The Growth of U.S. Natural Gas: An Uncertain Outlook for U.S. and World Supply

For

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By

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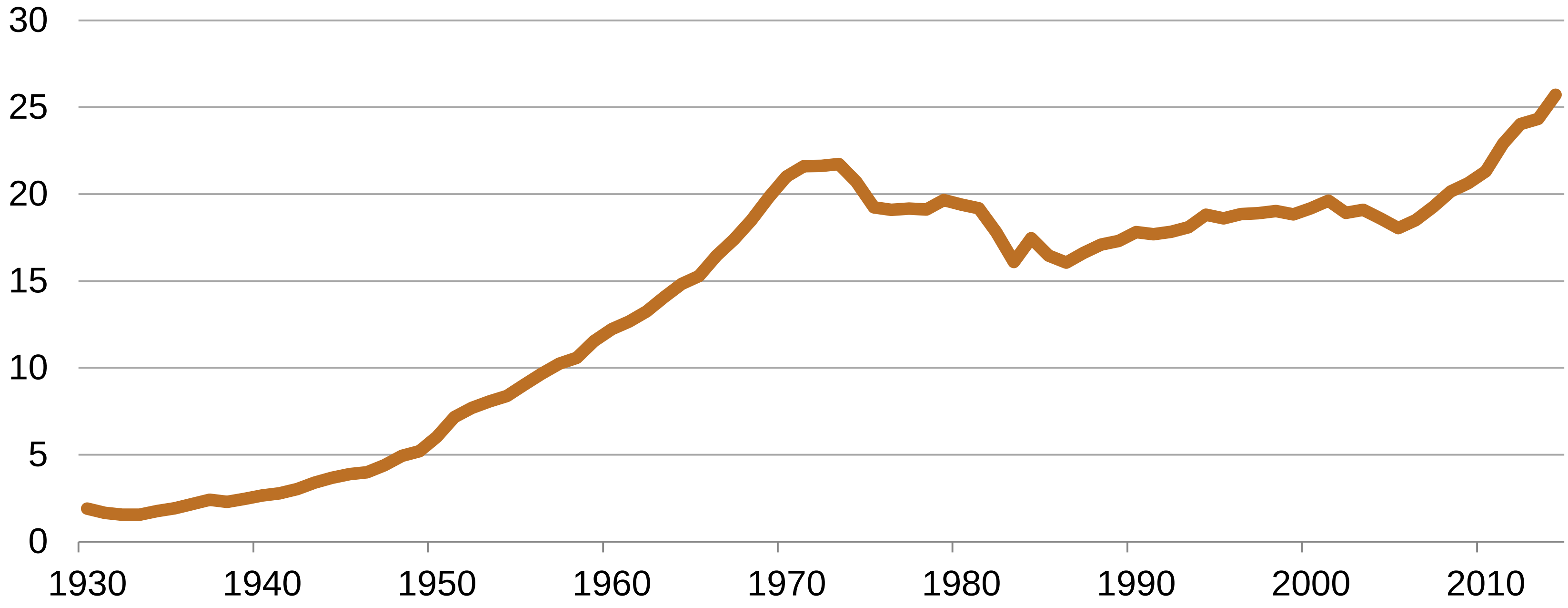
Outline

- Changes in U.S. natural gas
  - Why resource estimates change
- Why resource estimates produced with different methods should be different and are valuable
- What we need to know about a play to get a fairly accurate estimate
  - Intersection of geology, technology & above-ground factors (i.e. economics, regulations, taxes)
- What we know internationally

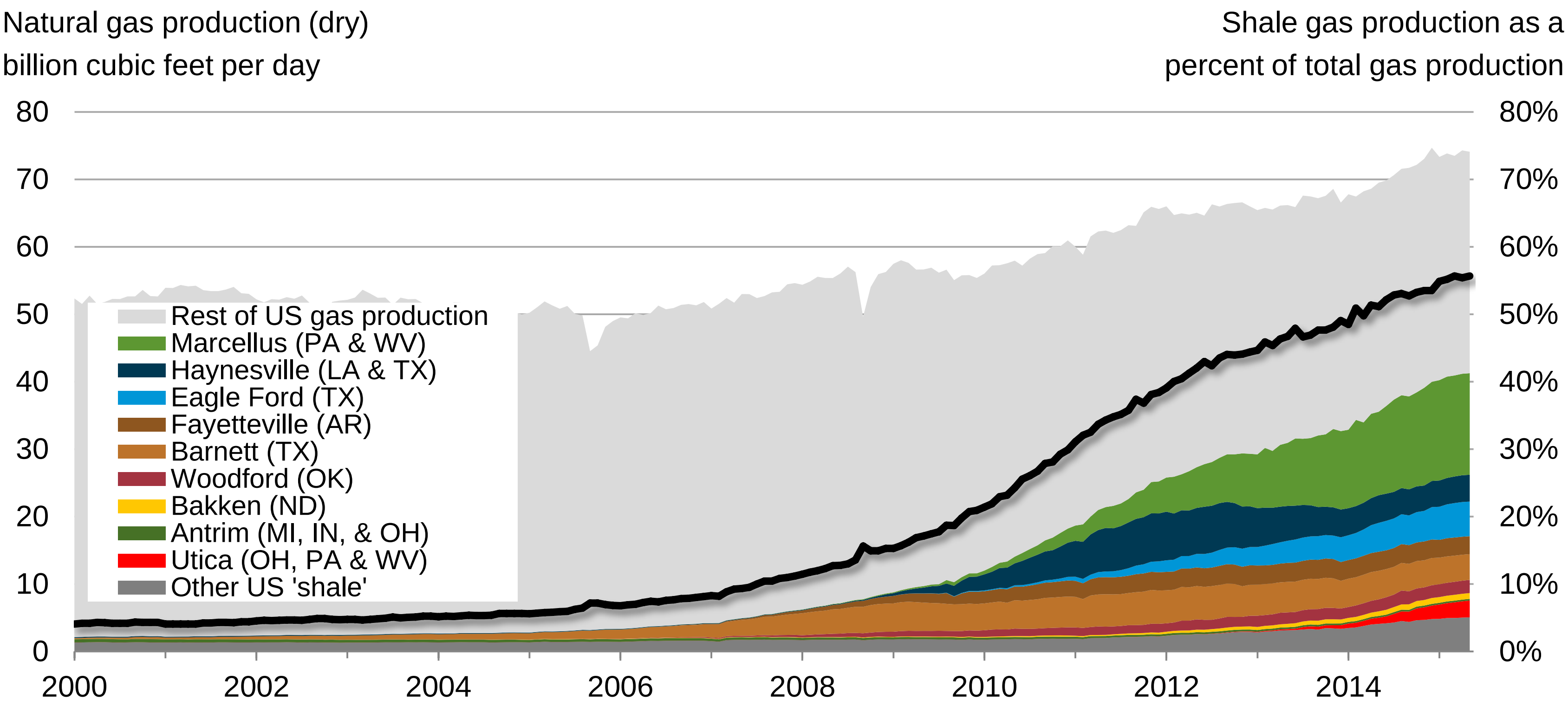
History is easy… cumulative U.S. dry natural gas production since 1930 is 1,200 Tcf

U.S. natural gas production (dry)
trillion cubic feet



Source: EIA

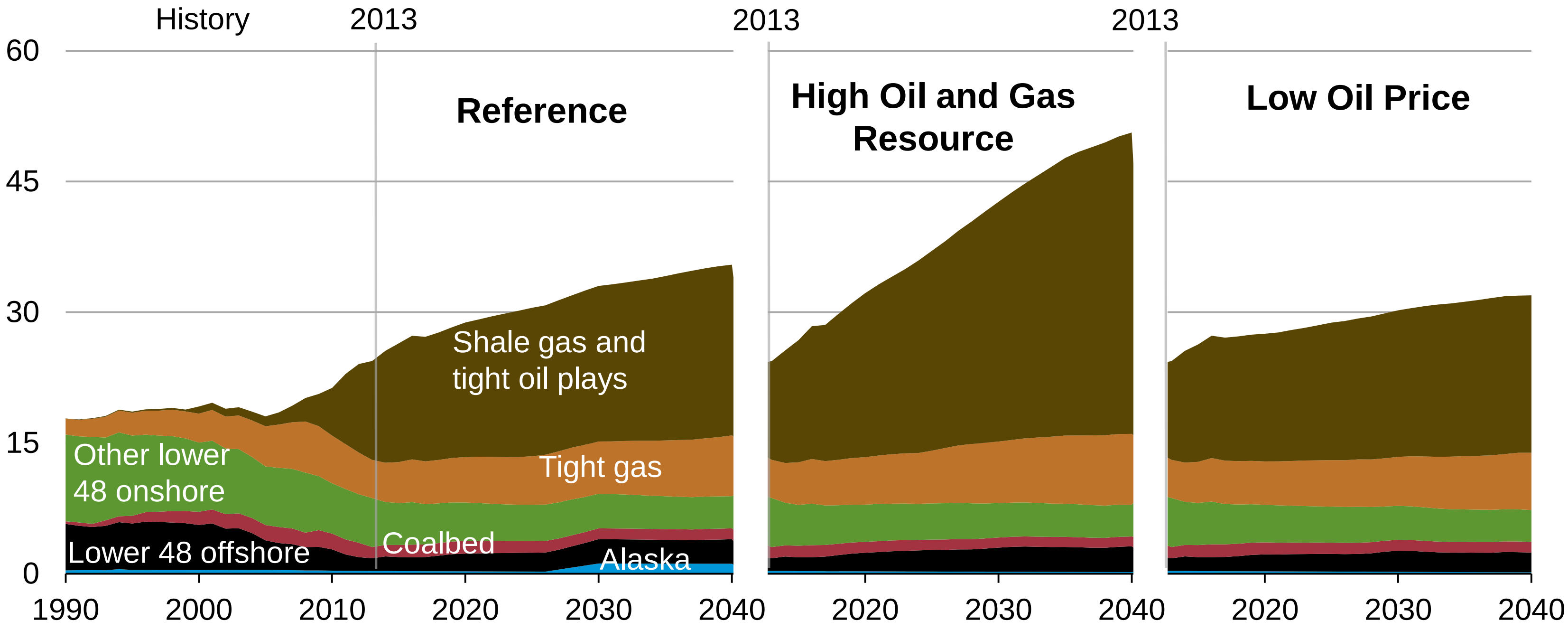
U.S. shale gas production was 5% of total U.S. dry gas production in 2004, 10% in 2007, and is now 56% in 2015



Sources: EIA Natural Gas Monthly data through December, STEO through May2015 and Drilling Info.

