADARKO
Woodford-Caney
Fayetteville
Woodford
ARKOMA
BLACK WARRIOR
Conasauga
PALO DURO
Bend
MARIETTA
ARDMORE
Chattanooga
Floyd-Neal
Floyd-Chattanooga
Barnett
TX-LA-MS SALT
Avalon-Bone Spring
Haynesville-Bossier
PERMIAN
FORT WORTH
Barnett-Woodford
Tuscaloosa
MARFA
Barnett-Woodford
WESTERN GULF
Eagle Ford
Pearsall

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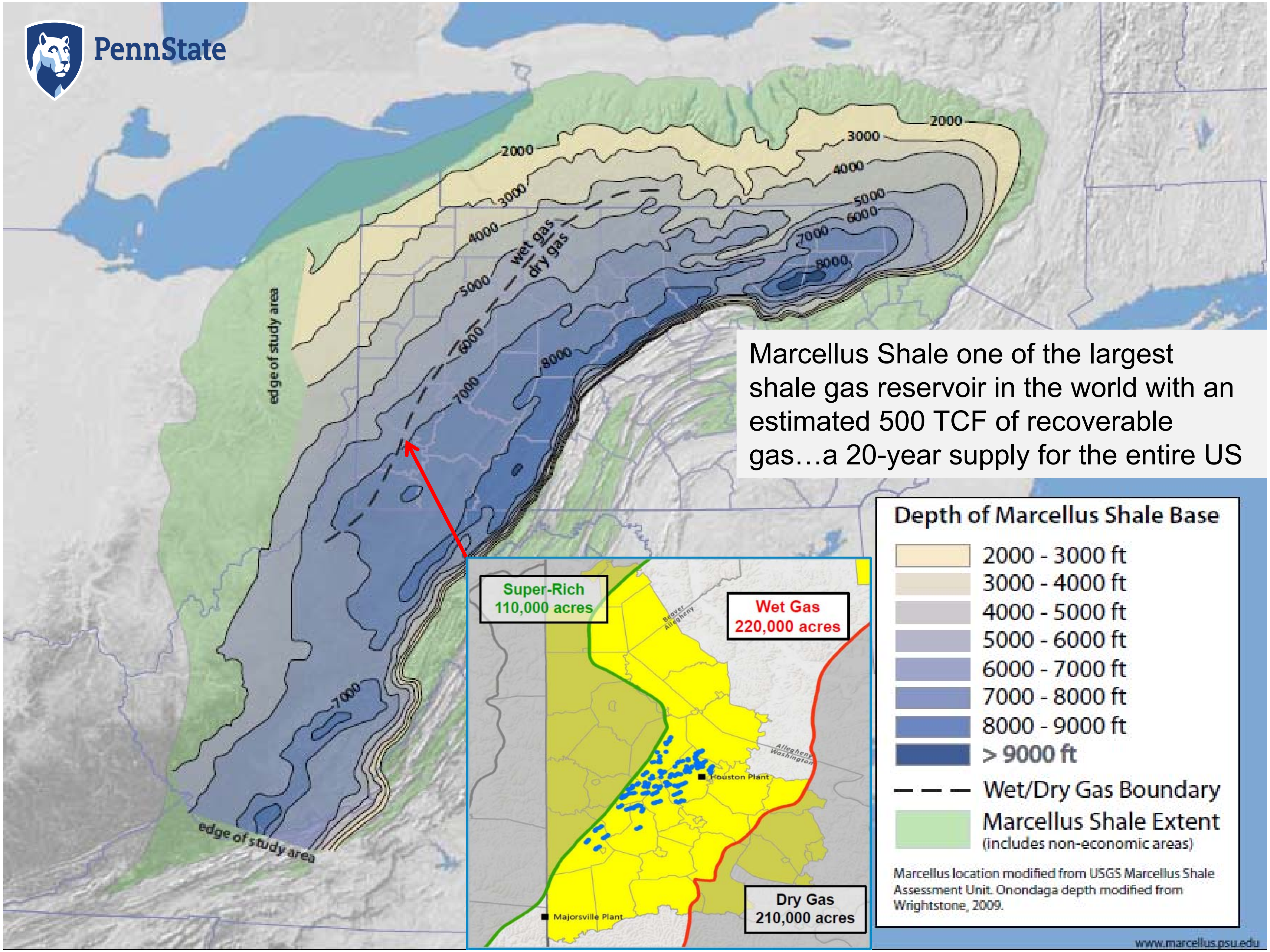
Marcellus Shale one of the largest shale gas reservoir in the world with an estimated 500 TCF of recoverable gas…a 20-year supply for the entire US



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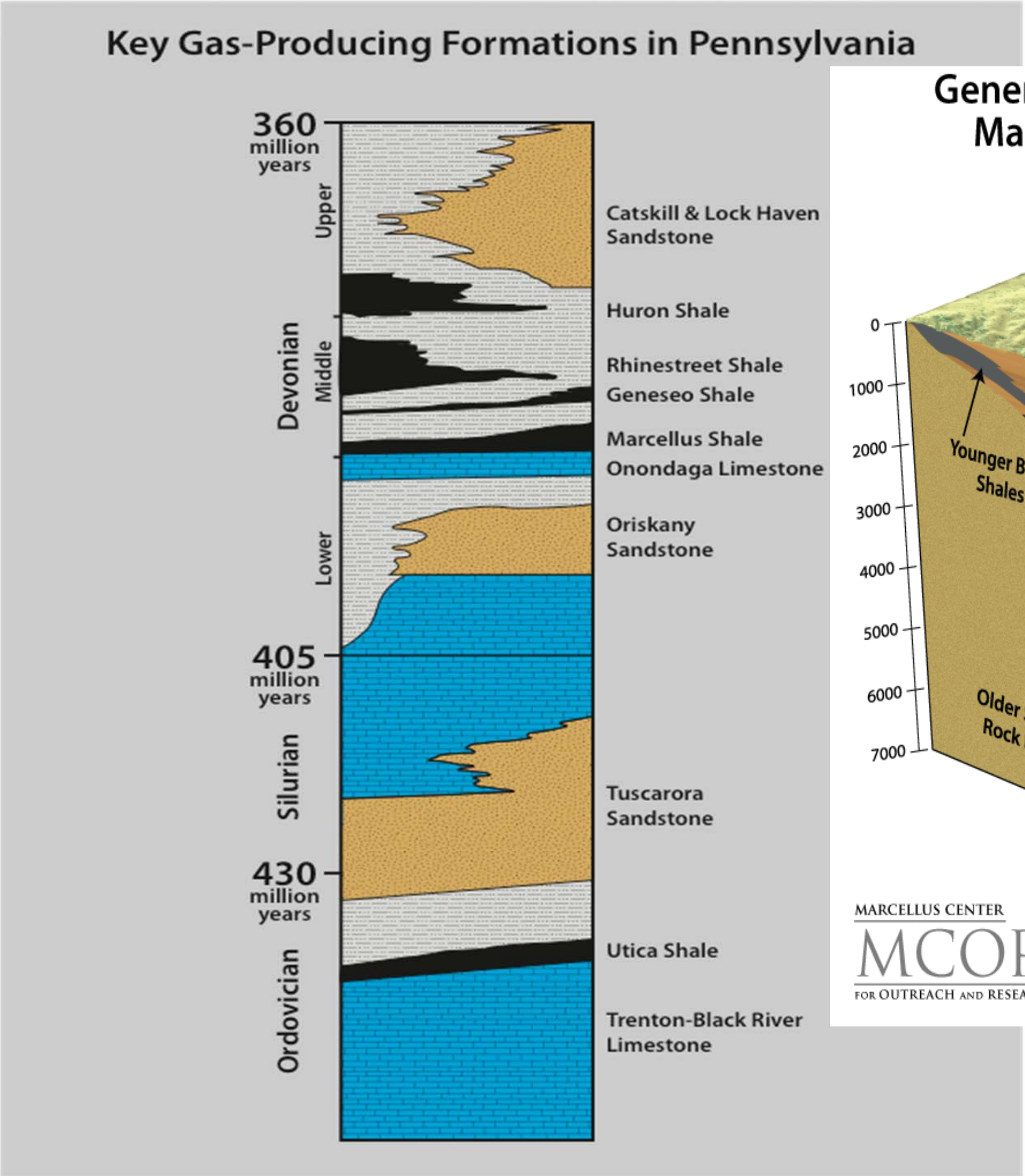
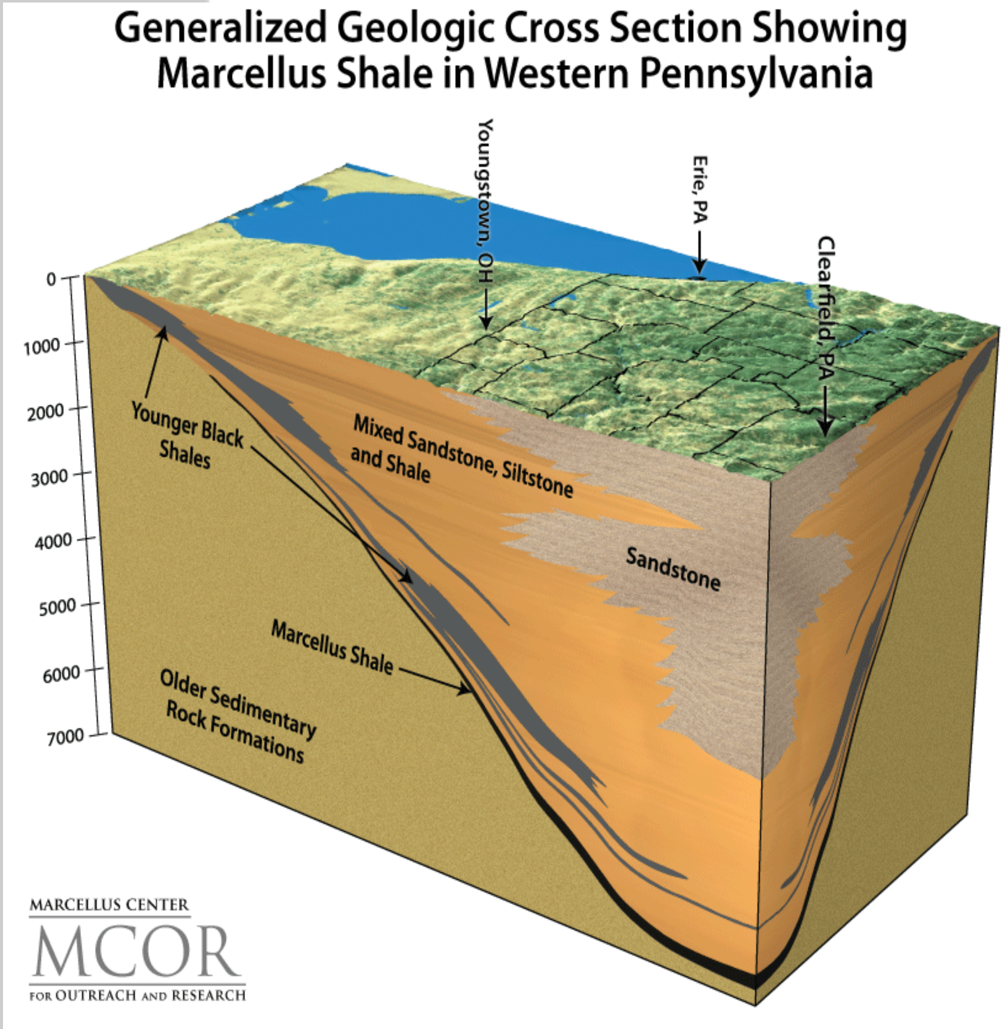
Emerging Shale Targets





