Energy: Its Sources, Uses & Impact
Part 1

Osher Lifelong Learning Institute

At Tufts University

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Energy Policy = Choice of Fuel(s)

“Use What You Have!”

BP “Six Megatrends”

1. Energy transitions and the dominant fuel

- Over time the energy sector experiences major transitions. For centuries, wood was the dominant fuel, then coal and now oil. As the 21st century develops, gas is now growing faster than any other fossil fuel - and renewables faster still.
- With these changes in energy types, allied with sharp changes in prices, you have a complex scenario. The world is changing dramatically: from a supply and demand perspective, a geopolitical perspective and, importantly, from a climate policy perspective. The 2015 Paris agreement, which aims to keep the global temperature rise this century to well below 2°C, will dictate the speed of these transitions.

2. Oil supply

- Over the past two decades, the energy world has moved from a situation where oil supply would peak and decline, to a situation where oil is so plentiful it has driven prices sharply downwards. That means a change in thinking is needed.
- The focus is now much more around peak oil from a demand side; that there will be a period when demand for oil will peak and then gradually start to decline. Broad consensus suggests that this ‘peak oil’ window is most probably somewhere between 2025 and 2040, but there is considerable uncertainty surrounding this.

3. Gas supply

- Natural gas resembles oil in being plentiful but differs in being used mainly for power and industry rather than transport. It has also tended to be traded within regions rather than across a single global market. However, this is changing - the amount of natural gas traded across borders is increasing as liquefied natural gas (LNG) surpasses pipeline imports as the dominant form of traded gas in the next 20 years.
- As with oil, there is a lot of gas available very cheaply. Nowhere in our demand forecasts for the next few decades do we see gas peaking, unlike oil. Of course, from a carbon perspective, it has half the CO_2 emissions of coal when burnt to produce power.

BP Six Megatrends

4. Growth of renewables

- BP is preparing for a world where power comes increasingly from renewable sources. Wind and solar power have been growing faster than fossil fuels, though from a low base and with the benefit of government subsidies in many regions. Now, in many situations, they are becoming competitive with fossil fuels and are poised to deliver substantial shares of energy.
- The growth of renewables has exceeded pretty much all forecasts. There has been double-digit growth for wind and solar in the past few years and because the manufacturing costs have come down as well, cost reductions have been about 80% in solar and about 50% in wind. However, what that ignores is the cost of intermittency because, of course, the sun does not shine all the time and the wind does not blow all the time. Therefore, in many places the existing grid and the existing fossil system are used to back up supply when energy from renewables is not available.

5. Electrification

- The transport sector is set to change significantly, with electric vehicles, driverless - or autonomous - vehicles and new types of business.
- I think there is no forecast anywhere that does not expect demand for electricity to grow and for electricity to become a more important part of the energy mix. There is also a sort of consumer desirability for newer electric vehicles, like the current Teslas, the new Tesla Model 3 that will be coming out at a much more competitive price and the BMW i8.
- I think the interesting area is the combination of vehicle electrification with new methods of mobility, car-pooling and ride-sharing such as we are seeing with the likes of Hailo and Uber. And the impact of vehicle autonomy could be enormous but the uncertainty range is large

6. Changes in demand

- The demographics of emerging economies and the demands of millennials - those born post-1980 - are likely to change consumption and work patterns. In the older economies, patterns of demand are changing with the generations. There is virtually no energy growth in the OECD (Organization for Economic Cooperation and Development) countries, particularly because of efficiency gains.
- Strong economic growth will mean the emerging economies - the non-OECD countries - are likely to account for nearly all of the energy growth in the coming decades.