Shale resources remain the dominant source of U.S. natural gas production growth, with a range of longer-term outcomes

U.S. dry natural gas production
trillion cubic feet

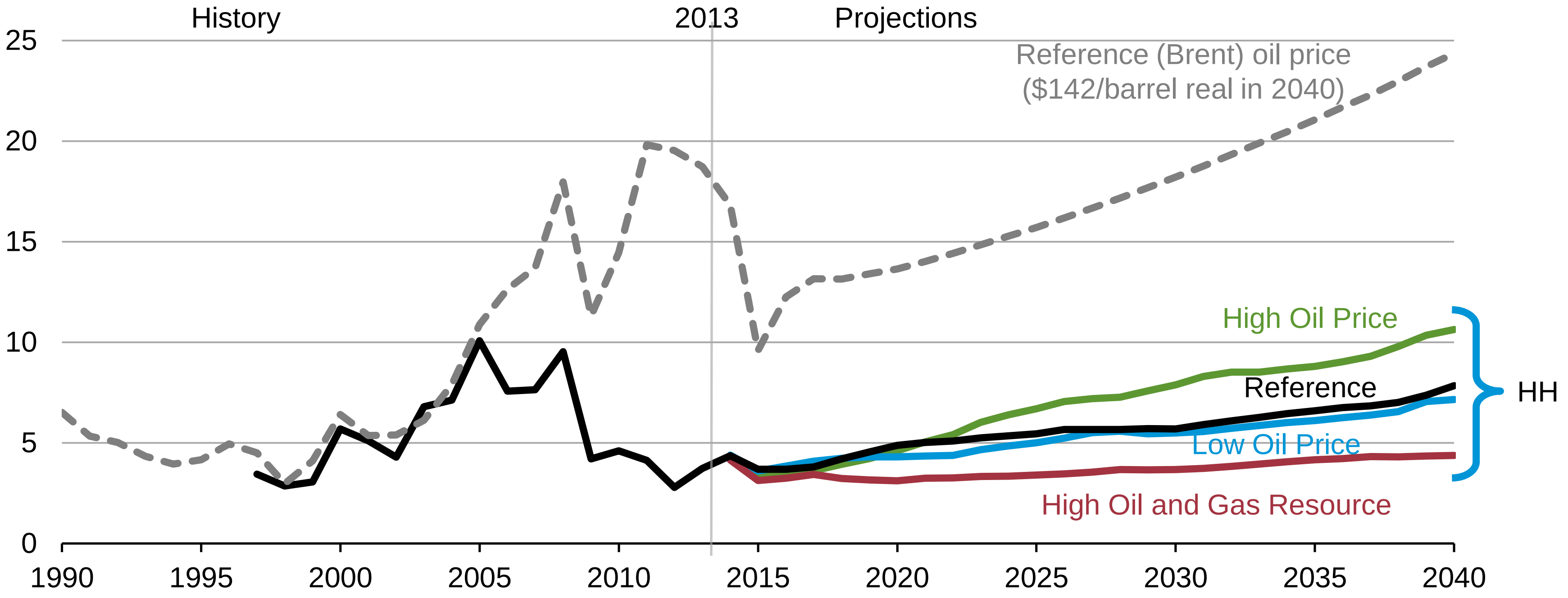


Source: EIA, Annual Energy Outlook 2015

Future domestic natural gas prices depend on both domestic resource availability and world energy prices

Average Henry Hub (HH) spot prices for natural gas

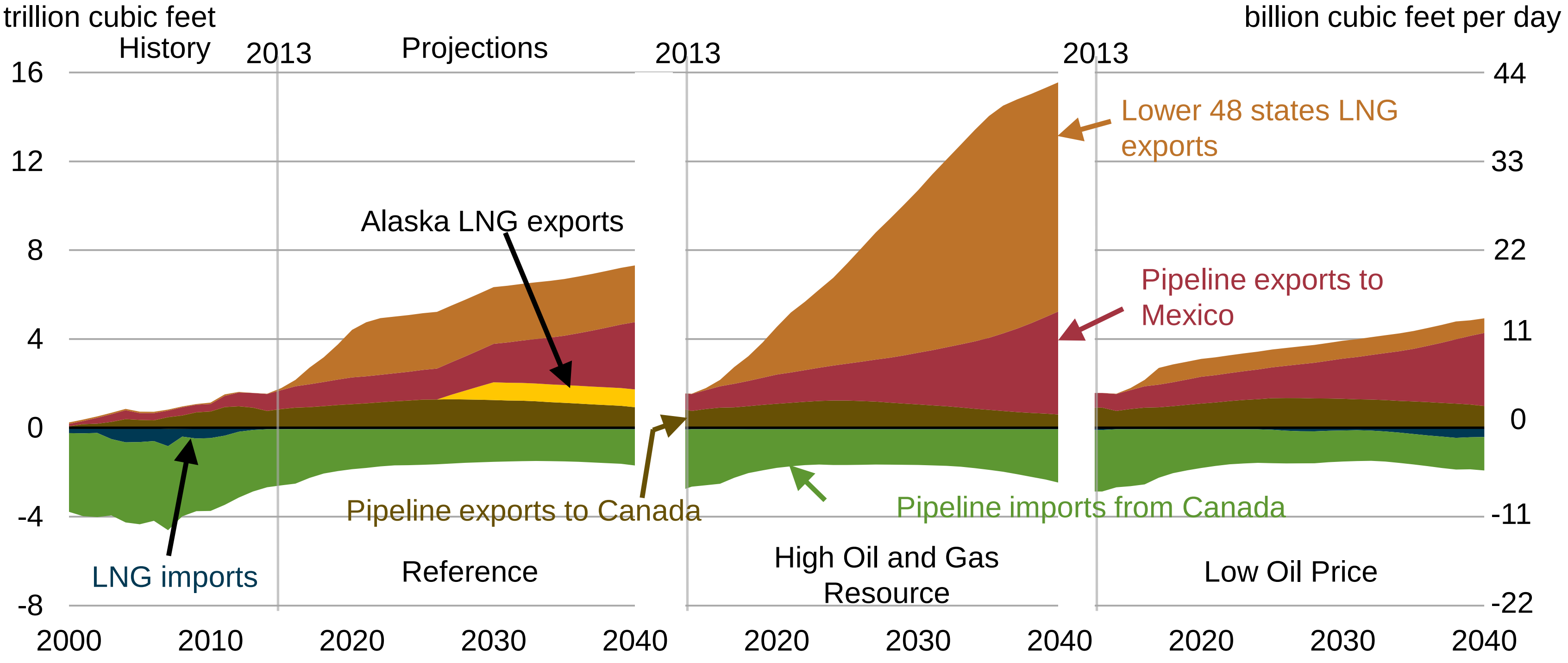
2013 dollars per million Btu



Source: EIA, Annual Energy Outlook 2015

Projected U.S. natural gas exports reflect the spread between domestic natural gas prices and world energy prices

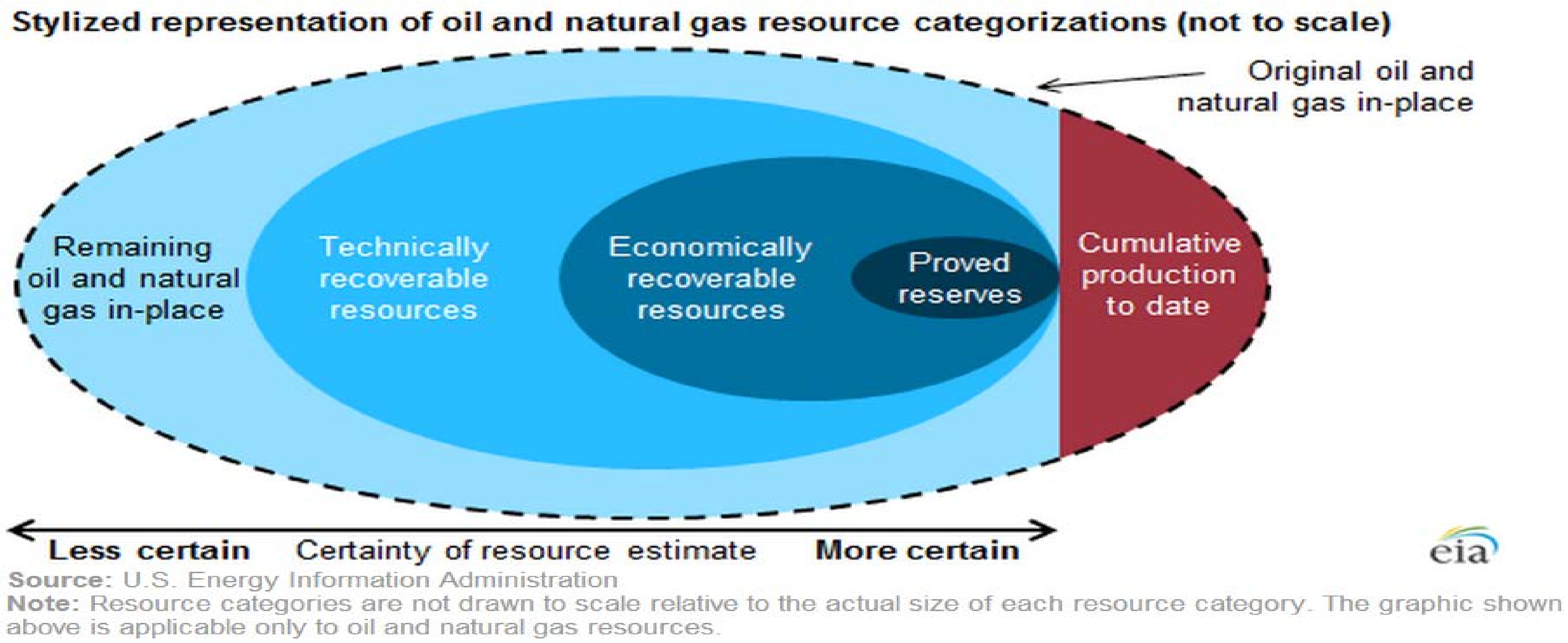
U.S. natural gas imports and exports



Source: EIA, Annual Energy Outlook 2015

Resource estimates for U.S.