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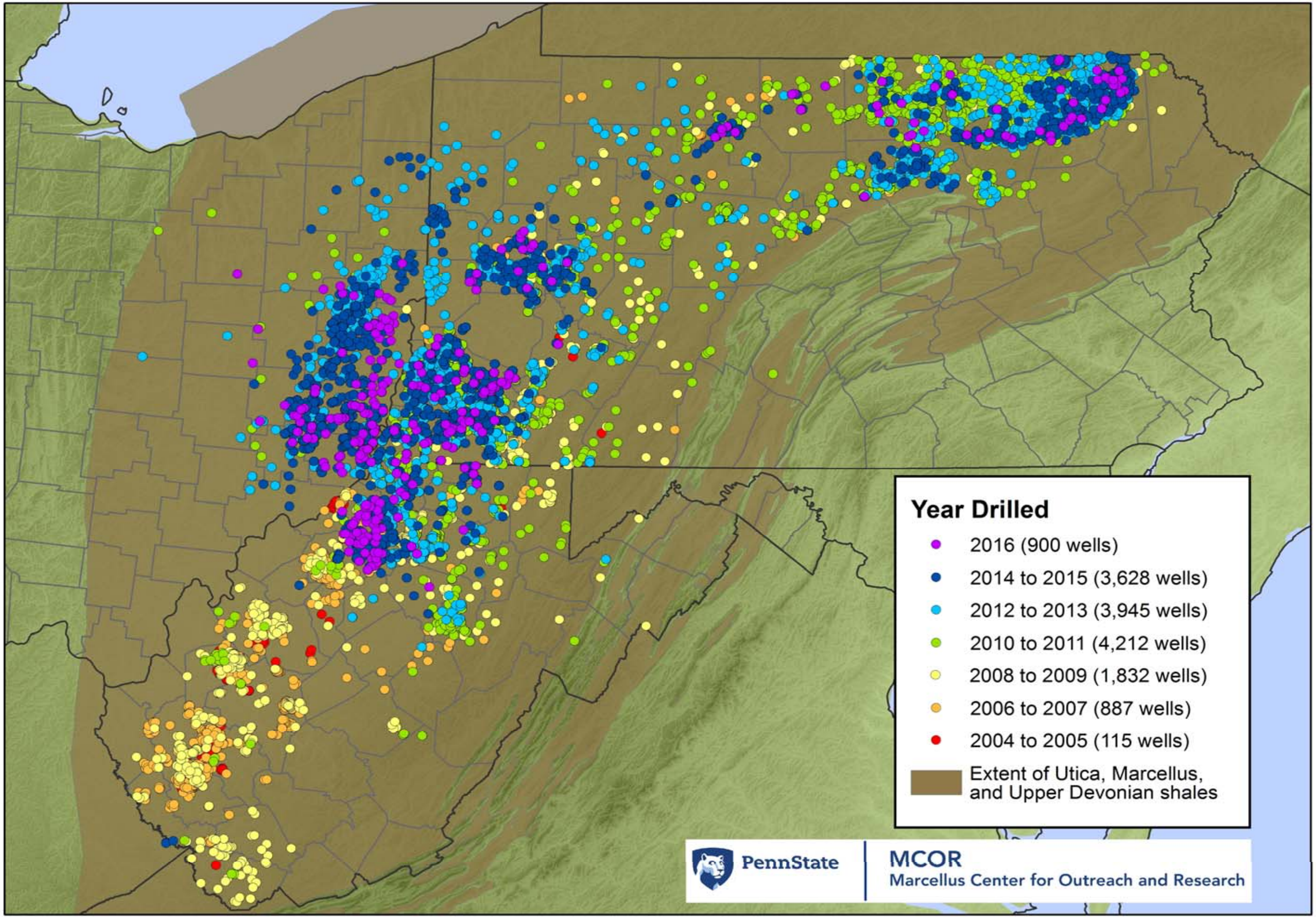
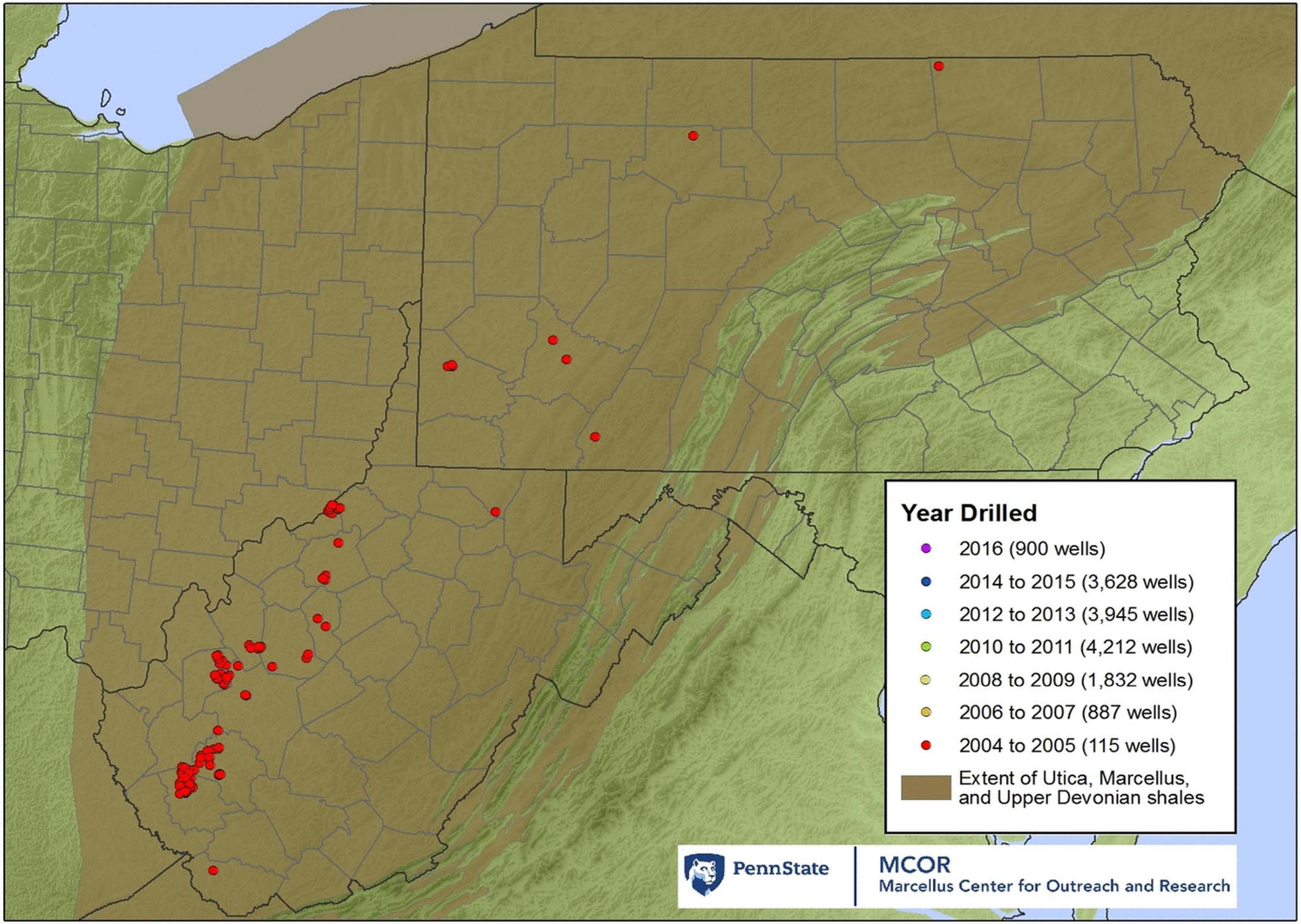
Unconventional Wells Drilled by Year



