Natural Gas Supply

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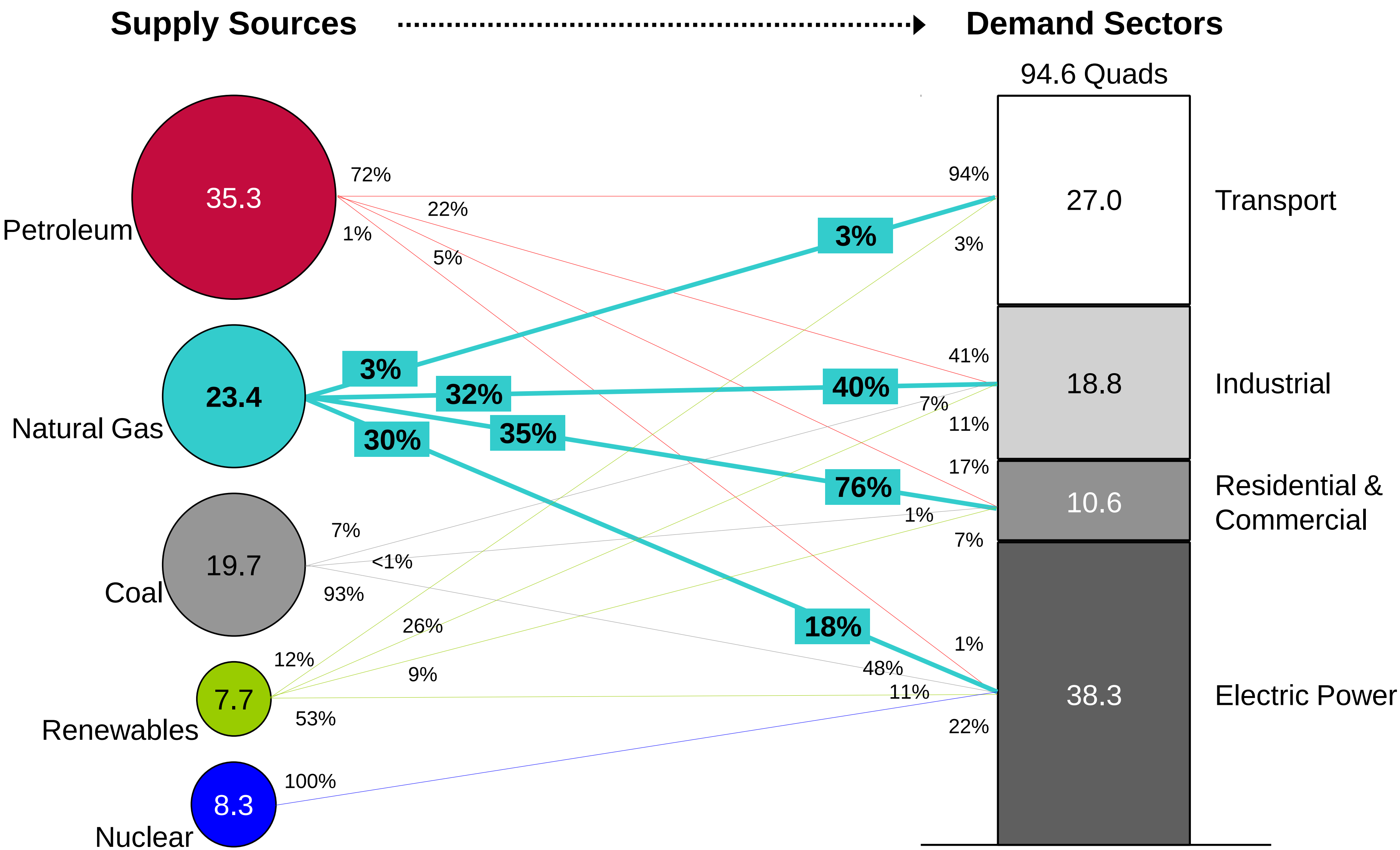
A review of 2009 U.S. primary energy consumption by source and sector reveals the broad systemic importance of natural gas

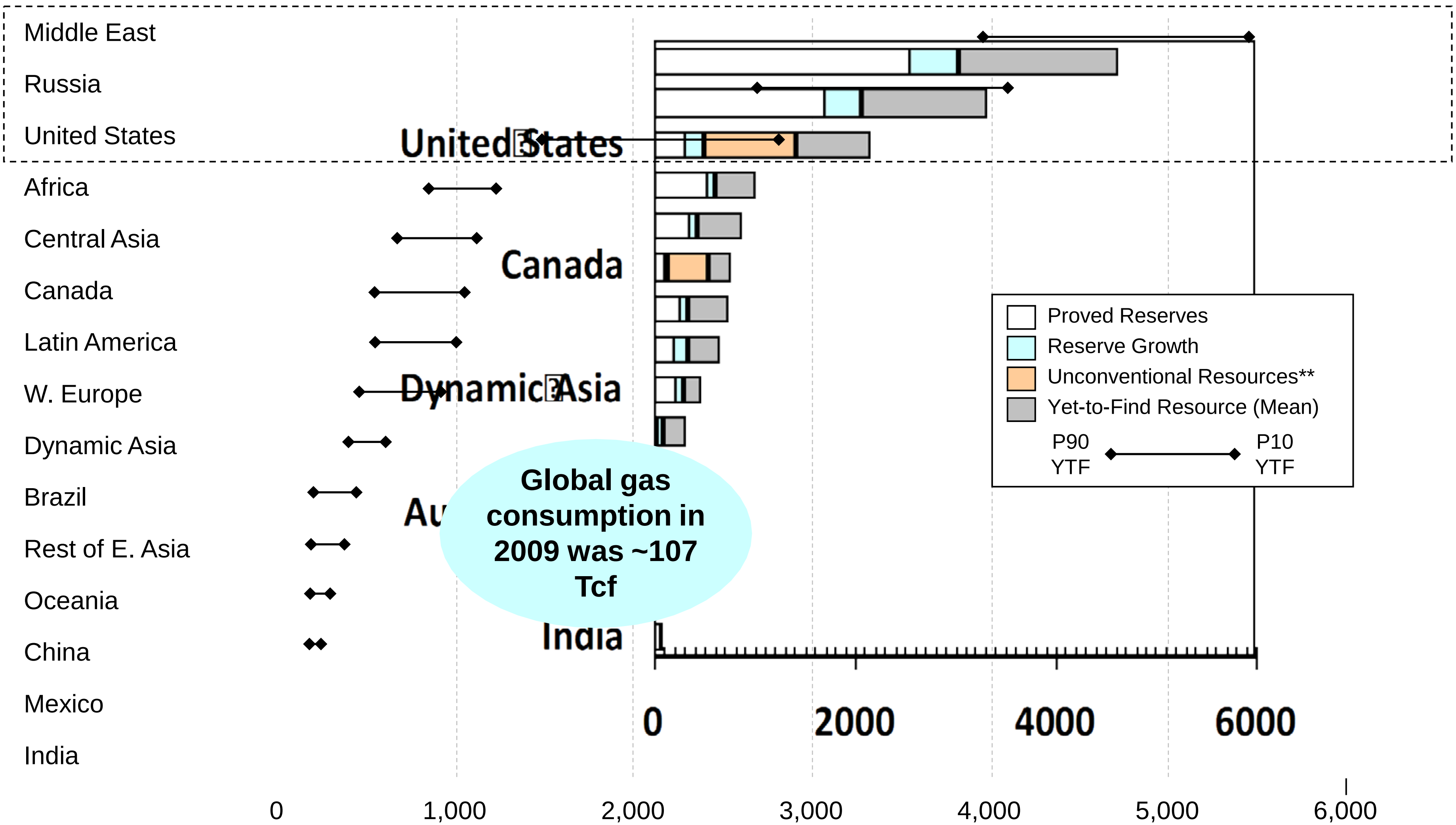


Source: EIA

The global natural gas resource

There is a lot of gas in the world, ~16,000 Tcf – but these resources are highly concentrated

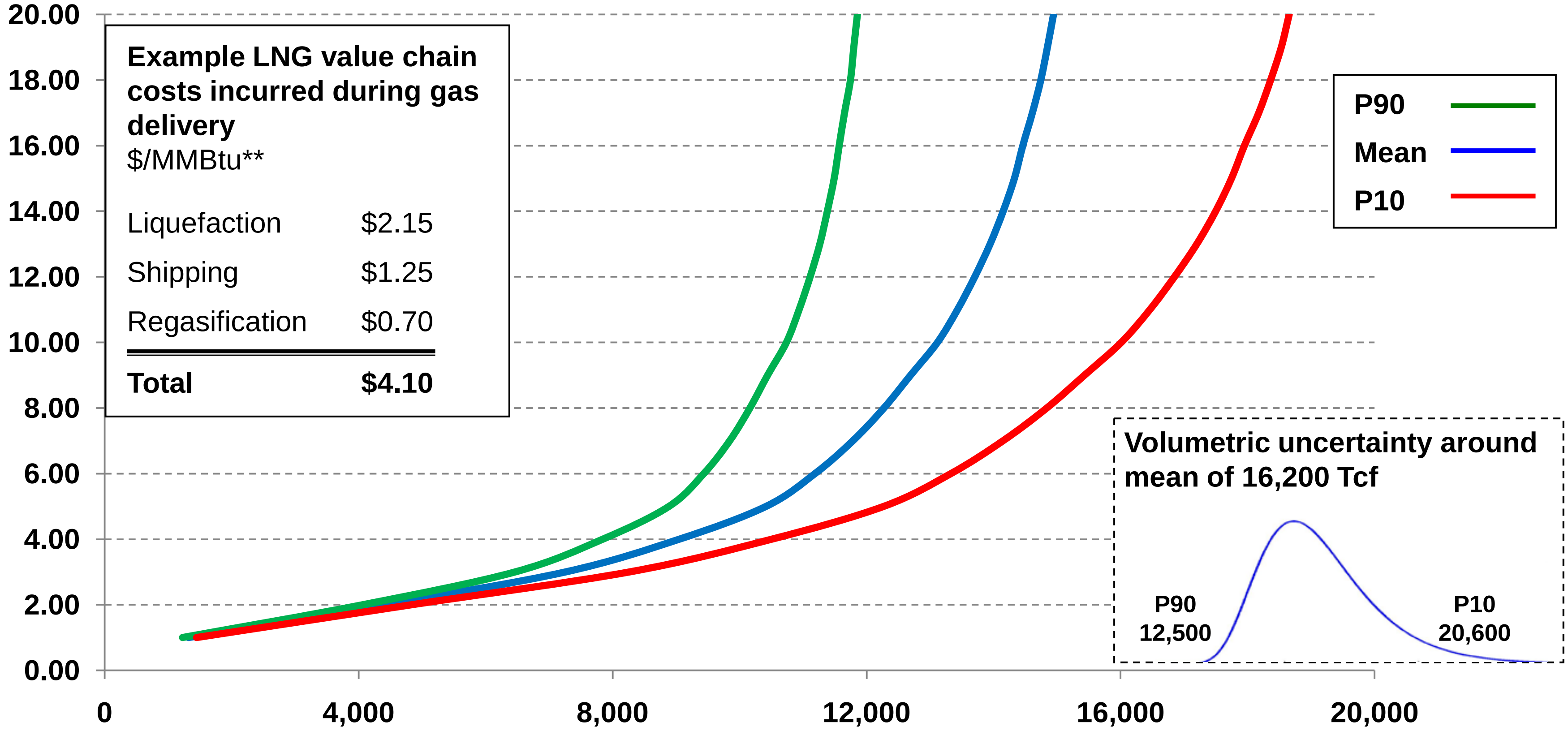
Breakdown of the total global remaining recoverable gas resources by EPPA region
Tcf of Gas