Oil and natural gas resource categories reflect varying degrees of certainty

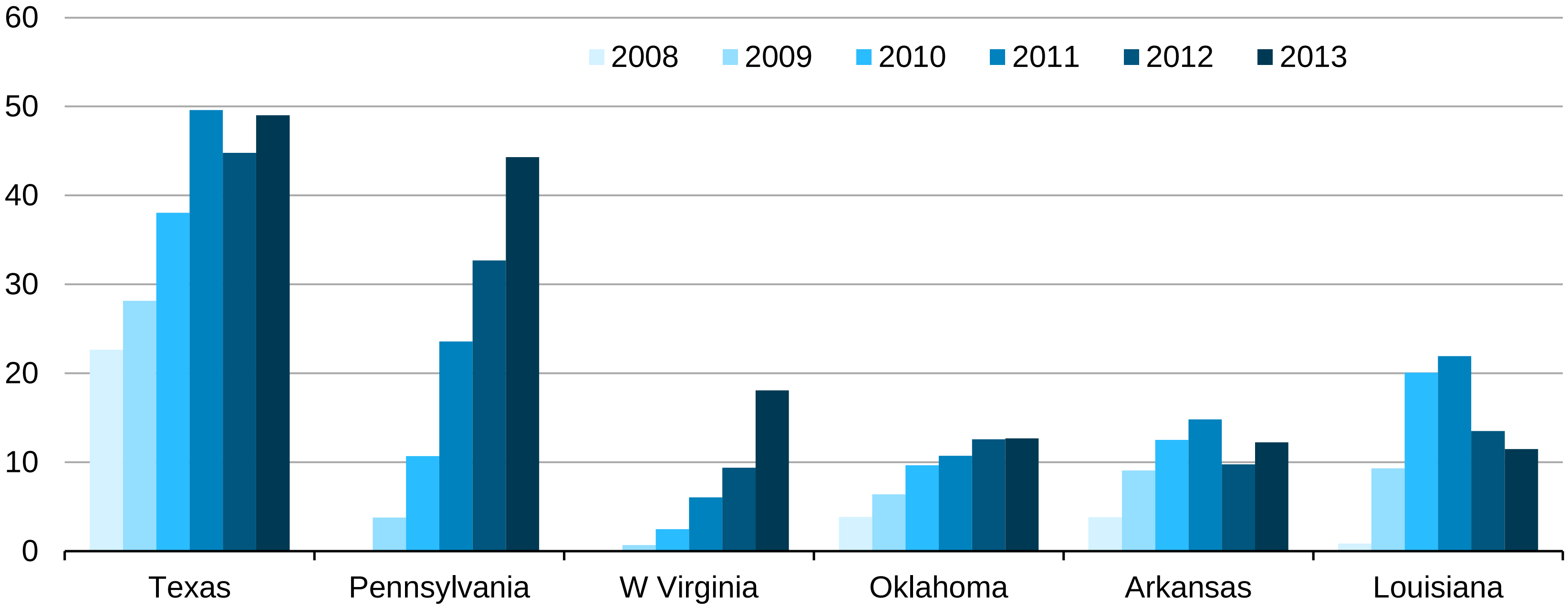


http://www.eia.gov/todayinenergy/detail.cfm?id=17151

Shale gas is 45% of the 354 Tcf total U.S. natural gas proved reserves as of 1/1/2014

Proved shale gas reserves of the top six U.S. shale gas reserves states, 2008-13

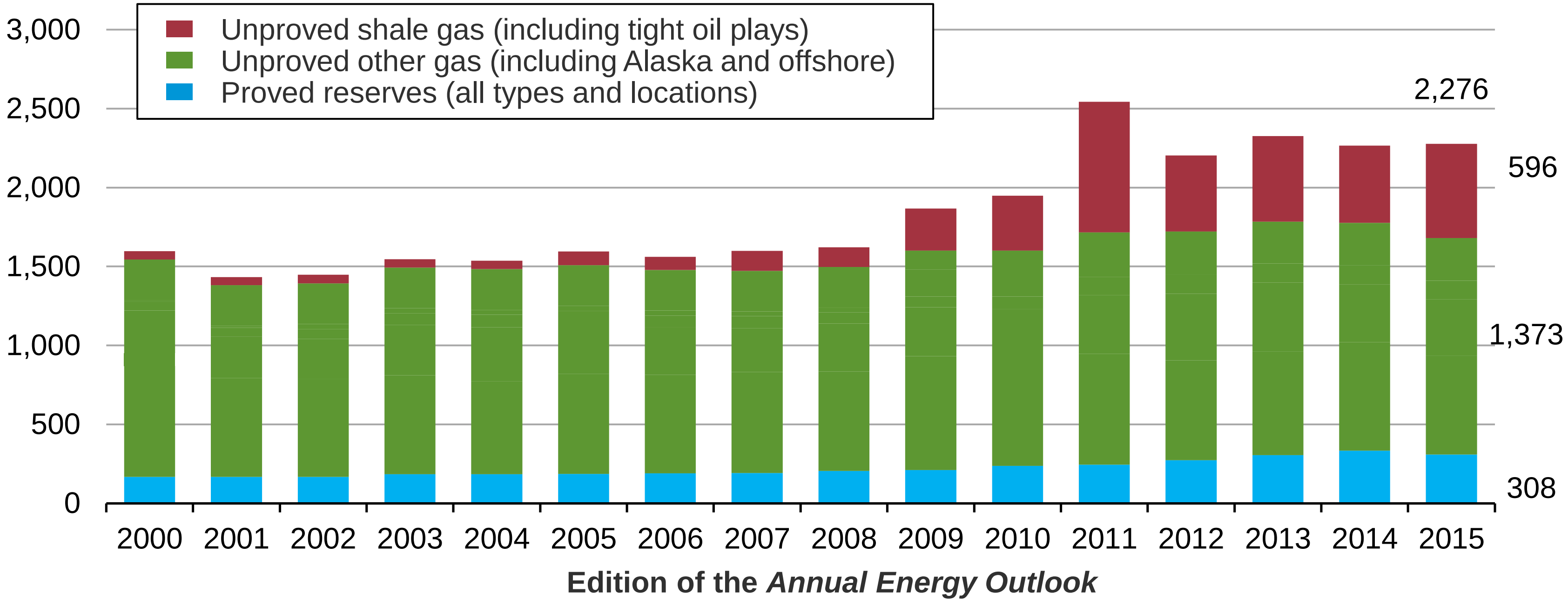
trillion cubic feet



Source: U.S. Energy Information Administration, Form EIA-23L, Annual Survey of Domestic Oil and Gas Reserves, 2008-13. (figure 13)

Technically recoverable natural gas resources reflect new information, a combination of assessments and EIA updates

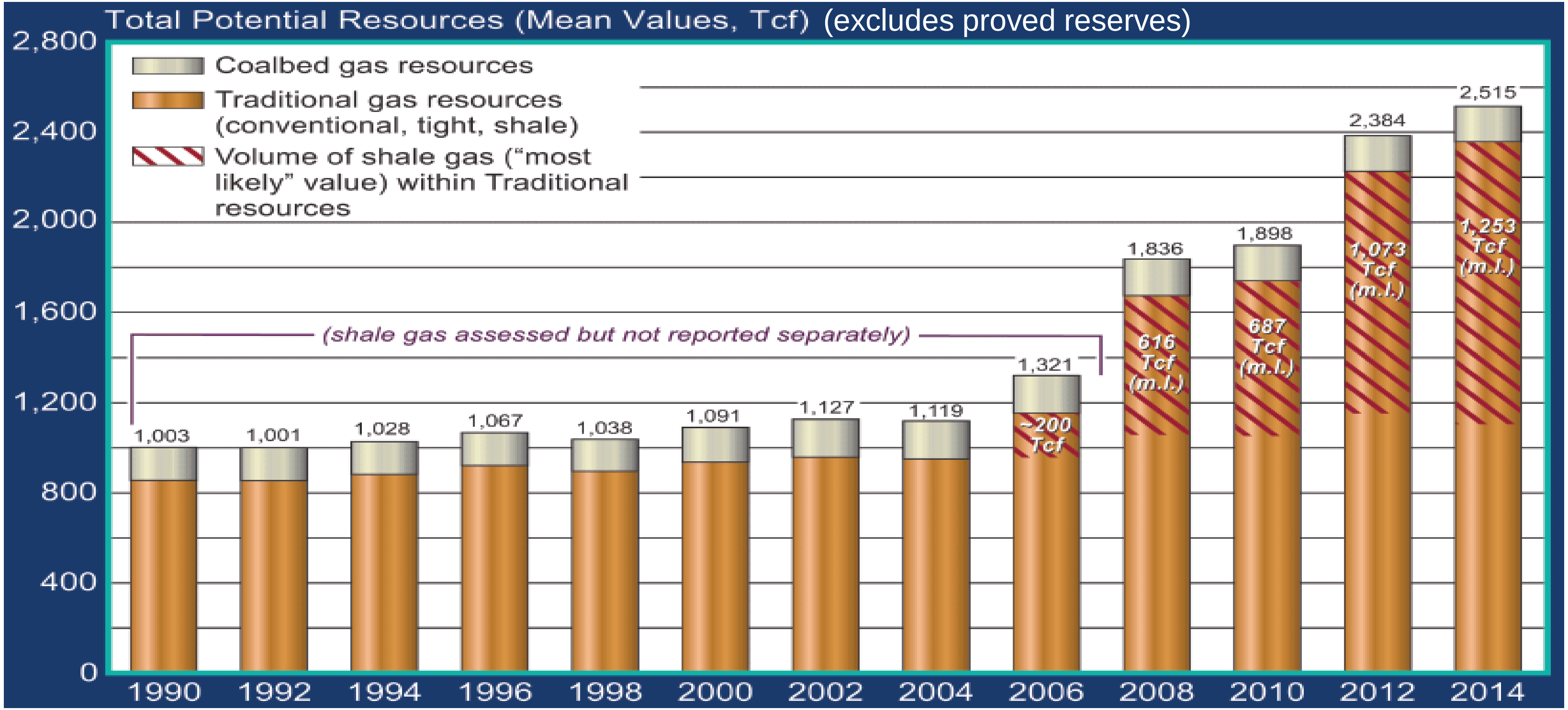
U.S. dry gas resources
trillion cubic feet



Source: U.S. Energy Information Administration, Annual Energy Outlook 2015 and prior editions

Note: Resources are as of January 1 of two years prior to the "edition" year of the AEO (e.g. AEO2015 is 1/1/2013).