Unconventional Wells Drilled by Year



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Eastern U.S. Multi-Well Pad

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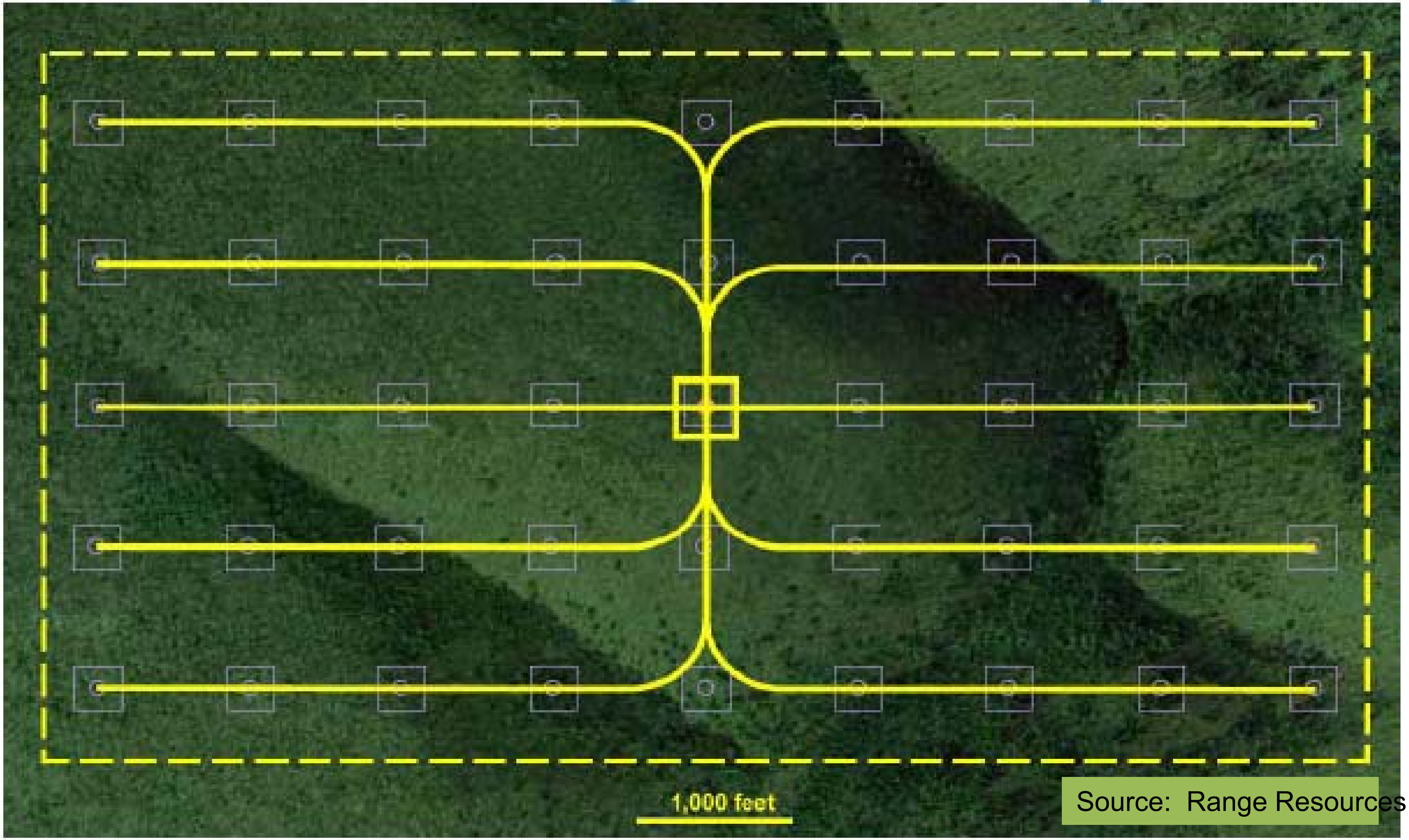
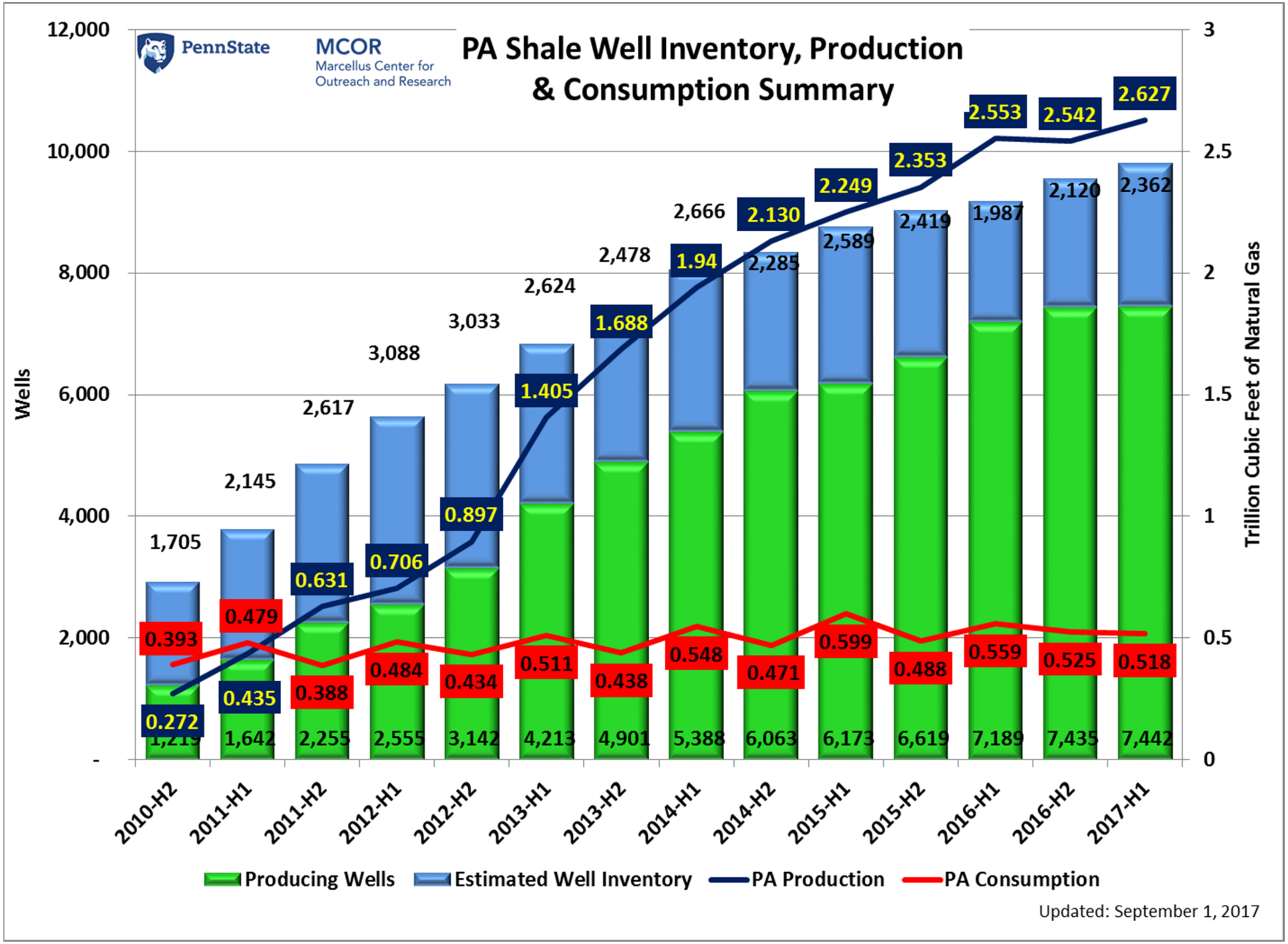
Multiple Wells Per Pad = Reduced Footprint



The ability to install multiple wells from one 2 hectare pad per 5 sq. km. reduces the surface footprint greatly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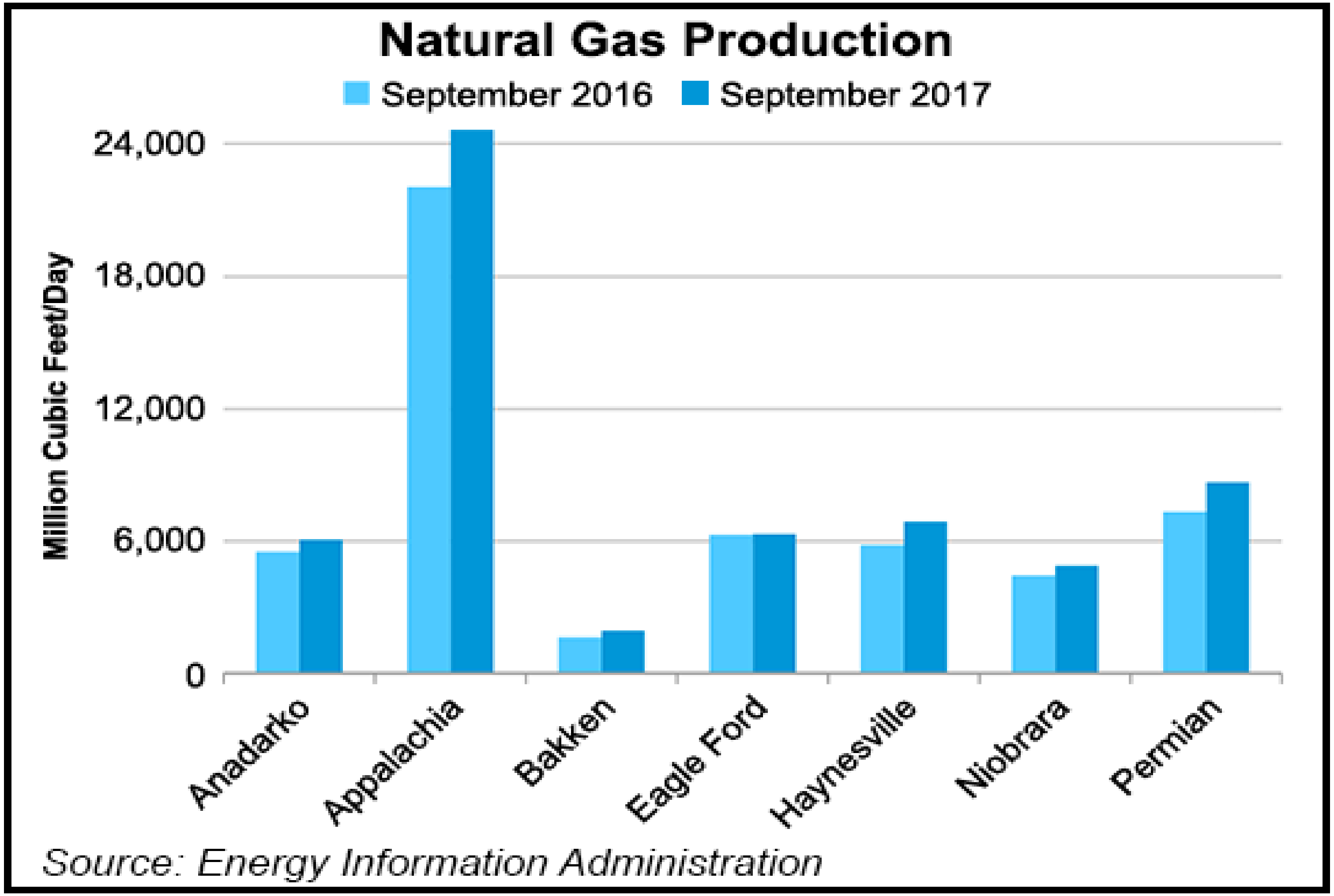
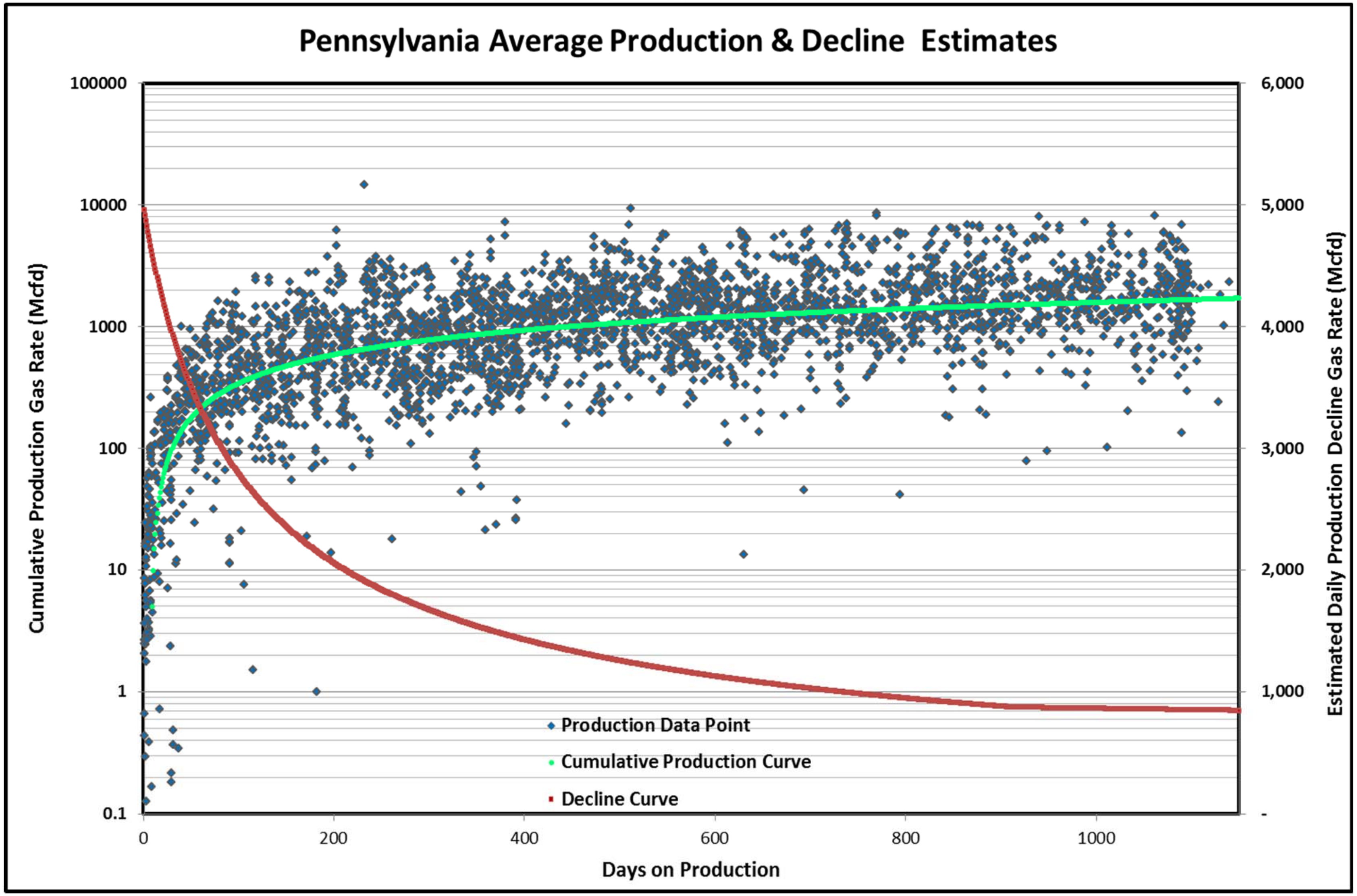
PA Shale Well Inventory, Production & Consumption Summary
Wells
Trillion Cubic Feet of Natural Gas
2010-H2
2011-H1
2011-H2
2012-H1
2012-H2
2013-H1
2013-H2
2014-H1
2014-H2
2015-H1
2015-H2
2016-H1
2016-H2
2017-H1
Producing Wells
Estimated Well Inventory
PA Production
PA Consumption
Updated: September 1, 2017