Source: MIT Gas Supply Team analysis

Much of this resource can be developed at low cost – but long distance transportation costs will significantly increase its delivered cost

Global breakeven gas price
$/MMBtu*



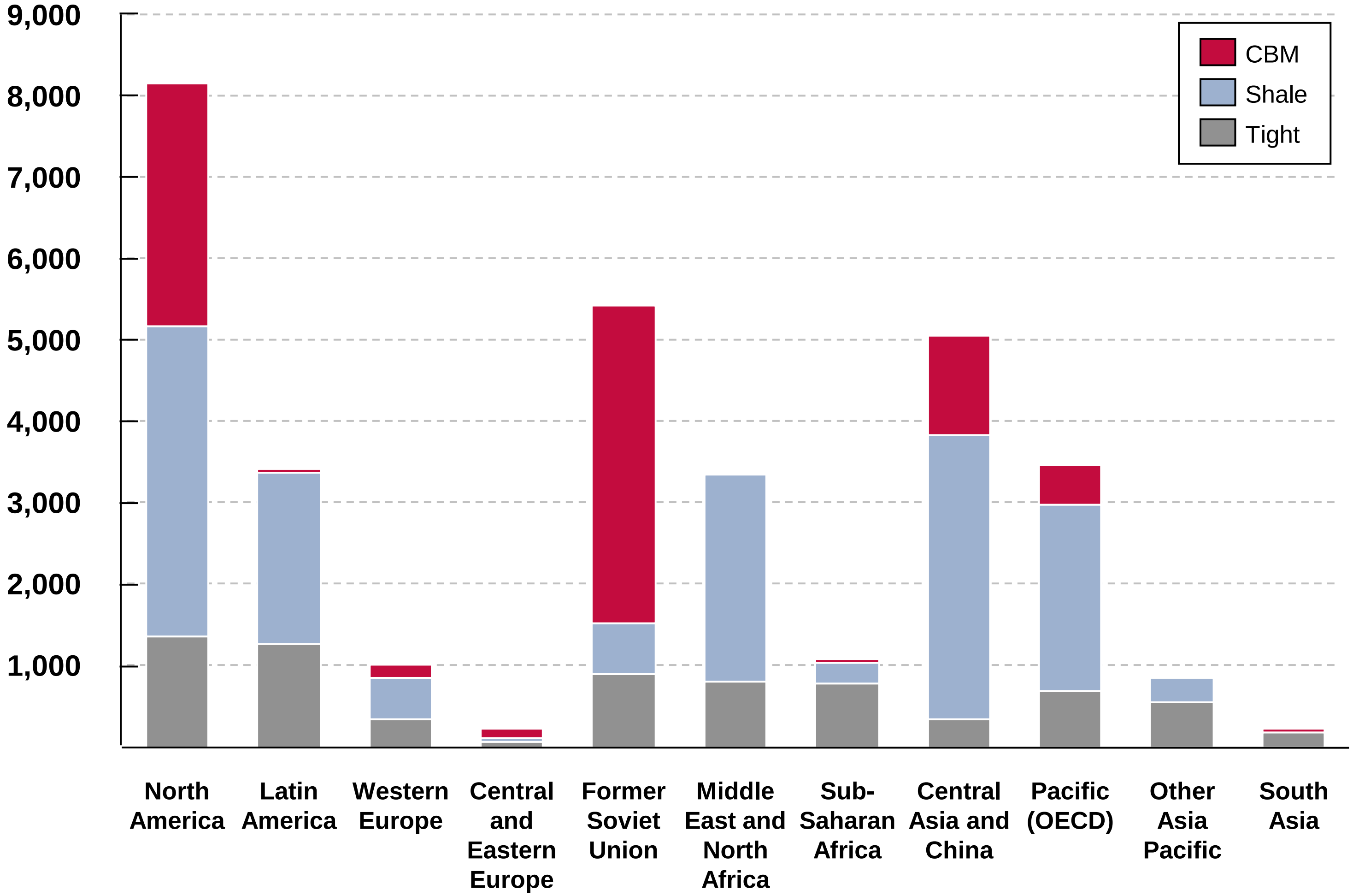
* Cost curves based on 2007 cost bases. North America cost represent wellhead breakeven costs. All curves for regions outside North America represent breakeven costs at export point. Cost curves calculated using 10% real discount rate

** Assumes two 4MMT LNG trains with ~6,000 mile one-way delivery run

Source: MIT Gas Supply Team analysis, ICF Hydrocarbon Supply Model, Jensen and Associates

Early analysis suggested that there may be very extensive global unconventional resources

Breakdown of global unconventional GIIP by region and type
Tcf of gas

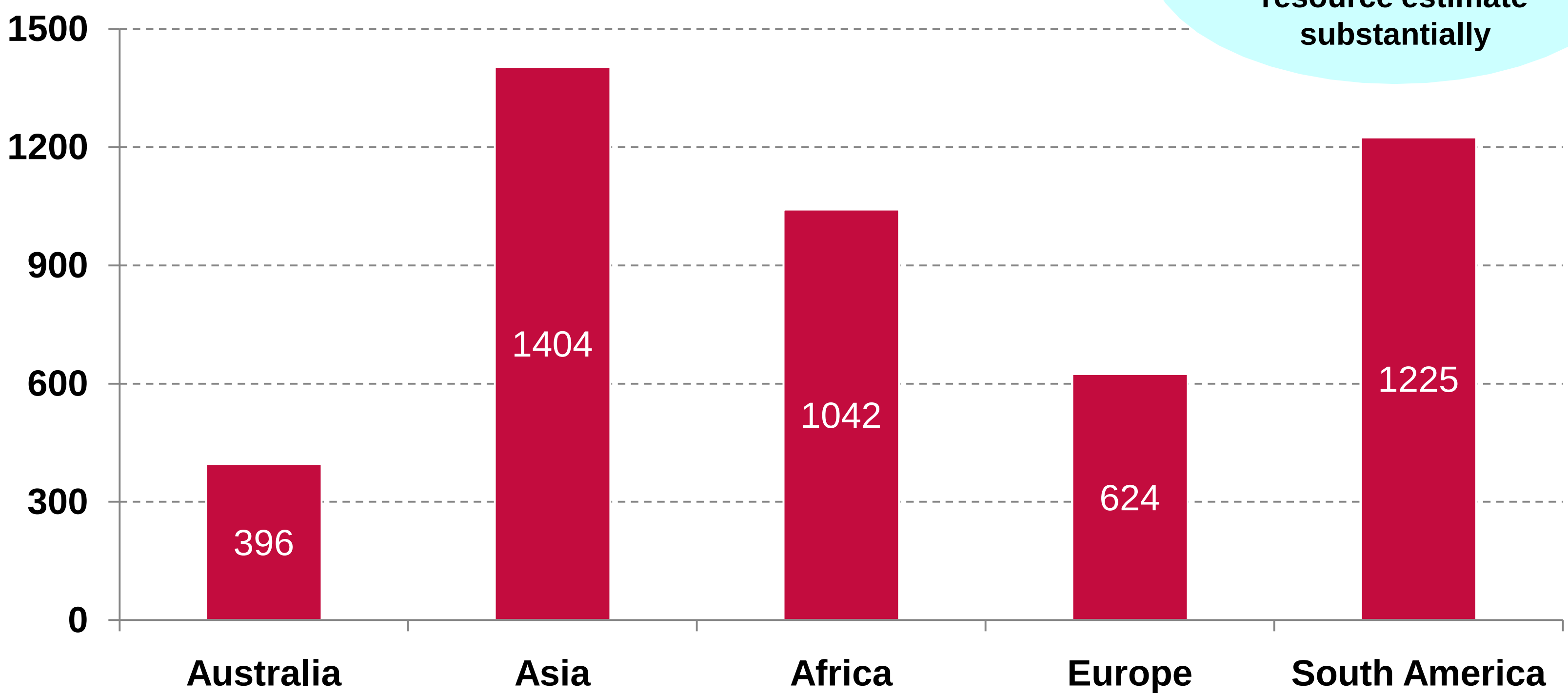


Source:"An assessment of world hydrocarbon resources", H-H Rogner, *Annu. Rev. Energy Environ.*, 1997

A recent global assessment of shale gas suggests at least 6,000 Tcf of recoverable resources, with over 1,200 Tcf located in China

Study only assessed 31 countries – Future work expected to increase the resource estimate substantially