Industry and NGO understanding of U.S. shale gas resources has increased substantially in the past decade



Source: Potential Gas Committee (2015)

Marcellus

Adding geology improves EUR estimate quality, offers higher resolution

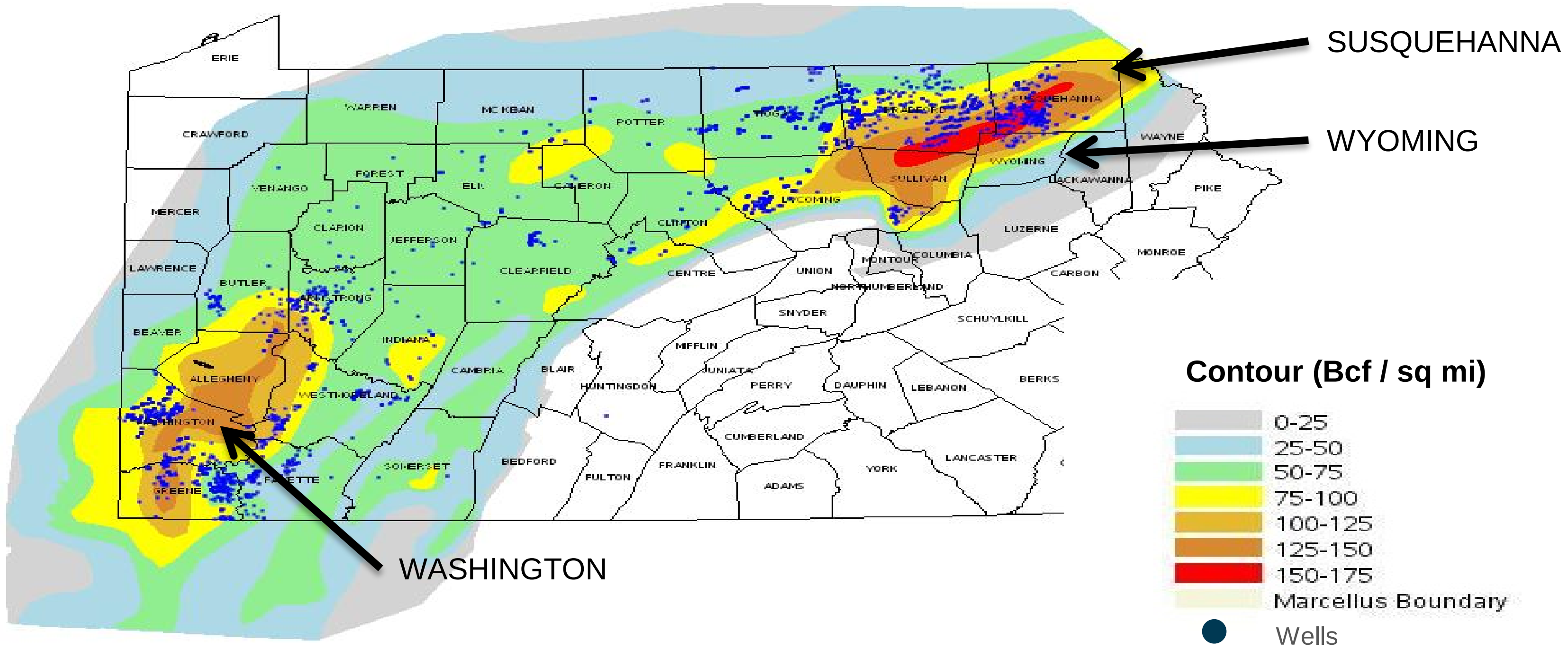
County	Average EUR (bcf)	Average EUR weighted by GIP tier (bcf)
ALLEGHENY	3.74	4.09
ARMSTRONG	0.91	2.72
BEAVER	2.74	2.44
BEDFORD	1.16	0.85
BLAIR	1.34	1.23
BRADFORD	5.70	3.94
BUTLER	1.74	2.72
CAMBRIA	1.46	2.43
CAMERON	0.33	2.69

County	Average EUR (bcf)	Average EUR weighted by GIP tier (bcf)
SUSQUEHANNA	6.14	4.92
TIOGA	2.98	2.49
UNION	2.80	0.30
VENANGO	0.83	2.49
WARREN	1.84	2.28
WASHINGTON	2.45	3.69
WAYNE	7.49	1.34
WESTMORELAND	1.85	2.84
WYOMING	8.85	3.42

EUR: Estimated ultimate recovery per well

Source: Energy Information Administration analysis, July 2014

Pennsylvania Marcellus – dry gas in the Northeast, wet gas in the Southwest

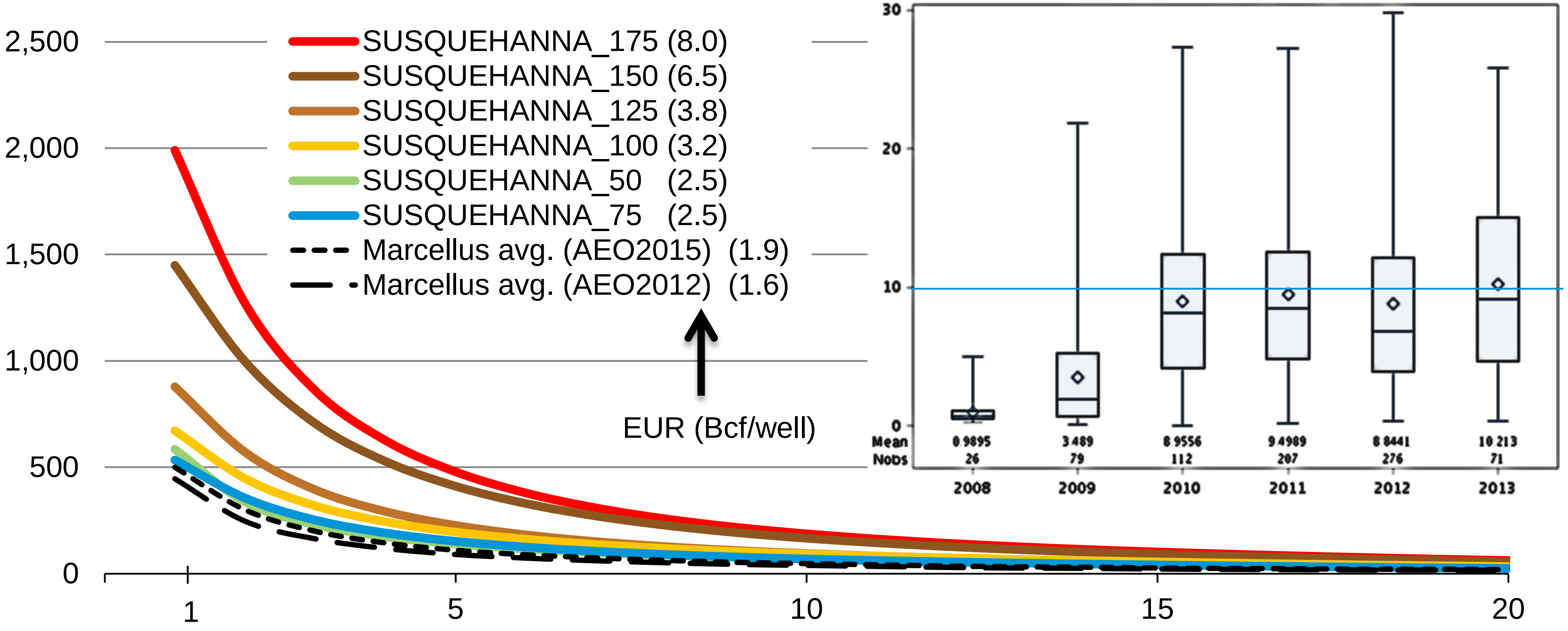


Source: Range Resources, Marcellus extent and Range Resources gas in-place outlines

Two additional years of data show increase in productivity of wells, and sub-county detail captures economic drivers

Dry natural gas production from average well over 20 years
million cubic feet per year