U.S. Shale Gas Production



Source: NGI

PennState PA Production Declines



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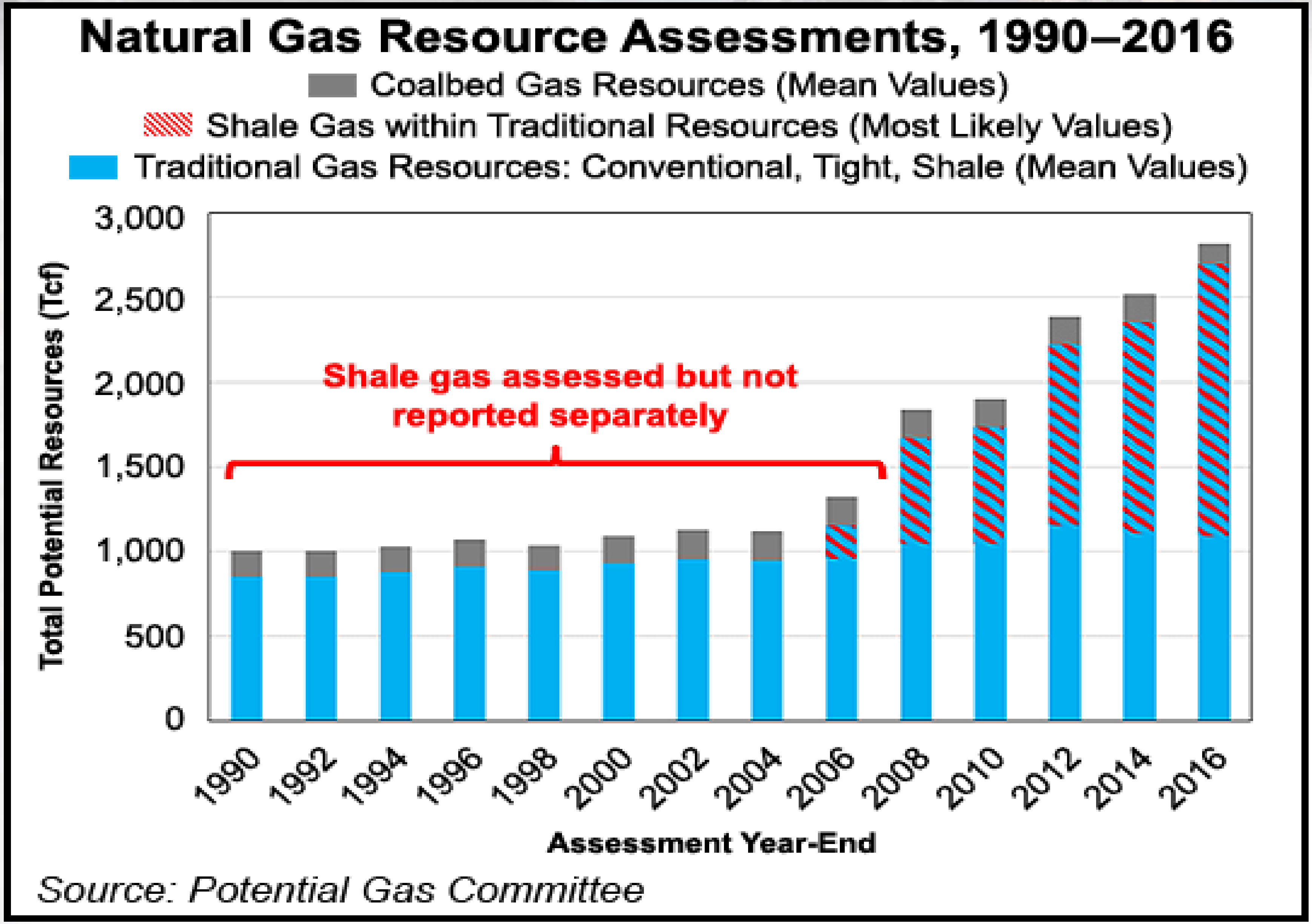

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Power Generation Trends

- Coal and NG trading spots for top U.S. power gen fuel
  - permanent??
  - Significant amount of natural gas resources fueling power generation
  - 18 new gas-fired projects w/9,690 MW in queue in eastern U.S.
  - 15% of coal gen went offline by 4Q16
- 25+ yr low in CO_2 emissions
  - Nat Gas paired with renewables
- Concerns
  - Pipeline constraints
  - Bias towards single fuel
  - Impacts to nuclear power
  - Impacts to new renewables

- Greater onshore production
  - Reduced price volatility?
  - Weather-based moves
  - Political shocks

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Recent and Proposed "Greenfield" Pipeline Projects

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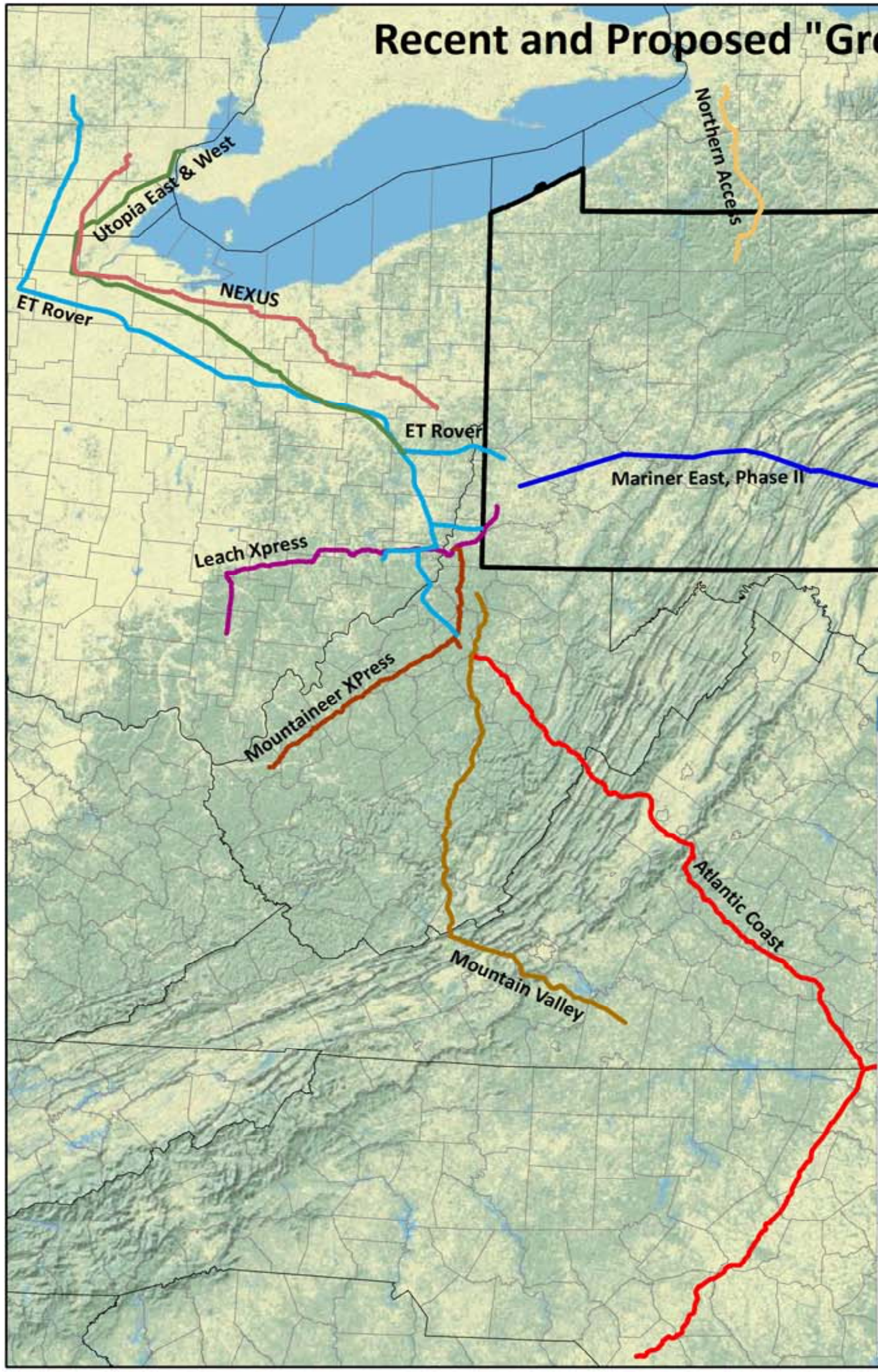
PennState Extension