Breakdown of global recoverable shale gas resources by region
Tcf of gas



Top two shale gas resource holders by region	Asia	Africa	Europe	South America
	China 1,275 Tcf	South Africa 485 Tcf	Poland 187 Tcf	Argentina 774 Tcf
	India 63 Tcf	Libya 290 Tcf	France 180 Tcf	Brazil 226 Tcf

Source: World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States, ARI 2011

Gas dynamics in the United States

The past 5 years have seen a dramatic increase in both proved reserves and more importantly in the technically recoverable resource – All due to shale

Illustration of US gas production, reserve and resource dynamics from '90 to '10
Tcf of gas

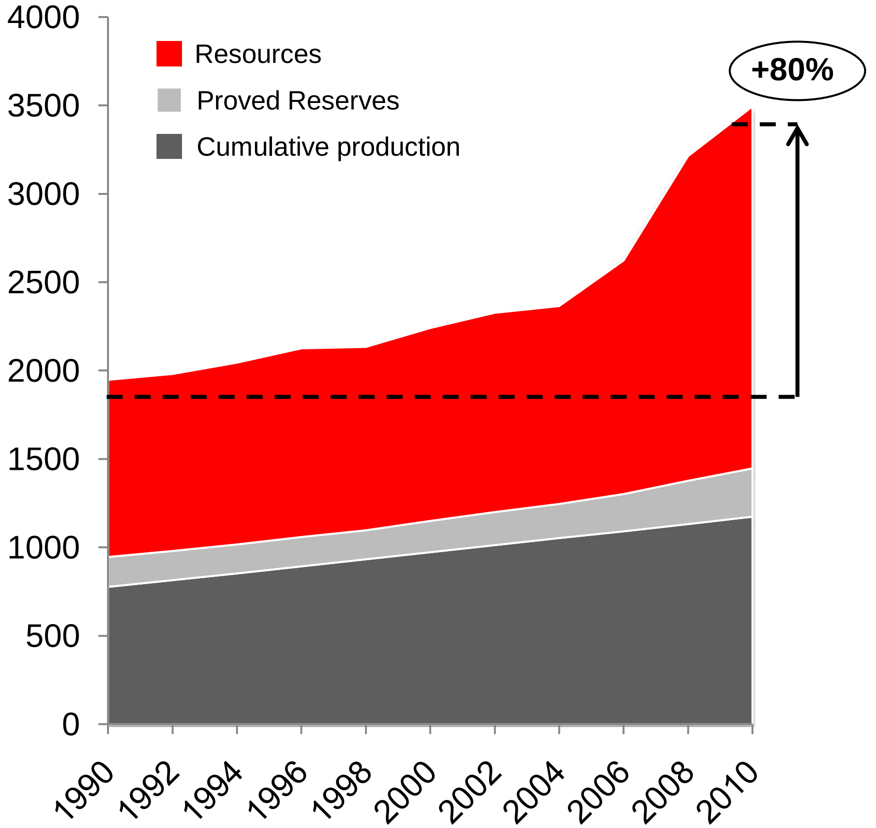
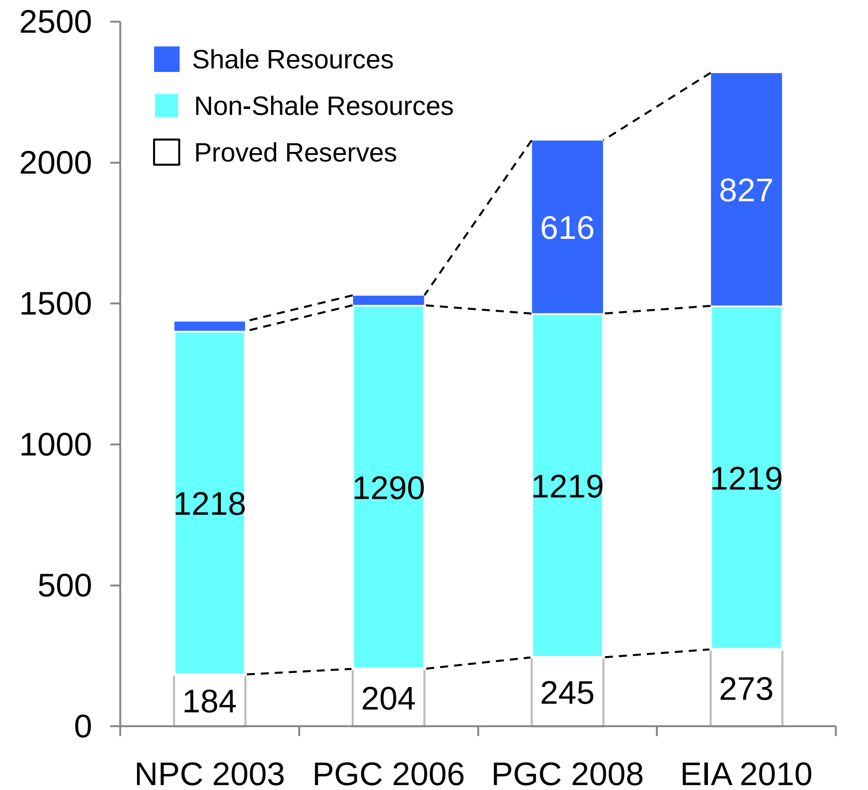


Illustration of the change in recoverable resource assessment by gas type over the past decade[1]
Tcf of gas

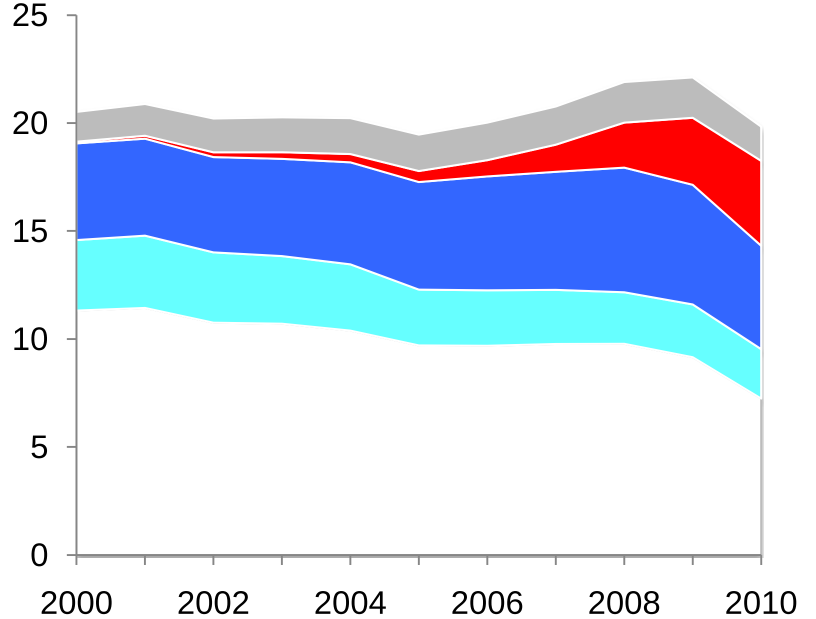


1. EIA 2010 assessment based on 2008 PGC assessment with updated estimates of technically recoverable shale gas volumes

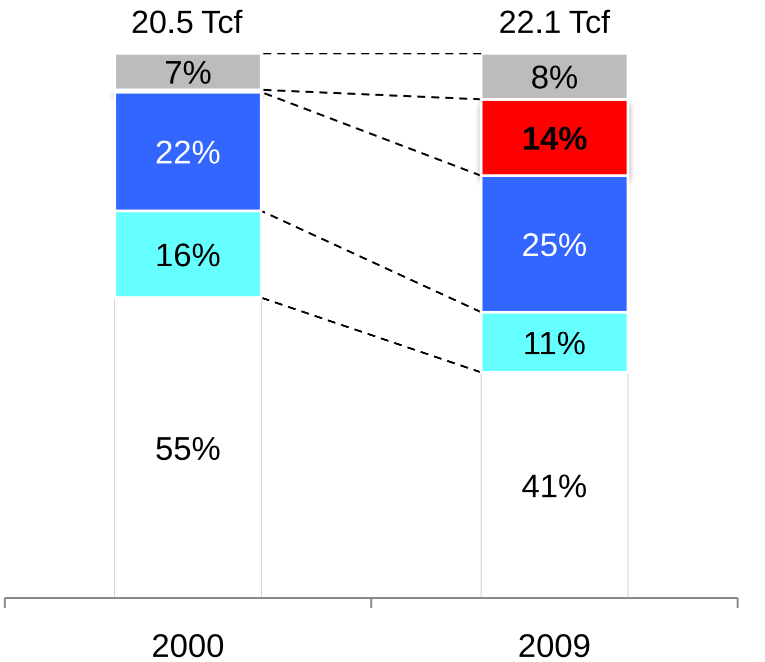
Source: NPC data, PGC data, EIA data

The emergence of shale gas as a recoverable resource is illustrated in the production dynamics – Shale gas is driving U.S. production growth

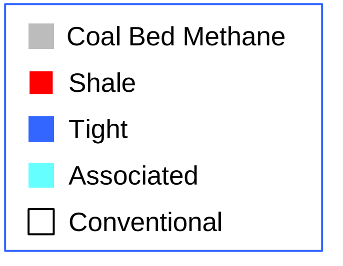
Breakdown of US gas production by type[1]
Tcf of gas



Comparison of production by type – ’00 vs. ‘09[1]
Percent of total production



- In 2000, **14.6 Tcf of conventional gas** was produced, representing **71%** of total US marketable production
- By 2009, **conventional production fell to 11.6 Tcf,** or just over **50%** of **total production**
- In the **same period shale gas** output **grew** from almost nothing **to over 3.5 Tcf**, and is now the **only production segment** that is **growing**



1. United States production figures represent marketable production, and so exclude gas produced in Alaska, which is subsequently reinjected