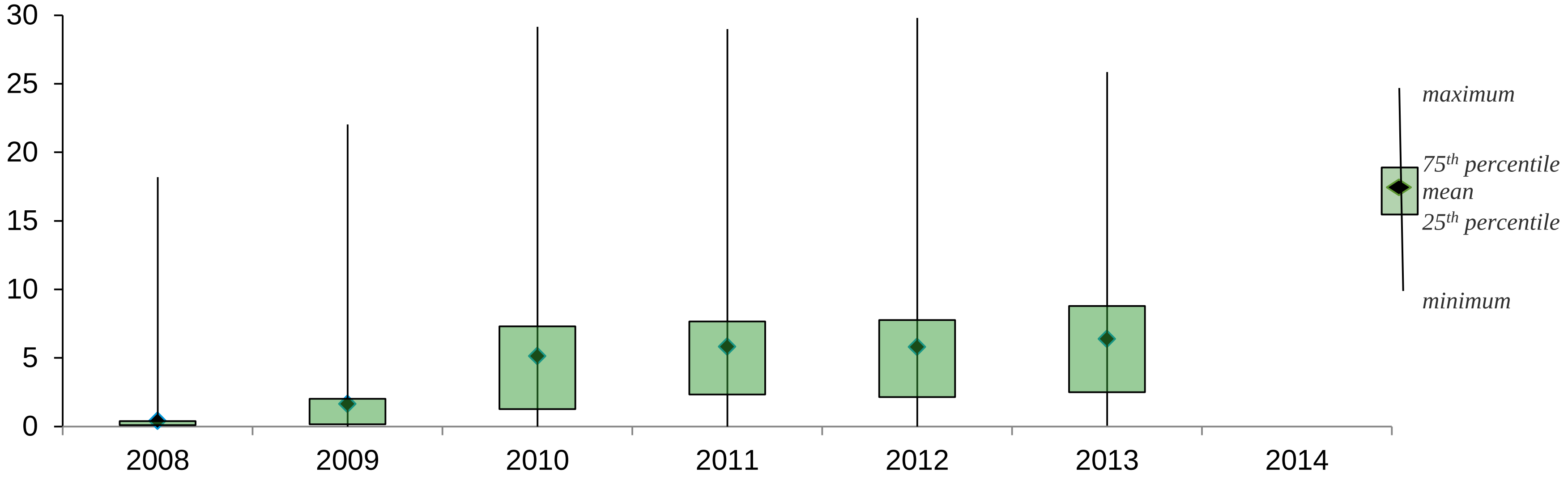
Susquehanna, PA EURs by vintage
billion cubic feet



Source: EIA, Annual Energy Outlook 2015

Distribution of EURs in the Marcellus

Cumulative dry natural gas production (i.e. EUR, Estimated ultimate recovery per well)
billion cubic feet



Mean EUR (bcf/well)	0.39	1.62	5.13	5.81	5.78	6.37	
Number of wells	1,200	1,030	1,474	2,277	2,191	302	

Source: EIA analysis for AEO2015 conducted in July 2014, and thus limited 2014 data available.

Estimates of Marcellus resources for Pennsylvania with no excluded areas

Table 1. Estimates of EUR and area for Pennsylvania contour areas in the Marcellus

Contour (bcf/sq mi)	Area (sq mi)	Average EUR (bcf)	Resource Est. (TCF)	Area (%)	Resource (%)
150-175	304.8	9.19	12.0	1.2	3.9
125-150	1408.3	5.59	33.8	5.3	10.9
100-125	1886.6	3.59	29.1	7.2	9.4
75-100	2,941.4	3.05	38.6	11.2	12.5
50-75	11798.7	2.55	129.4	44.8	41.8
25-50	6259.3	2.28	61.5	23.8	19.9
0-25	1734.2	0.68	5.1	6.6	1.6
		Total->	309.5		

Source: U.S. Energy Information Administration, Office of Energy Analysis, Petroleum, Natural Gas and Biofuels Analysis

Source: EIA http://www.eia.gov/workingpapers/pdf/geologic_dependencies.pdf October 2014

Technically recoverable tight/shale oil and gas resources in several shale gas regions

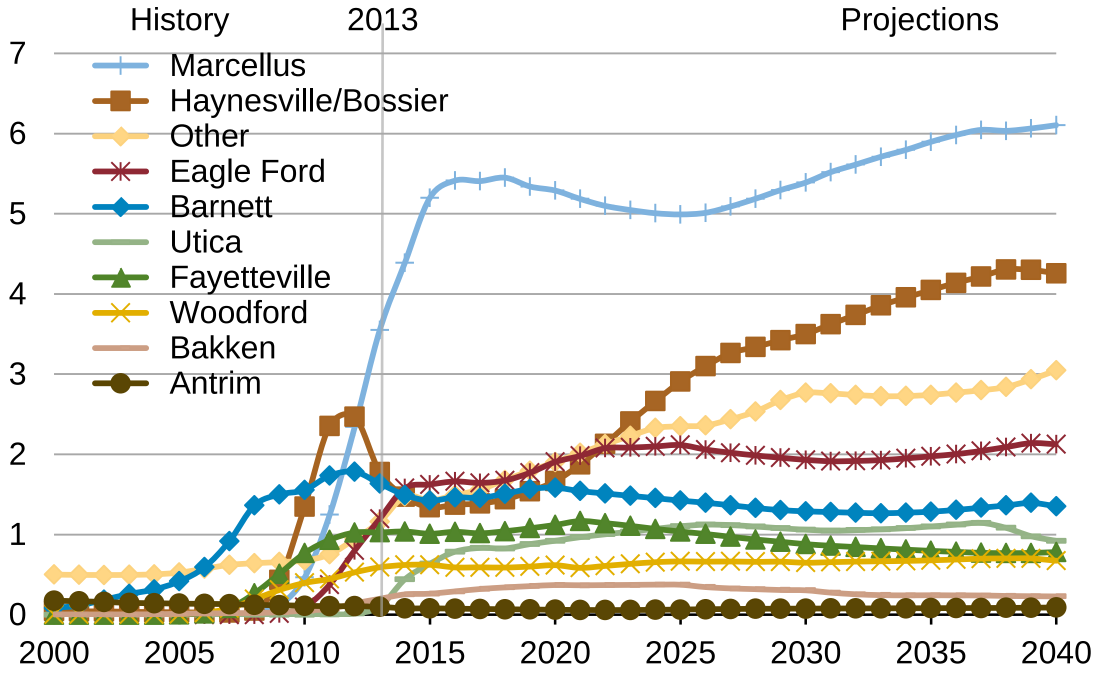
Play	Area with Potential[1] (mi²)	Average Well Spacing (wells/mi²)	Average EUR	Unproved Technically Recoverable Resources		Proved reserves	Cumulative production
			Natural Gas (Bcf/well)	Natural Gas (Tcf)	NGPL (Bbls)	Natural Gas (Tcf)	1990-2013 (Tcf)
Barnett-Core	363	8.0	1.621	**4.7**	0.2	26.0	12.6
Barnett-North	1,611	8.2	0.467	**6.2**	0.2		
Barnett-South	5,368	8.0	0.154	**6.6**	0.3		
Fayetteville-Central	2,065	8.0	0.973	**16.1**	0.0	12.2	4.6
Fayetteville-West	773	8.0	0.700	**4.3**	0.0		
Haynesville-Bossier-LA	1,883	6.0	4.279	**48.3**	0.0	16.1	8.7
Haynesville-Bossier-TX	1,521	6.0	2.735	**25.0**	0.0		
Marcellus Foldbelt	869	4.3	0.323	**1.2**	0.0	64.9	7.8
Marcellus Interior	17,200	4.4	1.897	**143.8**	5.5		
Marcellus Western	2,688	5.5	0.255	**3.7**	0.2		

1 Area of play that is expected to have unproved technically recoverable resources remaining

2 Includes lease condensate

The Marcellus is the largest shale gas play over the long-term

Dry shale gas production by selected plays
trillion cubic feet



Cumulative production
trillion cubic feet

	(1990-2013)	(2014-2040)
Marcellus	8	147
Haynesville/Bossier	9	79
Other	9	63
Eagle Ford	2	52
Barnett	13	38
Utica	0	27
Fayetteville	5	26
Woodford	3	17
Bakken	1	8
Antrim	3	2
Total	**52**	**459**

Source: EIA, Annual Energy Outlook 2015

The shale gas technology story is only beginning, with much yet to be written

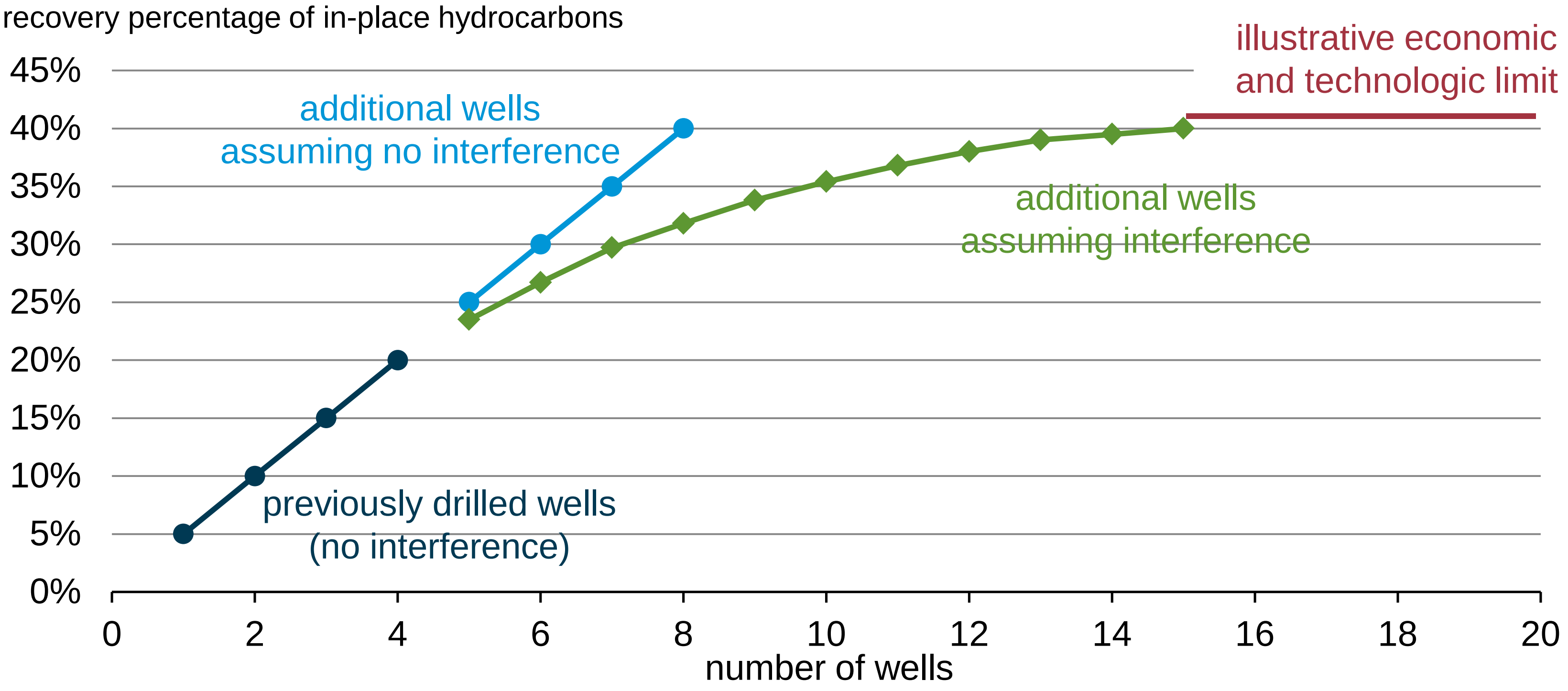
- Technology is creating new resources out of rocks
- Production data provides a rearview mirror perspective
  - see the changes, but with a delay
  - EIA does not anticipate step changes in technology applications
  - EIA does recognize and incorporate long-term technological change
- Annual re-estimating of U.S. plays is necessary
  - new data is providing significant new detail of what production is possible
- Broad implications exist for world wide oil and gas production

