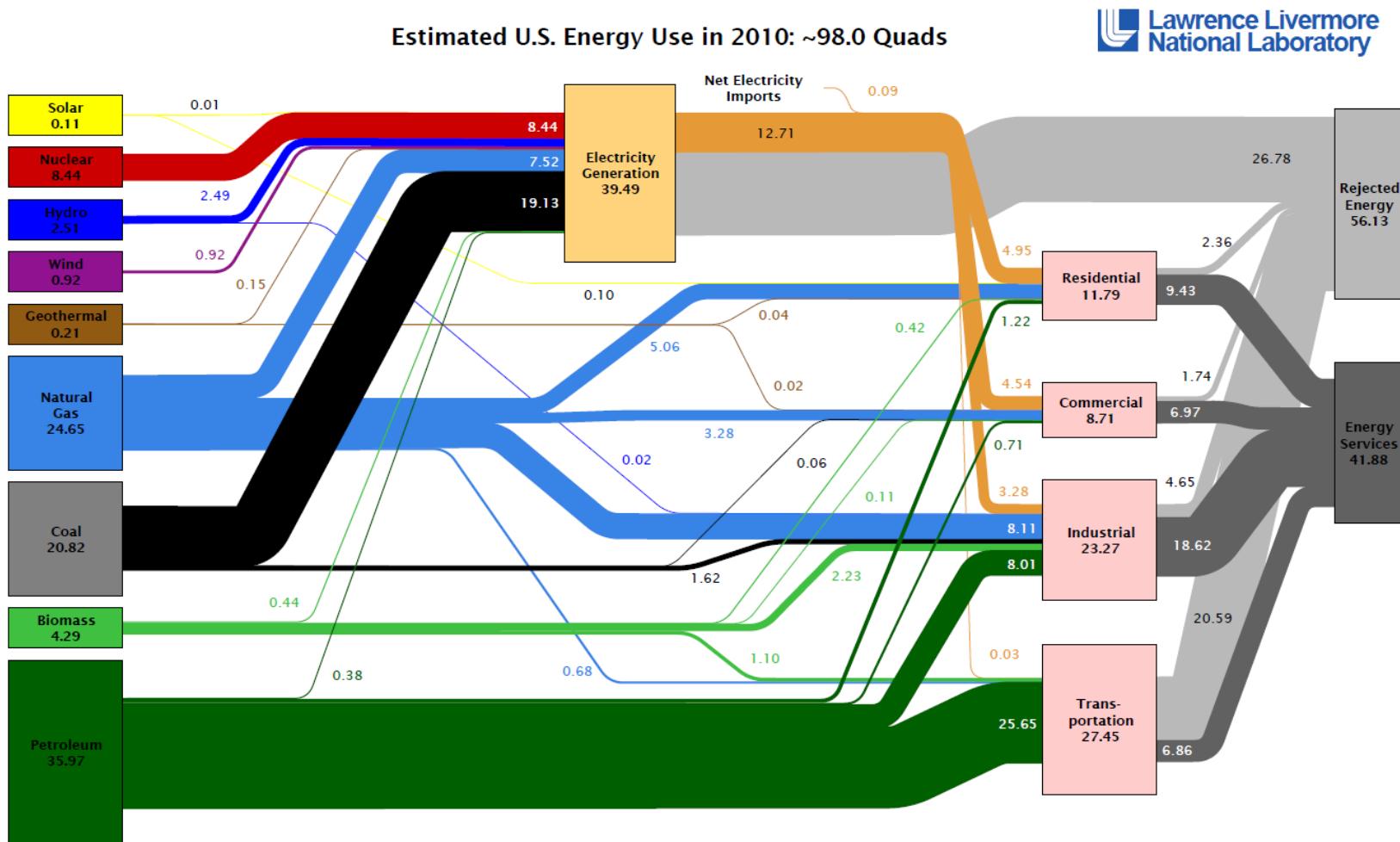


Non-Renewable Energy Resources

Lecture 15

Non-Renewable Resources: 92% of US Primary Energy

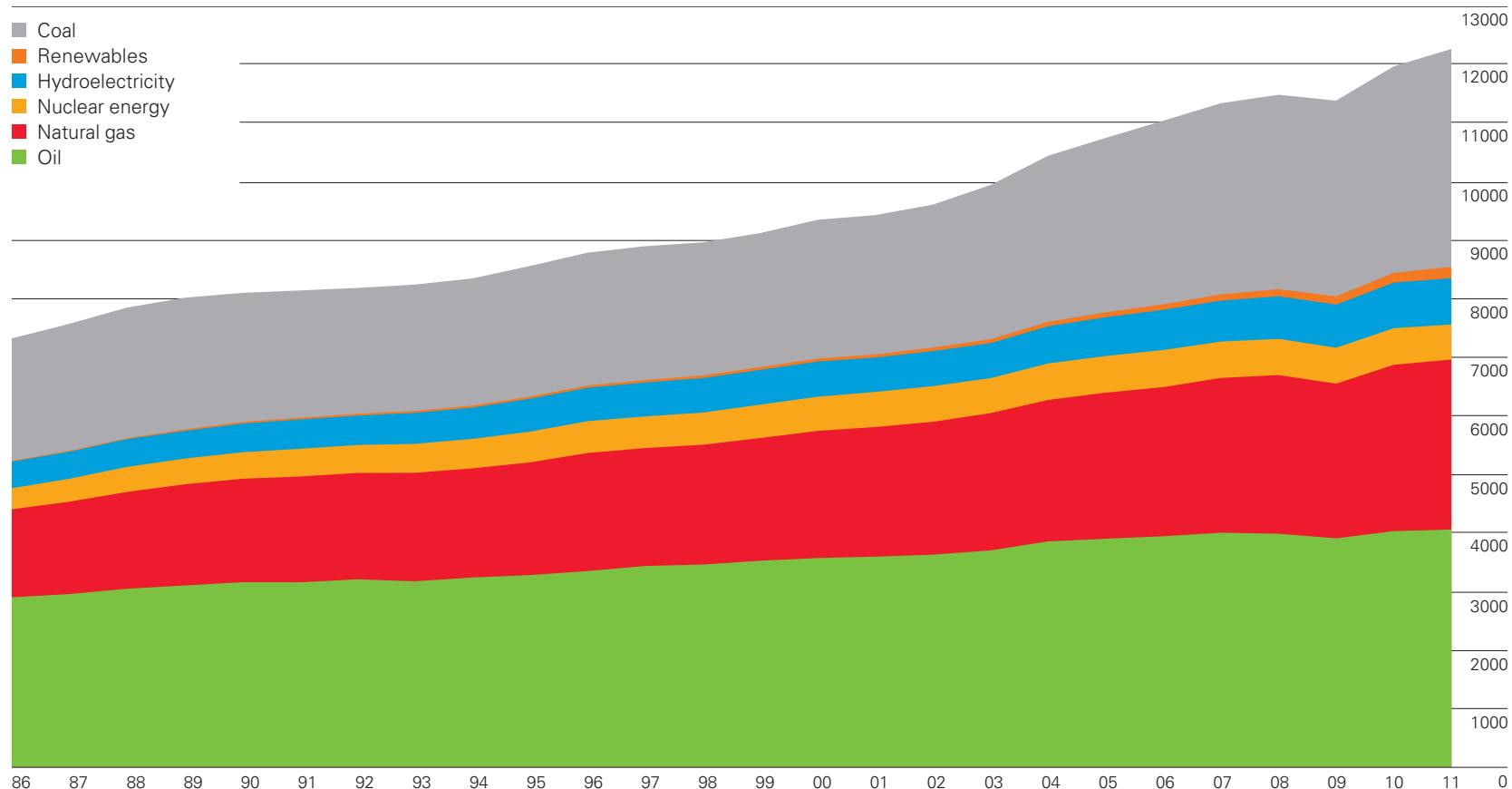


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Also 92% of World Marketed Primary Energy

