Coal and Natural Gas – The Evolving Nature of Supply and Demand

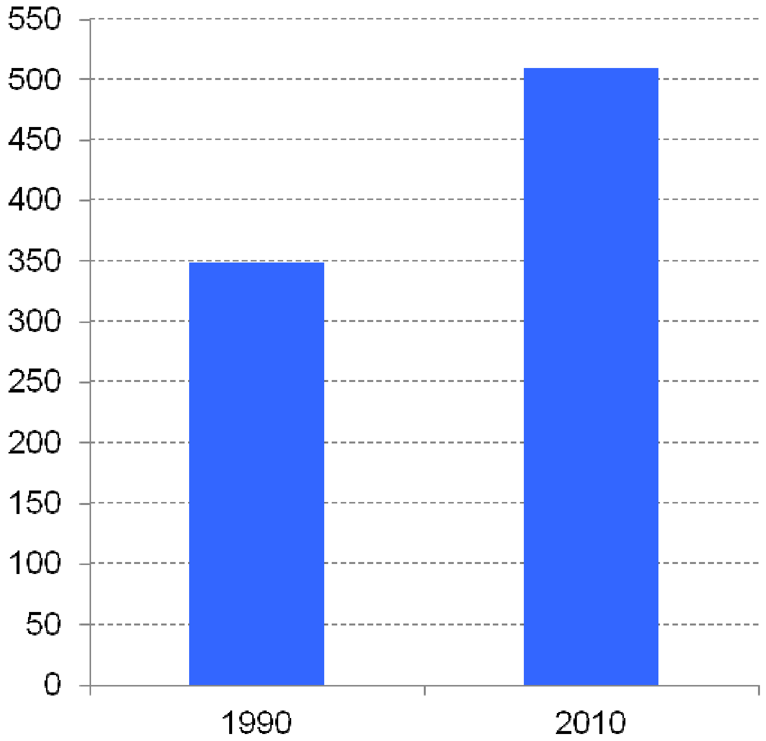
Dr. Francis O'Sullivan

February 13th, 2014

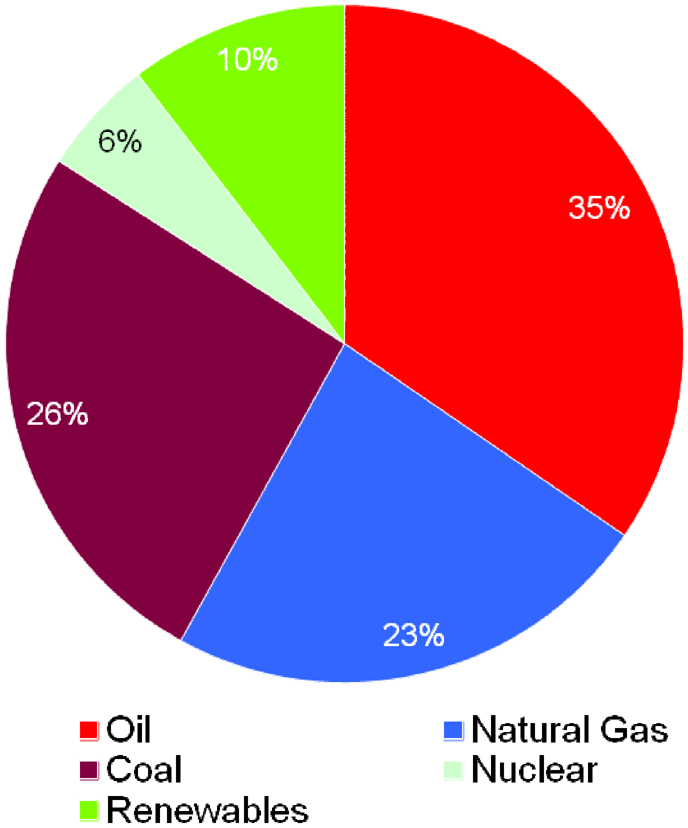
Global energy supply – Where does it come from?

Current annual global energy consumption is approximately 500 Quads ($i.e. 500x10^{15}$ Btu, or $528x10^{18}$ J) **and is mainly supplied by fossil sources**

Global energy consumption in 1990 & 2010
Quadrillion Btu



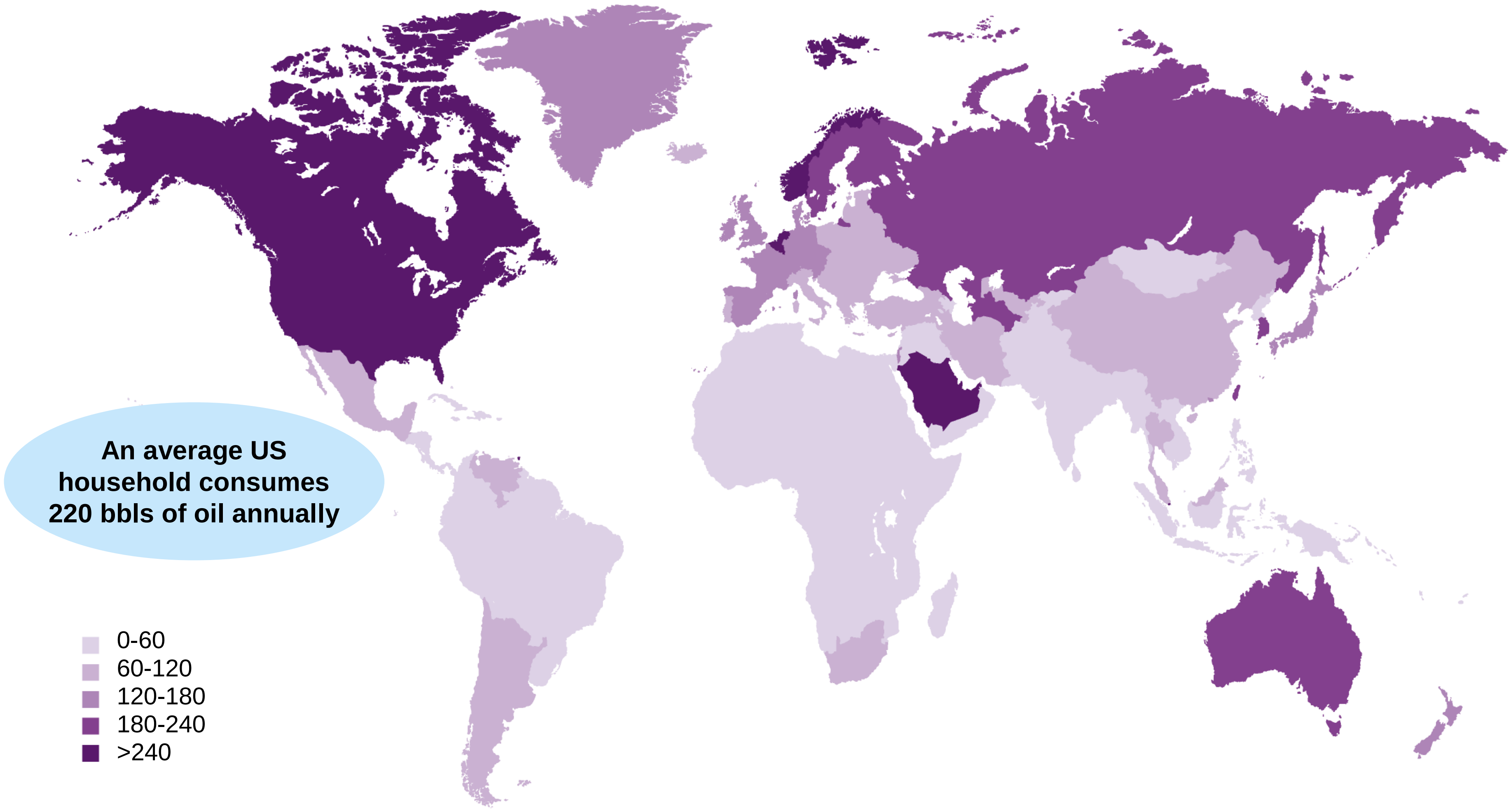
Global energy by type in 2010
Quadrillion Btu, Total = 510 Quads



Source: IEA, EIA

The consumption of energy on a per capita basis varies dramatically – Unsurprisingly, North America is particularly energy intensive

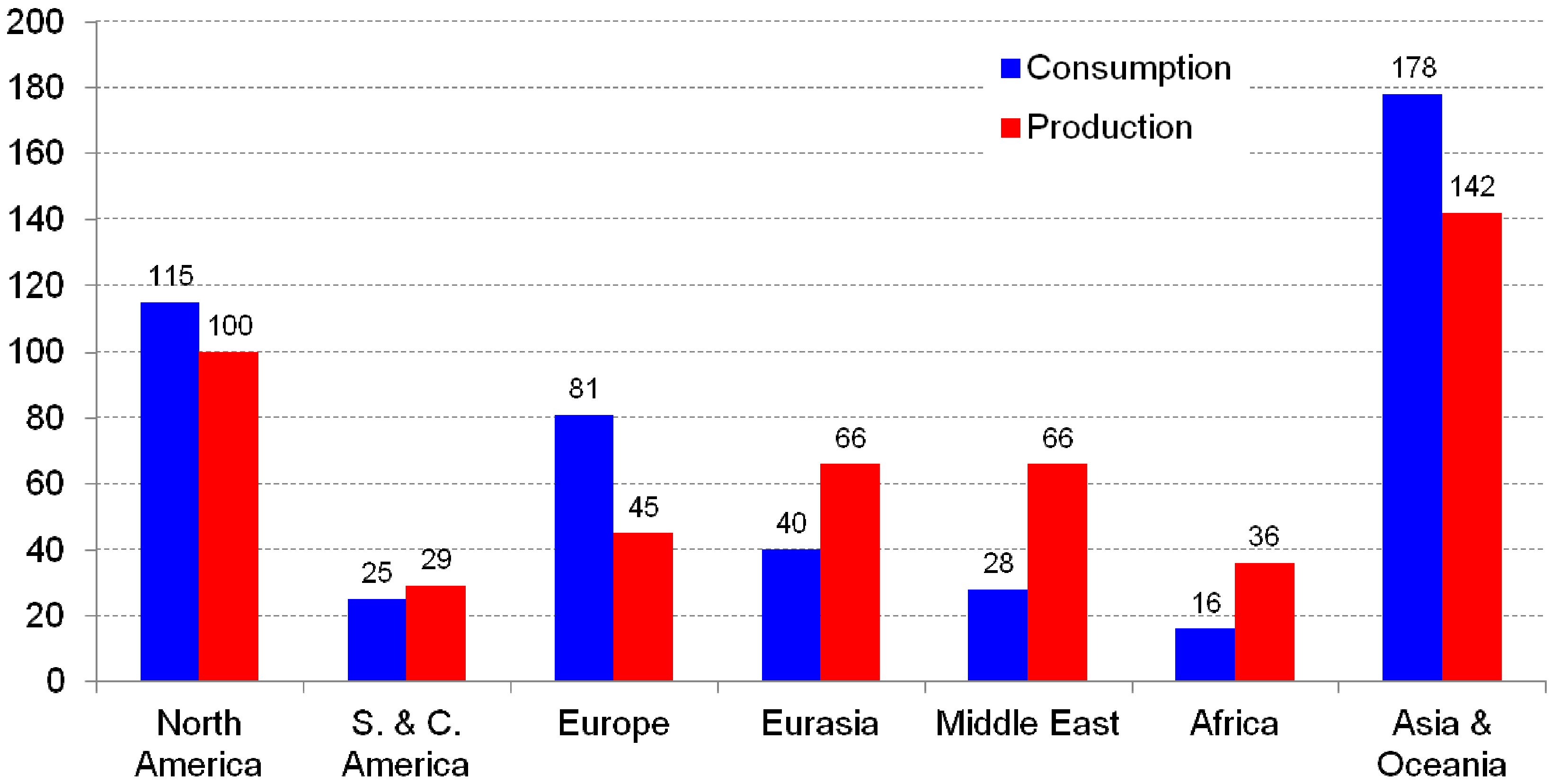
Breakdown of 2012 global per capita energy consumption
Million Btu per capita