TRR Does Not Reflect the Expected Future

- TRR is a comparative benchmark metric, but its magnitude is difficult to interpret physically
  - Good estimator of relative potential of different plays
  - Consistent under-estimator of total volume of gas that will be extracted in future

- TRR intentionally ignores sources of significant, coupled uncertainties (conservative estimate):
  - Future technology improvements – Although continuous incremental improvements can be modeled a la Moore's Law for microprocessors, the emergence of disruptive technologies is difficult to predict
  - Economic considerations – The price of natural gas can drive investments, leading to greater recoverability than estimated in TRR
  - Political/Regulatory environment – Changes can change access to and/or economic feasibility of certain plays

Accounting for interference may require substantially more wells than a non-interfering expectation

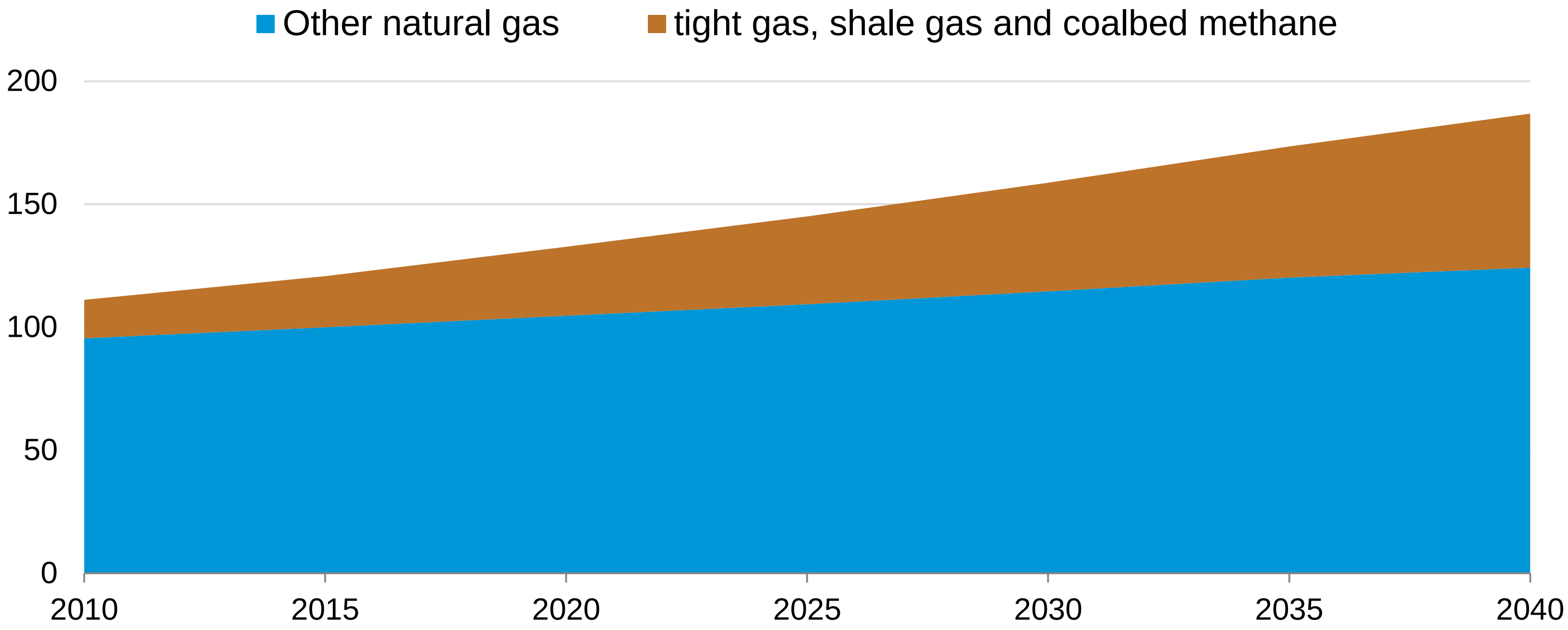


Source: EIA illustration

International

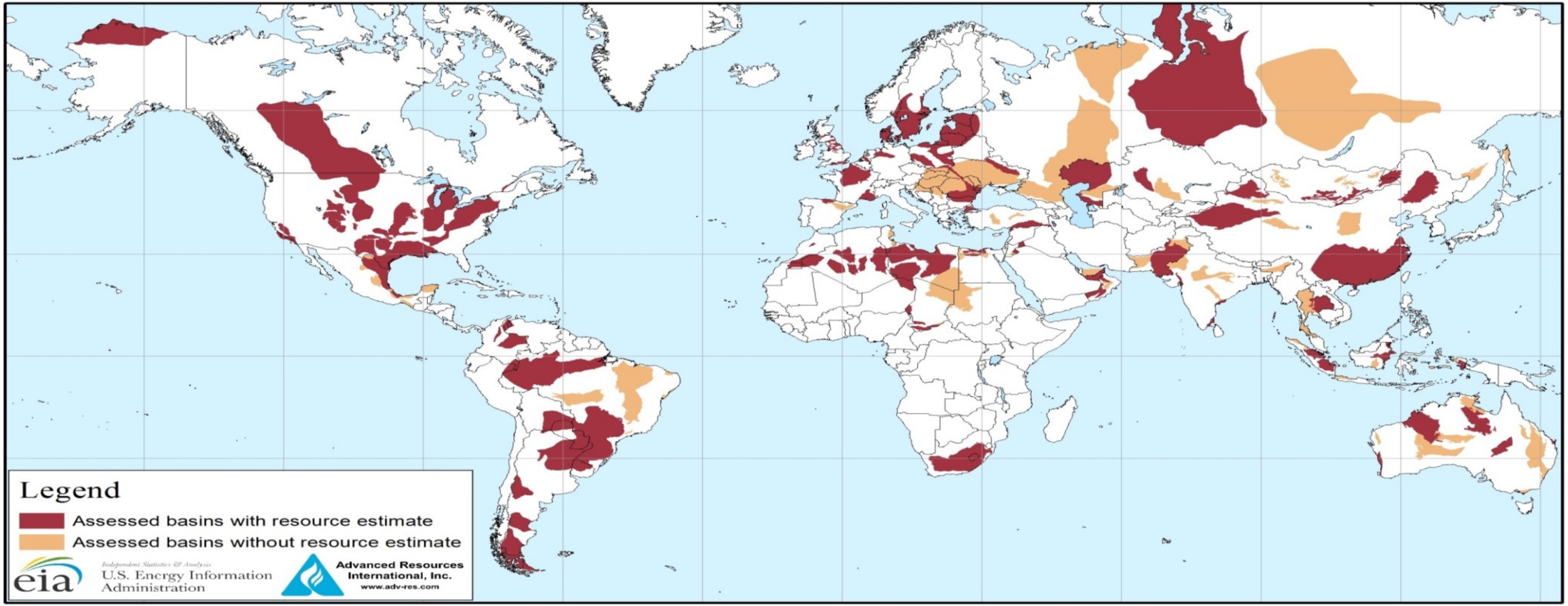
World natural gas production will diversify

Natural gas production
trillion cubic feet



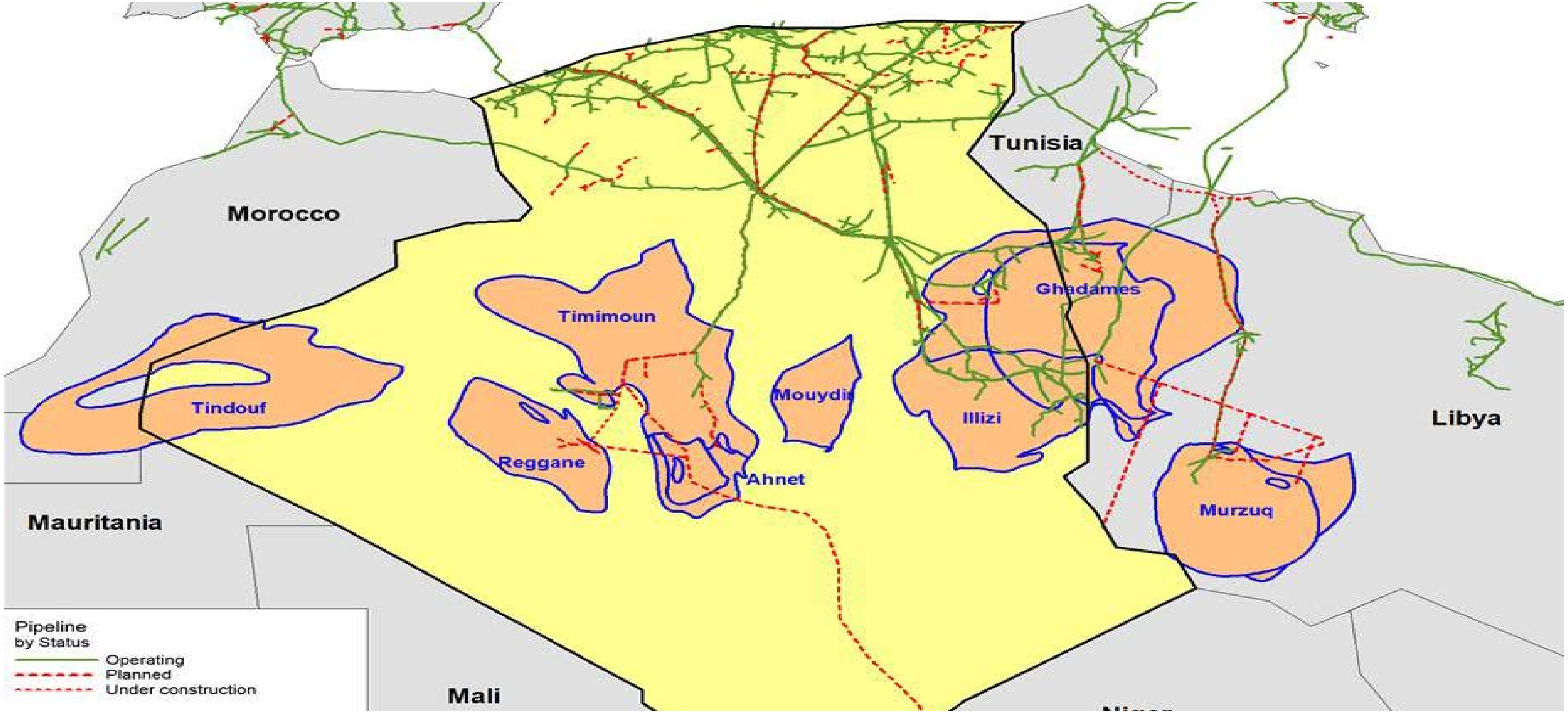
Source: EIA International Energy Outlook 2013, Reference case