Basic Comparisons

	China	USA	India	Japan	Germany	Russia
Population - July 2014 est	1,373,541,278	323,995,528	1,266,883,598	126,702,133	80,722,792	142,355,415
Population Growth Rate	0.45%	0.78%	1.22%	-0.16%	-0.17%	-0.04%
Area - km^2	9,596,960	9,826,675	3,287,263	377,915	357,022	17,098,242
GDP - Purchasing Power Parity ($trillion)	21.2	18.6	8.7	4.9	4.0	3.7
Installed Generating Capacity GW	1,505	1,075	311	313	198	248
% of World at 7089 GW	21%	15%	4%	4%	3%	3%
Electric Production TWh	5,388	4,103	1,218	980	591	1,064
Electric Consumption TWh	5,523	3,913	973	934	533	1,065
Aggregate Load Factor	40.9%	43.6%	44.7%	35.7%	34.1%	49.0%
Natural Gas Production - BCM	123.5	766.2	30.4	4.7	9.5	603.9
Natural Gas Consumption - BCM	181.1	773.2	52.1	131.3	79.2	453.3
Refined Petroleum Products Production - mmbbl/d	10.4	19.9	4.7	3.5	2.2	6.1
Refined Petroleum Products Consumption - mmbbl/d	11.1	19.5	3.7	4.1	2.4	3.7
Coal Production - Million Tonnes Oil Equivalent	1827.0	455.2	283.9	0.7	42.9	184.5
Coal Consumption - Million Tonnes Oil Equivalent	1920.4	396.3	407.2	119.4	78.3	88.7

CIA World Factbook

World Total Installed Electrical Generating Capacity 7,089 GW

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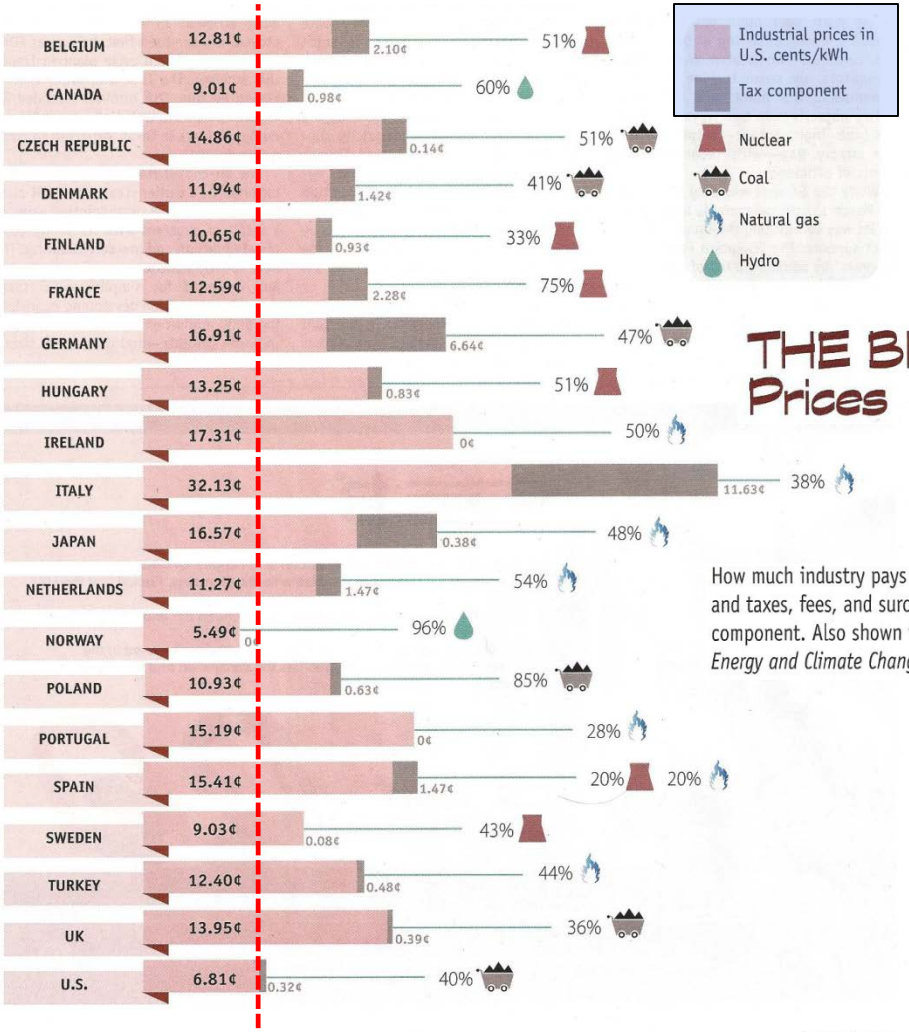
"Practical Strategies for Emerging Energy Technologies"