Source: 2013 BP Statistical Review of World Energy

North America is responsible for almost one quarter of global energy consumption; however, Europe has the greatest supply deficit

Breakdown of 2009 global energy consumption and production by region
Quadrillion Btu

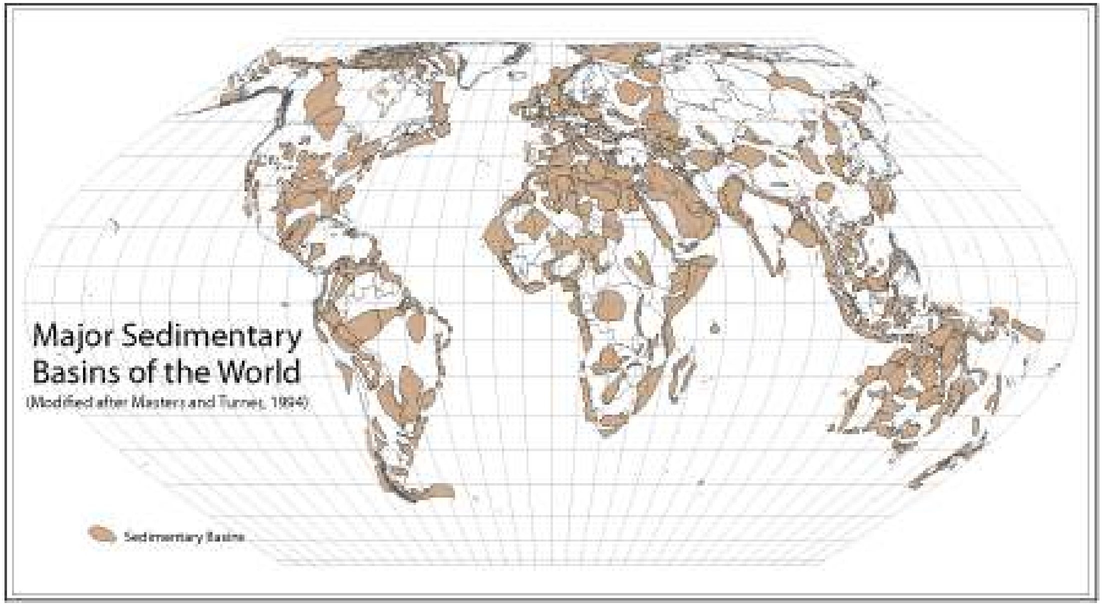


Source: IEA, EIA

A little on the origins of coal and natural gas

Our coal and natural gas resources are the product of the breakdown of organic matter in sedimentary rock deposits

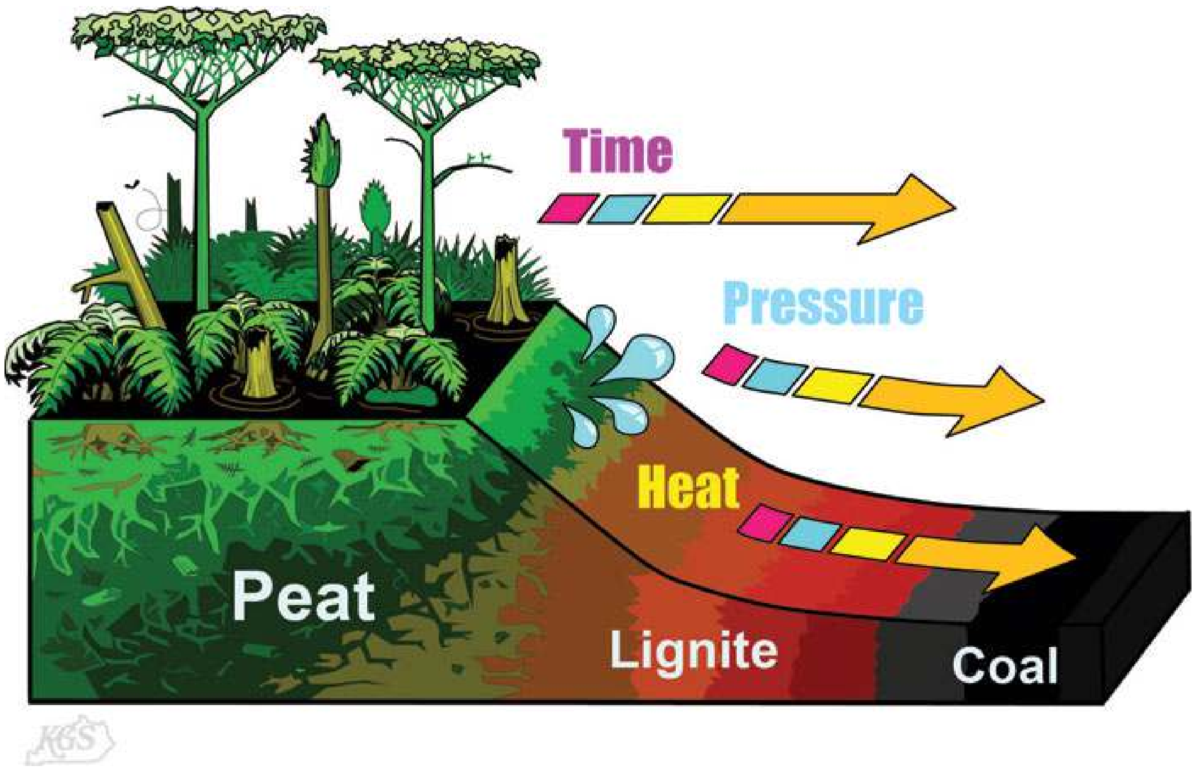
Global sedimentary basins – lots of places for coal and gas to form



- The earth is about 4.54 billion years old
- Since earth's formation its structure has continually changed
- During this change there have been times when areas of "organic rich" sediment formed
- These "basins" are where coal, gas and oil originate

Source: United States Geological Survey

Coal deposits were formed from plant matter – When plants died and were buried, increased pressure and temperature changes converted that "organic matter" into what we know today as coal



- "Peat", is a waterlogged layer of decaying plant matter that is the precursor to coal formation
- If peat is buried, much of the water is squeezed out and the chemistry of the matter is changed
- Over millions of years, 10s of meters of peat can become a 1 meter of coal

Source: University of Kentucky

The burial process associated with coal formation can be seen today in regions where peat and coal are mined

A peat bog in Ireland

A coal mine in Wyoming USA

Source: Geograph.ie, SPE.org

Natural gas formation takes place within what are know as "source rocks" – Unlike coal though, the gas can move and leave that rock

North American sedimentary basins – lots of source rock

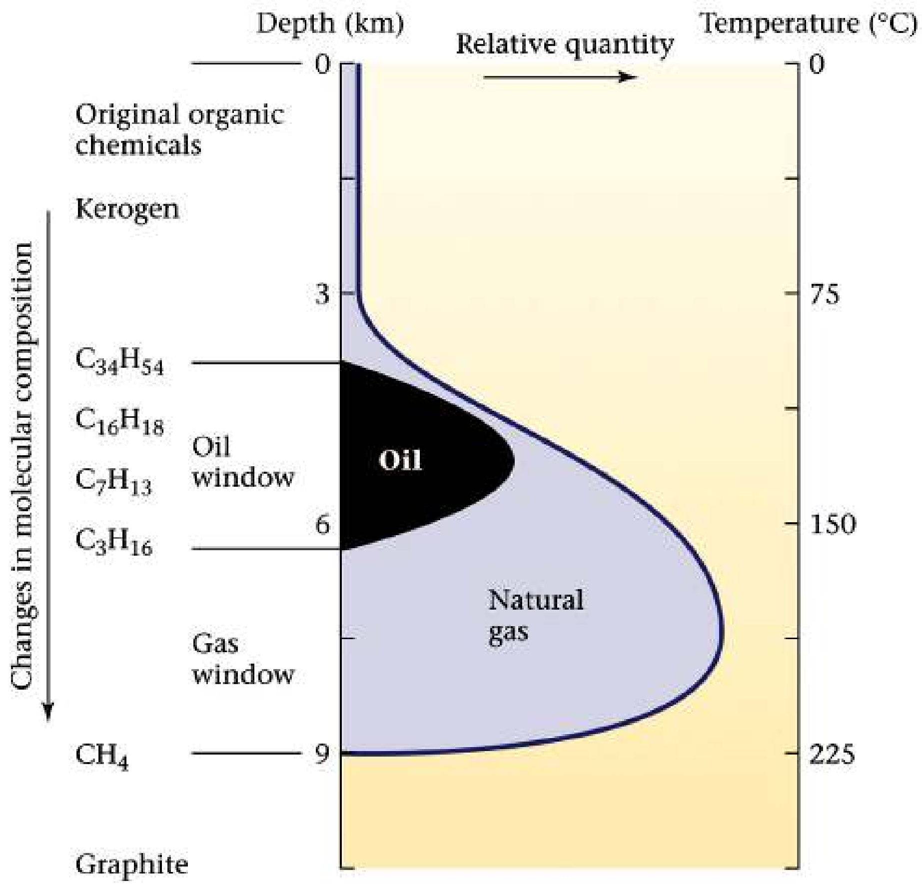
Source rock formation

- Natural gas deposits have have their origins in the deposition of organic matter in a marine environment
- The layers of organic matter mixed with and were slowly covered by layers of non-organic sediment
- This gradual burying process leads to the formation of "kerogen"
- Increasing pressure and temperature then "cracks" the kerogen
- Depending upon the conditions in the "kitchen" the cracking produced oil, gas or a combination of both

The burial depths and temperatures source rock experiences determine the types of hydrocarbons produced – Typically, the hotter it gets the more natural gas produced

Oil and Gas Kitchen

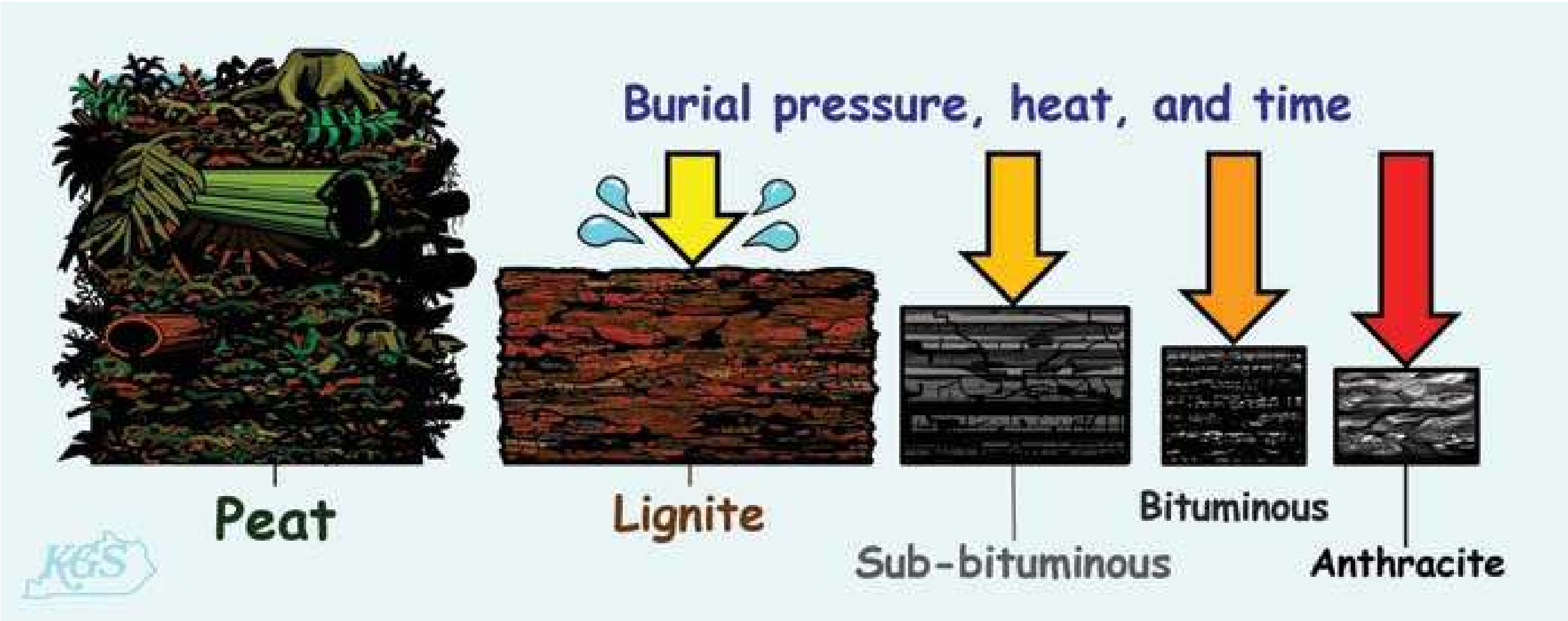
Oil Window: 90-150˚ C Gas Window: 140-220˚ C