Map of 106 basins assessed for shale oil and shale gas resources in 46 countries



Source: EIA/ARI Supplement 2015 Preliminary Release

Algeria's pipeline infrastructure proximity to shale basins



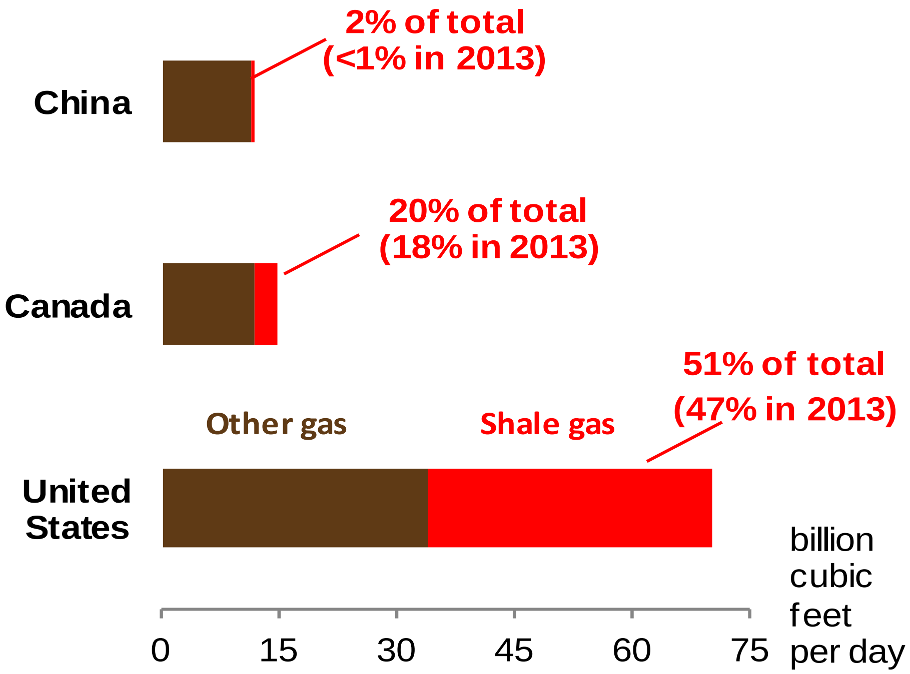
Source: EIA, ARI, IHS_EDIN

Technically recoverable shale gas resources are about 30% of total world natural gas resources

	Wet natural gas (trillion cubic feet)
United States	
Shale gas	665
Non-shale	1,766
Total	**2,431**
Shale as a percent of total	**27%**
Total World	
Shale gas	7,299
Non-shale	15,583
Total	**22,882**
Shale as a percent of total	**32%**

Source: EIA; EIA/ARI 2013; O&GJ Dec. 2012 and USGS 2012

Countries producing shale gas oil in 2014



Source: US EIA, Canada National Energy Board, Fact Global Energy, Chevron, Yacimientos Petroliferos Fiscales

Areas of uncertainty in the outlook

- Global development of tight oil and shale gas resources
  - EIA is gathering geology and production information, and conducting outreach
- Increasing global trade of natural gas and HGL in addition to oil
  - EIA is integrating the representation of oil and natural gas supply and other hydrocarbons
- Impact of geopolitical tensions on energy supply
  - EIA exploring options for representing these uncertainties in the outlook

Why long-term projections ~~might~~ ~~could~~ will be wrong

- Different relative fuel prices
- Faster / slower demand growth
- Changing policies and regulations
- Changing consumer preferences
- Faster / slower technological progress
- Technological breakthroughs

For more information

U.S. Energy Information Administration home page | www.eia.gov

Annual Energy Outlook | www.eia.gov/forecasts/aeo

Short-Term Energy Outlook | www.eia.gov/forecasts/steo

International Energy Outlook | www.eia.gov/forecasts/ieo

Today In Energy | www.eia.gov/todayinenergy

Monthly Energy Review | www.eia.gov/totalenergy/data/monthly

State Energy Portal | www.eia.gov/state

Drilling Productivity Report | www.eia.gov/petroleum/drilling

Supplemental Slides

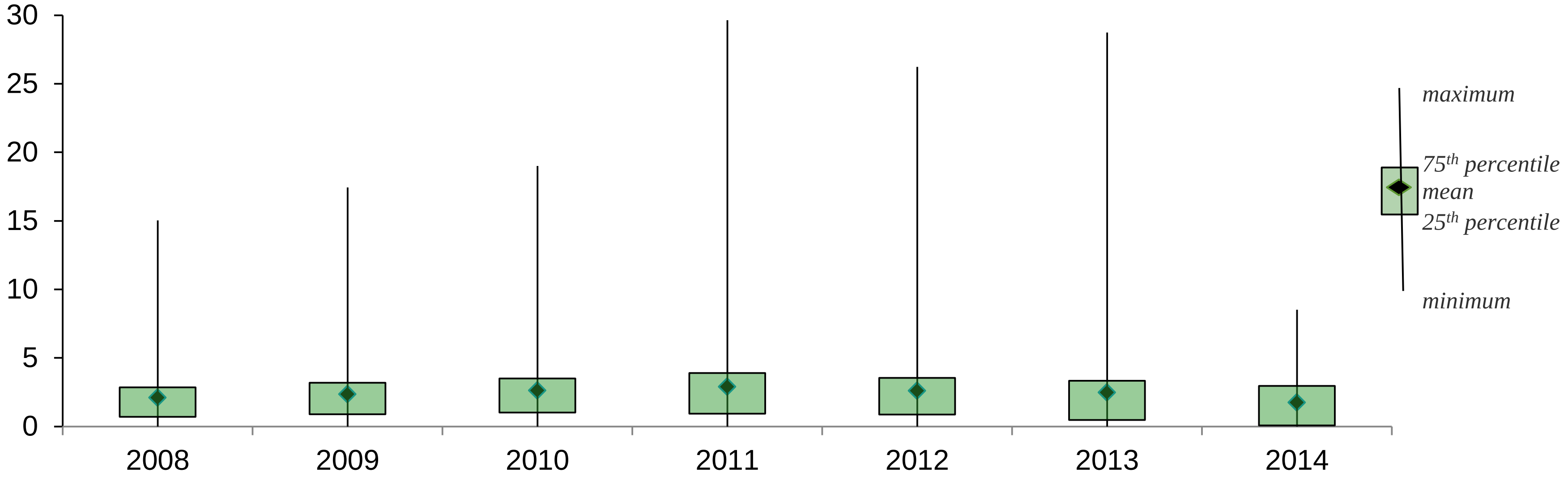
Comparison of methodologies

- Volumetric approach
  - Volume of rock
  - Identify share of area with potential
  - Estimate oil and gas in-place based on pore space
  - Apply geology and above-ground risk factors to “de-risk” the developable resource
  - Multiply by a recovery factor (informed from U.S. experience)
    - Generally 20% to 30% for natural gas

- Performance approach
  - Areal extent of shale
  - Identify share of area with potential for development, using detailed information on geology within individual formations that are being assessed.
  - Number of wells per unit area
  - Estimated average production over the life of a well (estimated ultimate recovery (EUR)) from similar types of shale formations in U.S.