World consumption

Million tonnes oil equivalent

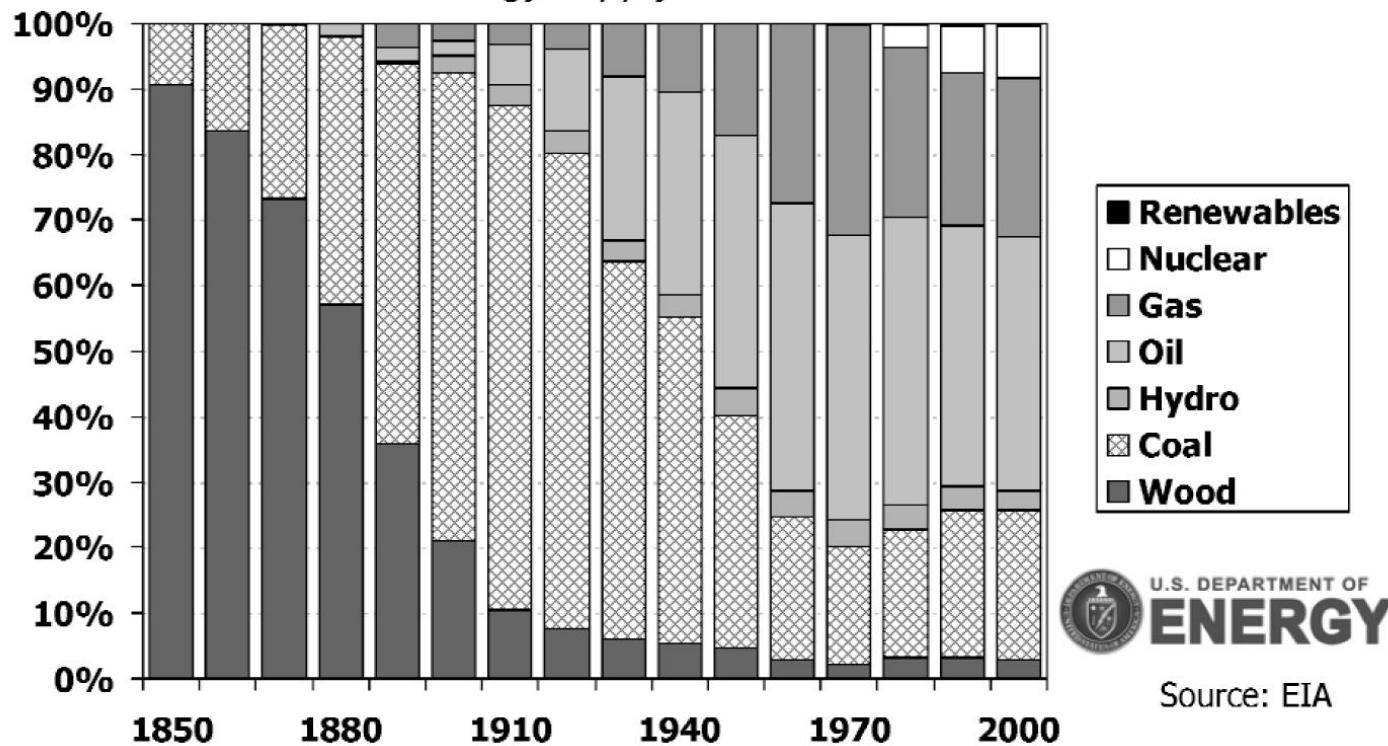


World primary energy consumption grew by 2.5% in 2011, less than half the growth rate experienced in 2010 but close to the historical average. Growth decelerated for all regions and for all fuels. Oil remains the world's leading fuel, accounting for 33.1% of global energy consumption, but this figure is the lowest share on record. Coal's market share of 30.3% was the highest since 1969.

Non-Renewables Likely Dominant for Many More Decades

Energy technologies change slowly

US energy supply since 1850



Source: EIA

Topics

- Economic theory of non-renewable resources
 - Classic Hotelling theory
 - Recent advances & implications
- Some basic facts about the markets for
 - Petroleum
 - Coal
 - Uranium
 - Natural gas, Part 1

Classic Hotelling Theory: The Timing Decision

- Suppose you own a well containing exactly 1,000 barrels of oil. Each barrel can be produced for \$30. You have complete flexibility as to when to produce the oil. Currently the price of oil is \$80 per barrel.
- If you knew future oil prices, how would you decide when to produce your oil?
 - Pick t (or t_s) to max discounted net revenue: $(P_t - MC)/(1 + R)^t$
- If *all* the oil in the world is produced from oil wells *exactly* like yours, what will happen to the price of oil?
 - $(P_t - MC)/(1 + R)^t = (P_0 - MC) > 0$; $(P - MC)$ rises at interest rate
 - If LHS < RHS, raise output today, which lowers today's price...
 - Note: $P > MC$ despite competition; today's output lowers later revenue; there is an opportunity cost of producing today

Classic (Hotelling) Theory II

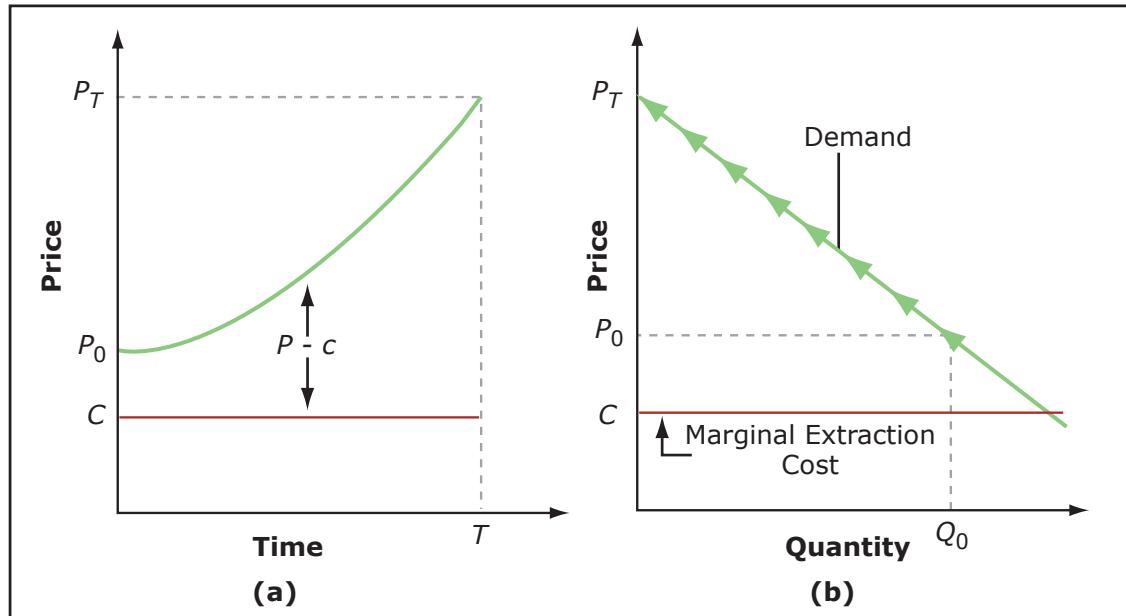


Image by MIT OpenCourseWare.