Source: HPDI commercial production database

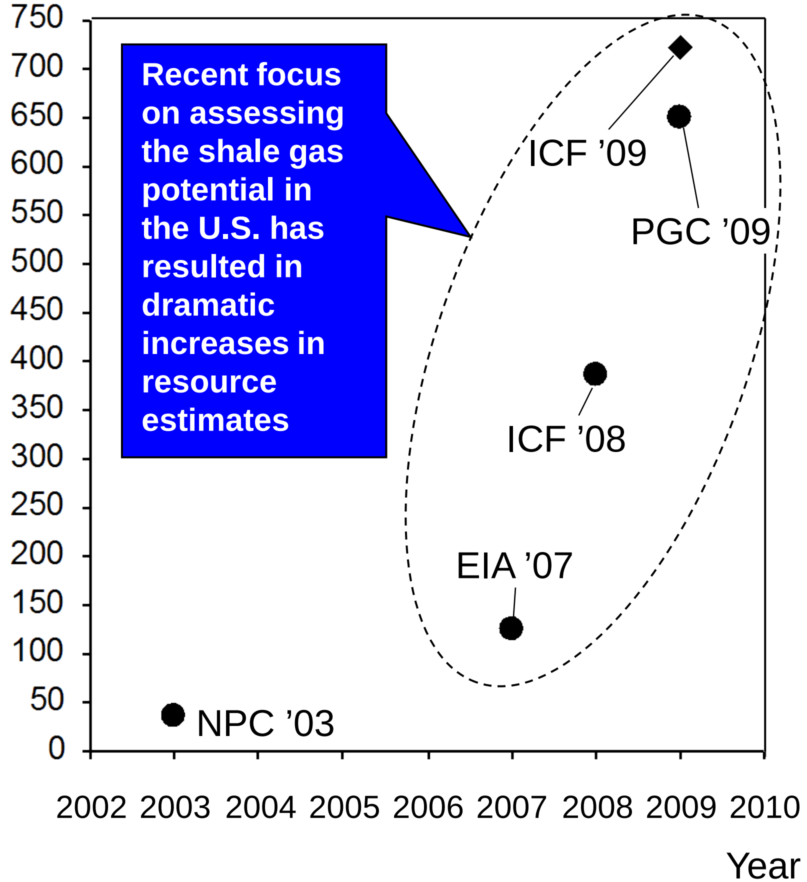
United States shale rock deposits include some very large deposits near major gas consuming centers in the Northeast

Map of United States shale deposits

Source: EIA

The focus on shale gas has led to large increases in mean resource estimates; however, these mean estimates are accompanied by wide error bars

Comparison of mean estimates of shale gas resources in the United States
Tcf of Gas



Breakdown of the PGC 2009 shale gas resource estimates by major U.S. shale play*
Tcf of Gas

	Min	Mean	Max
Fort Worth Basin: Barnett Shale	25	59	100
Arkoma Basin: Fayetteville/Woodford	70	110	146
E. TX & LA Basin: Haynesville Shale	60	112	182
Appalachian Basin: Marcellus/Ohio/Utica Shale	92	227	549
Anadarko/Permian Basins: Barnett/Woodford Shales	3	6	16
Other Basins:	51	100	224
Total Mean Estimate:	301**	**616**	1217**

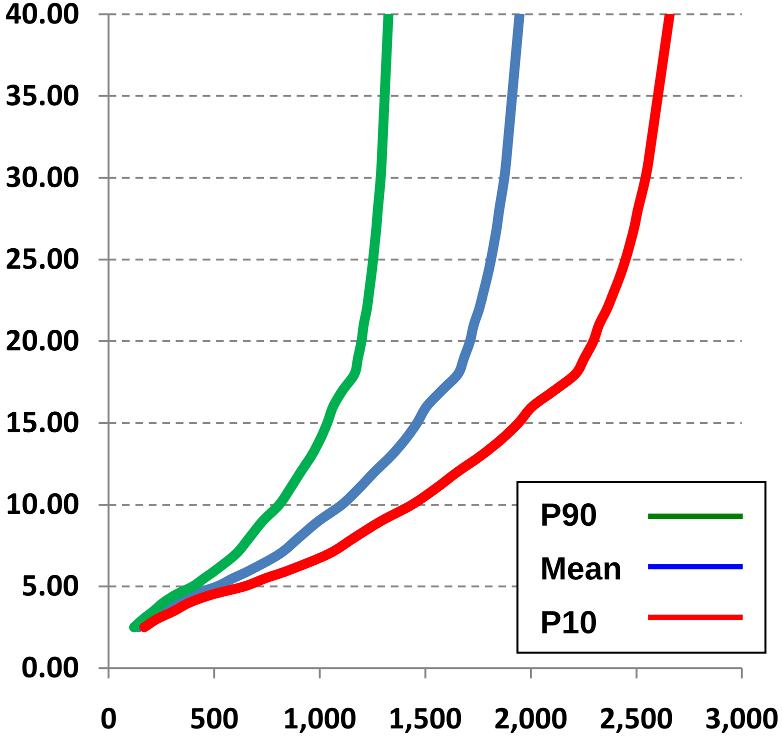
* Mean volumes represent the "most likely" estimates reported by the PGC and can be aggregated by arithmetic addition to yield an aggregated mean estimate of shale gas resources in the United States. The per basin min and max numbers reported here assume perfect statistical correlation within basins

** US min and max totals are for illustrative purposes only, and are calculated by direct addition of volumes, not statistical aggregation

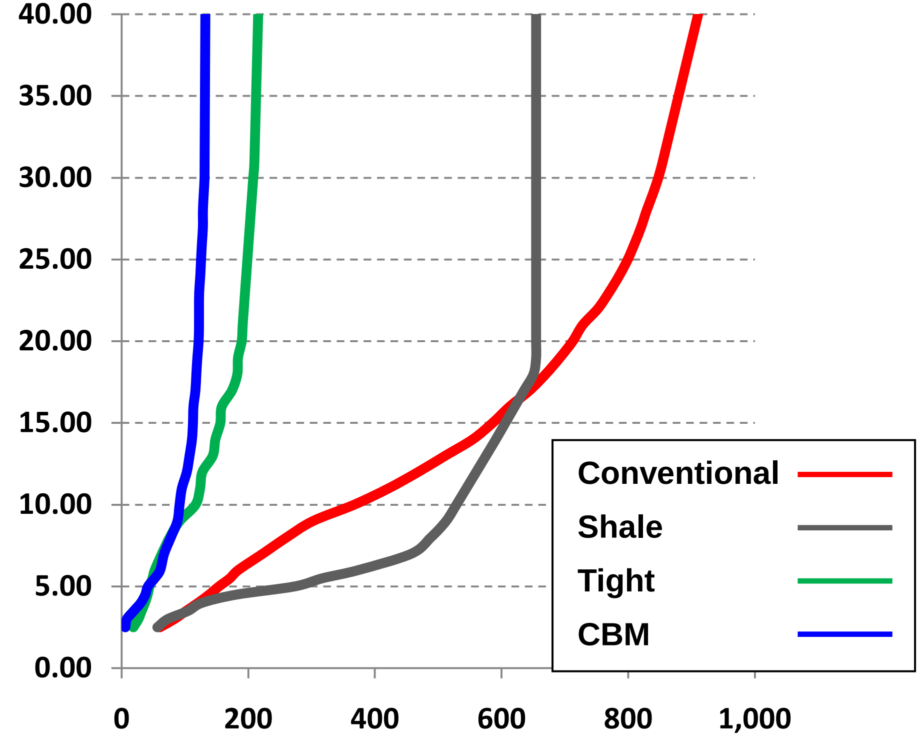
Source: Various commercial and institutional resource assessments

The US gas supply curves reveal large volumes of relatively cheap gas – Remarkably, shale gas is the most important source of low cost resource

United States breakeven gas price
$/MMBtu*



Breakdown of United States breakeven gas price by resource type
$/MMBtu*

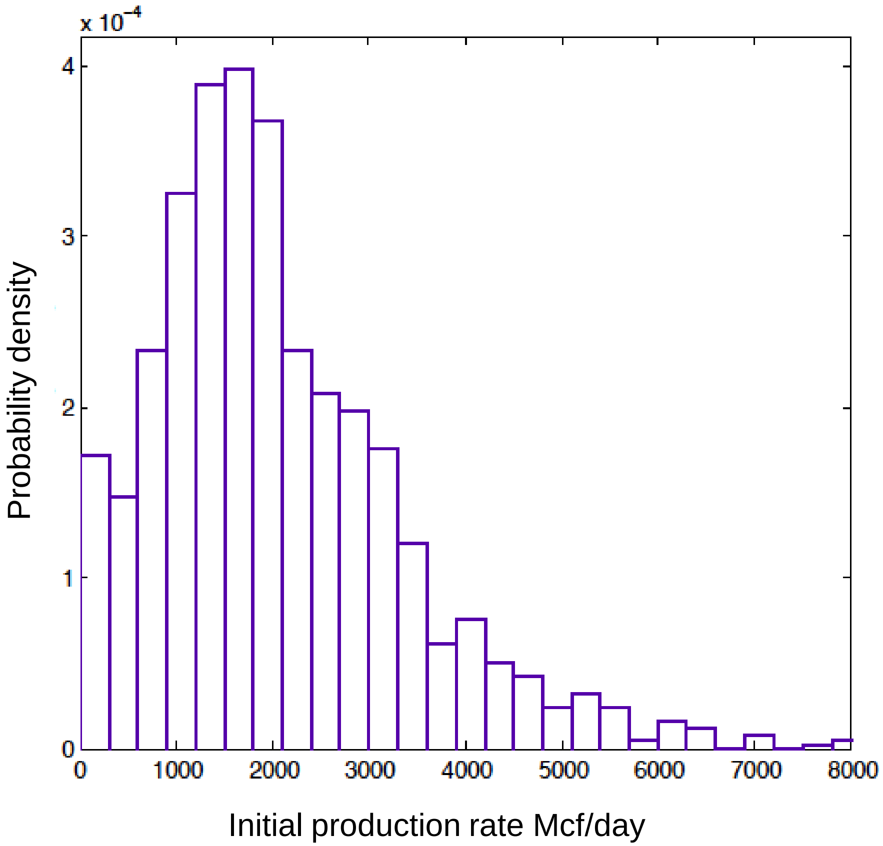


* Cost curves calculated using 2007 cost bases. U.S. costs represent wellhead breakeven costs. Cost curves calculated assuming 10% real discount rate