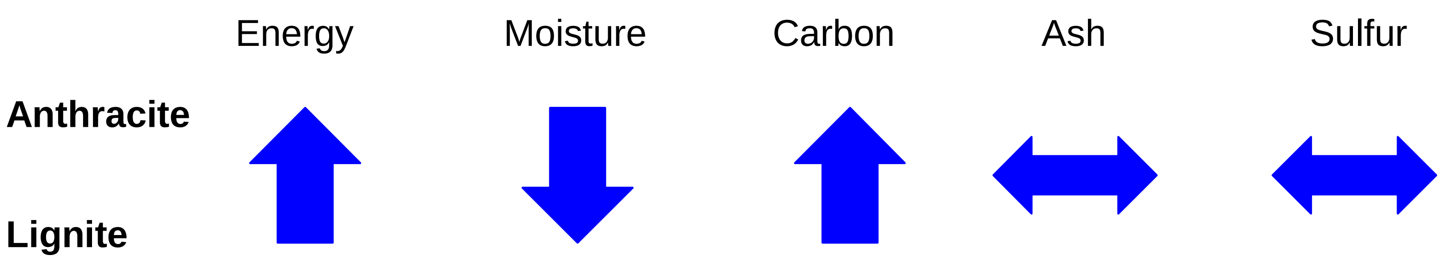


How do we classify coal and natural gas?

Coal comes in a variety of forms or "ranks" – Low rank coal is younger and has lower energy content

Illustration of various coal ranks





Source: MIT, University of Kentucky

The rank of coal used has major environmental implications – Low sulfur and ash levels help reduce local air quality impacts when coal is burned

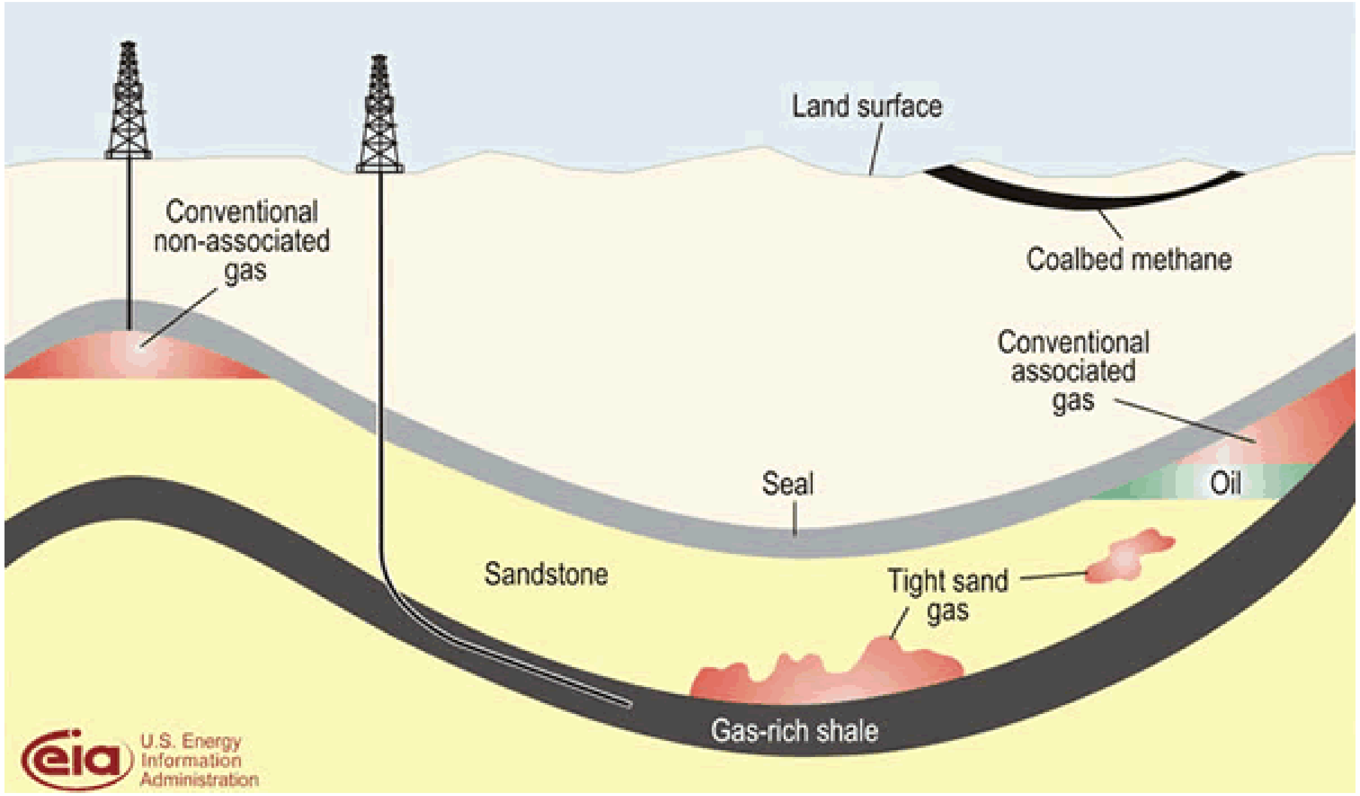
Map of major U.S. coal producing regions

How the Rank of major coal types differ

	Higher Heating Value (kJ/kg)	Moisture Content (%wt)	Carbon Content (%wt)	Ash Content (%wt)	Sulfur Content (%wt)	Minemouth Coal Cost (2005 $/ton)
Anthracite	30,000[1] – 31,500[2]	2.1[2]–12[1]	72[1]–87[2]	6.9[2]–11[1]	0.5[2]–0.7[1]	44–87[3]
Pittsburgh # 8	30,800[2] – 31,000[4]	1.1[4]–5.13[1]	73[4]–74[3]	7.2[3]–13[4]	2.1[3]–2.3[4]	45–55[3]
Illinois #6	25,400[3]– 25,600[4]	8.0[4] –13[3]	60[4]–61[3]	11[3]–14[4]	3.3[3]–4.4[4]	32–39[3]
Chinese Coal	19,300– 25,300[6]	3.3–23[6]	48–61[6]	28–33[6]	0.4–3.7[6]	N/A
Indian Coal	13,000– 21,000[7]	4[7]–15[8]	30–50[8]	30–50[7]	0.2–0.7[7]	14–19[7]
WY Powder River Basin	19,400[3]– 19,600[4]	28[4]–30[3]	48[3]–49[4]	5.3[3]–6.3[4]	0.37[3]–0.45[4]	6–17[5]
Texas Lignite	14,500[9]– 18,300[10]	30[10]–34[9]	38[9]–44[10]	9[10]–14[9]	0.6[10]–1.5[9]	14[11]– 15[12]
ND Lignite	14,000[9]– 17,300[4]	32[4]–33[9]	35[9]–45[4]	6.6[9]–16[9]	0.54[4]–1.6[9]	9[13]

Source: MIT Future of Coal Study

Natural gas classification is based not its composition, but where it is found – Conventional and unconventional gas are really defined by the "tightness" of the reservoir rock



Conventional gas

- Gas trapped in reservoir rock – typically sandstone
- High permeability: > 0.1 mD by definition, typically much higher - 100's of mD.
- Extremely high recovery of gas-in-place possible: 80-90%

Unconventional/Continuous gas

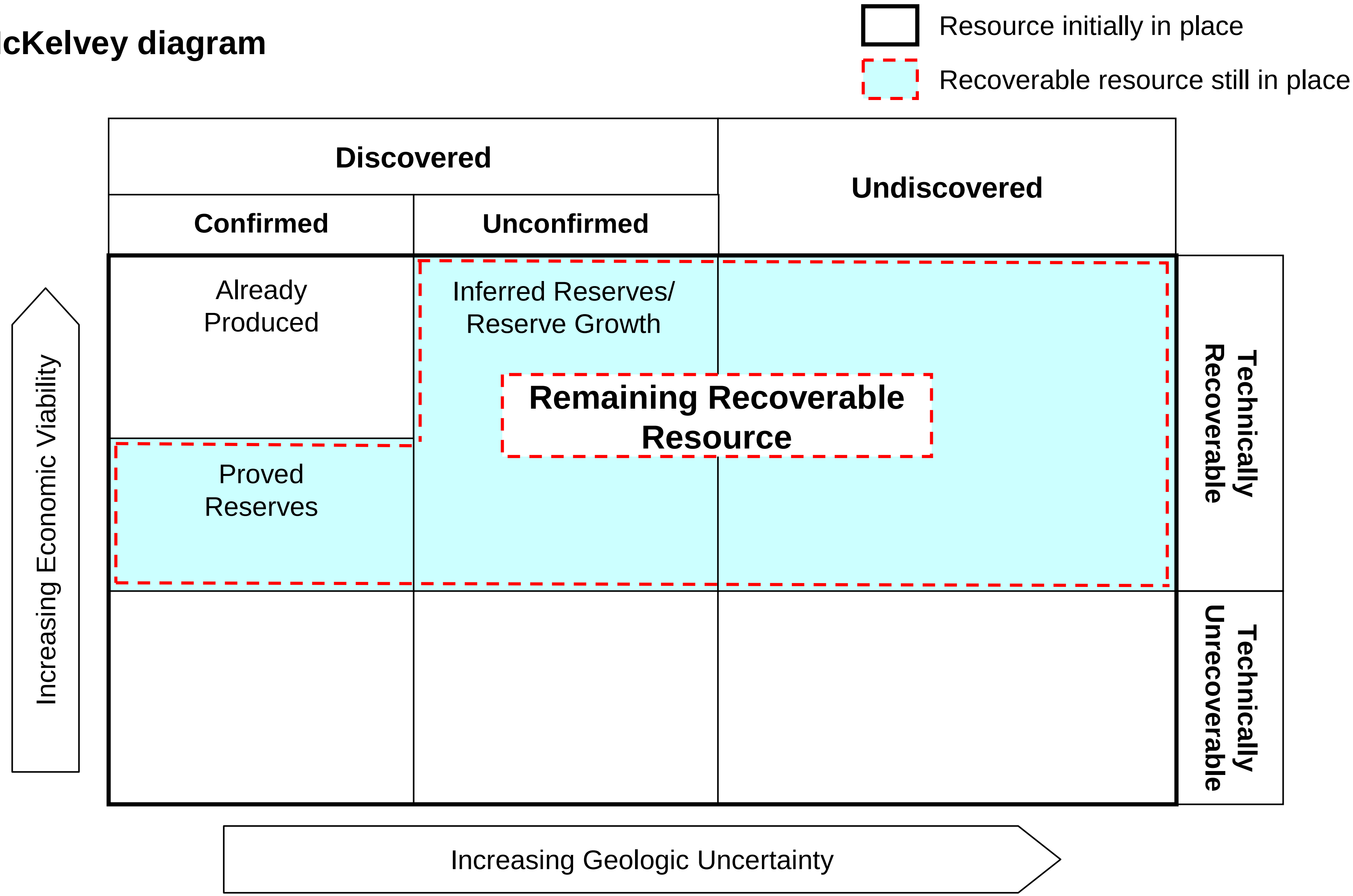
- Gas trapped in either reservoir or source rock – sandstones, shales, coalbeds
- Low permeability: < 0.1 mD by definition, often in the sub micro-darcy range.
- Low recovery rates: 10-30%

Source:EIA, MIT

How much coal and natural gas is available?