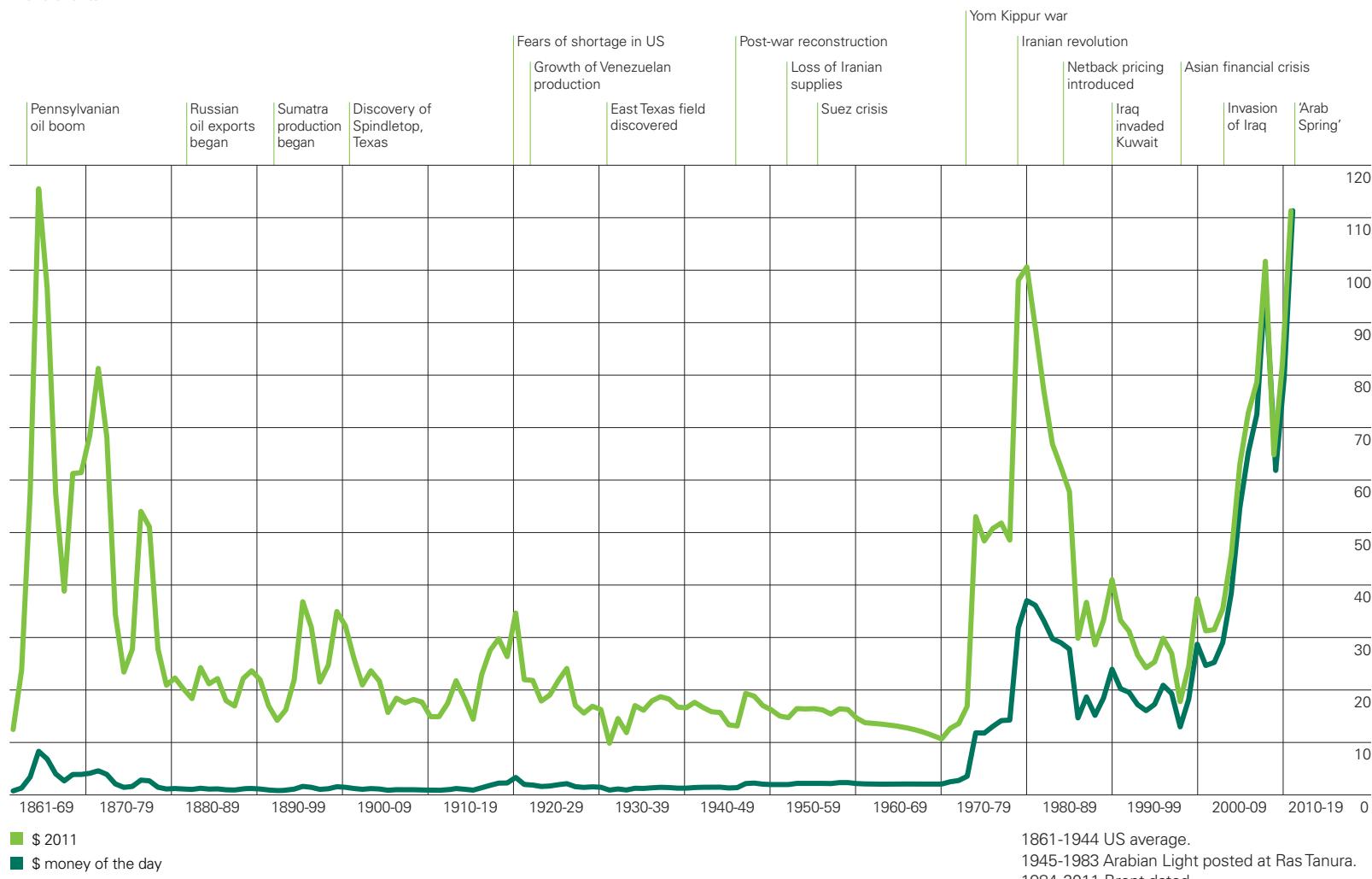
- Under those assumptions, when should you produce your oil?
 - Doesn't matter
- What if a monopoly has 99.5% of all oil, $MC = \$30$?
 - $(MR - MC)$ rises at rate R ; P typically rises more slowly, so produce NOW

But Prices of Non-Renewables Don't Rise Smoothly!

Crude oil prices 1861-2011

US dollars per barrel

World events



What's Missing from the Classic Theory?

- **Exploration:** Reserves are an *inventory*; decisions to search, to prove, & to drill are intertemporal choices, like classic model.
 - End 1976 to end 2009, US proved reserves ↓ 10.26 B bbl.; production?
 - Production during that period was 78.45 B bbl.
- **Depletion:** Costs of finding, extracting likely to rise as more is produced from any given area (e.g., US).
- **Innovation:** Technologies for finding, extracting improve over time – a race with depletion.
- **Uncertainty:** Future demand, supply are not known.
- **SR Inflexibility:** Simple model over-states flexibility in output choice – little SR supply flex for oil + inelastic demand ⇒ SR P volatility.
- **Cartel Behavior:** OPEC behavior is complicated
- **Politics:** Why else drill miles deep, miles offshore when it is much cheaper to produce in the Middle East?

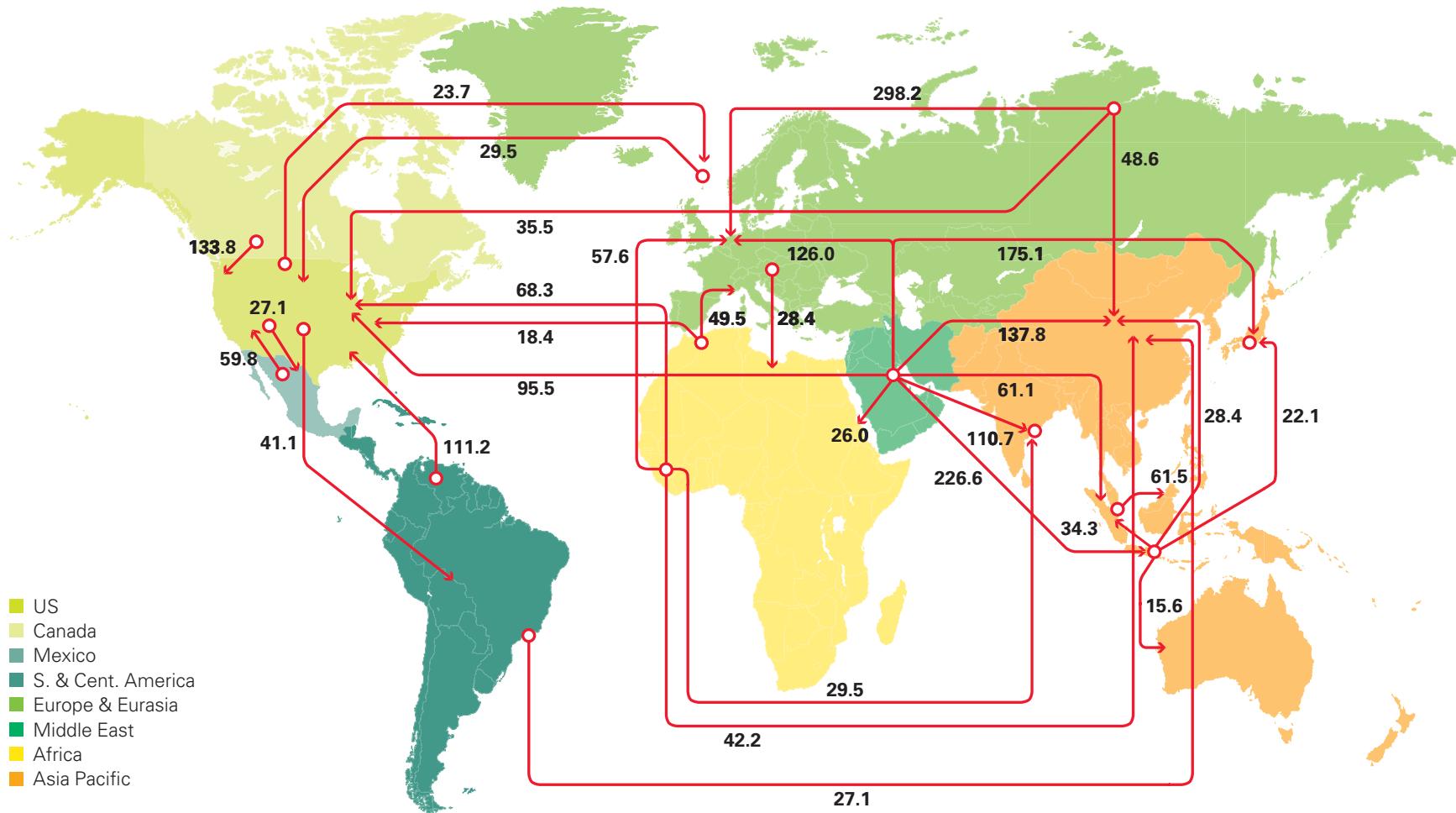
Basic Market Facts: Oil

- Transport (pipelines, ships) relatively cheap; market has been global (single pool) since at least 1970s
 - Active spot and *futures* markets, with good data; the latter used for hedging and speculation
- Production is concentrated geographically, reserves even more so; much of both in unstable nations
- OPEC is a cartel of the big (national) oil firms, power has varied; Saudi Arabia has historically been the main holder of excess capacity
- As we have seen, price has been volatile since the 1973-74 embargo