Source: MIT Gas Supply Team analysis, ICF Hydrocarbon Supply Model, Data strictly for illustrative purposes only

IP rate variability is a major issue with shales – In the Barnett, IP rates vary by 3X between P20 and P80 performance, while other shales display even greater variability

2010 Probability distribution of initial production rates for Barnett wells
Mcf per day (30 day average)



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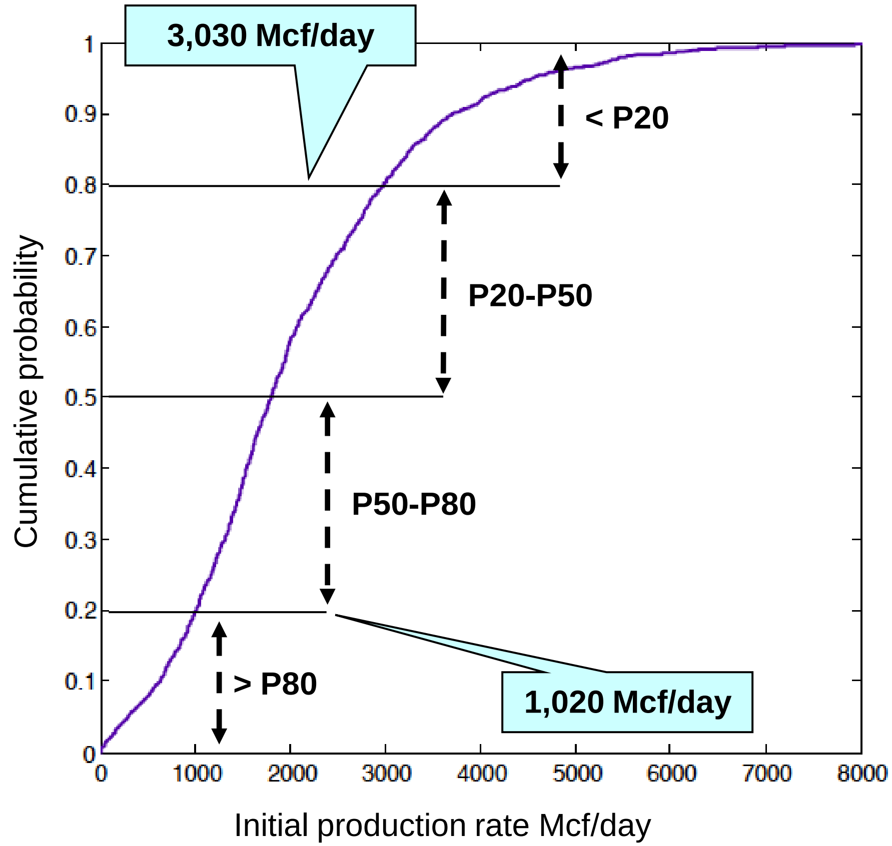
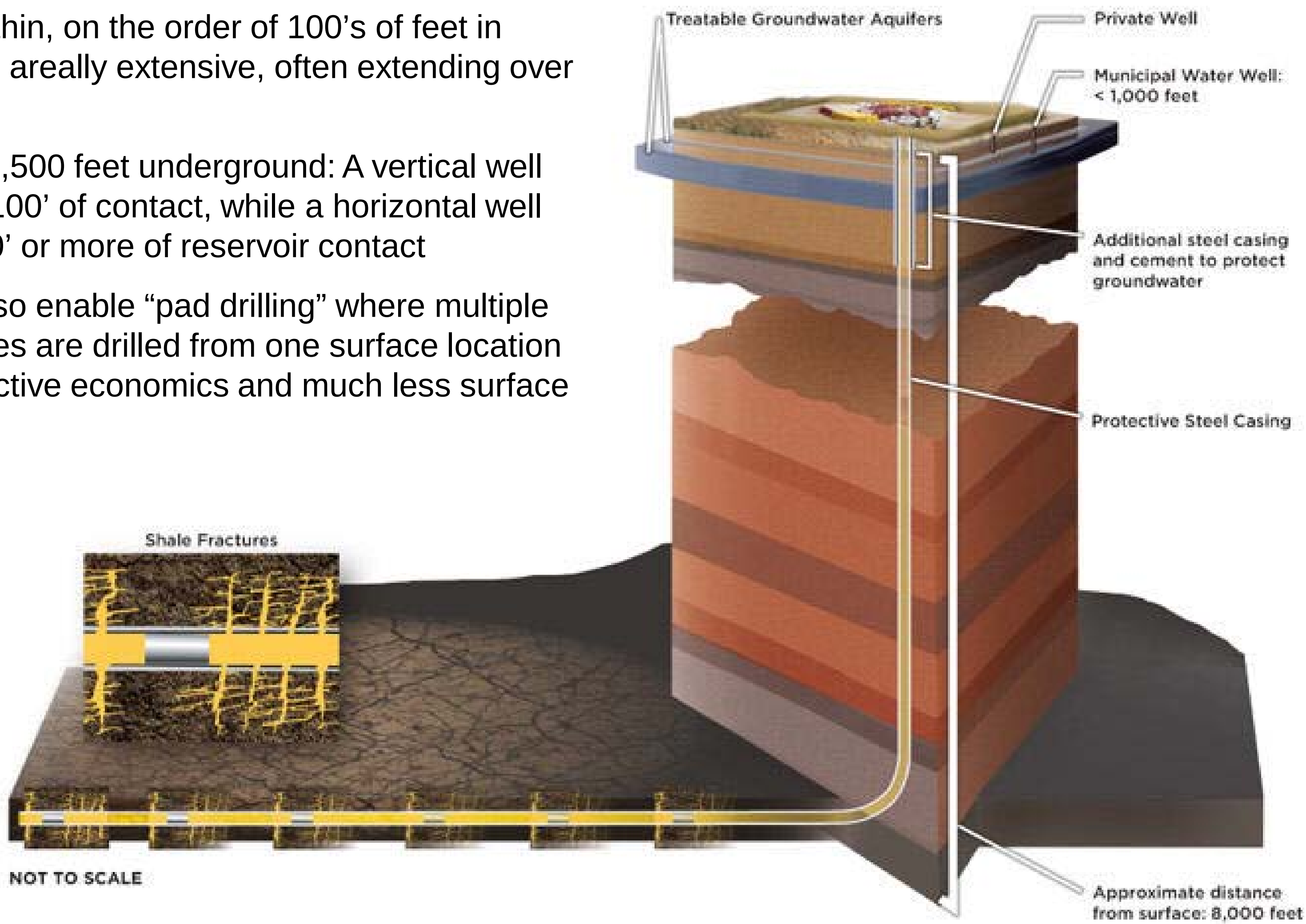


Source: MIT Gas Supply Team analysis, HPDI commercial production database

Shale gas – technological and environmental considerations

Shale is extremely “tight”, and so to produce gas from it economically, it is necessary to create as much “reservoir contact” as possible – horizontal wells help to achieve this

- Shales tend to be thin, on the order of 100’s of feet in depth, but they are areally extensive, often extending over 1000’s of acres
- Consider a shale 7,500 feet underground: A vertical well will only provide ~100’ of contact, while a horizontal well could provide 5000’ or more of reservoir contact
- Horizontal wells also enable “pad drilling” where multiple horizontal well bores are drilled from one surface location – Much more attractive economics and much less surface disturbance



Source: MIT Gas Supply Team

Hydraulic fracturing has evolved rapidly in recent years – A move to Open Hole Multi Stage fracking has enabled more frac stages in less time

Typical frac site – Pumpers, water, sand and additive tankers along with control vehicles

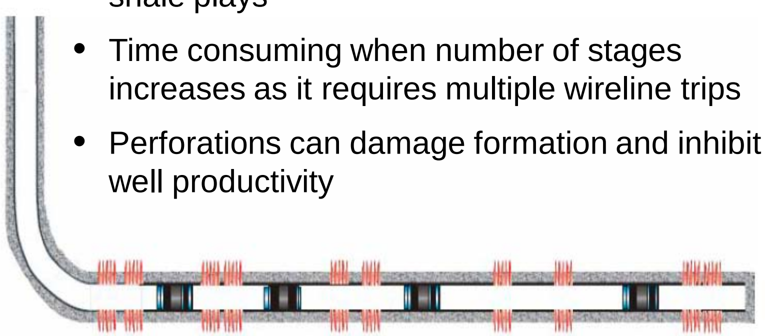
Wellhead rigged for fracing – This is the "goat head"

Elements required to carry out hydraulic fracturing

- Horse power – 8-10 2,500 HP pumpers required for typical frac job
- Pumpers must be pressure rated to 15,000 psi
- Each pumper is typically rated to 15 bblPM at operating pressures
- 5 M gallons of water required for a typical 10 stage frac job
- 2000 MT of sand required for a typical 10 stage frac job

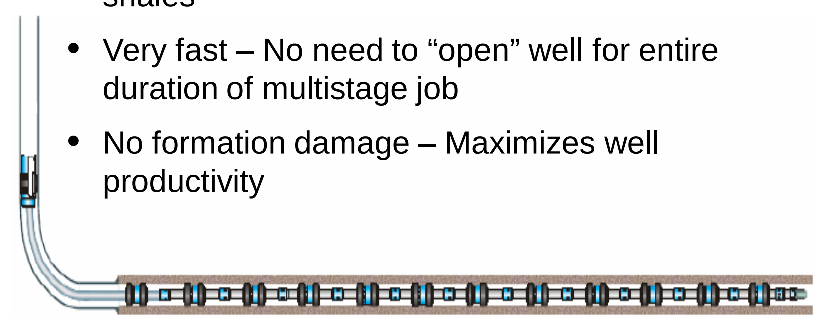
Cemented liner, plug and perforate multistage fracturing – The original approach

- Original approach to multistage fracturing in shale plays
- Time consuming when number of stages increases as it requires multiple wireline trips
- Perforations can damage formation and inhibit well productivity