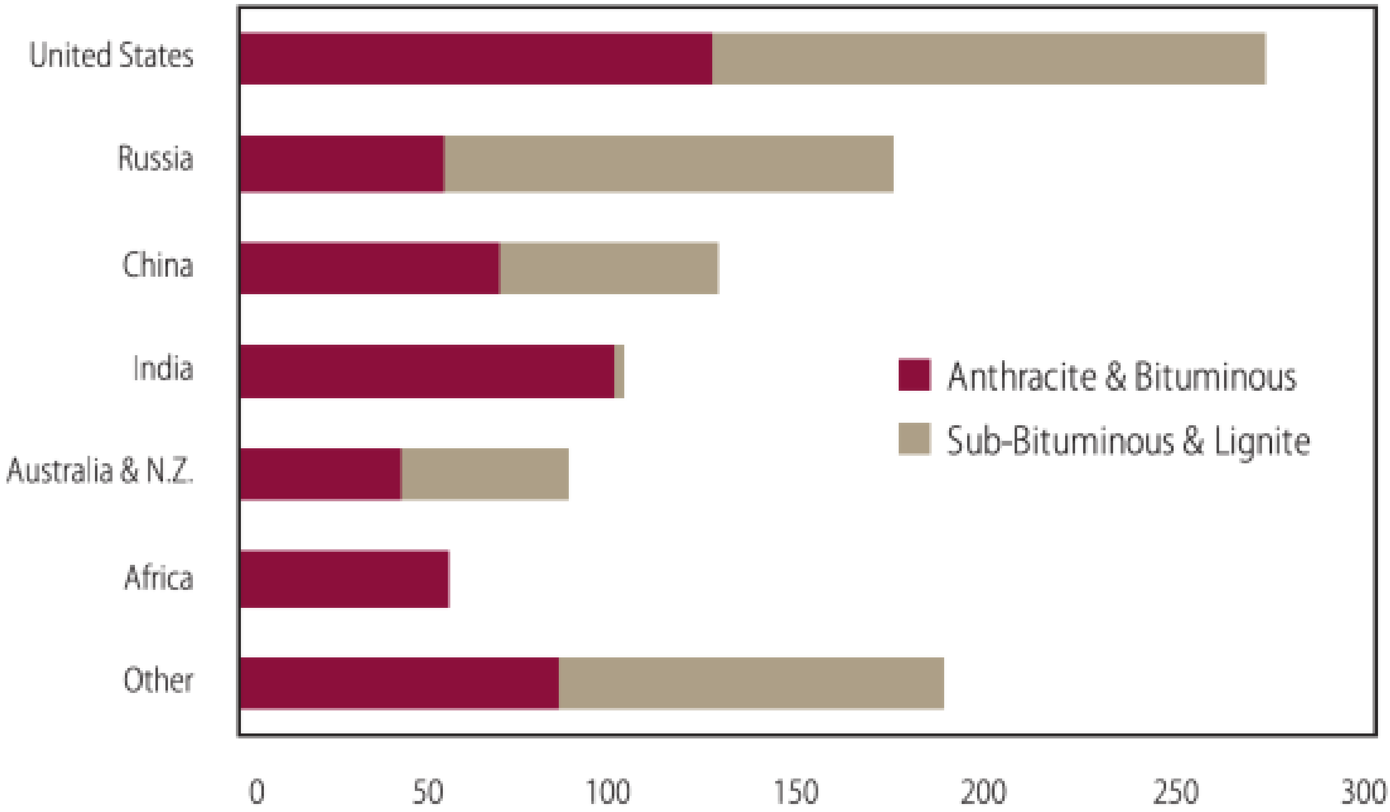
Quantifying the availability of natural resources like coal and gas is complex – The more uncertainty, the bigger the number.

McKelvey diagram



The global recoverable coal resource is about 1 trillion short tons – More than 25% of the global resource is in North America

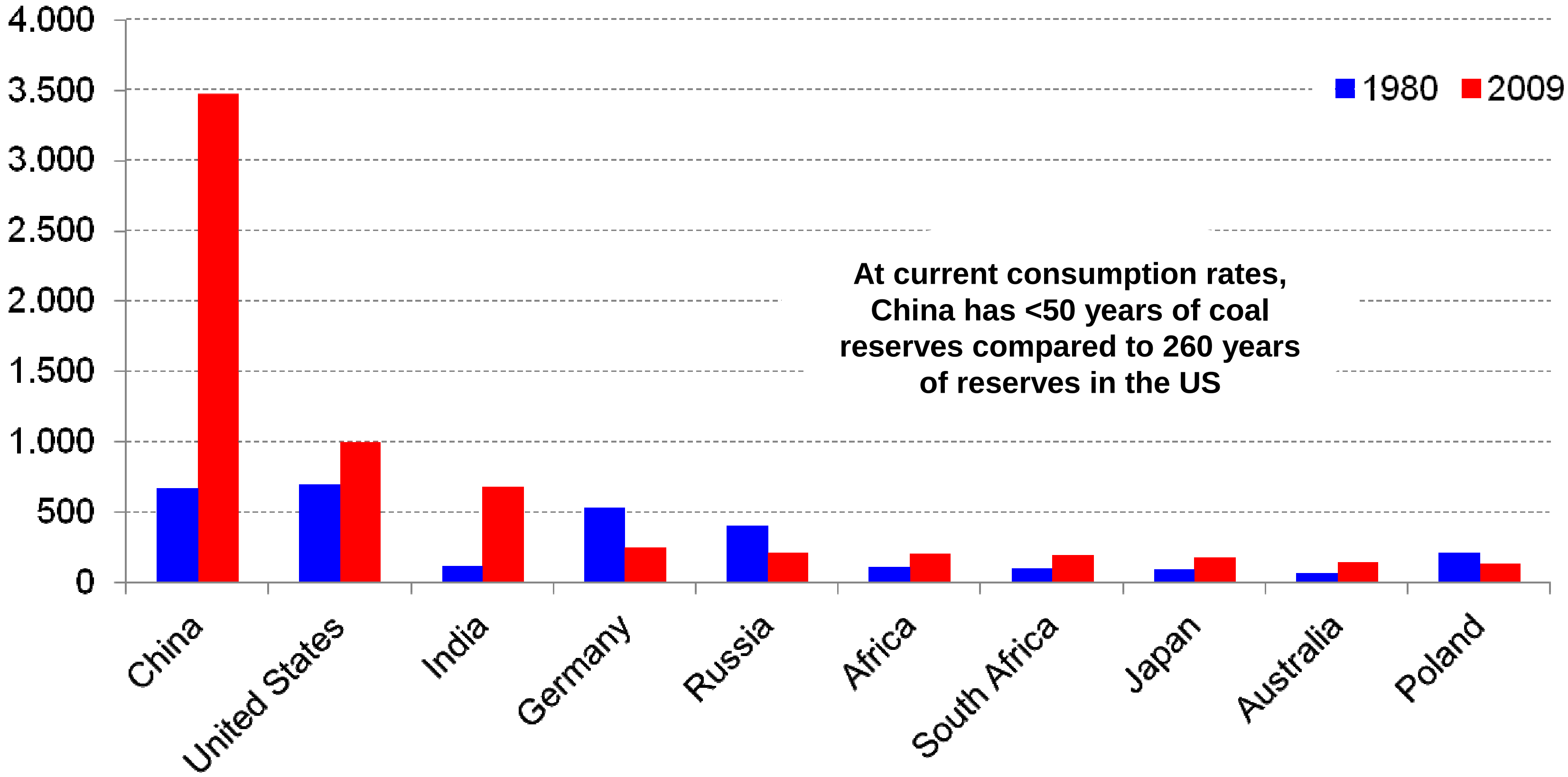
Breakdown of the global recoverable coal resource
Billions of short tons



Source: MIT Future of Coal Study

China and India have seen their coal consumption grow by more than 400% over the past 30 years driven by increased electricity demand

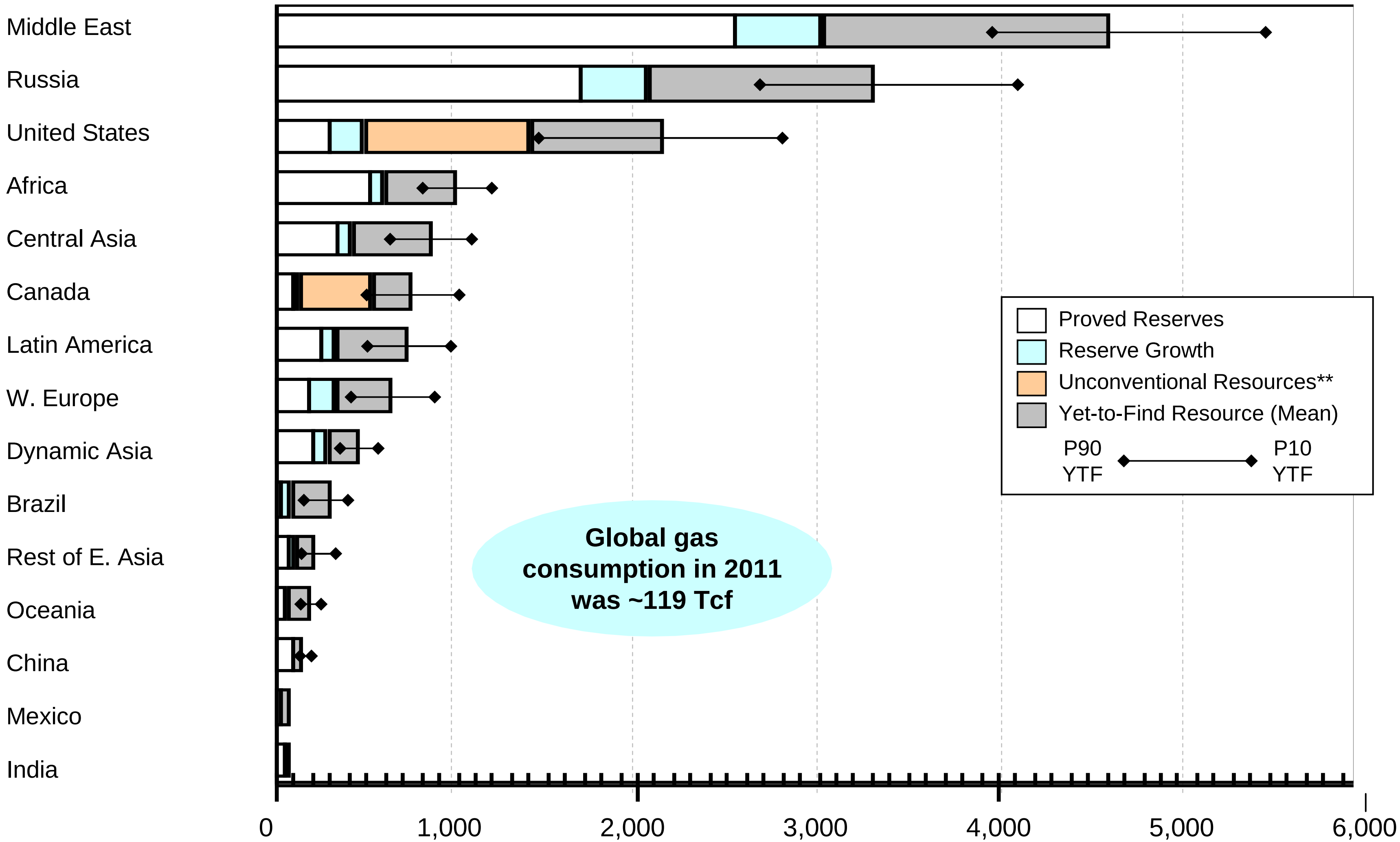
Top 10 coal consuming nations in 2010
Millions of short tons per year