International Oil Trade: 65% of Production

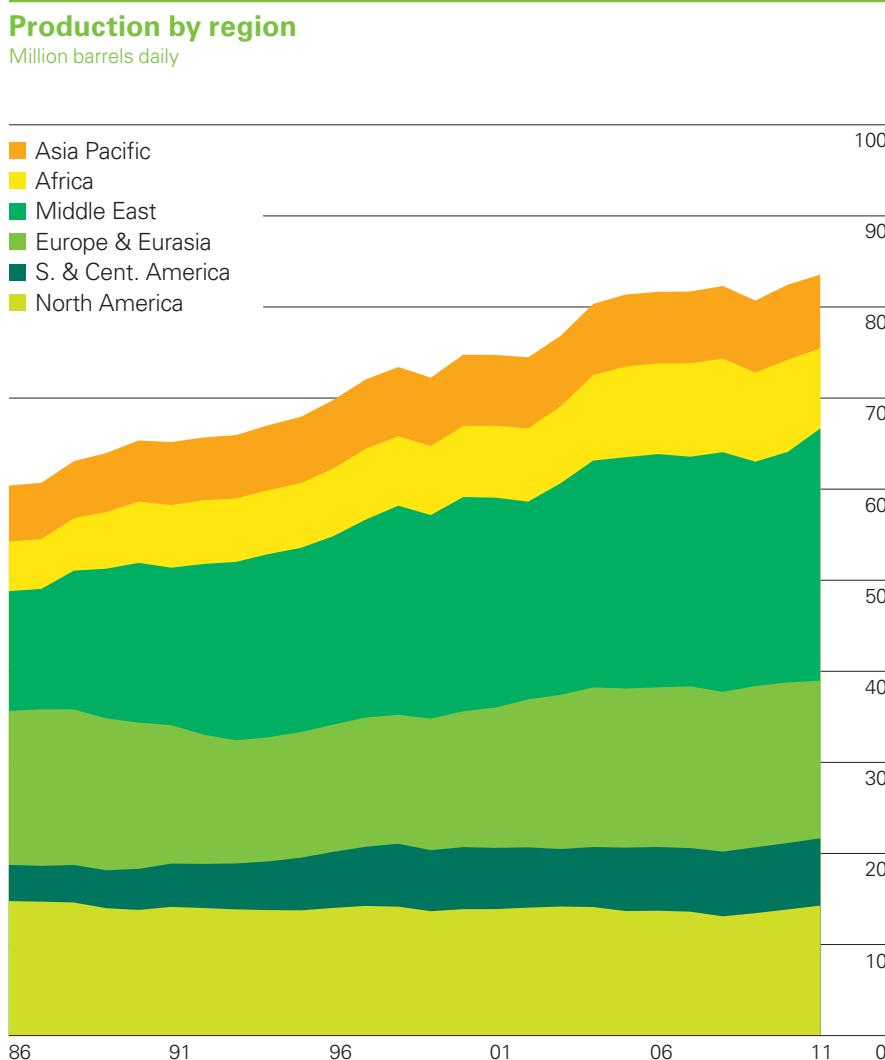
Major trade movements 2011

Trade flows worldwide (million tonnes)



Courtesy of BP Statistical Review of World Energy June 2012. Used with permission.

Middle East: 30% of World Production



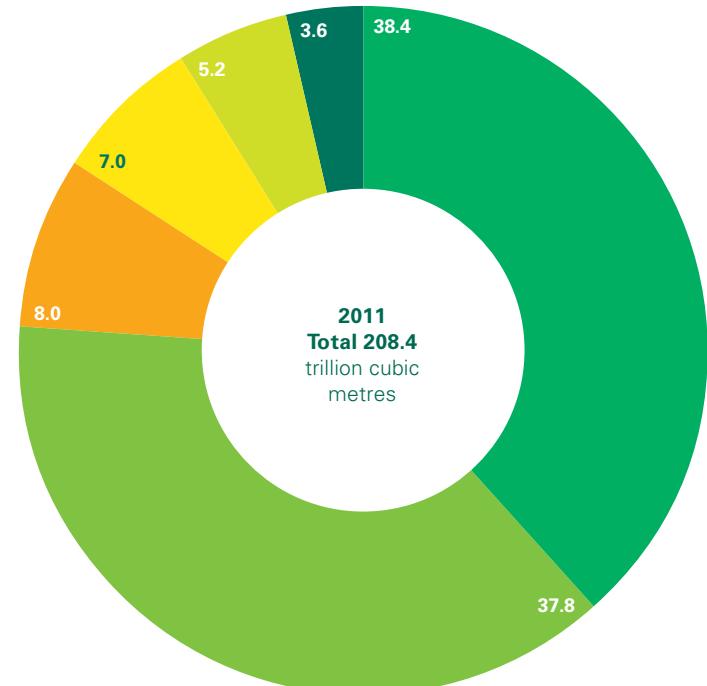
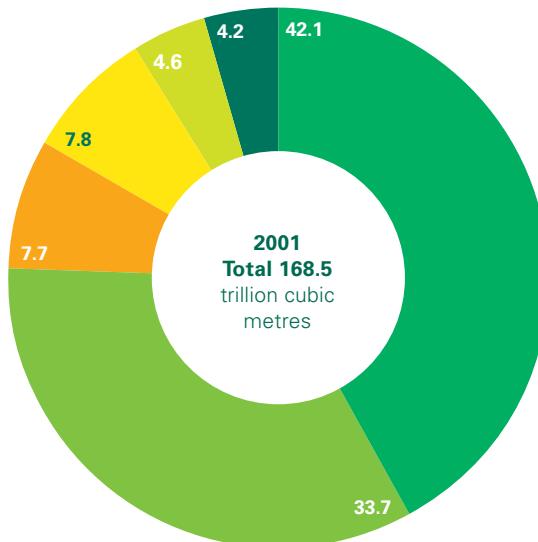
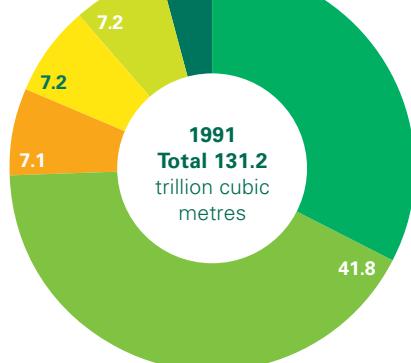
Courtesy of BP Statistical Review of World Energy June 2012. Used with permission.