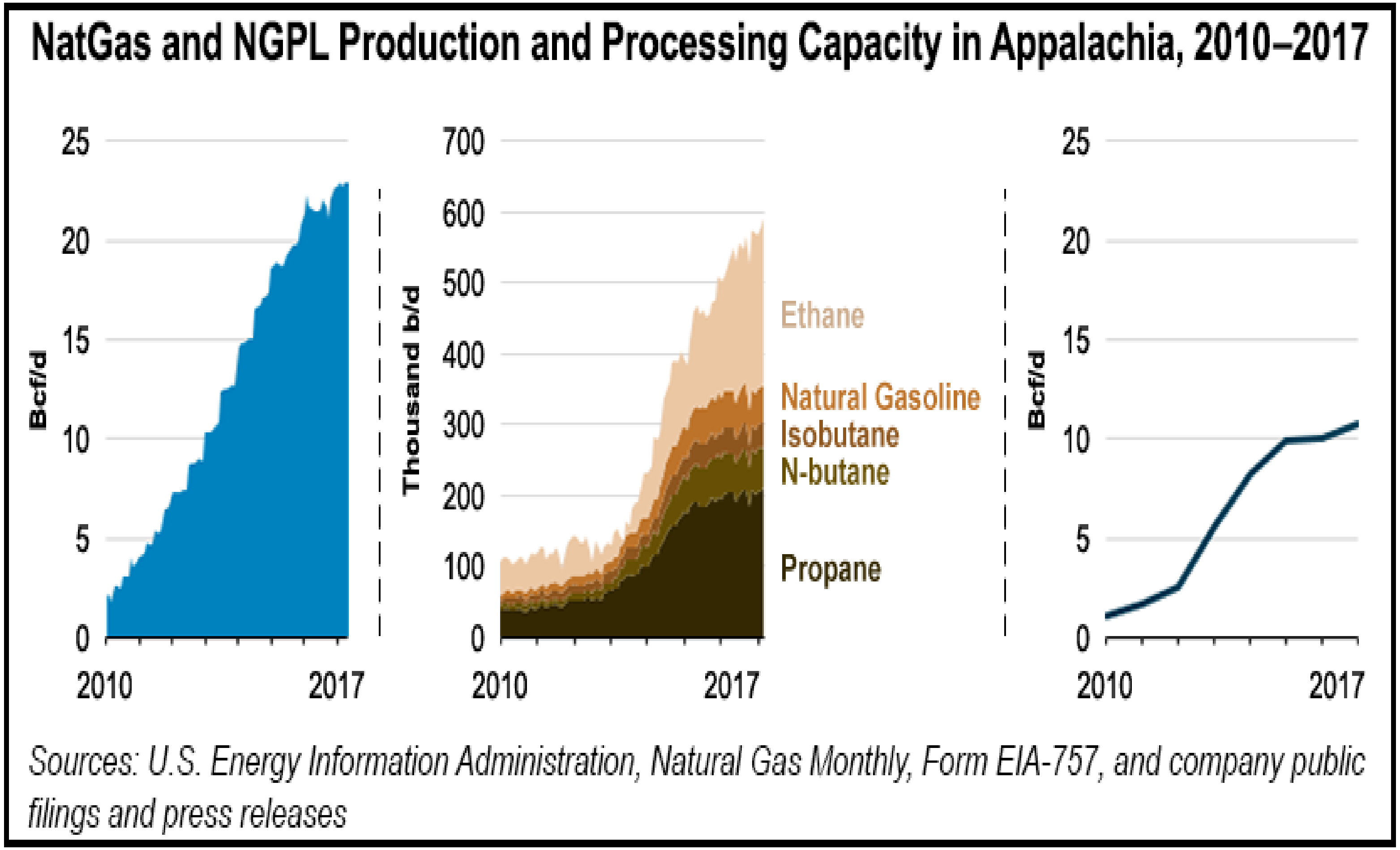
Legend	Name	Company	Capacity	Miles	Planned Inservice	Status
	Atlantic Coast	Duke Energy, Piedmont Natural Gas, AGL Resources, Dominion	1.5 BCF/d	550	Late 2019	Under FERC review.
	Atlantic Sunrise	Williams	1.7 BCF/d	178	Mid 2018	Received FERC Certificate on 2/3/17
	Constitution	Williams, Cabot Oil & Gas, WGL Holdings, Piedmont Natural Gas	0.65 BCF/d	124	TBD	Received FERC certificate on 12/2/14. NYDEC permit under appeal.
	ET Rover	Energy Transfer Partners	3.25 BCF/d	590	Fall 2017	Received FERC Certificate on 2/3/17
	Leach Xpress	TransCanada	1.5 BCF/d	160	Late 2017	Received FERC Certificate on 1/19/17
	Mariner East, Phase II	Sunoco Logistics	70,000+ bpd	300	2018	Non-FERC jurisdictional. Under construction.
	Mountain Valley	EQT, NextERA, Con Edison Transmission, WGL Midstream, and RGC Midstream	2.0 BCF/d	330	Late 2018	Under FERC review.
	Mountaineer XPress	TransCanada	2.7 BCF/d	165	Fall 2018	Under FERC review.
	Nexus	Embridge	1.5 BCF/d	~250	Late 2017	Under FERC review.
	Northern Access	National Fuel	350K Dth/d	96.49	TBD	Received FERC Certificate on 2/3/17. NYDEC permit under appeal.
	PennEast	AGL Resources, NJR Pipeline, PSEG Power, South Jersey Industries, Spectra Energy Partners, UGI Energy Services	1.0 BCF/d	105	2018	Under FERC review.
	Sunbury	UGI Energy Services	NA	35	Janaury 2017	Completed January, 2017
	Utopia East & West	Kinder Morgan	50,000+ bpd	240	Early 2018	Non-FERC jurisdictional. Under construction.

Note: The "Proposed Pipeline Projects" map offers a guide to potential greenfield pipeline projects. Greenfield projects are subject to significant changes in route, inservice dates, regulatory review, final investment decisions, etc. Mapped pipeline routes represent best estimates based on publicly available information. Actual locations may vary. Existing pipeline maintenance, upgrades, looping systems and compression changes are not included.

http://extension.psu.edu/natural-gas

August 10, 2017

Nat Gas Liquid Production



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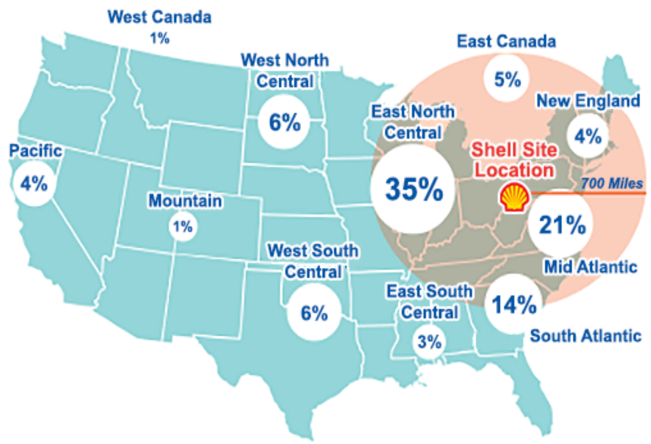
Petrochemical Trends

Share of Leading North American Petrochemical Customers



Source: Pennsylvania Department of Community and Economic Development

- $310B new U.S. investment??
  - Shale gas driven
  - Significant workforce additions
  - New manufacturing capacities
  - $105B/yr contribution to economy
  - Competitive globally
  - Recent announcement by Shell for ethylene production in Marcellus/Utica region. Large quantities of ethane/NGLs
- Ethane exports to Norway and Scotland from Pennsylvania/Ohio/West Virginia
- Other energy intense industrial utilization, particularly power gen, CNG

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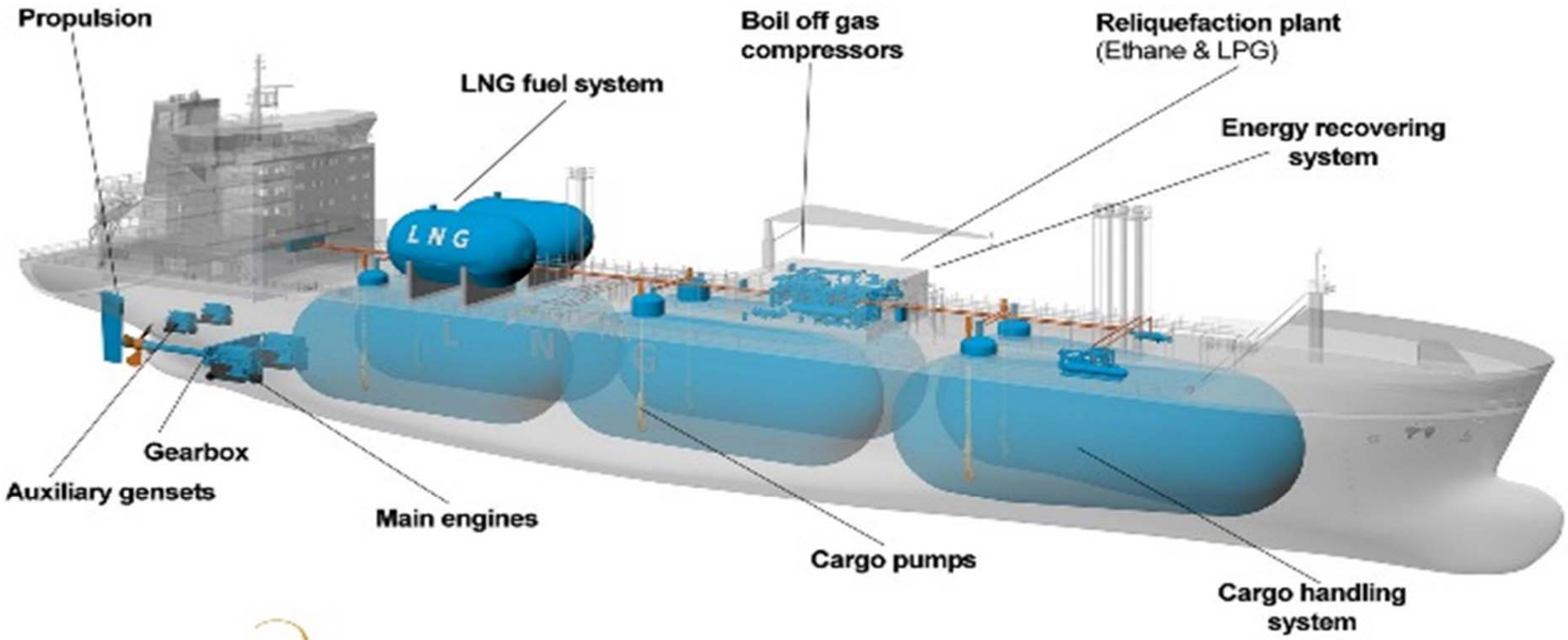
Evolving Ethane Markets