Source: EIA

There is a lot of recoverable conventional natural gas in the world, more than 16,000 Tcf – This represents more than 100 years at current consumption rates

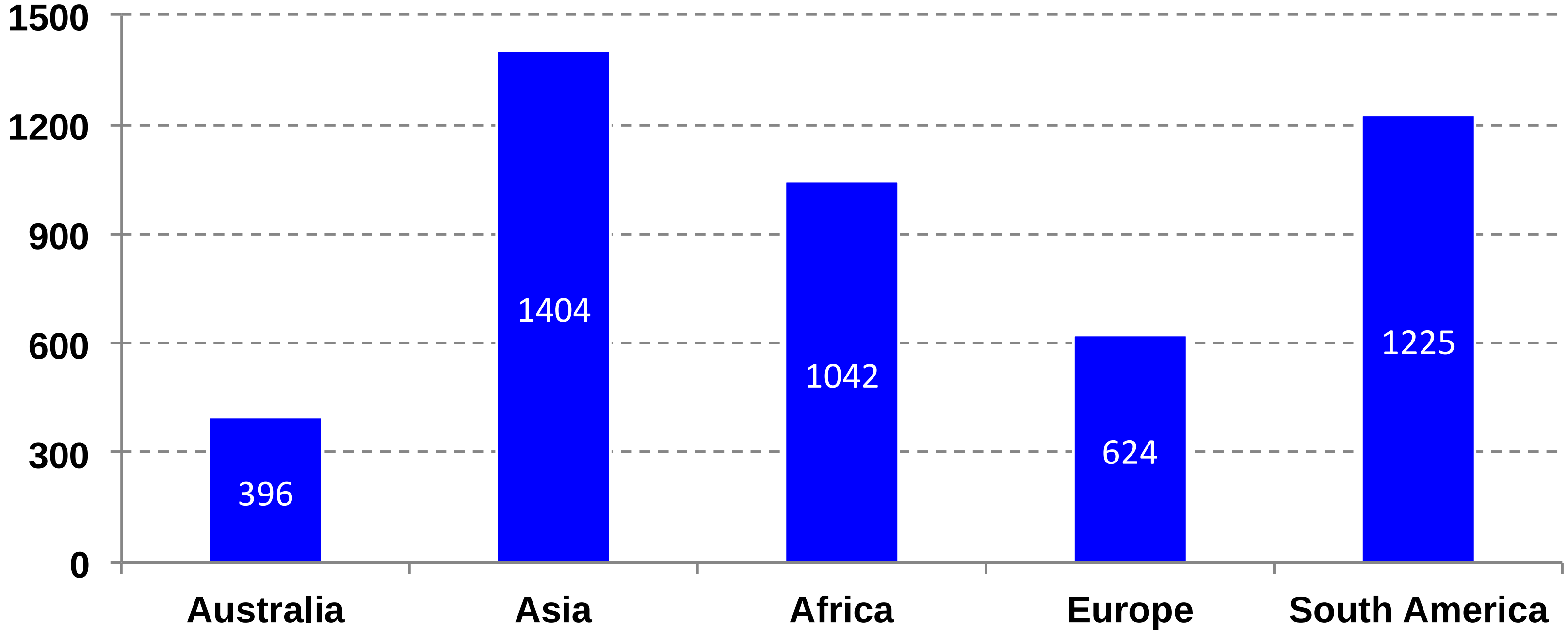
Breakdown of the total global remaining recoverable gas resources[1]
Tcf of Gas



1 Only includes unconventional gas resources in the United States and Canada – Estimates for other regions too uncertain for use
Source: MIT Gas Supply Team analysis

New technology is making gas resources in shale formations accessible and this is increasing the overall availability of gas – It is estimated that the global shale gas resource could be at least 6,000 Tcf

Breakdown of global recoverable shale gas resources outside North America
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	Brazil: 226 Tcf
	India: 63 Tcf	Libya: 290 Tcf	France: 180 Tcf	Argentina: 774 Tcf

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

Estimates of U.S. gas resources have grown dramatically since 2005 due to the emergence of shale as a recoverable resource – The resource's ability to support rapid production growth has also been notable

Illustration of growth in US natural gas proved reserve and resource estimates from '90 to '10
Tcf of gas

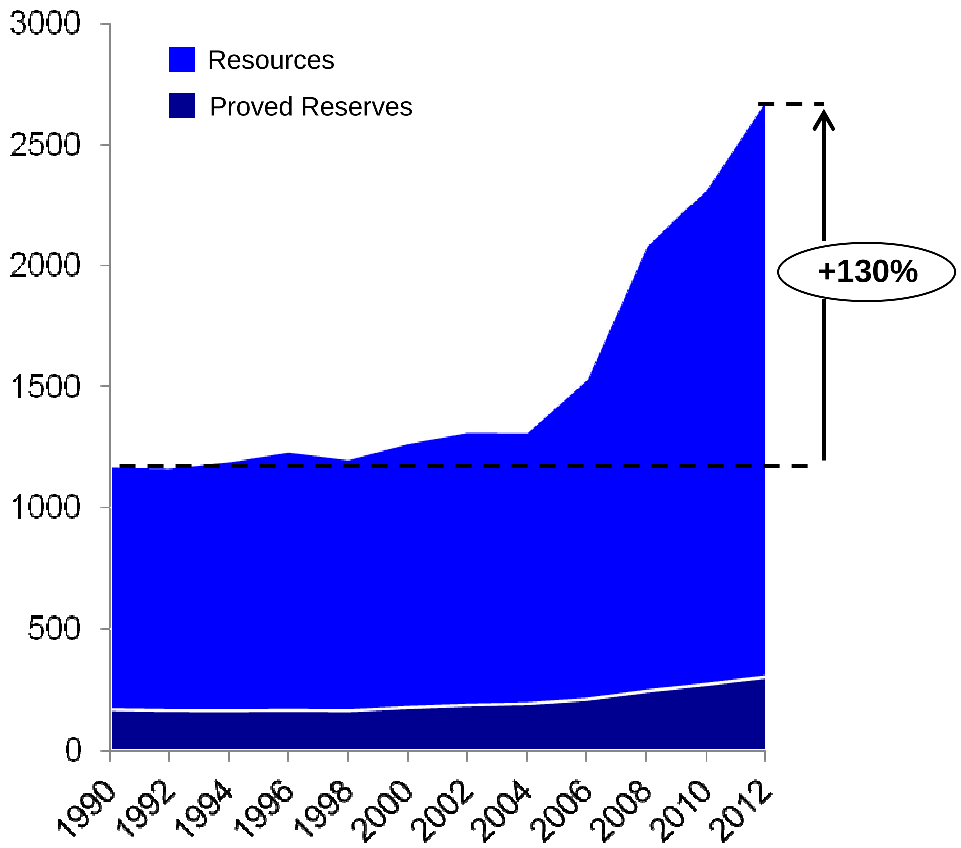
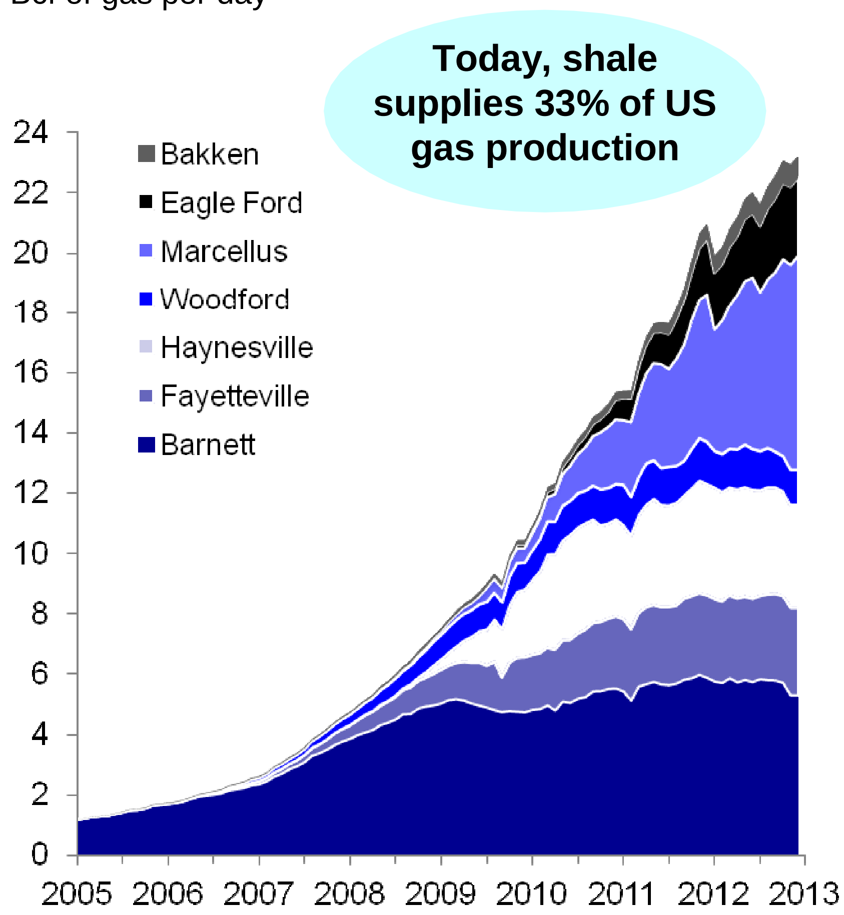


Illustration of production growth in the main U.S. shale plays since 2005
Bcf of gas per day

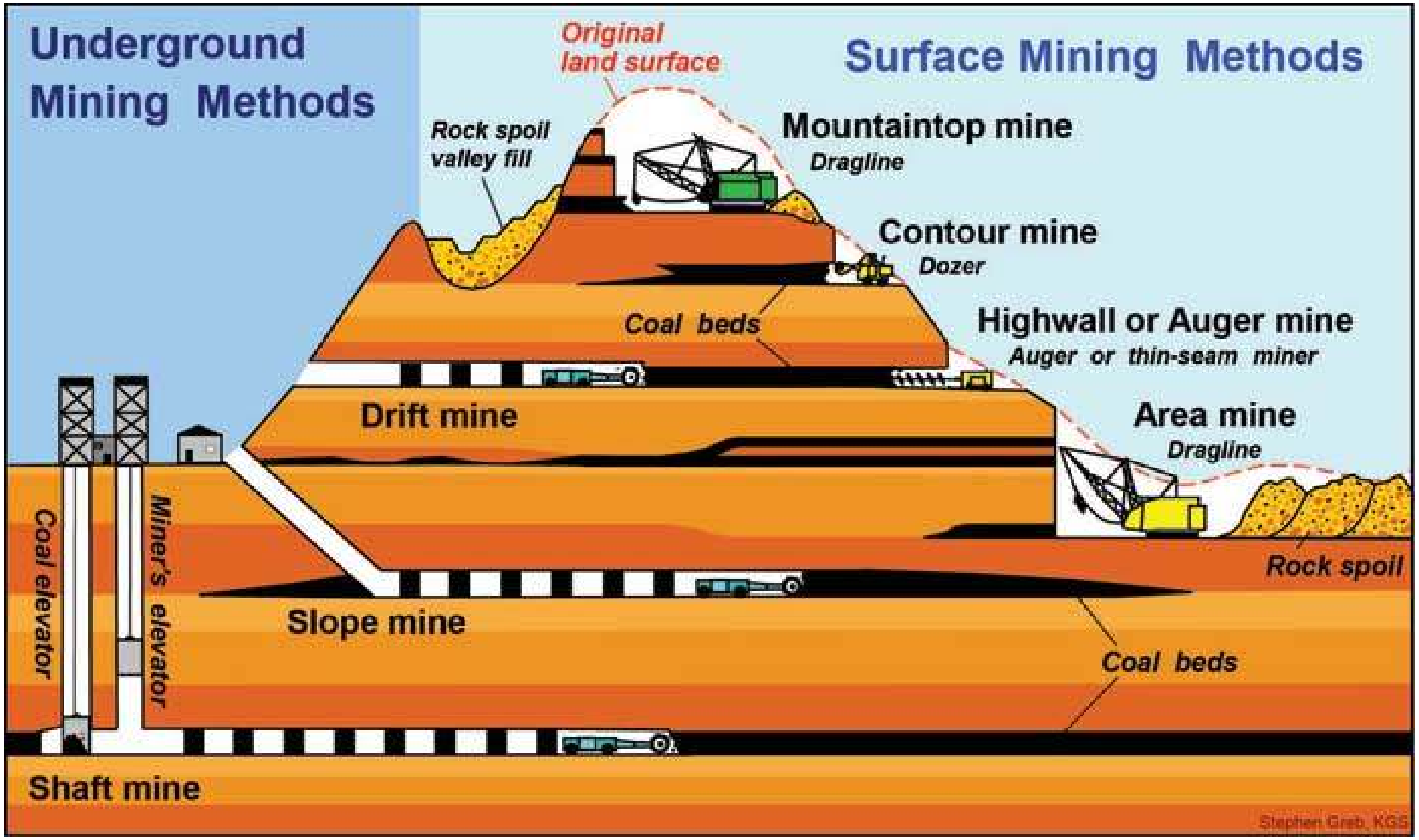


1. EIA 2010 assessment based on 2008 PGC assessment with updated estimates of technically recoverable shale gas volumes
Source: F. O'Sullivan, NPC data, PGC data, EIA data

How do we produce coal and natural gas?