Middle East: Over Half of Proved Reserves

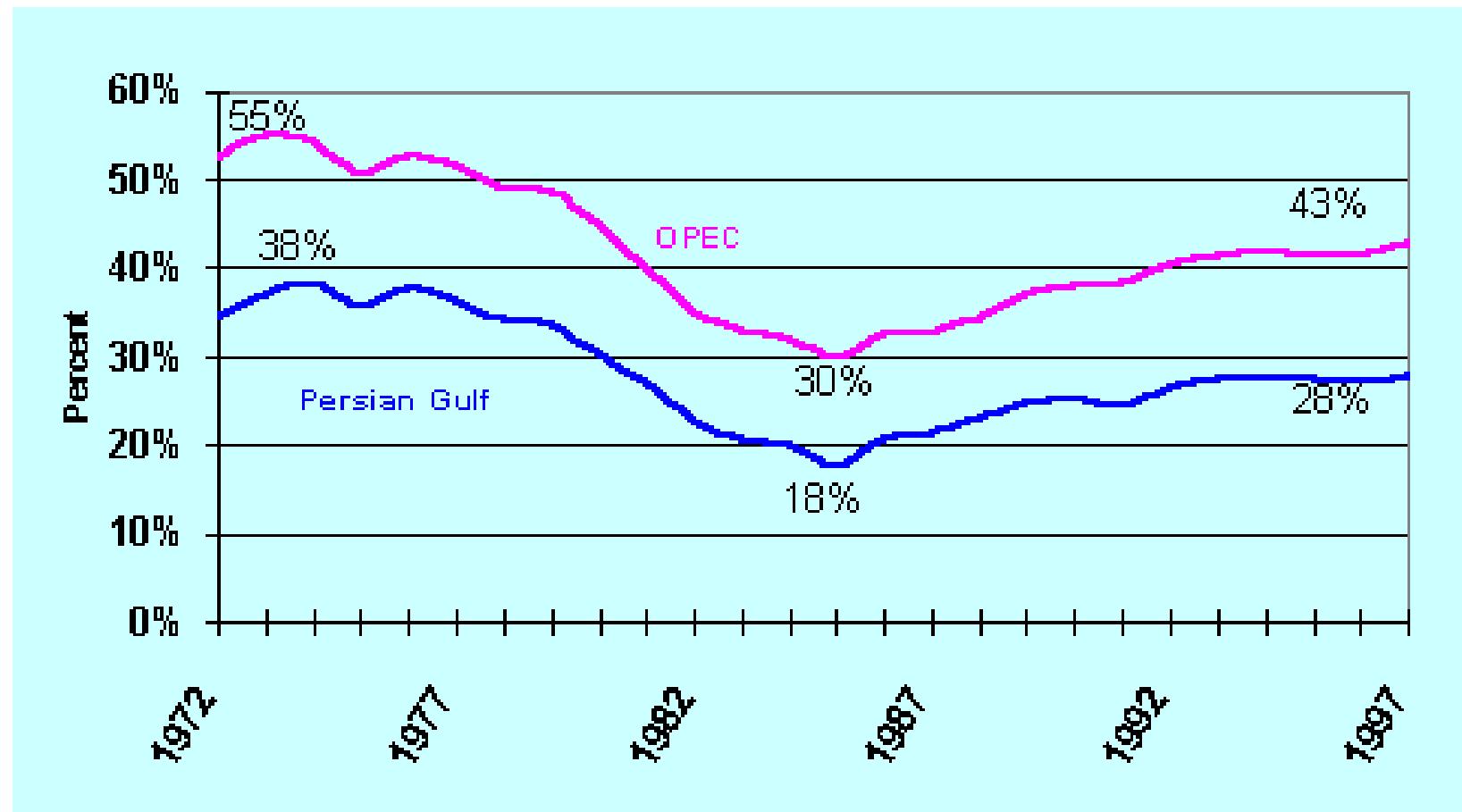
Distribution of proved reserves in 1991, 2001 and 2011

Percentage

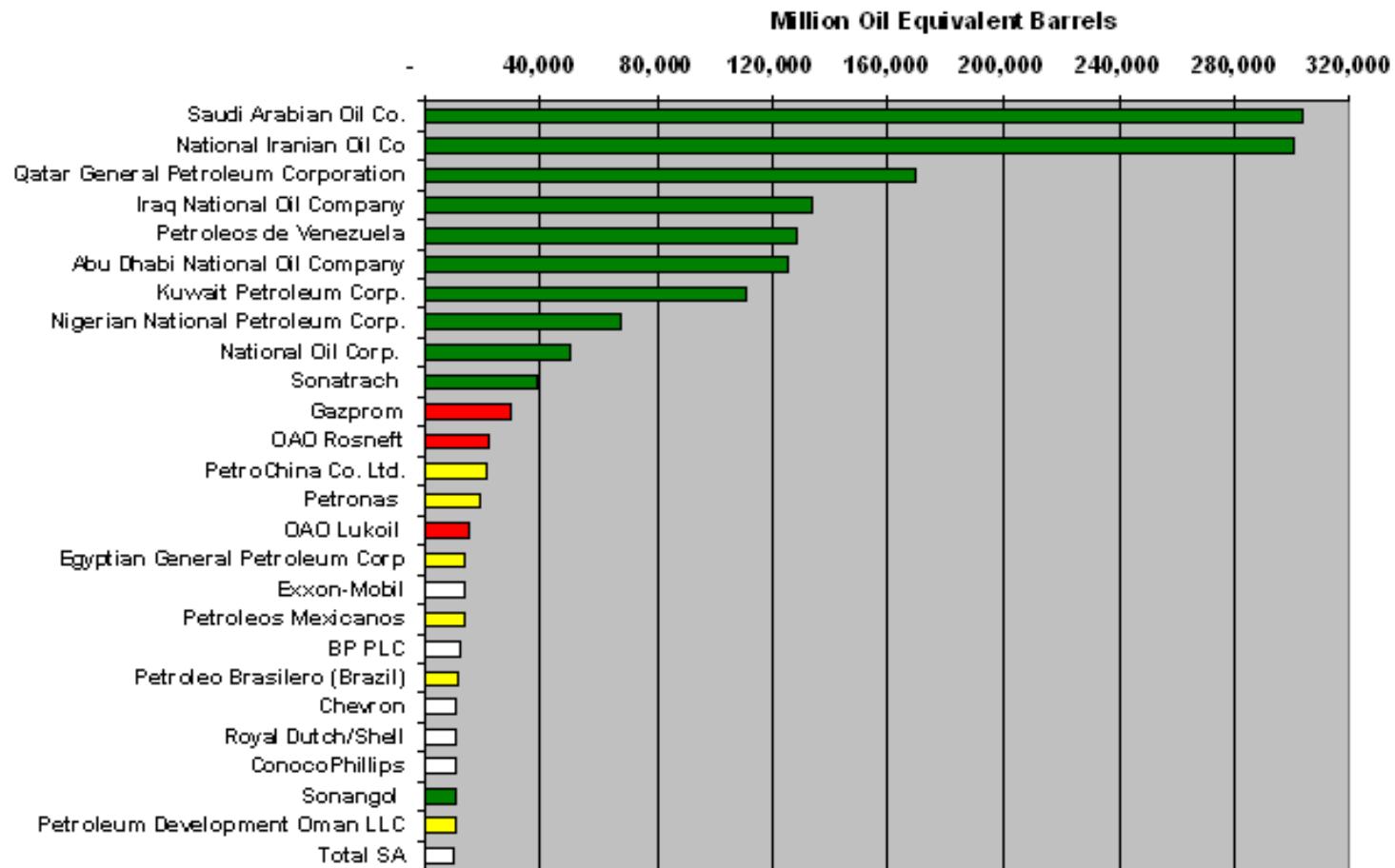
- Middle East
- Europe & Eurasia
- Asia Pacific
- Africa
- North America
- S. & Cent. America



OPEC's Share of World Output Has Varied



The Big Oil/Gas Companies are National



Companies ranked in order of 2007 worldwide oil equivalent oil/gas reserves as reported in "OGJ 200/100", *Oil & Gas Journal*, September 15, 2008.

Basic Market Facts: Coal

- Reserves, production concentrated in a few leading nations in several regions
- Mainly moved by rail and ship; high weight-to-value ratio limits trade
- Markets tend to be mainly national; US has abundant supplies, relatively low prices, regional differences
- Long-term contracts dominate; spot and (since 2001) futures markets less important
- **Huge** recent increase in Chinese use of coal

Production, Reserves Fairly Concentrated

	<u>2010, Pct. of World</u>	
	Output	Reserves
China	48.3	13.3
United States	14.8	27.6
Australia	6.3	8.9
India	5.8	7.0
Russia	4.0	18.2
Total	79.2	75.0

Coal Exports: 15% of Production

Leading Exporters, 2010

Country	Share
Australia	27.1
Indonesia	26.1
Russia	10.1
U.S.	6.9

Leading Importers, 2010

Country	Share
Japan	17.5
China	16.6
S. Korea	10.7
India	8.6

Prices Differ; Not a Global Market

US dollars per tonne	Northwest Europe market price	US Central Appalachian coal spot price index	Japan coking coal import cif price	Japan steam coal import cif price
1990	43.48	31.59	60.54	50.81
1991	42.80	29.01	60.45	50.30
1992	38.53	28.53	57.82	48.45
1993	33.68	29.85	55.26	45.71
1994	37.18	31.72	51.77	43.66
1995	44.50	27.01	54.47	47.58
1996	41.25	29.86	56.68	49.54
1997	38.92	29.76	55.51	45.53
1998	32.00	31.00	50.76	40.51
1999	28.79	31.29	42.83	35.74
2000	35.99	29.90	39.69	34.58
2001	39.03	50.15	41.33	37.96
2002	31.65	33.20	42.01	36.90
2003	43.60	38.52	41.57	34.74
2004	72.08	64.90	60.96	51.34
2005	60.54	70.12	89.33	62.91
2006	64.11	62.96	93.46	63.04
2007	88.79	51.16	88.24	69.86
2008	147.67	118.79	179.03	122.81
2009	70.66	68.08	167.82	110.11
2010	92.50	71.63	158.95	105.19

*Source: McCloskey Coal Information Service. Prices for 1990-2000 are the average of the monthly marker, 2001-2010 the average of weekly prices.