Dragon Class 27,500 m3 liquid gas carrier intended for transatlantic shipments of Marcellus ethane



WÄRTSILÄ

Source: Wärtsilä USA.

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A Global Market for Gas

National Natural Gas Market Overview: World LNG Landed Prices

Federal Energy Regulatory Commission • Market Oversight • www.ferc.gov/oversight

World LNG Estimated Landed Prices: Apr-17

Source: *Waterborne Energy, Inc.* Data in $US/MMBtu. Landed prices are based on a netback calculation.
Note: Includes information and Data supplied by IHS Global Inc. and its affiliates ("IHS"); Copyright (publication year) all rights reserved.
Prices are the monthly average of the weekly landed prices for the listed month.

Updated: May-17

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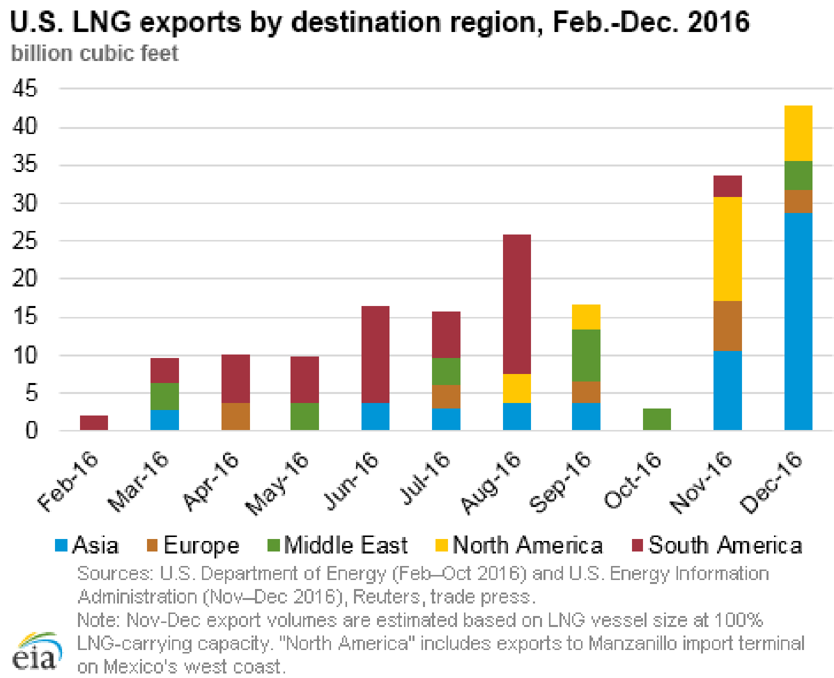
U.S. LNG Trends

- Brownfield sites vs. greenfields
  - Lower environmental cost?
  - Existing social license??
  - Key components already in place
    - pipeline, storage, piers
- Numerous projects approved
  - All East and Gulf coasts
  - Some expanding
  - Additional 20+ in queue
- Panama Canal expansion
  - more LNG cargos transiting
  - 80% of LNG carriers
  - Expand markets in both Atlantic & Pacific basins
  - Reduced time to west coast Mexico regasification from 27 to 10 days
- Crude linked price versus newer “tolling” model based on U.S. Henry Hub price
- Canadian LNG facilities??



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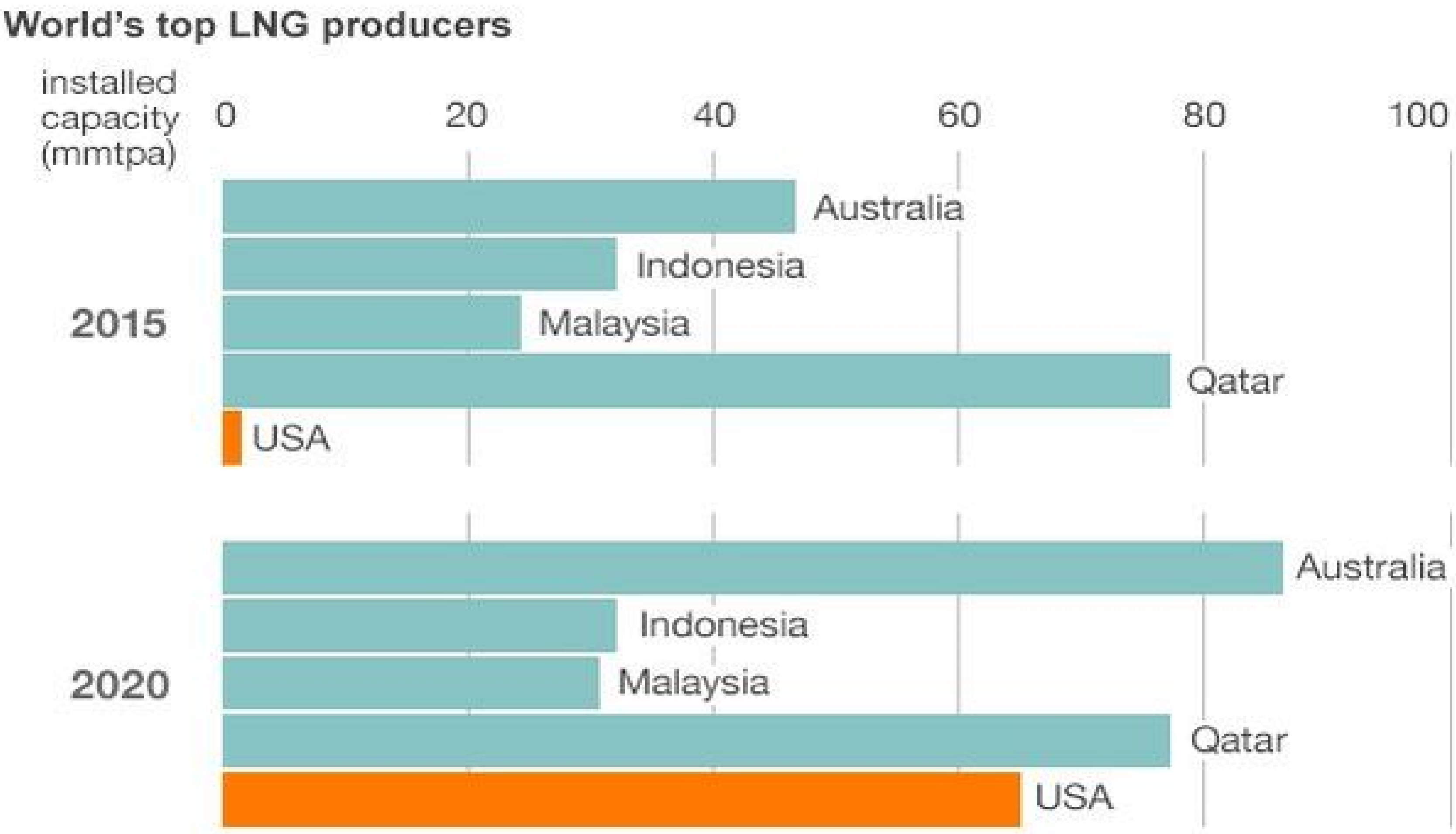
World LNG Producers