Ps… .Total Value of Outstanding Student Loans - $1.4 trillion
U.S. health care cost 2014 - $3.2 trillion
U.S. Household Debt 2017 - $12.7 trillion

The Big Picture: World Industrial Power Prices



THE BIG PICTURE: World Industrial Power Prices

How much industry pays for power varies tremendously by country, owing to variations in generation costs, network costs, and taxes, fees, and surcharges. This comparison shows average industrial electricity prices in 2013, with each nation's tax component. Also shown is the fuel source that dominated each nation's power mix in 2013. *Source: UK Department of Energy and Climate Change, Eurostat, International Energy Agency* ***—Copy and artwork by Sonal Patel, associate editor***

Power – “Still in the Dark”

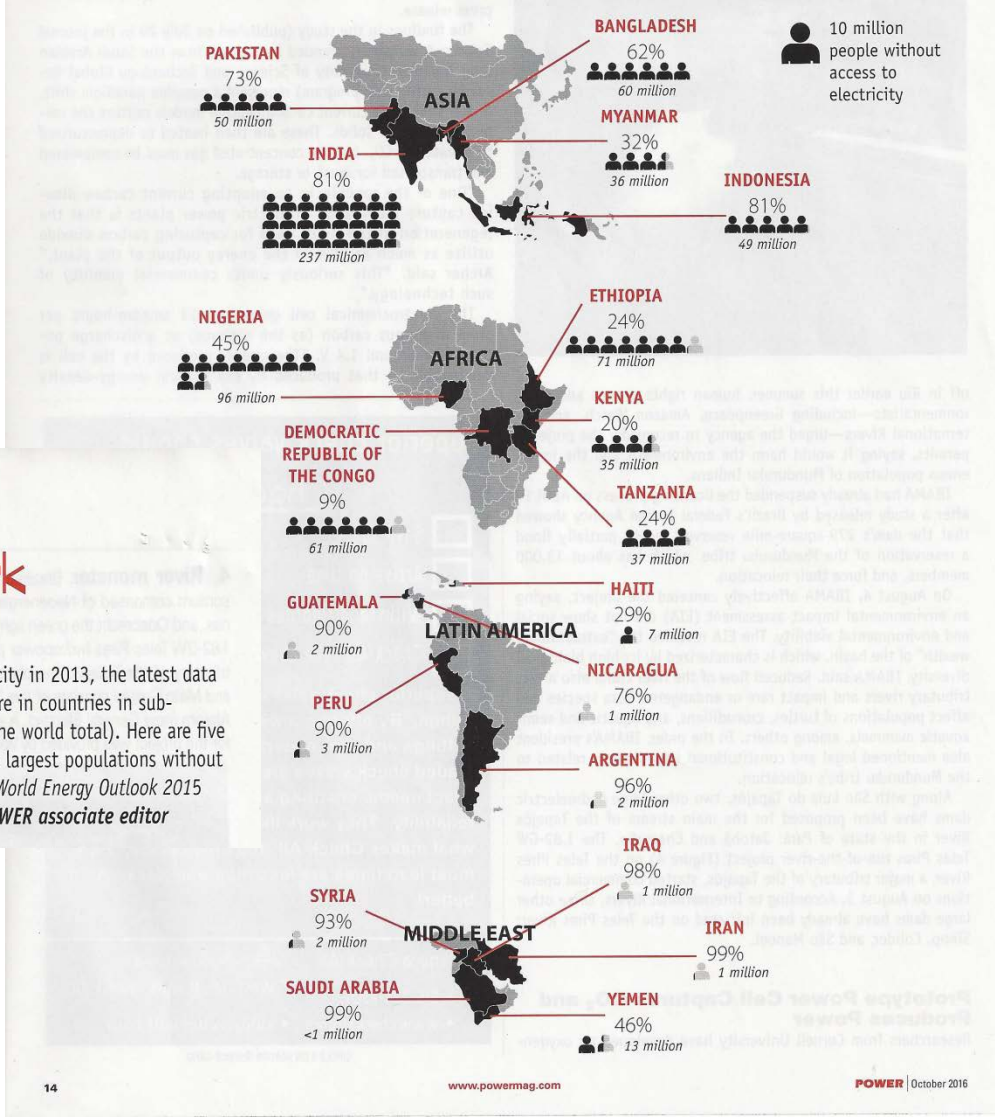
1.2 billion people
17% of Global
Population do not
have access to
electricity