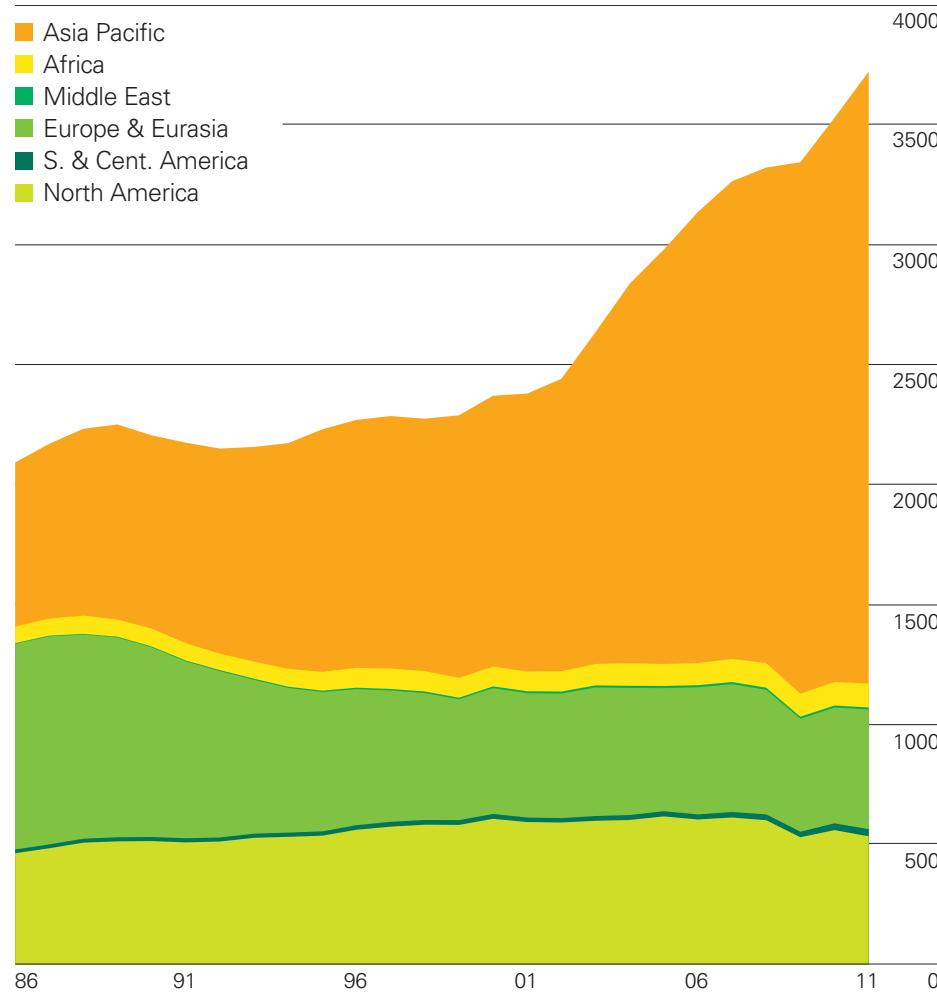
**Source: Platts. Prices are for CAPP 12,500Btu, 1.2 SO₂ coal, fob. Prices for 1990-2000 are by coal price publication date, 2001-2010 by coal price assessment date.

Note: CAPP = Central Appalachian; cif = cost + insurance + freight (average prices); fob = free on board.

Large Increase in Chinese Coal Use

Consumption by region

Million tonnes oil equivalent



Courtesy of BP Statistical Review of World Energy June 2012. Used with permission.

US: Production Concentrated, Usage Less So

Leading States' % Shares of Total US 2007 Coal

	<u>Production</u>		<u>Consumption*</u>
Wyoming	39.6	Texas	9.8
West Virginia	13.4	Ohio	6.6
Kentucky	10.1	Indiana	5.8
Pennsylvania	5.7	Illinois	5.4
Montana	3.8	Pennsylvania	5.3
Total	72.5	Total	33.0

*For electric power only, 93.3% of total consumption

Basic Market Facts: Uranium

- Market for uranium is global; economically recoverable reserves fairly dispersed:
- Low prices caused mine closures through the mid-90s
- Subsequent tripling of prices then through 2010 induced new mining activity
- No organized market; Long-term contracts dominate; short-term volatility on (thin) spot market

Known Recoverable Resources* of Uranium 2007

	tonnes U	percentage of world
Australia	1,243,000	23%
Kazakhstan	817,000	15%
Russia	546,000	10%
South Africa	435,000	8%
Canada	423,000	8%
USA	342,000	6%
Brazil	278,000	5%
Namibia	275,000	5%
Niger	274,000	5%
Ukraine	200,000	4%
Jordan	112,000	2%
Uzbekistan	111,000	2%
India	73,000	1%
China	68,000	1%
Mongolia	62,000	1%
other	210,000	4%
World total	5,469,000	

Courtesy of World Nuclear Association. Used with permission.

Global Market, Production Fairly Concentrated

- EIA: 92% of uranium delivered in 2010 was imported:
 - 44% from Australia and Canada
 - 33% from Kazakhstan, Russia, & Uzbekistan
- Production of U_3O_8 is more concentrated than reserves:

2010 Production Shares	
Country	Share
Kazakhstan	33.2
Canada	18.2
Australia	11.0
Namibia	8.4
Niger	7.8
Russia	6.6
Uzbekistan	4.5
U.S.A.	3.1
Total:	92.8