Source: Poyry Management Consulting

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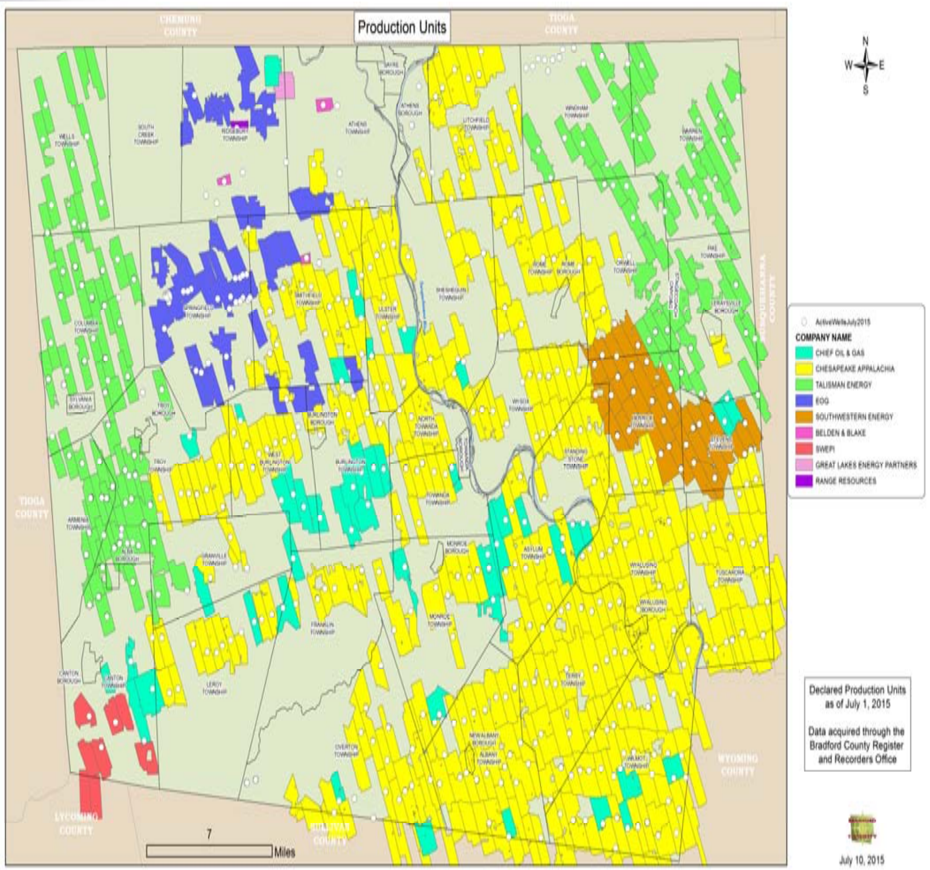
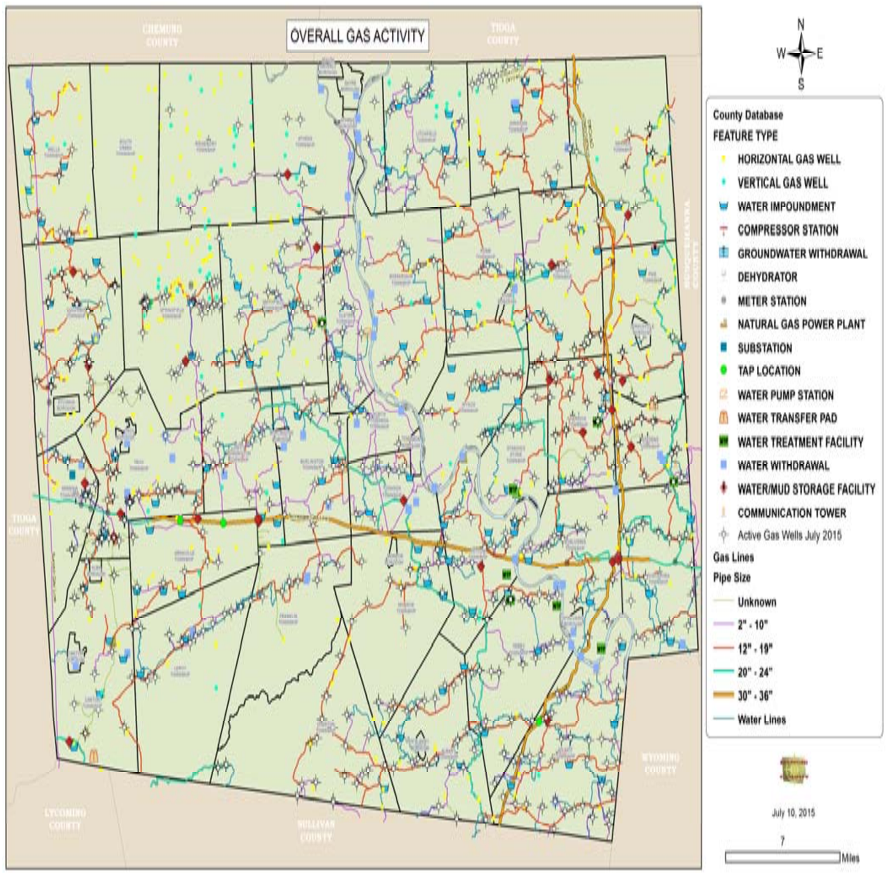
Non Legacy Development





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Better Public Education – Better Outcomes

- Community of “impacted” stakeholders has changed
  - Local interest and implications
  - global influence, distant “ownership”
  - So who to engage? Who is the citizen?
- Social media has changed the rules, critical now
- Value of “social license”
- Everyone connected in mobile world
  - Expectations for a short message about the science of energy
- Need to address concerns
  - Science-based response
  - Transparent process

Stakeholder Engagement

- Understanding the difference in the questions asked
  - "**<u>whether or not</u>**" is addressed with broader energy and public policy education
  - "**<u>How to</u>**" is covered with technical and regulatory dialogue

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“If not this, then what…”

- Energy development often described in jobs and positive economic activity.
- Has the community planned for future changes?
- Is the discussion inclusive? Transparent?
- Are there allowances for changing demographics?
- Are there lines that can’t be crossed?
- Is the planning comprehensive and reviewed periodically?
- And is it realistic…

Conveying Benefit vs. Risk

- What are the reasons for producing the energy
  - Demand for all energy
  - Economic rewards
  - New commercial and industrial development --utilization
  - Workforce opportunities
  - "Bridge" to something else
    - Fossil vs. renewables
    - "all the above" strategy
  - Geopolitical opportunity
  - Environmental
    - climate

- What are the risks
  - Separating possible vs. probable risk with all energy dev'l
  - Wellbore integrity
  - Water contamination
    - Chemicals
    - Methane
  - Air emissions
  - Health
  - Climate
  - Gaps in research??

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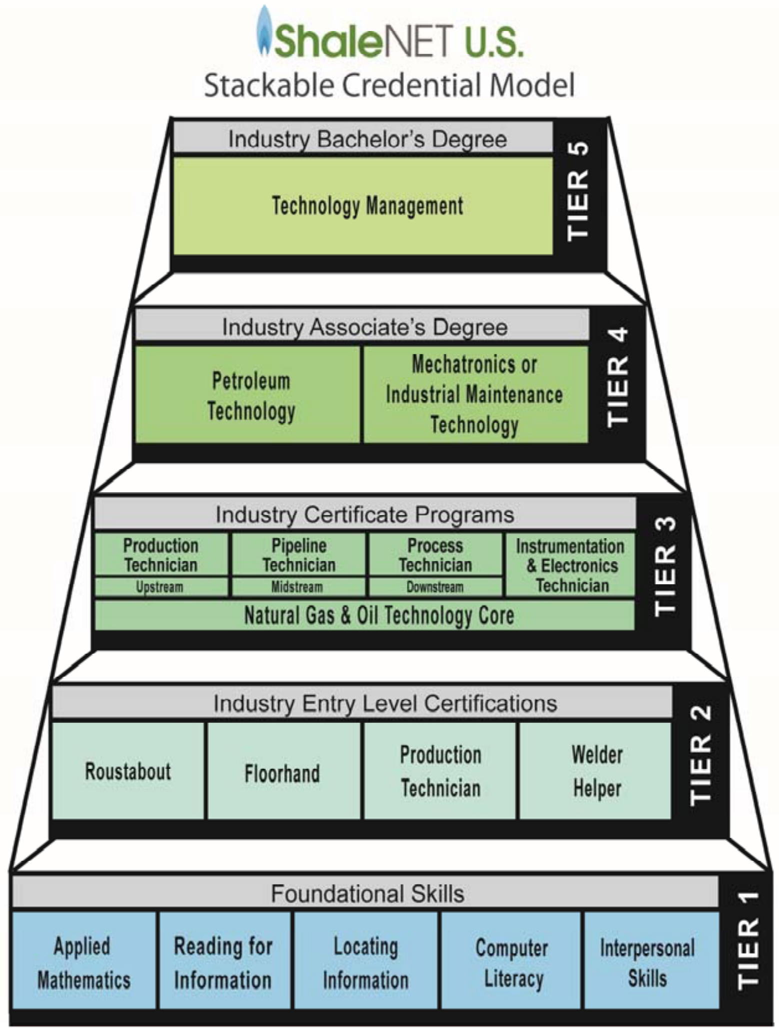
Workforce and Business Trends

- "Localizing" the worker
- 75% blue collar/technical
- Front loaded on well's lifecycle
- Matching demand to availability of labor
- Institutional capacity to train and not "overproduce"
- Housing requirements and required infrastructure
- Key part of social license



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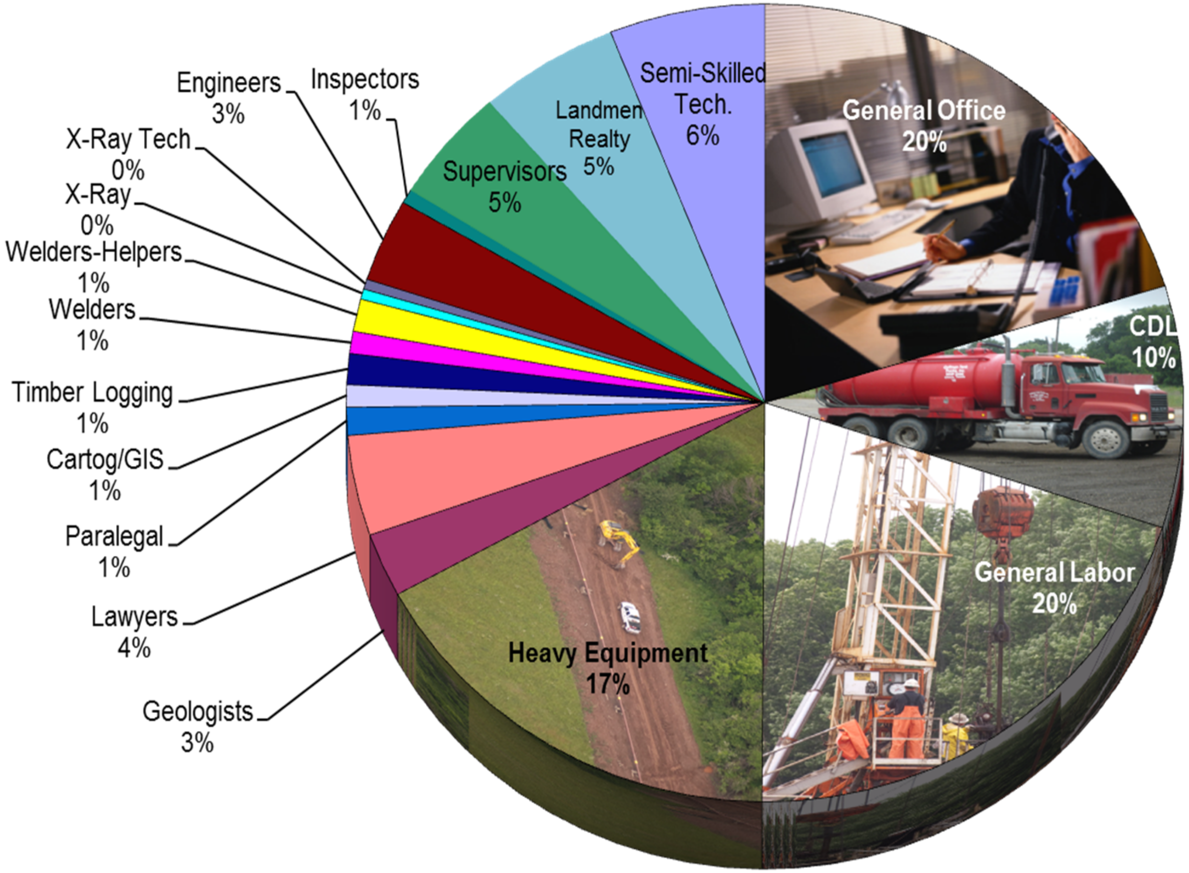
UPSTREAM WORKFORCE ASSESSMENT TO DOWNSTREAM UTILIZATION