GLOBAL MONITOR

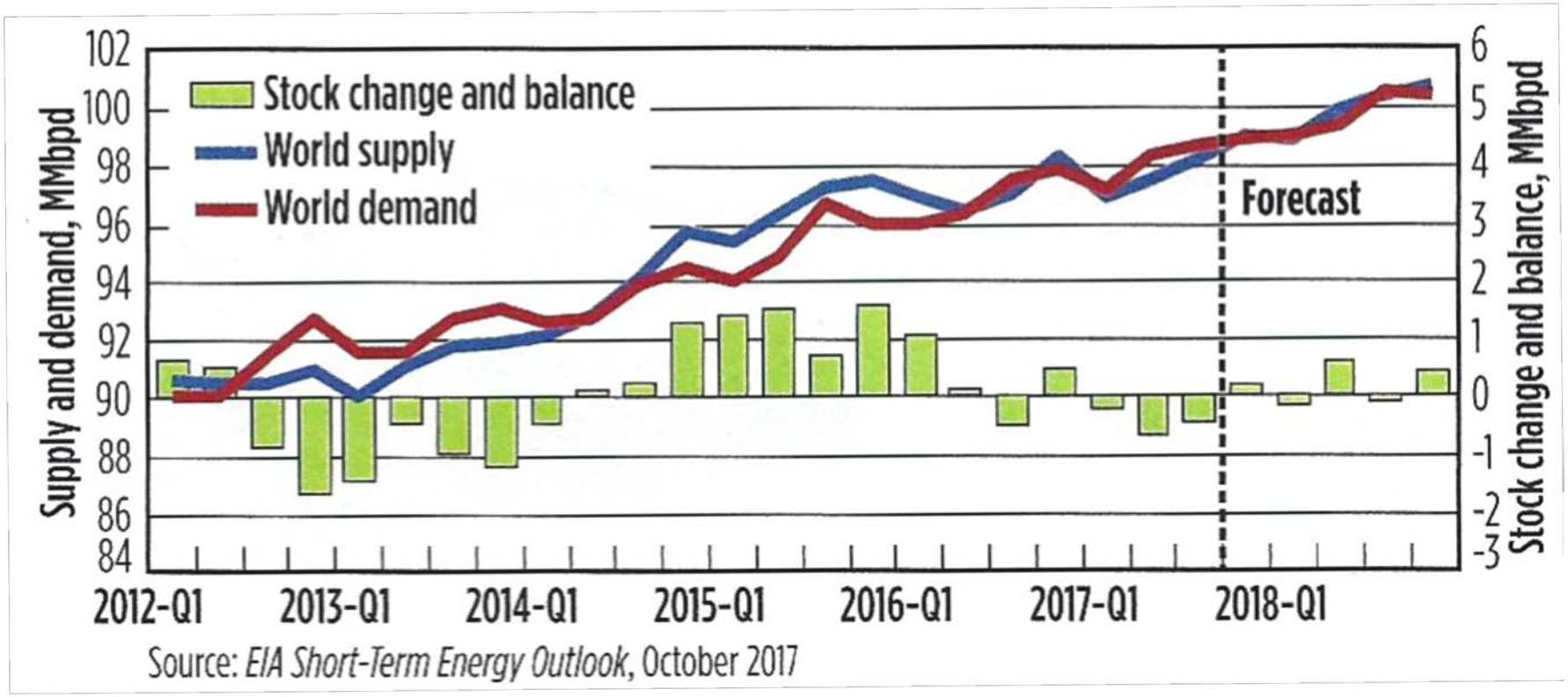
THE BIG PICTURE: Still in the Dark

An estimated 1.2 billion people—17% of the global population—did not have access to electricity in 2013, the latest data from the International Energy Agency show. More than 95% of those living without electricity are in countries in sub-Saharan Africa and developing Asia, and they are predominantly in rural areas (around 80% of the world total). Here are five countries per region (developing Asia, Africa, Latin America, and the Middle East) that have the largest populations without access to electricity. Also noted is that country's national electrification rate (%). *Source: IEA, World Energy Outlook 2015*