Open hole multistage hydraulic fracturing – The state-of-the-art

- State-of-the-art fracturing techniques for gas shales
- Very fast – No need to "open" well for entire duration of multistage job
- No formation damage – Maximizes well productivity



Source: MIT Gas Supply Team

The rapid expansion of drilling and fracking activities in shale plays has led to some significant environmental concerns

Some key environmental concerns include:

Water:

- **Freshwater aquifers** could become **contaminated by** fluids used for **fracking**
- **Surface water** sources could become **contaminated by** fluids used for **fracking**
- Post use treatment and **disposal of fracking fluids** could be **hindered** by a **lack of appropriate facilities**
- Sourcing adequate volumes of water for **fracking operations** could **strain** overall **water availability** at a local level

Surface:

- Drilling activities may lead to **well blowouts** which could **endanger** both **life and property**
- Intensive **shale drilling will result in** significant **surface disturbance and habitat interference**
- **Drilling and fracking** activities lead to significantly **increased traffic** in **areas lacking** appropriate road **infrastructure**
- **Drilling and fracking** operations will **result in** significant **noise and air pollution**

Source: MIT Gas Supply Team

Shale gas production is facing a wide range of surface issues relating to water sourcing, transport and disposal

Some Challenges:

- Shale well drilling and completion can requires 5 million of more gallons of water
- Large volumes of injected frac water return to the surface – 20-70% flowback depending on situation
- Flowback water can be heavily polluted and needs to be treated
- Recovered water needs to be completely contained on site and properly disposed of to avoid pollution
- Permitted water treatment facilities not capable of handling frac fluid and drilling waste
- Underground injection capacity not adequate in some plays – PA in particular
- High transportation costs to haul frac water to treatment facilities

Illustration of shale well site and fluid containment pond

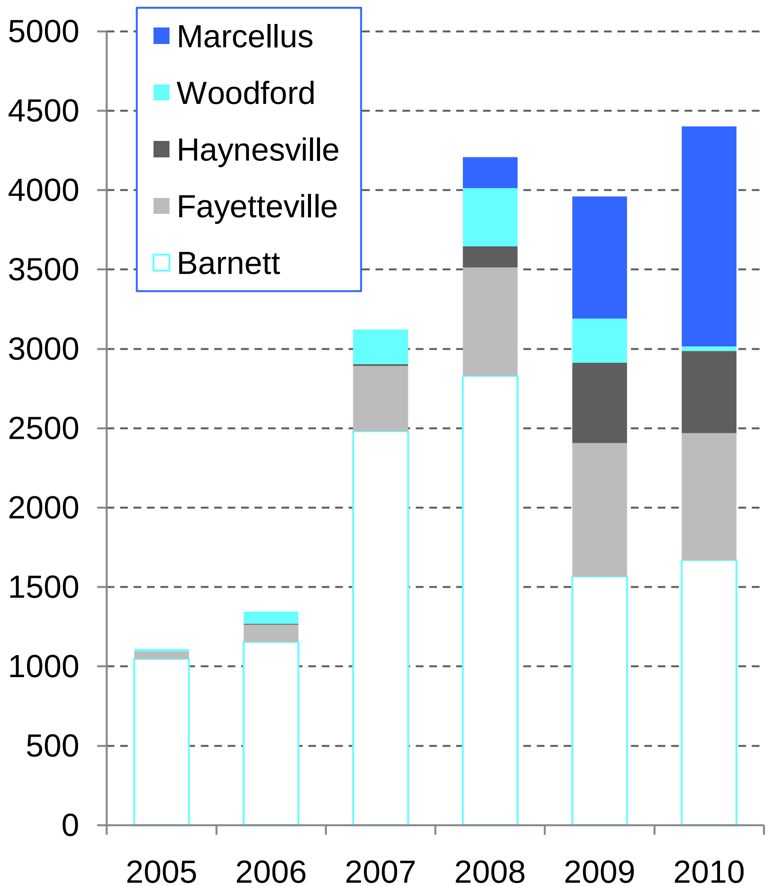
There is a strong economic incentive for operators to find solutions:

- On-site water treatment facilities and closed loop water reuse systems are being developed
- More efficient frac procedures are being deployed to reduce fluid injection volumes
- Operators are making more use of centralized production operations (pad well development) to reduce the need for water hauling

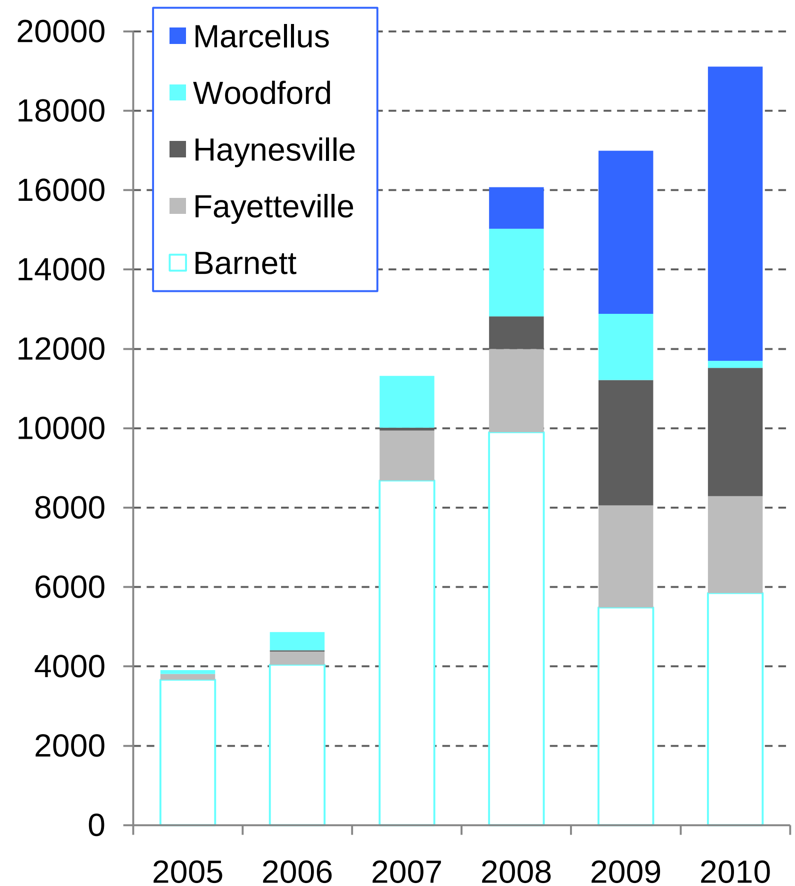
Source: MIT Gas Supply Team

The growth in shale gas production and the size of frac jobs has meant that annual shale gas related water demand is now at 20 billion gallons per year

Annual well additions in each of the major U.S. shale plays from 2005 – 2010
# of wells



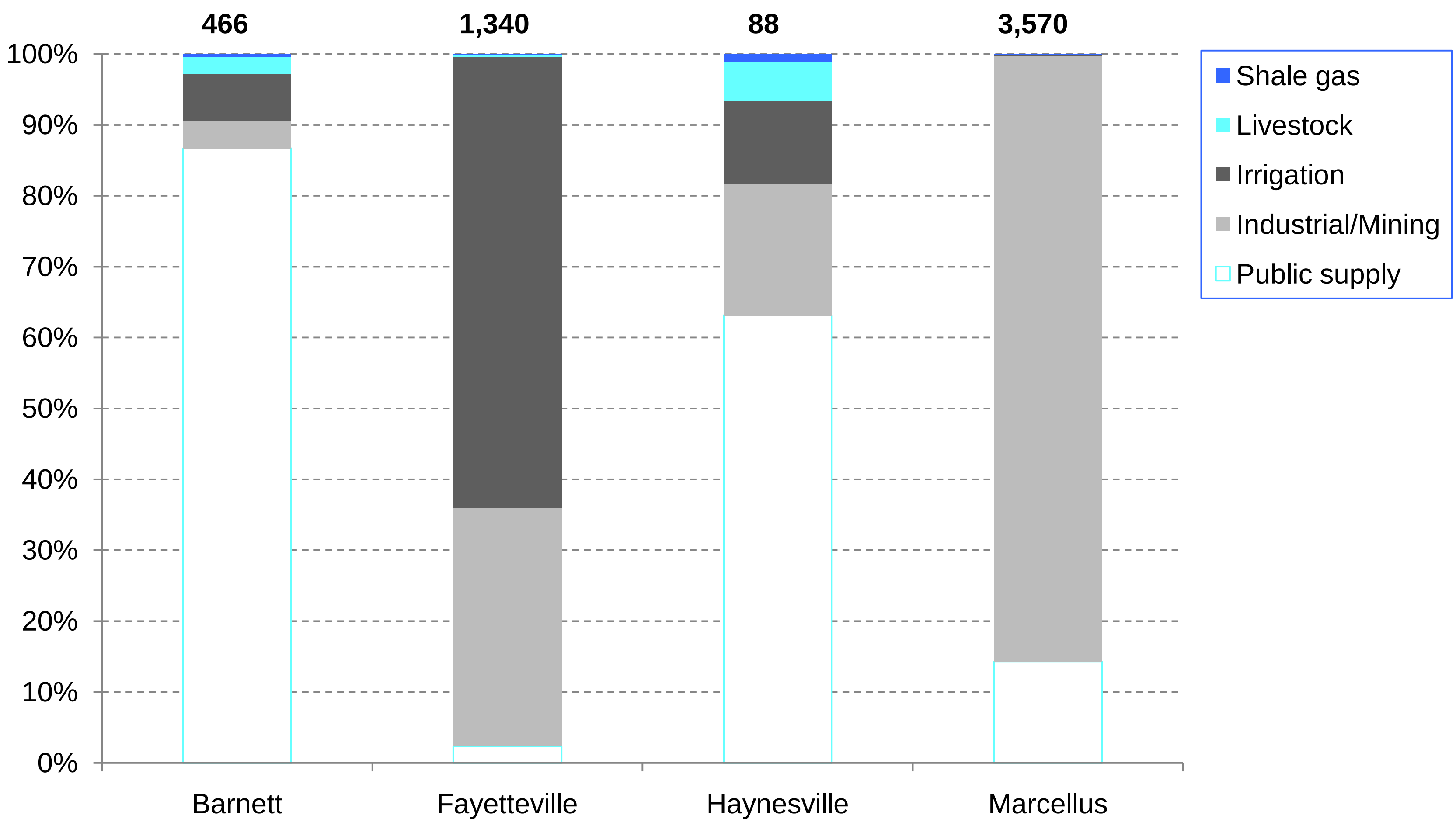
Annual water requirements for drilling and fracking in the major U.S. shale plays from 2005 – 2010
Millions of gallons of water