--Above average wage levels

- strong career pathways
- 75% of employees require technical training -25% academic
- Percentage Local Hire: 55+%

--Drilling a single well requires 420 people in 150 occupations

--17 long-term jobs/100 wells drilled

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Municipalities Use of Impact Fees in PA(2015)

Impact Fee Use	Amount	Impact Fee Use	Amount
Public Infrastructure Construction	$27.606 million	Planning Initiatives	$0.516 million
Capital Reserve Fund	$17.885 million	Information Technology	$0.228 million
Emergency Preparedness Fund	$6.830 million	Water Preservation & Reclamation	$0.125 million
Amount Not Reported	$3.190 million	Judicial Services	0.039 million
Storm Water/Sewer Systems	$1.791 million	Social Services	$0.037 million
Environmental Programs	$1.277 million	Housing	$0.011 million
Tax Reductions	$0.849 million	Career & Technical Centers	$0.005 million

Key Steps to Engage Stakeholders

- Build capacity and fill knowledge gaps
  - Create institutional ability to train, repurpose, retool
- Encourage community-level participation
- Explain trends and demographics
- Create environment of reasonable dialogue
- One size doesn't fit all –customize community engagement
- Engage early and often
  - Creating trust is a multi-step process, not a single event
  - Explain true risks and mitigation strategies

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MARCELLUS CENTER
MCOR
FOR OUTREACH AND RESEARCH

PENNSTATE

Water Usage and Sourcing

- 16 to 24 million liters. per well (ave.)
- 60 million liters used in PA Marcellus per day
  - 0.15% of all water withdrawals in PA daily
    - 40 billion liters/day for all uses
- Declining amount of water utilized for hydraulic fracturing is trucked
  - Strongly trending towards piped/rail water vs. trucks
- 75%+ is sourced from surface supply vs. wells
- Public transparency??

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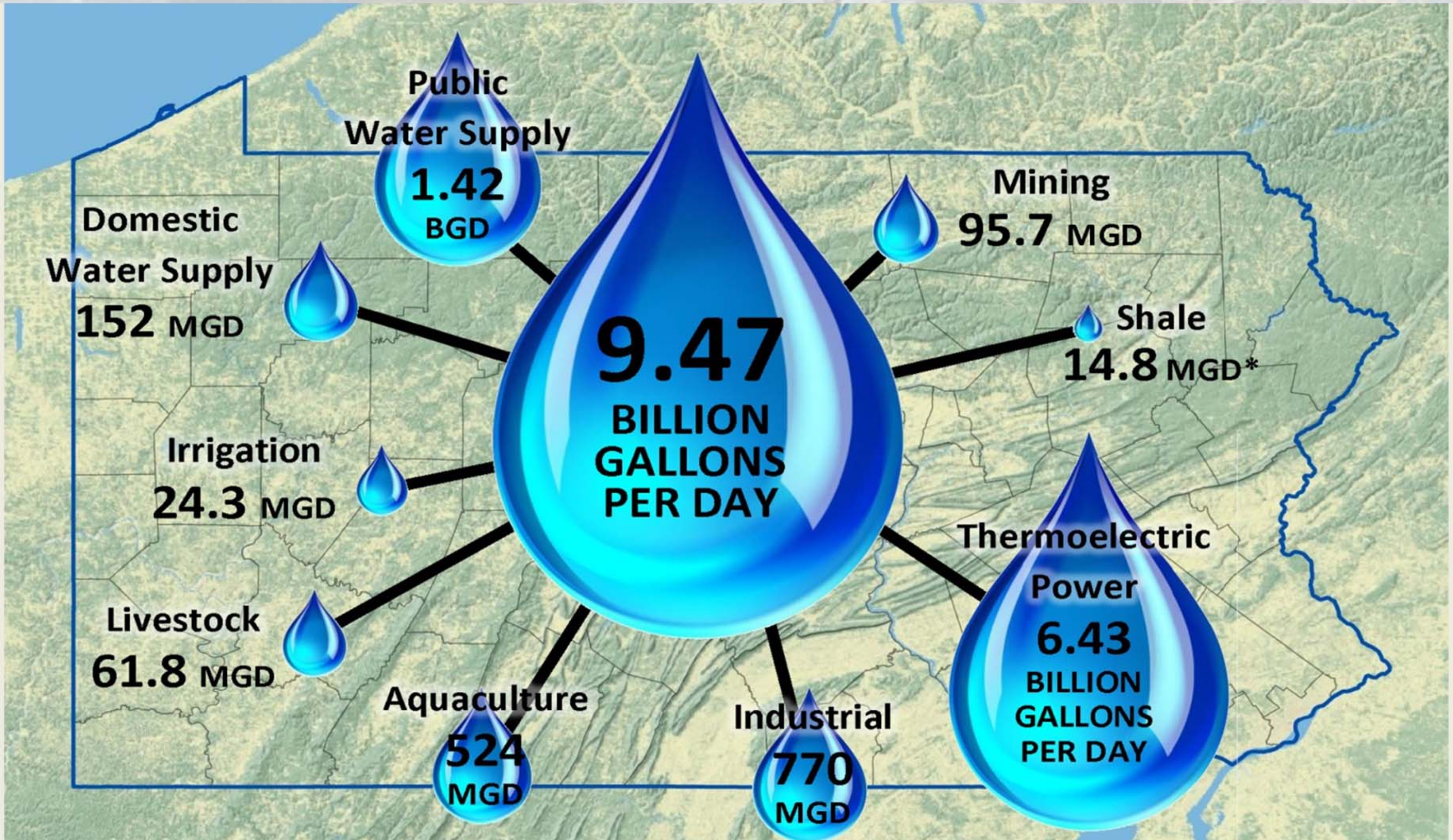

Sources: J. F. Kenny, N. L. Barber, S. S. Hutson, K. S. Linsey, J. K. Lovelace and M. A. Maupin. 2009. *Estimated Use of Water in the United States in 2005*, U.S. Geological Survey, Circular 1344

Graphic update based on *Pennsylvania Angler & Boater*. PA Fish & Boat Commission. January/February, 2011

*Shale estimate based on 1,200 wells per year at 4.5 million gallons per well = 14.8 mgd total water demand - ~3 mdg of water reuse

Penn State **Extension**

marcellus.psu.edu

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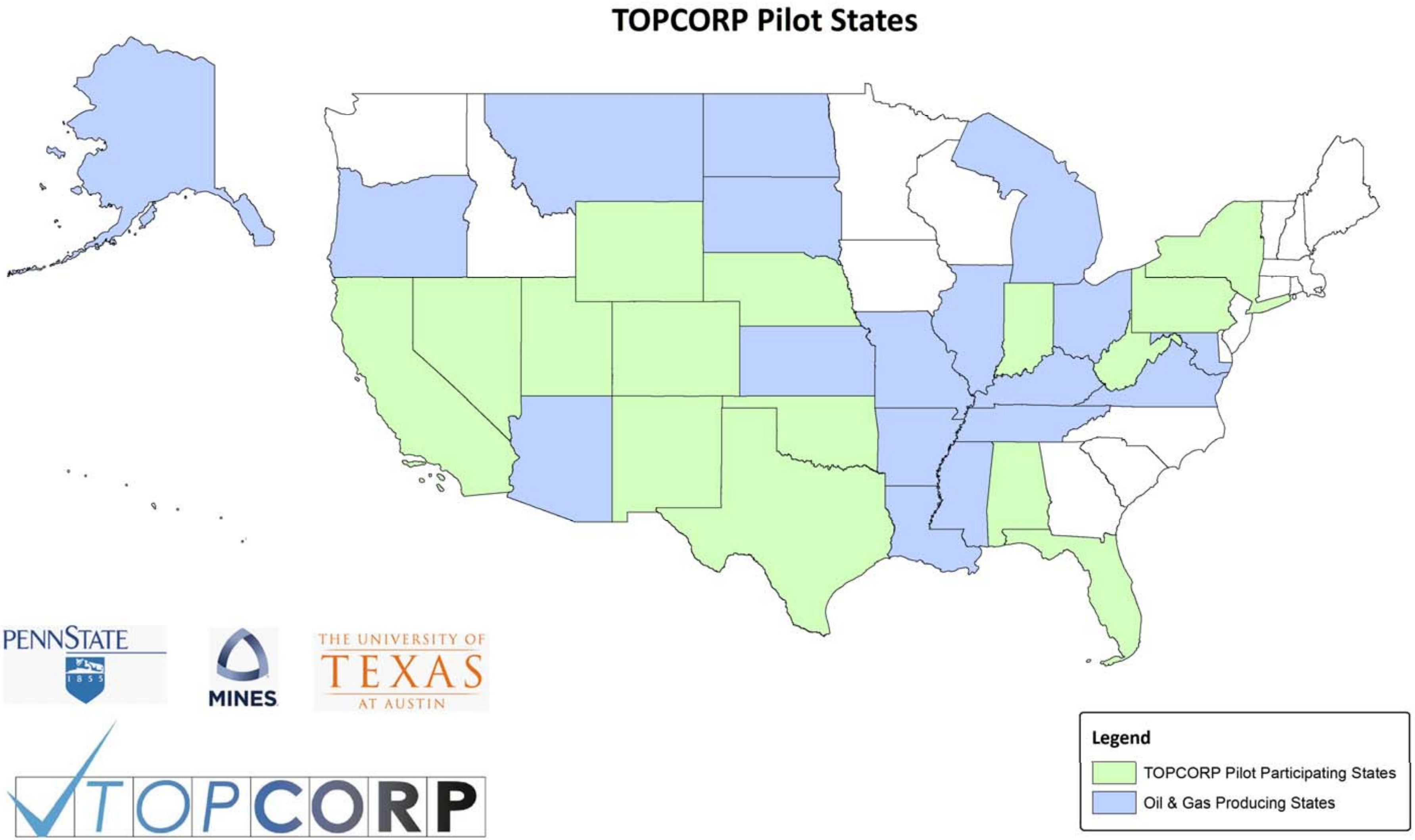
PennState TOPCORP Regulator Training



PENNSTATE 1855

MINES

THE UNIVERSITY OF TEXAS AT AUSTIN

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New Small Scale LNG Shipments

New Fortress Energy to ship containerized LNG to Jamaica Public Service (JPS), Montego Bay, Jamaica

Source: U.S. Energy Information Administration