Depending on where the seam is located, coal can be mined either from the surface directly or from underground mines – Surface mining is much lower cost, though the environmental impacts are severe.

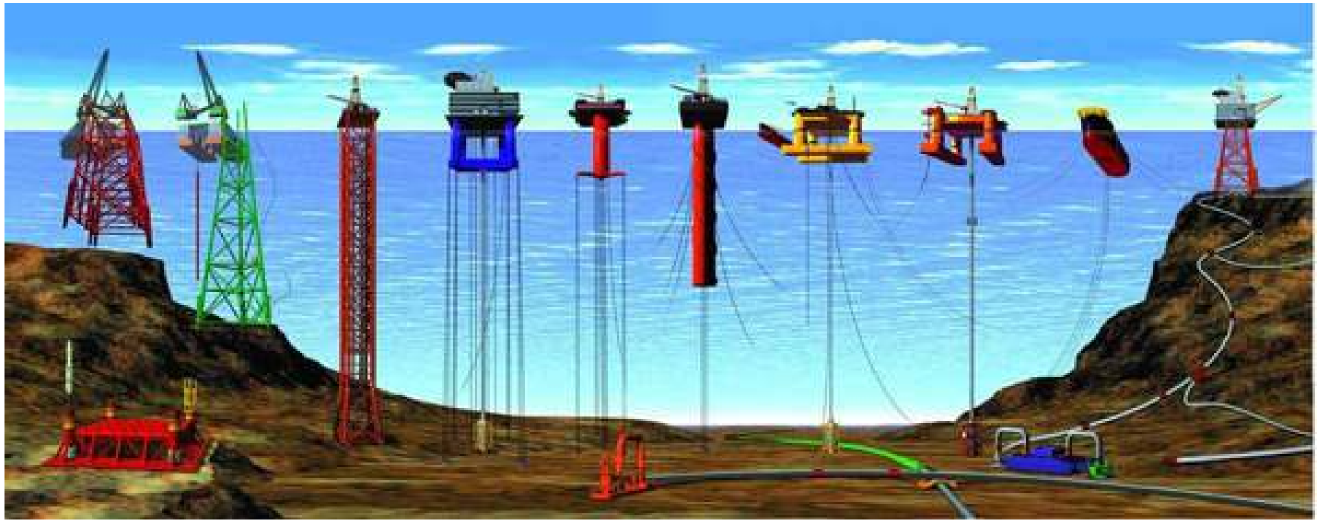
Methods of coal mining



Source: University of Kentucky

Unlike coal, gas production takes place both on and off-shore – Recent years have seen a significant increase in on-shore drilling owing to the emergence of shale gas

Off-shore gas rig types



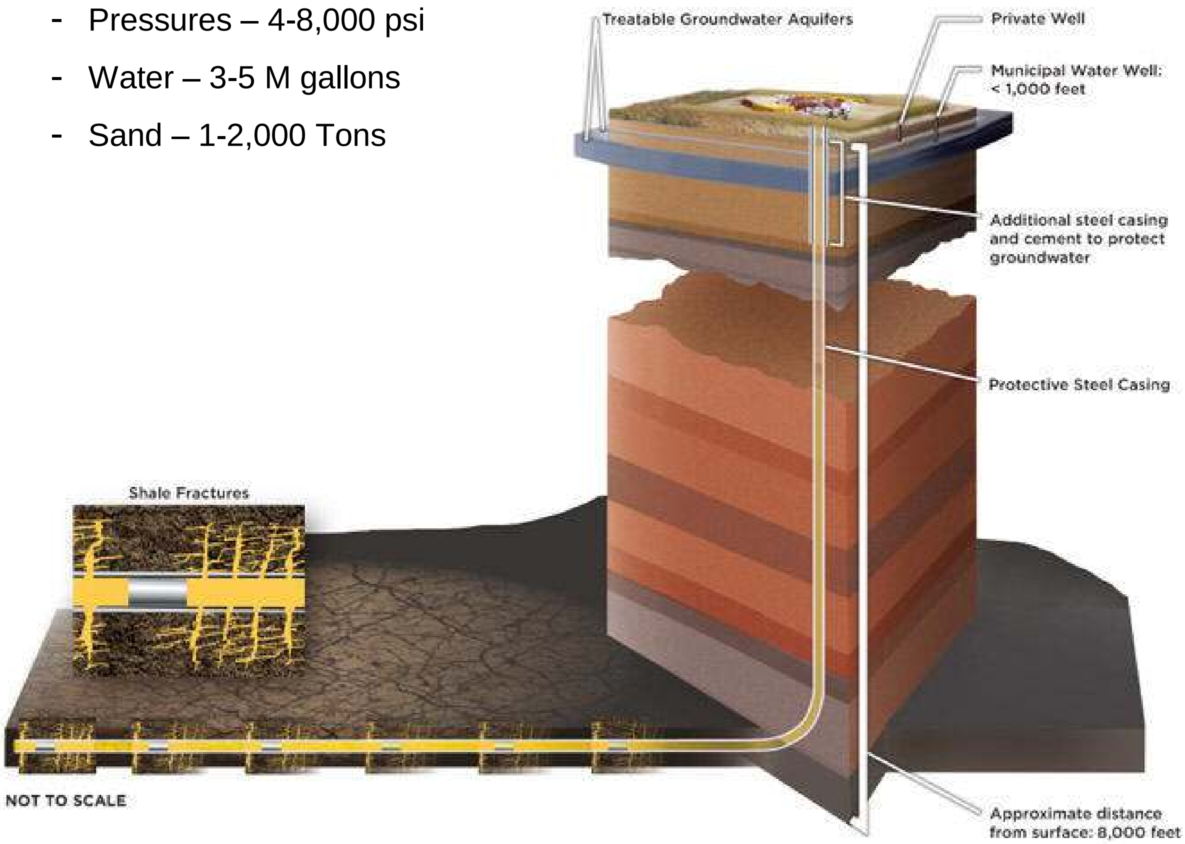
Onshore gas rig

Source: NOAA, BP

Today, gas production relies heavily on hydraulic fracturing and horizontal drilling – These techniques have grown in prominence owing to the growth in production from unconventional reservoirs including shale formations

Contemporary hydraulic fracturing

- Hydraulic fracturing a single well demands:
  - Horse power – 20–30,000 HP
  - Pressures – 4-8,000 psi
  - Water – 3-5 M gallons
  - Sand – 1-2,000 Tons

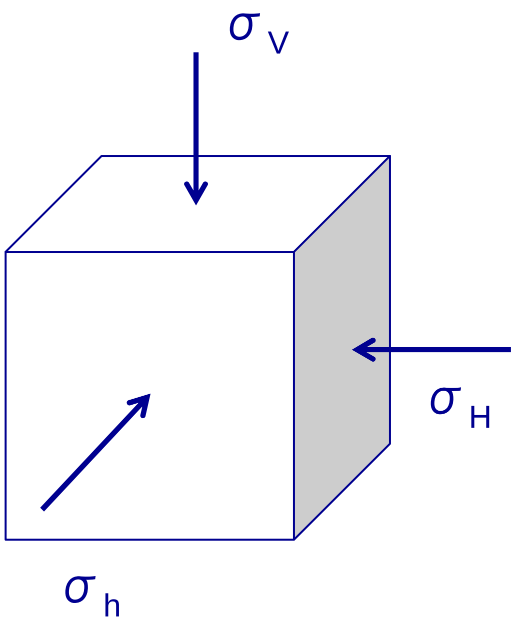


Some of the environmental issues associated with hydraulic fracturing

- **Water impacts**
  - Ground water and surface water contamination
  - Very large and impulsive demand on limited local resources
- **Air impacts**
  - Fugitive methane leakage
  - VOC emissions and other local air quality impacts
- **Community impacts**
  - Heavy traffic and surface disturbance
  - Ecosystem fragmentation

Rock strata in the lithosphere exist in a complex stress environment that has important implications on hydraulic fracturing – Induced fractures will generally form normal to the direction of the smallest principal *in situ* stress

Illustration of in situ principal stresses acting on a rock layer



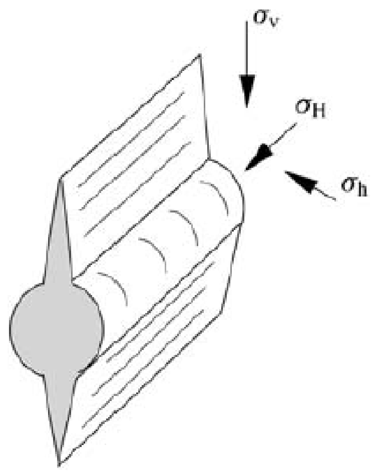
It is typical that the vertical stress be the largest which has implications for fracture orientation

$$\sigma_V > \sigma_H > \sigma_h$$

Fracturing from horizontal wells

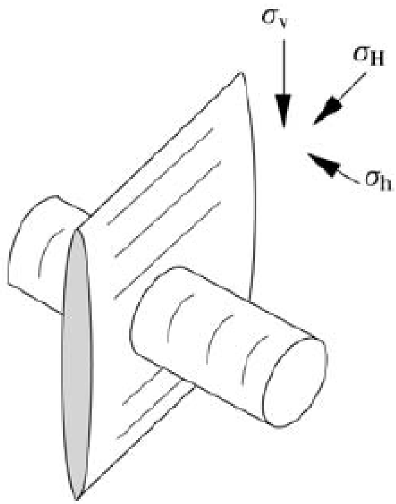
Case 1: Well bore azimuth parallel to maximum horizontal stress