Source: MIT Gas Supply Team, HPDI commercial production database

However, it appears that water consumption for shale gas activities still represents a small portion of the total water usage in the major shale plays

2008 water use by type in the major shale gas plays*
Percent of total, Billions of gallons per year



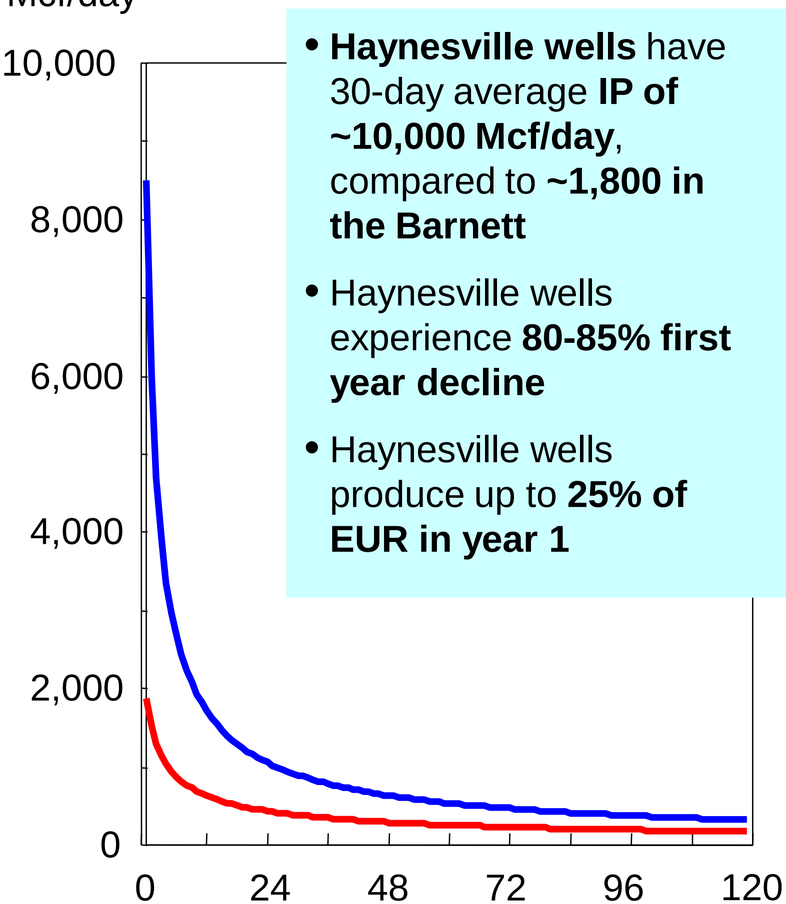
* "Modern Shale Gas: A Primer," United States Department of Energy, April 2009
Source: MIT Gas Supply Team

Comments & Questions?

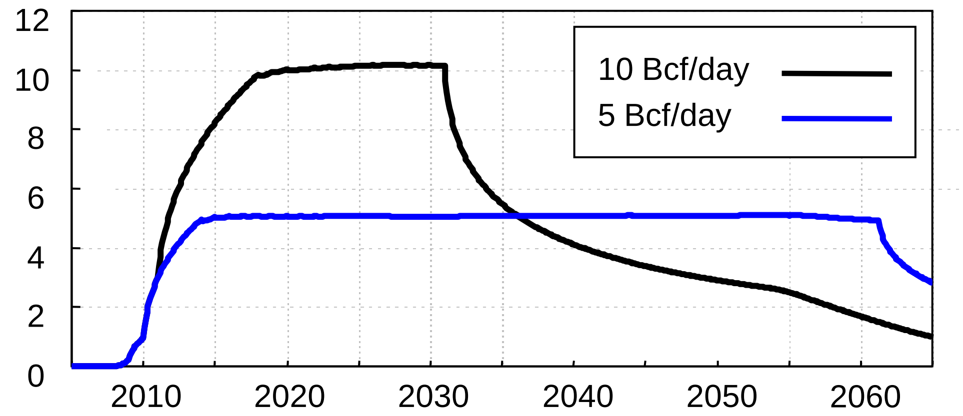
Supplemental materials

Along with intra-play variation, there is huge inter-play variation among the big shale plays – The Haynesville is very different to the Barnett

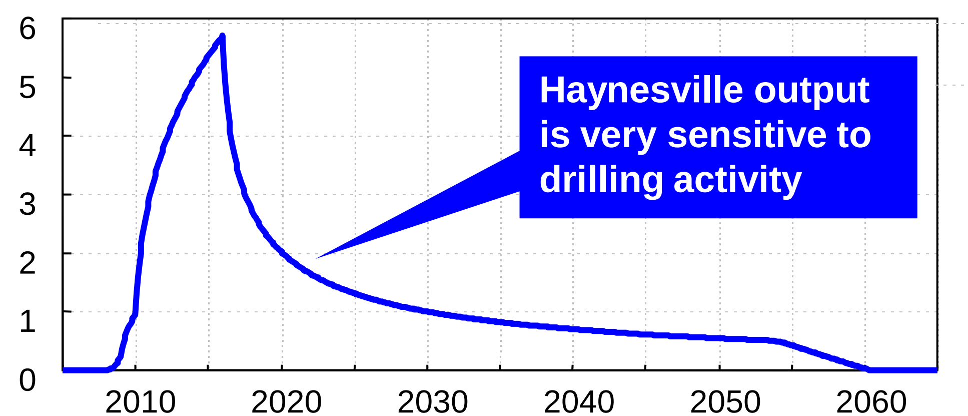
Difference between a typical Haynesville and Branett decline curve over the first 10 years
Mcf/day



Decline onset sensitivity to output in Haynesville assuming EUR of 112 Tcf
Bcf/day



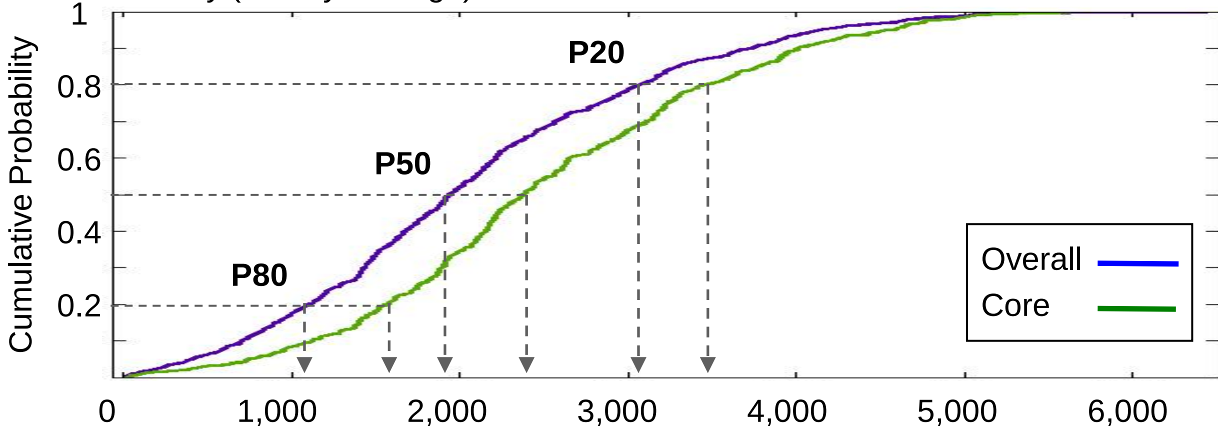
Decline in output upon cessation of drilling in the Haynesville shale
Bcf/day



Source: MIT Gas Supply Team analysis, HPDI commercial production database

The analysis of well performance across shale plays is illustrating the variation in per-well economics that exists between and within the plays

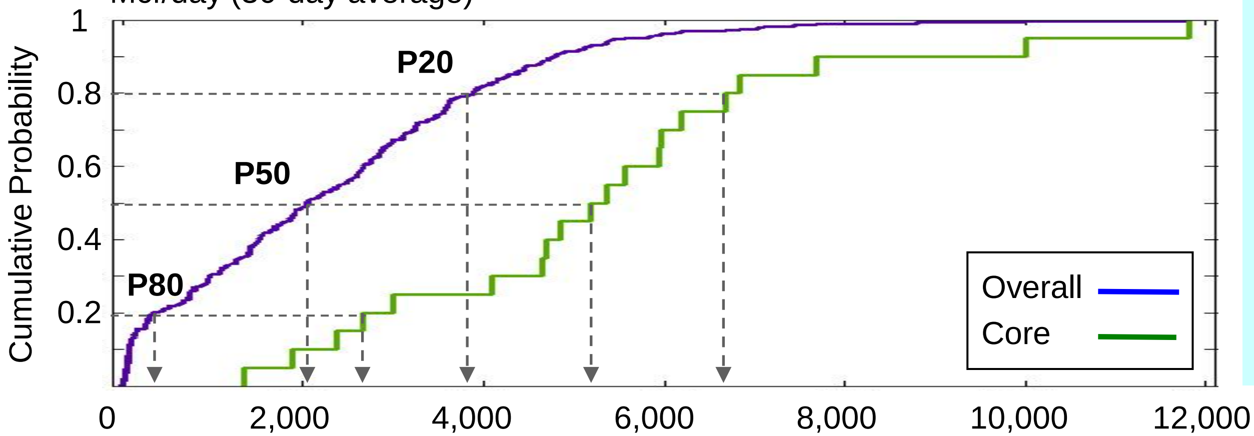
Cumulative probability of peak production rates of Fayetteville wells drilled in 2009
Mcf/day (30-day average)