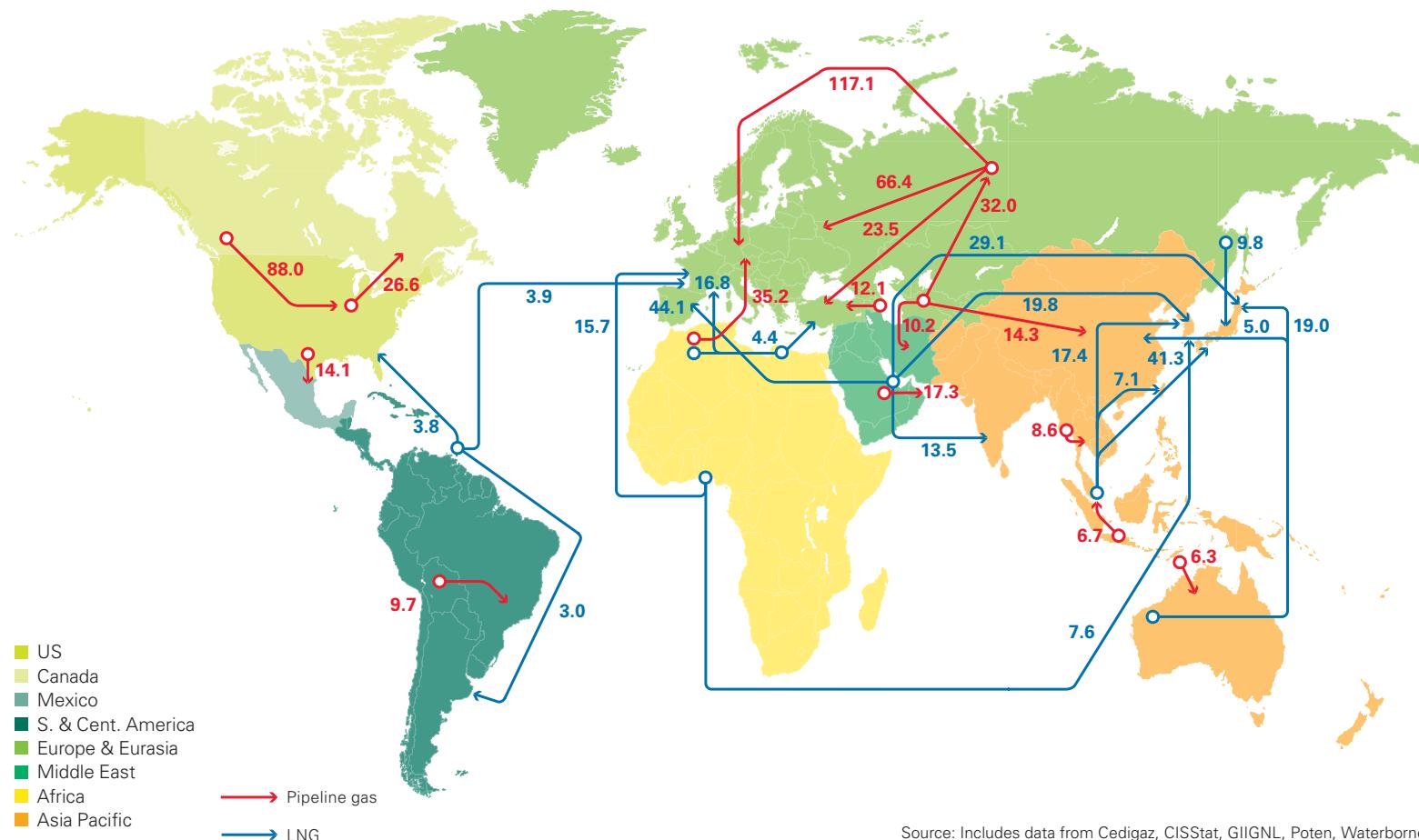
Basic Market Facts: Natural Gas

- “Natural” distinguishes from gas manufactured from coal, in US since 1816 (Baltimore)
- Gas can be moved by pipeline, but must be liquified (expensive) to go by ship (LNG); market is not global
- US supplies: 84% domestic, 12% Canadian
- US prices < EU (Russian gas), << Asia (LNG).
- Gas tends to occur with oil; historically gas reserves also concentrated in unstable regions, **BUT**
- Next class: recent advances in hydraulic fracturing (fracking) make shale gas cheap; lots in the US
 - If exploited, serious market & CO₂ impacts,
 - but also serious environmental issues.

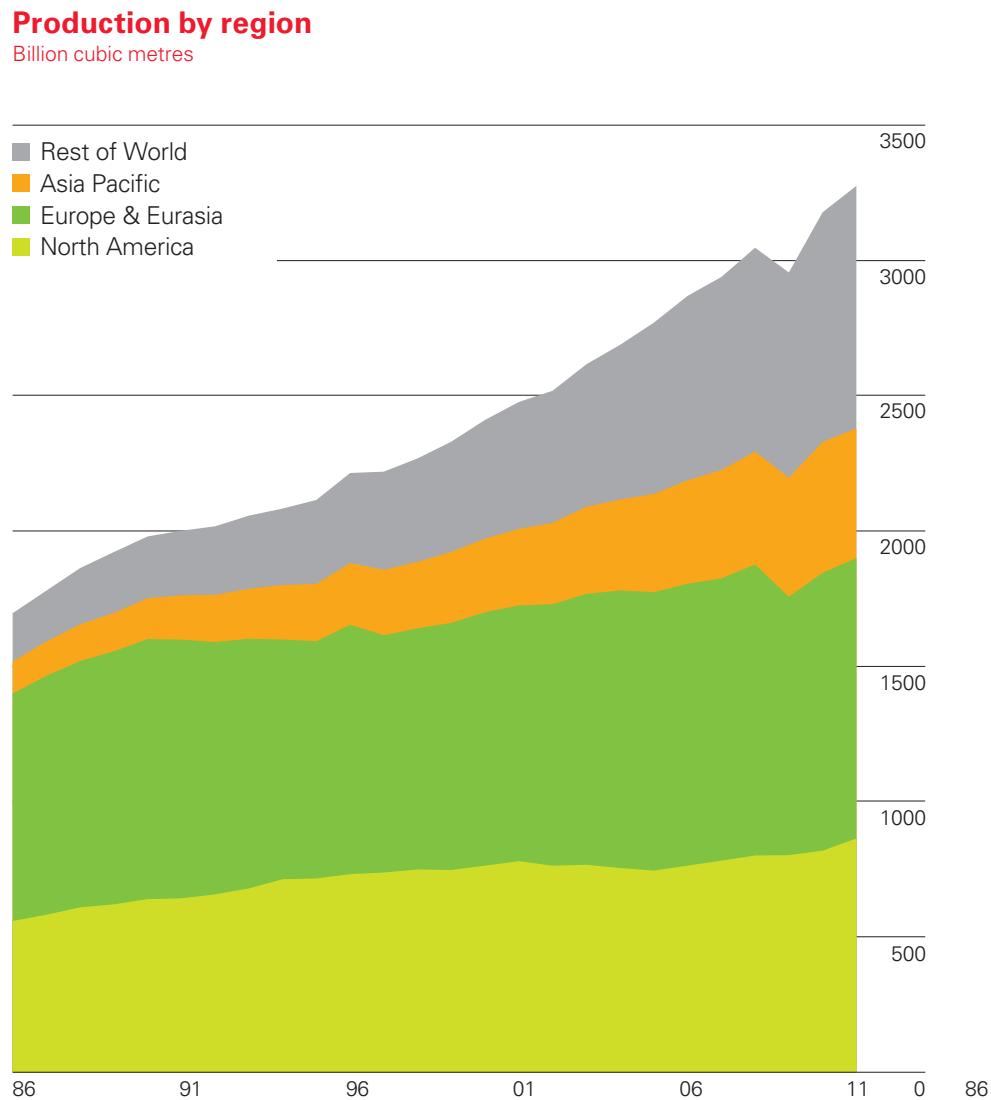
Gas Trade: 31% of Use (69% via pipelines)

Major trade movements 2011

Trade flows worldwide (billion cubic metres)



Output: Russia 15%, Middle East 14%



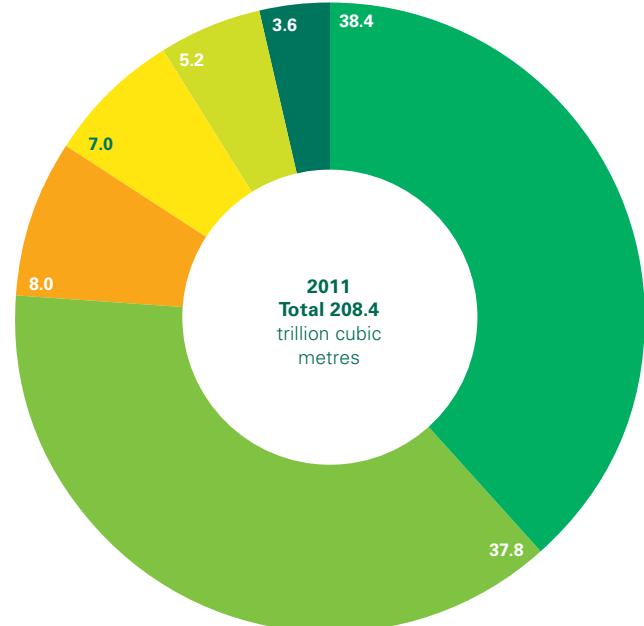
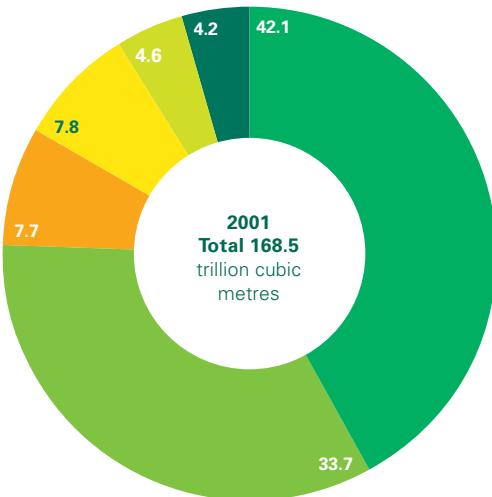
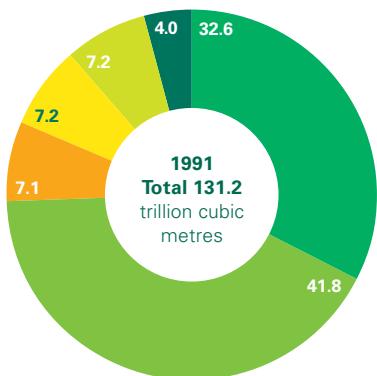
Courtesy of BP Statistical Review of World Energy June 2012. Used with permission.