Fracture will be parallel to well bore



Case 2: Well bore azimuth parallel to minimum horizontal stress

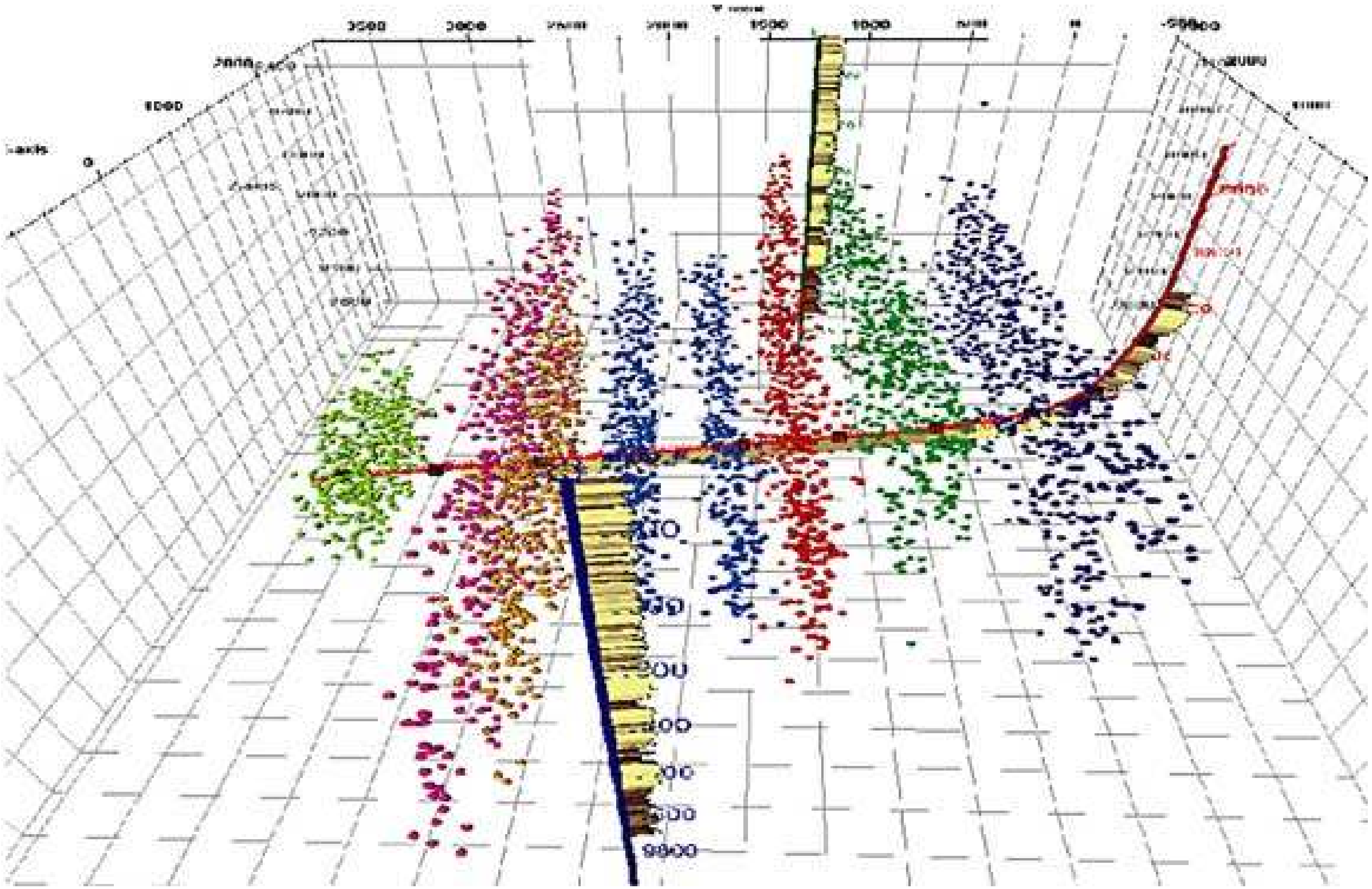
Fracture will be normal to well bore



Source: Petroleum Related Rock Mechanics, 2008

Monitoring fracture placement and growth coupled with improved reservoir characterization is helping optimize production – Microseimic logs are now widely used to evaluate fracture placement and stimulated volumes

Illustration of microseismic log of a horizontal shale well:



Source: Schlumberger

How do we move coal and natural gas?

Coal, much like oil is a easy fuel to handle and cheap to transport – The vast majority of coal is moved by ship and train

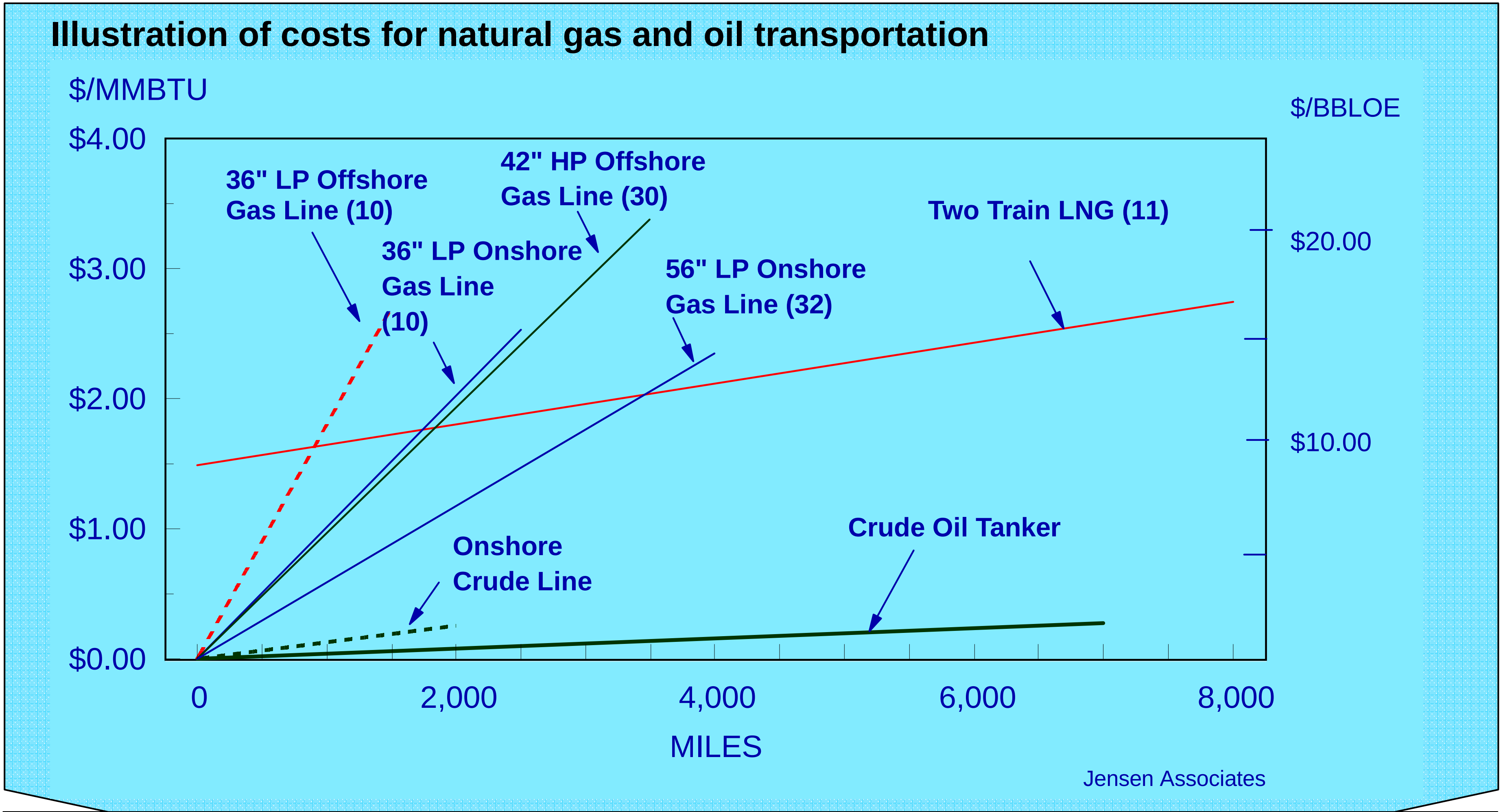
A key drawback of natural gas as an energy source is the difficulty of its transportation relative to other energy sources like oil or coal

- The low density of natural gas makes its transportation much more challenging and expensive than is the case for oil or coal
- Today, the vast majority of gas is transported either in the gaseous-phase via pipeline, or in the liquid-phase via LNG tanker
- Distance is a key determinant of whether gas is transported via pipeline or LNG

Natural gas pipeline

LNG tanker

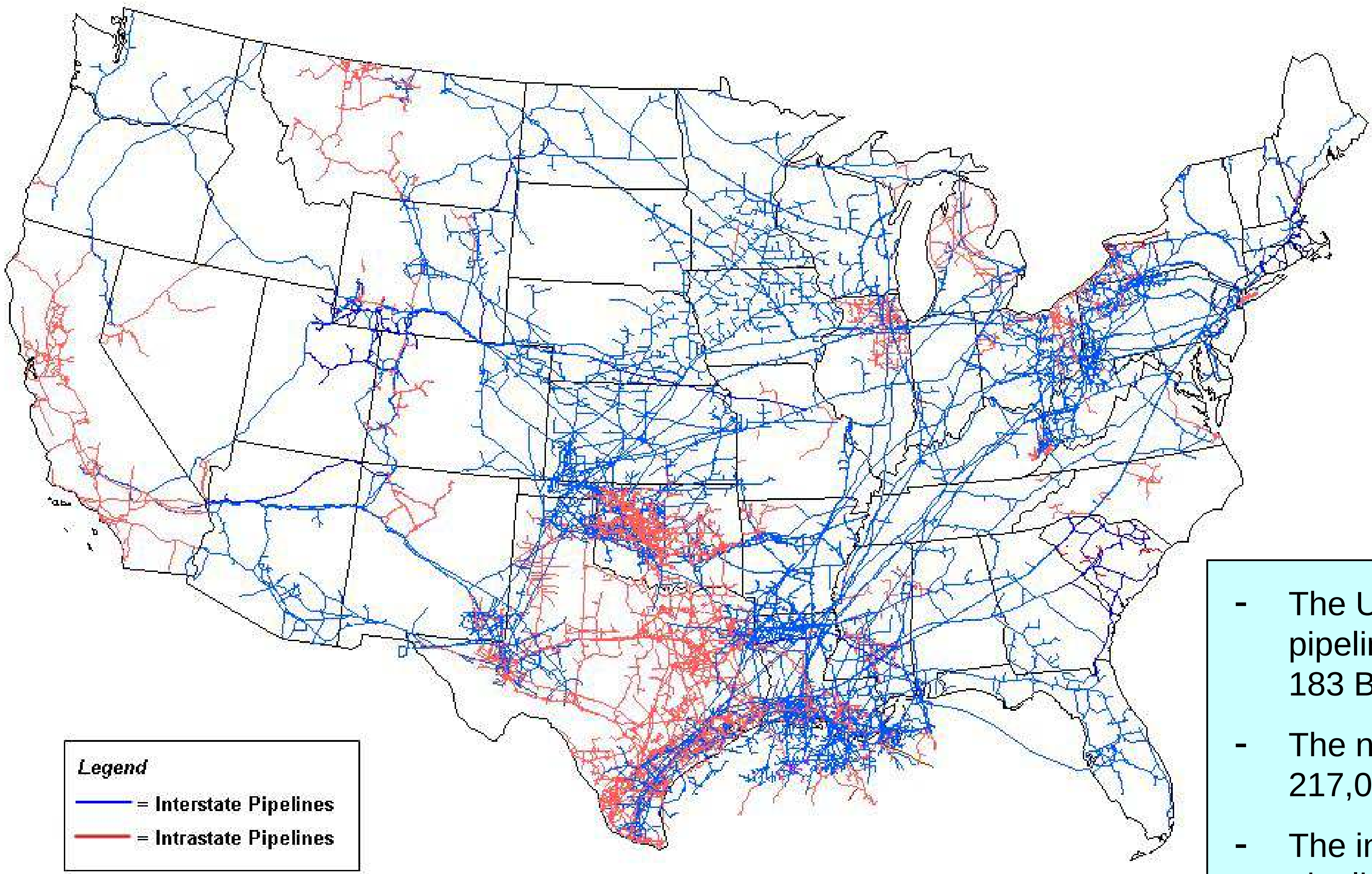
The transport costs for natural gas can be an order of magnitude greater than for oil on a per-unit energy basis



- LNG typically becomes more economically attractive at distances of >3-4,000 miles
- LNG huge disadvantage is the enormous capital required for liquifaction

Natural gas transportation is completely dominated by pipelines in the United States, where they account for 98% of all gas movements