Variation in breakeven gas price for the '09 Fayetteville shale well population
$/MMBtu

	P20	P50	P80
Overall	$3.74	$5.37	$8.77
Core	$3.41	$4.65	$6.47

Cumulative probability of peak production rates of Woodford wells drilled in 2009
Mcf/day (30-day average)



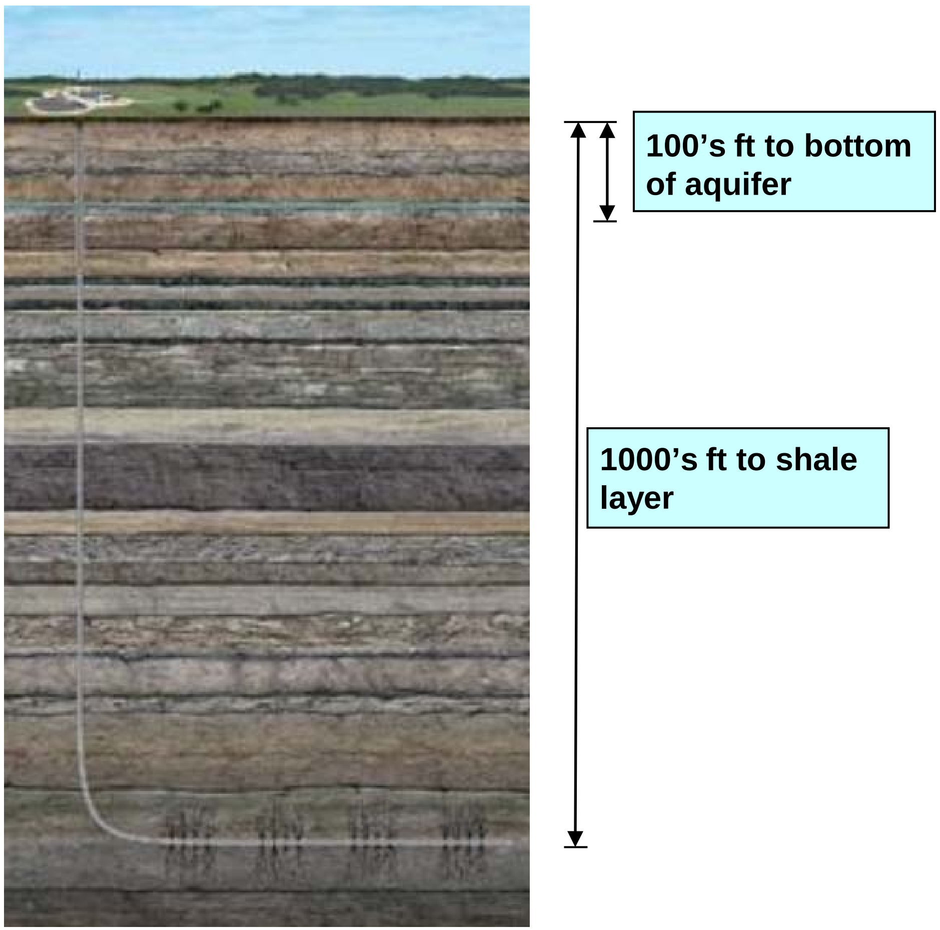
Variation in breakeven gas price for the '09 Woodford shale well population
$/MMBtu

	P20	P50	P80
Overall	$4.71	$8.04	$20.12
Core	$3.18	$3.73	$6.60

Source: MIT Gas Supply analysis HPDI production database

Concern exists about direct contamination of fresh water aquifers due to fluid migration from a frac zone – analysis would suggest this is unlikely once wells were correctly completed

Illustration of the scale of separation between freshwater aquifers and shale deposits



Depths to freshwater aquifers and producing layers in major shale plays*

Basin	Depth to shale (ft)	Depth to aquifer (ft)
Barnett	6,500 – 8,500	1,200
Fayetteville	1450 – 6,700	500
Marcellus	4,000 – 8,500	850
Woodford	6,000 – 11,000	400
Haynesville	10,500 – 13,500	400

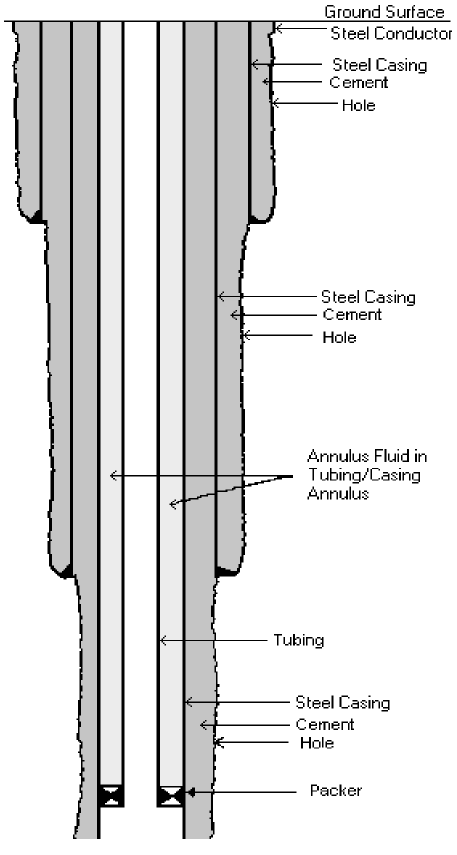
Shale gas resources are separated from freshwater aquifers by 1,000s of feet of alternating layers of siltstones, shales, sandstones

* “Modern Shale Gas: A Primer,” United States Department of Energy, April 2009

Source: MIT Gas Supply Team

There is a strong operational incentive to eliminate any fluid leakage since containment of the fluids in the shale is critical to the success of the "frac job"

Illustration of multiple well casing used to isolate produced fluids from the aquifer in a gas well



Extensive regulation exists at State level regarding the protection of groundwater during oil and gas operations

- Current well design requirements demand extensive hydraulic isolation
- At depths coincident with the aquifer, groundwater will be separated from produced gas and fluids by at lease three layers of steel and three layers of cement
- The integrity of the isolation measures is tested

Probabilistic analysis for injection wells suggests the likelihood of a well leaking given properly installed casing is less than 1 in 1 million*

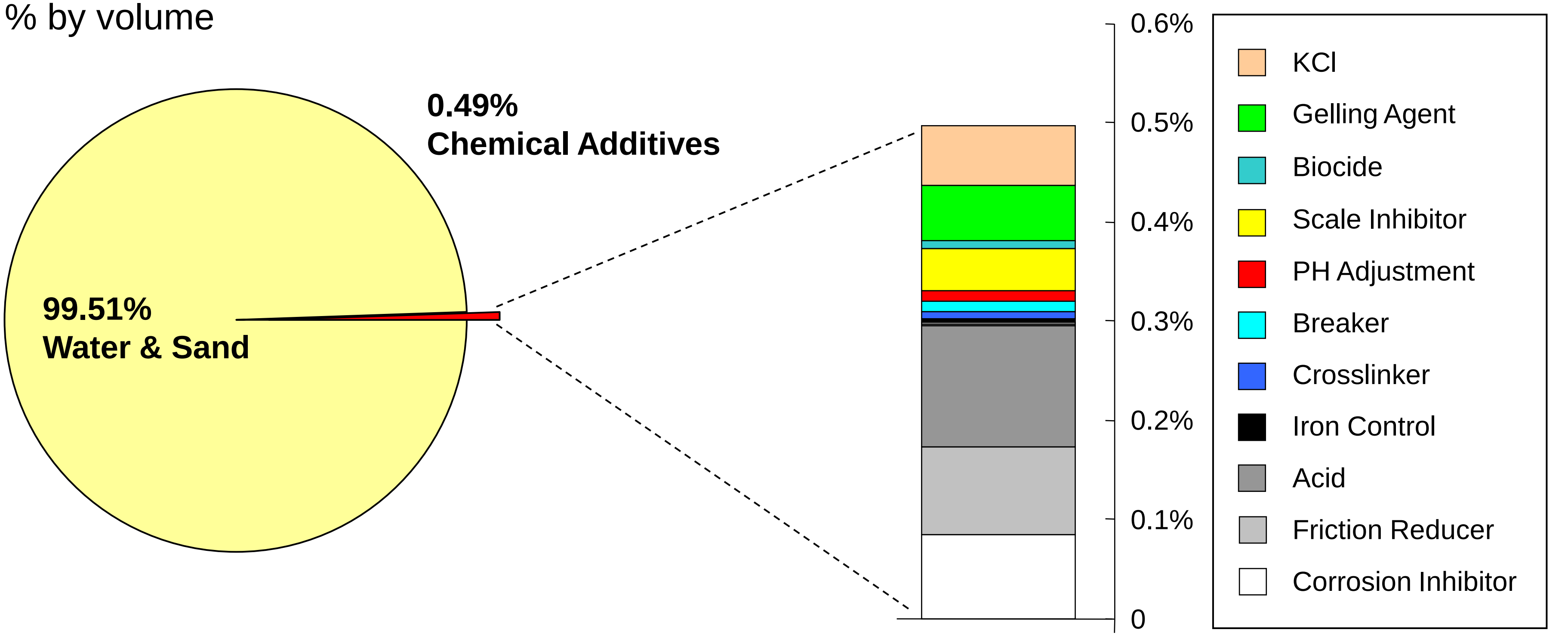
- Injection wells are consistently operated at high pressure, while production well pressure declines, further reducing the probability of leakage

* Michie & Associates. 1988. *Oil and Gas Water Injection Well Corrosion.* Prepared for the American Petroleum Institute.1988

Source: MIT gas supply team

Although frac fluids are almost entirely comprised of water and sand, a range of other chemicals are also present

Illustration of the composition of a typical fracing fluid*
% by volume



- Frac fluid composition varies from play to play due to the underlying geology; however, the vast majority of fluids are >98% sand and water
- Legitimate concerns have been raised about what additives are used in frac fluids, which the operators need to address in a more transparent manner

* "Modern Shale Gas: A Primer," United States Department of Energy, April 2009
Source: MIT gas supply team