Proved Reserves: Russia 24%, Middle East 40%, US 5%

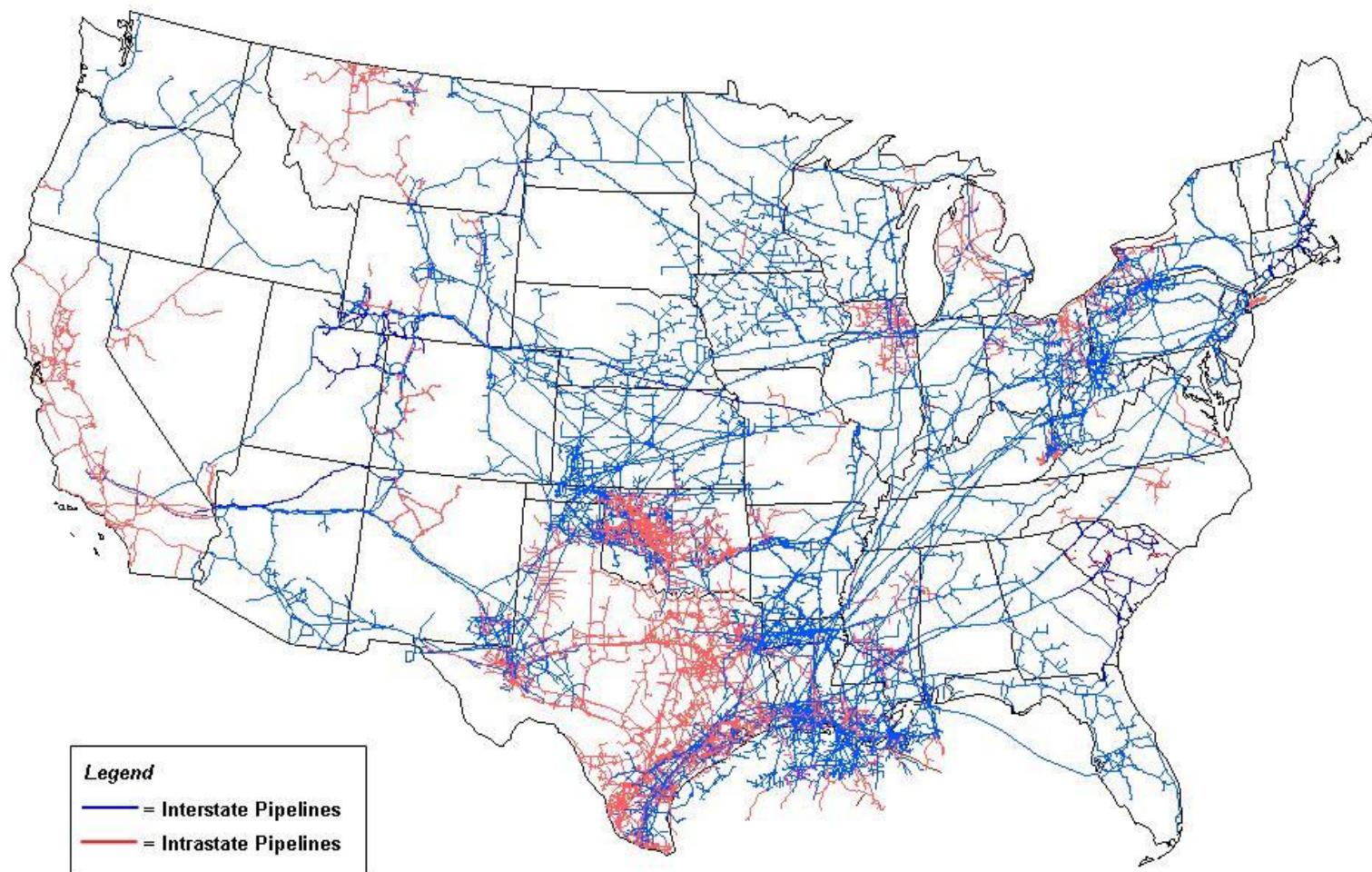
This picture will change...

Distribution of proved reserves in 1991, 2001 and 2011
Percentage

- Middle East
- Europe & Eurasia
- Asia Pacific
- Africa
- North America
- S. & Cent. America



The US Natural Gas Pipeline Network



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

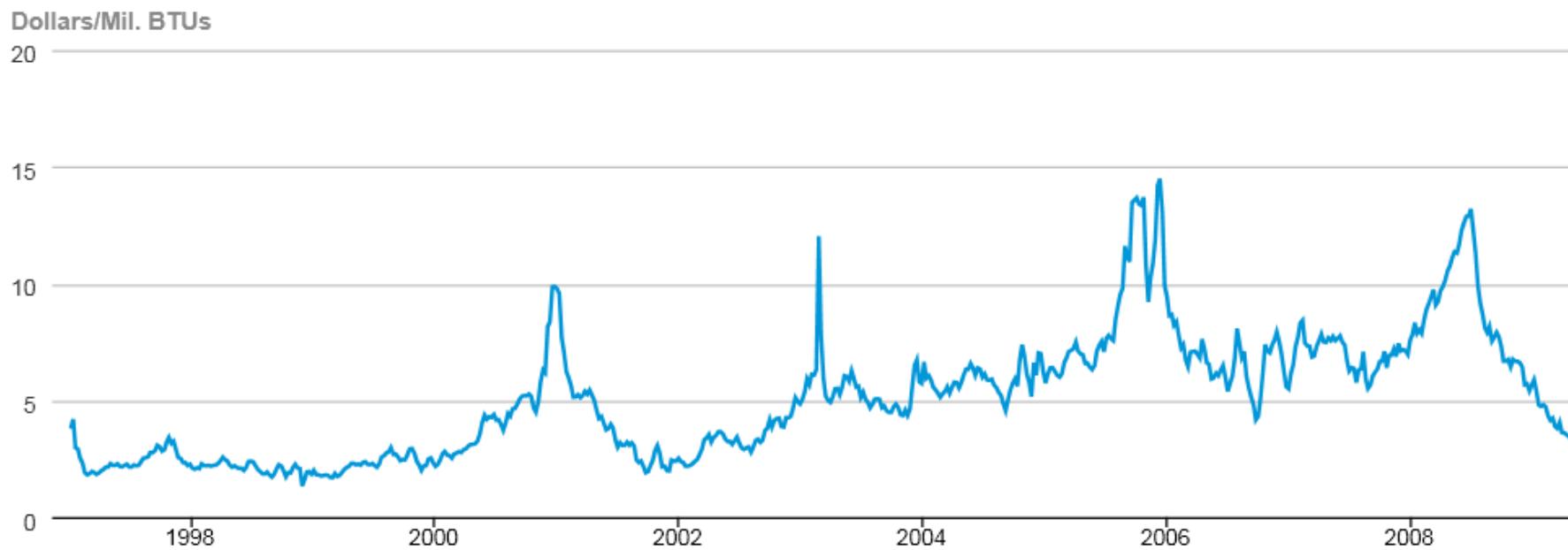
The “Henry Hub” is in south-central Louisiana; a junction of 13 pipelines; the pricing point for futures contracts.

Three Regional Markets, For Now...?



US Prices Historically Volatile

Henry Hub Gulf Coast Natural Gas Spot Price



Source: EIA. Weekly averages shown; most recent years omitted.

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