Map of the inter and intrastate trunk pipeline network in L48 United States

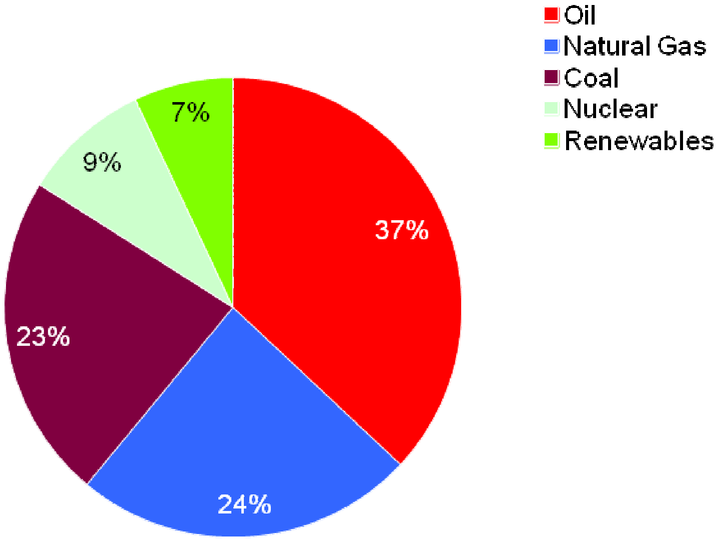


- The US interstate pipeline system has a 183 Bcf/day capacity
- The network involves 217,000 miles of pipe
- The interstate gas pipeline network is regulated by FERC

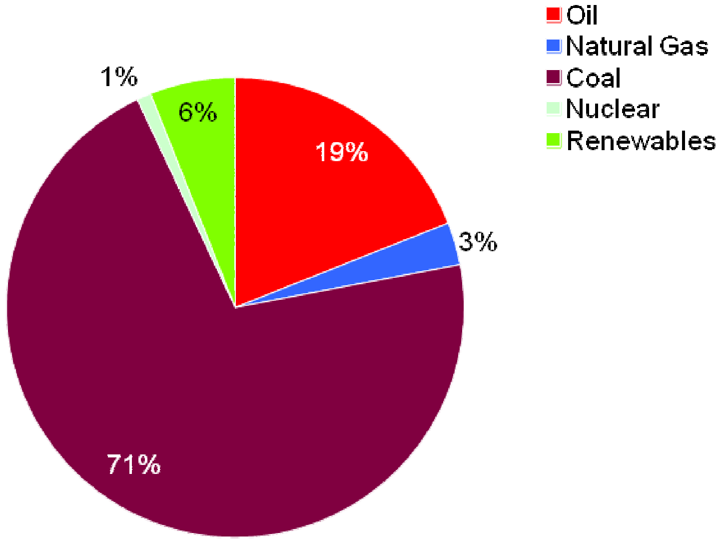
How are coal and natural gas consumed?

How coal and gas are consumed varies by region – The U.S. and China, the world’s largest consumers, have different usage patterns

United States energy use by type in 2008
Percent, Total = 99.2 Quads



Chinese energy use by type in 2008
Percent, Total = 85 Quads

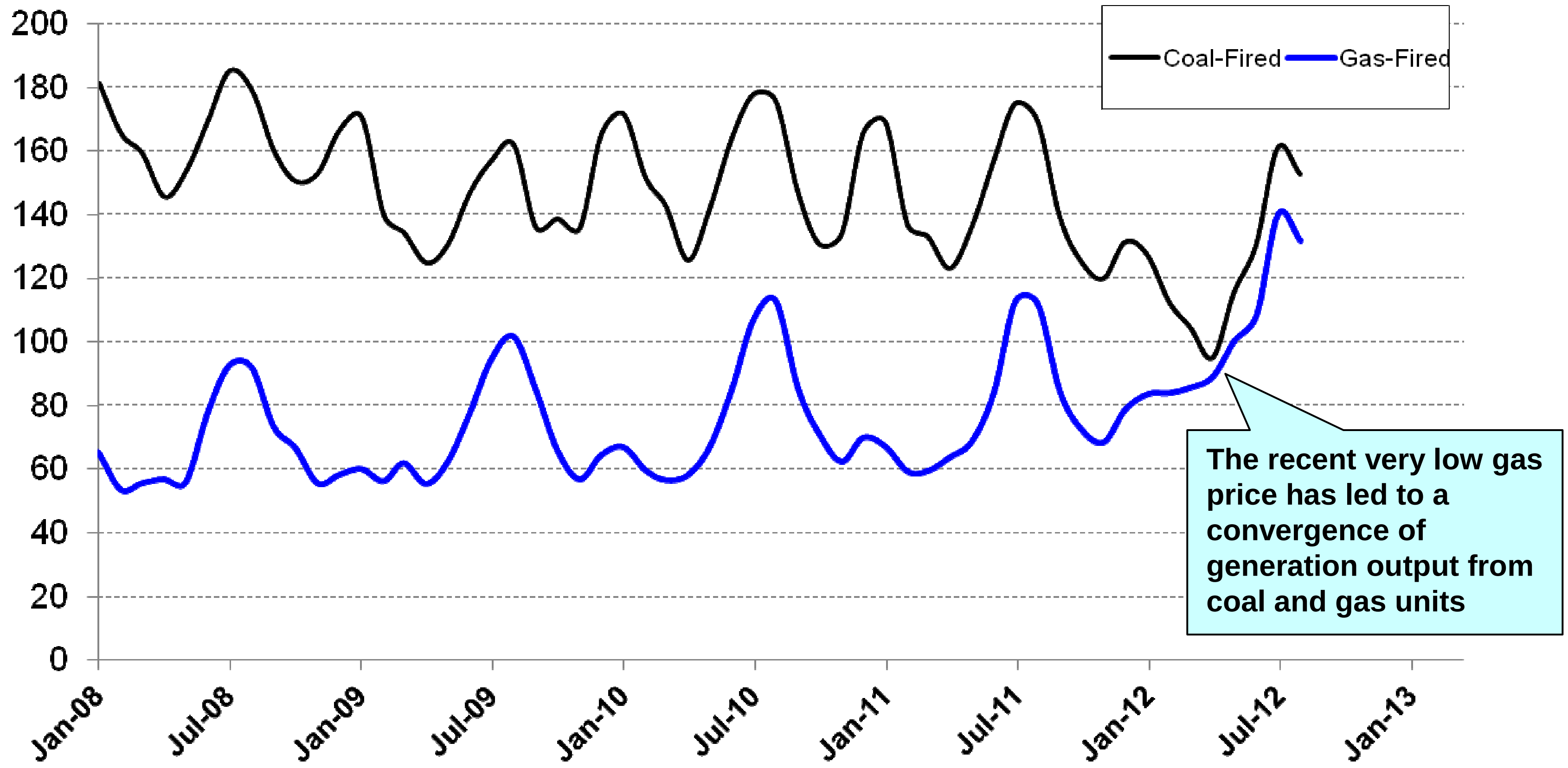


China’s dependency on coal means its emits more greenhouse gases per unit of energy consumed

Source: EIA

In the United States coal's share of total energy supply is falling and gas is growing – Lower cost gas is more attractive for power generation

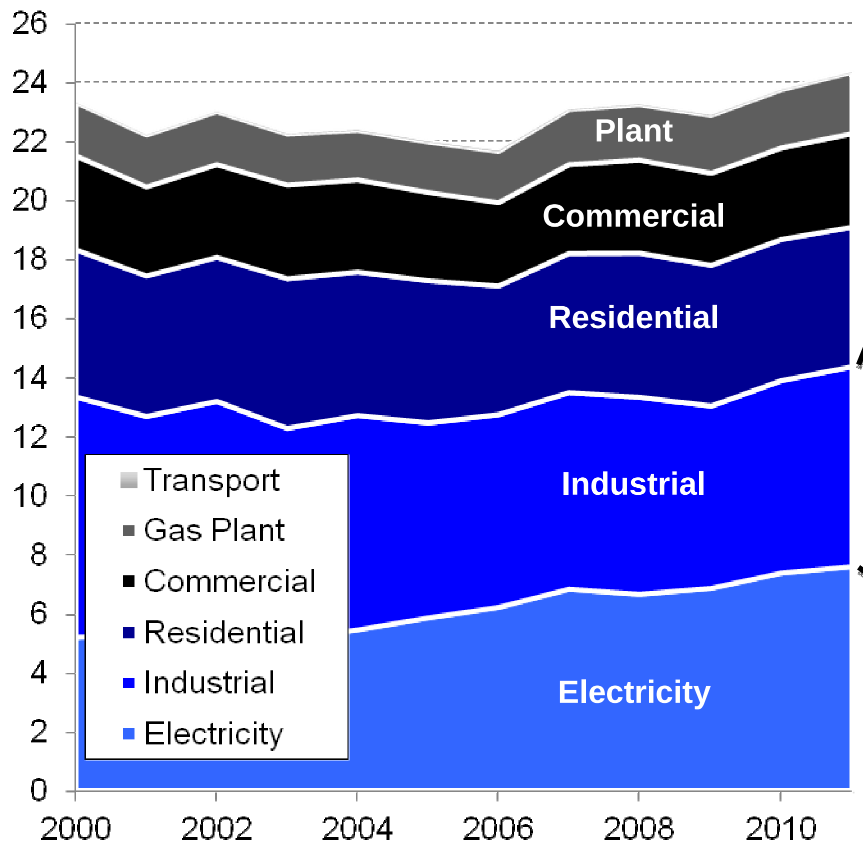
Comparison of coal and gas-fired power generation levels in the U.S. since January 2008
TWhrs



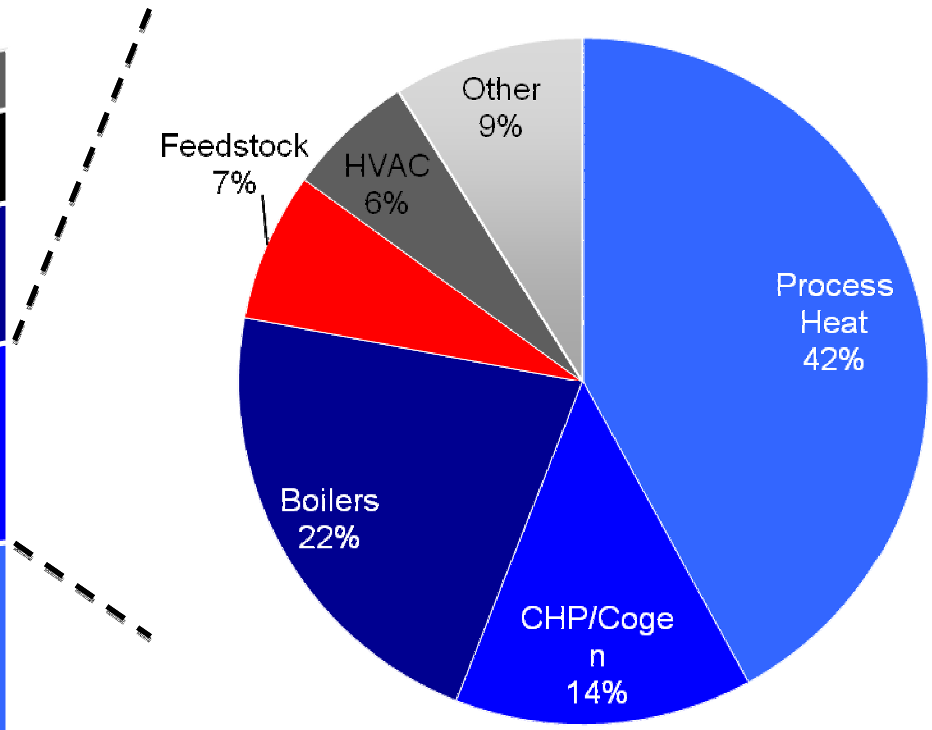
Source: F. O'Sullivan, United States Energy Information Administration

Natural gas has a much more complex consuming base than coal – In the industrial sector some gas is used as a feedstock; however, it mainly used for heat

US natural gas consumption by consumer type between 2000 and 2011
Tcf of gas



Breakdown of 2011 industrial natural gas use
% of total. 100% = 6.8 Tcf



Source: EIA