Distribution of EURs in the Barnett

Cumulative dry natural gas production (i.e. EUR, Estimated ultimate recovery per well)
billion cubic feet

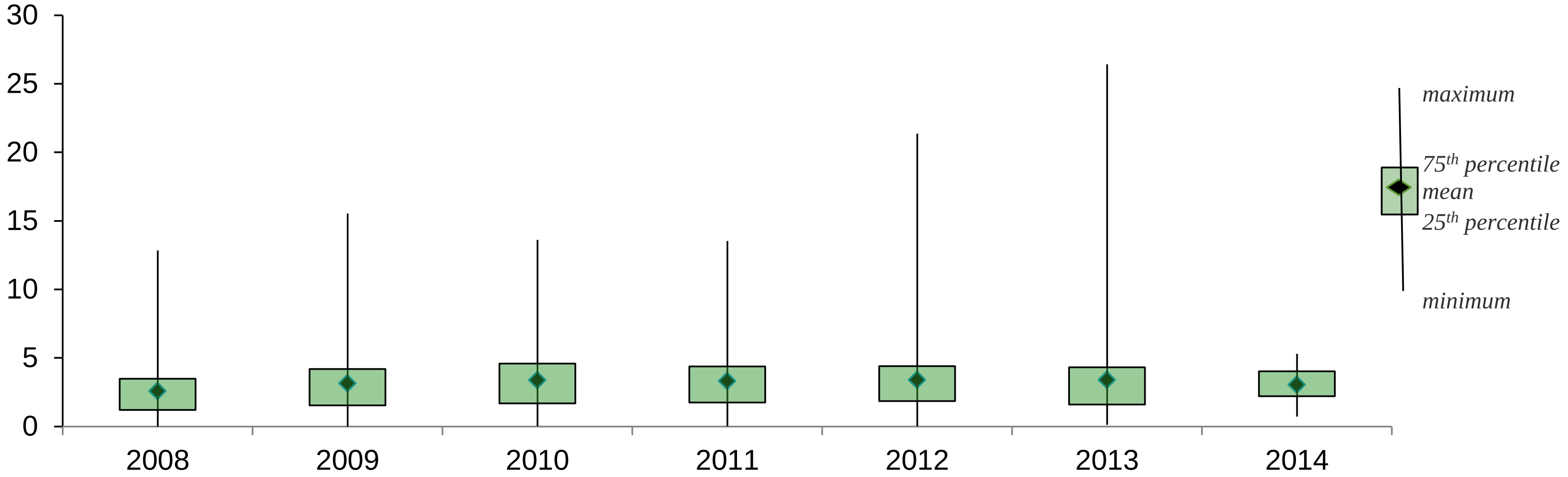


	2008	2009	2010	2011	2012	2013	2014
Mean EUR (bcf/well)	2.08	2.35	2.62	2.89	2.59	2.47	1.74
Number of wells	4,872	2,785	3,112	2,800	1,919	1,118	97

Source: EIA analysis for AEO2015 conducted in July 2014, and thus limited 2014 data available.

Distribution of EURs in the Fayetteville

Cumulative dry natural gas production (i.e. EUR, Estimated ultimate recovery per well)
billion cubic feet

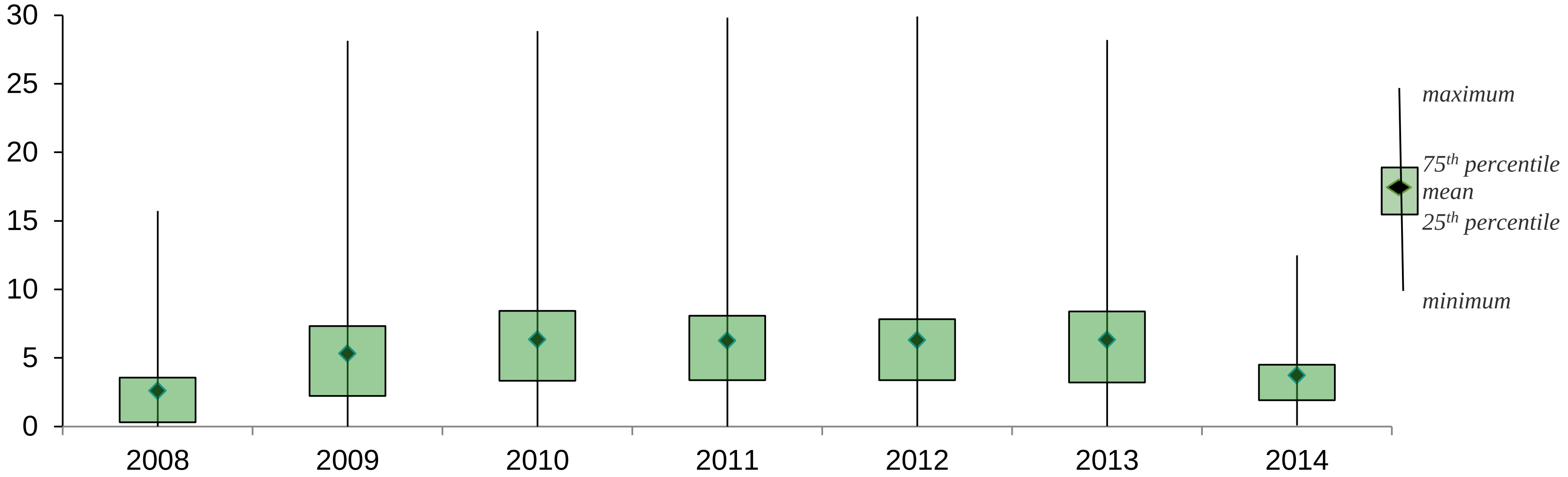


Mean EUR (bcf/well)	2.57	3.14	3.38	3.3	3.38	3.38	3.03
Number of wells	1,338	1,650	1,726	1,634	1,423	960	35

Source: EIA analysis for AEO2015 conducted in July 2014, and thus limited 2014 data available.

Distribution of EURs in the Haynesville

Cumulative dry natural gas production (i.e. EUR, Estimated ultimate recovery per well)
billion cubic feet



	2008	2009	2010	2011	2012	2013	2014
Mean EUR (bcf/well)	2.6	5.32	6.33	6.24	6.29	6.32	3.72
Number of wells	237	981	1,713	1,973	889	388	39

Source: EIA analysis for AEO2015 conducted in July 2014, and thus limited 2014 data available.

Key concepts

- Gas in place (GIP)
  - Total amount of gas that exists in reservoirs (including shale) in a field (field: geographic area, geologically related)
  - GIP cannot be directly measured, only inferred from maps of geologic parameters
- Technically recoverable resources (TRR)
  - Amount of gas that could be produced from a field using currently available technology and production practices, but regardless of economic viability
  - Includes historical production, known proved reserves, plus estimate of areas not yet tested
- Economically recoverable resources
  - Amount of gas that would be produced economically from a field using currently available technology and production practices, and assuming current economic (e.g., costs, prices) conditions continue without change
- Estimated ultimate recovery per well (EUR)
  - Estimate of total gas that will be produced by any given well
  - Based on historical production data and decline curve fit

For more information

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Resource and technology assumption changes from Reference to High Resource case

Shale gas specific (L48)	High Resource case
New plays	Focused on tight oil in plays not considered in the Reference case
Well spacing	100% more wells/area (50% reduction in acre spacing)
Interference effects (diminishing returns)	IP rate increased 20%, but decline curve shifted to lower estimated ultimate recovery (EUR) to 80% of Reference once drill # of Ref case wells in county
Technology: production	Well EURs 50% larger 1% increase/year with no end date

Other resources	High Resource case
Offshore	50% increase in undiscovered resources
Alaska: undiscovered resources	50% increase in undiscovered resources

Ongoing work to improve projections

- Leverage the Bayesian inference approach already used by AEO modelers (EIA currently operates at higher levels of resolution than many other organizations active on this issue)

- Incorporate geologic dependencies to inform model assumptions of future well performance
  - presented to American Statistical Association in November 2013
  - prototype is under construction

- Conduct geo-statistical analysis to improve empirical measures of optimal well spacing and the profile of diminishing returns from infill drilling

- End result: separate impact of incremental technological change from geologic information when describing potential changes in resource size estimates

Play-level EURs are based on historical well performance

- Individual well performance analyzed (2008-2013)

- Historical production fit to hyperbolic decline curve

$$Q_t = \frac{Q_i}{(1 + b \times D_i \times t)^{1/b}}$$

where, $0 < b < 2$ and $0 < D_i < 1$

  – **Step 1**: Solve for Qi, b, and Di with 0.001 < b < 2 and 0 < Di < 1
  – **Step 2**: If not converged, set b = median b determined in previous step then solve for Qi and Di with 0 < Di < 1
    - median b by drill_type, vintage_year, field, and county
    - use lowest available disaggregated median
  – **Step 3**: If still not converged, set b = median b by drill_type and vintage_year from Step 1

- Extend production through 360 months -- convert to exponential decline when annual decline rate reaches 10%

Top ten countries with technically recoverable shale resources

Shale gas

Rank	Country	Trillion cubic feet
1	China	1,115
2	Argentina	802
3	Algeria	707
4	United States*	596
5	Canada	573
6	Mexico	545
7	Australia	429
8	South Africa	390
9	Russia	287
10	Brazil	245
	Total for 46 countries	**7,550**

Shale oil

Rank	Country	Billion barrels
1	Russia	75.8
2	United States*	78.2
3	China	32.2
4	Argentina	27.0
5	Libya	26.1
6	UAE	22.6
7	Chad	16.2
8	Australia	15.6
9	Venezuela	13.4
10	Mexico	13.1
	Total for 46 countries	**418.8**

- Excluding U.S. proved shale reserves (10 billion barrels of tight oil and 159 trillion cubic feet of natural gas)
- Source: EIA, USGS and ARI 2015 Preliminary Results

Composition of natural gas plant liquids

State	ETHANE	PROPANE	BUTANE	ISOBUTANE	PENTANES PLUS
AK ALASKA	0%	1%	28%	11%	59%
AL ALABAMA	41%	27%	11%	7%	15%
AR ARKANSAS	7%	27%	19%	12%	35%
CA CALIFORNIA	0%	44%	0%	29%	26%
CO COLORADO	39%	29%	11%	6%	15%
IL ILLINOIS	40%	40%	3%	12%	5%
KS KANSAS	31%	38%	8%	11%	12%
KY KENTUCKY	3%	63%	18%	5%	12%
LA LOUISIANA	41%	29%	10%	8%	13%
MI MICHIGAN	37%	30%	10%	12%	11%
MS MISSISSIPPI	33%	33%	14%	7%	13%
MT MONTANA	0%	49%	25%	8%	19%
ND NORTH DAKOTA	2%	52%	24%	5%	17%
NM NEW MEXICO	45%	29%	9%	5%	11%
OH OHIO	1%	51%	18%	13%	17%
OK OKLAHOMA	36%	34%	12%	6%	13%
PA PENNSYLVANIA*	43%	32%	10%	5%	10%
TN TENNESSEE	39%	36%	11%	4%	9%
TX TEXAS	43%	29%	5%	12%	12%
UT UTAH	21%	35%	13%	9%	23%
WV WEST VIRGINIA	2%	57%	18%	8%	15%
WY WYOMING	33%	33%	16%	3%	15%

**Ethane was adjusted from the published volumes to account for the ethane rejected.*

Source: EIA analysis of various sources for input into Annual Energy Outlook 2015 modeling