—Copy and artwork by Sonal Patel, a POWER associate editor

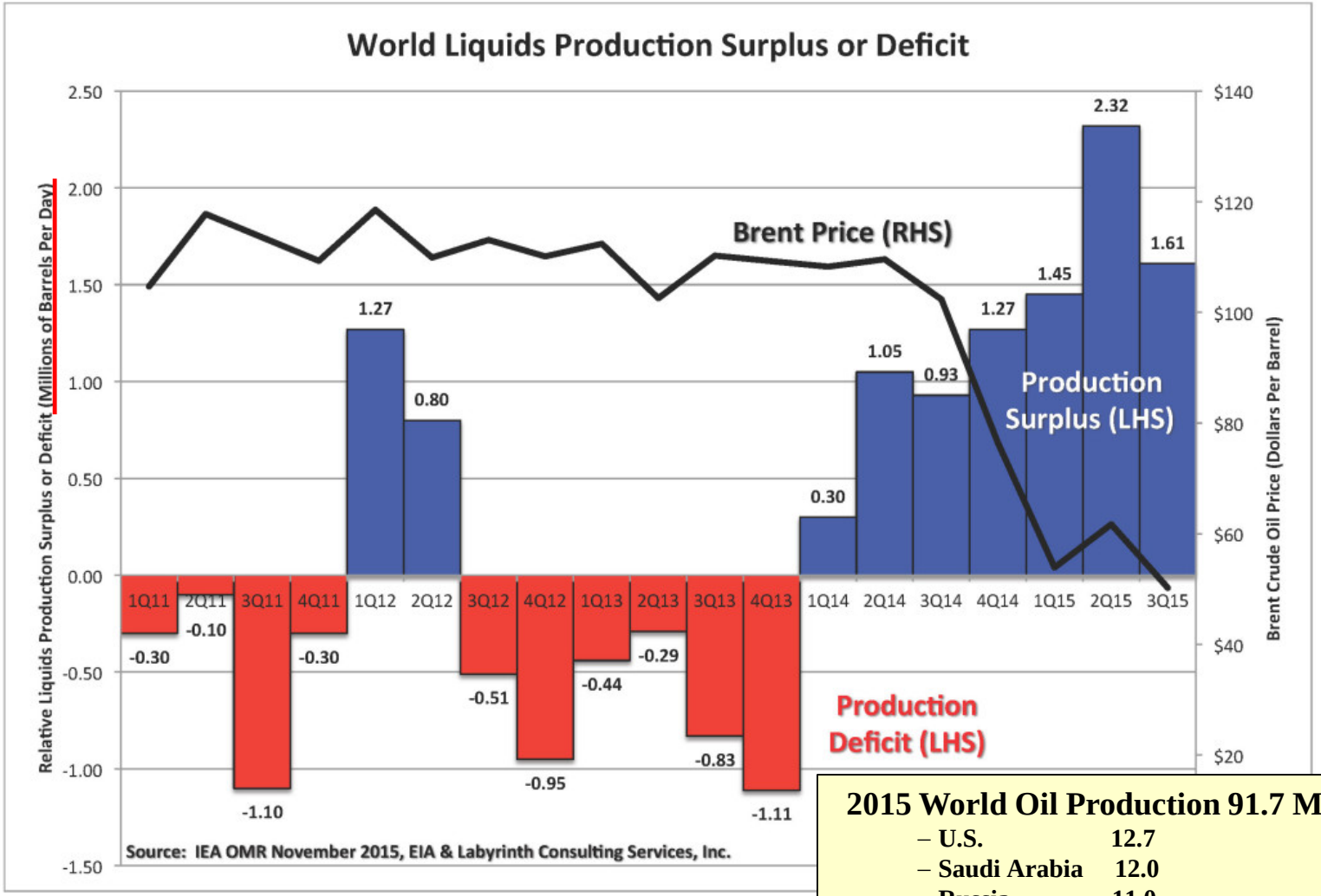


World Oil Supply/Demand Balance, MMbpd



Source: Hydrocarbon Processing November 2017

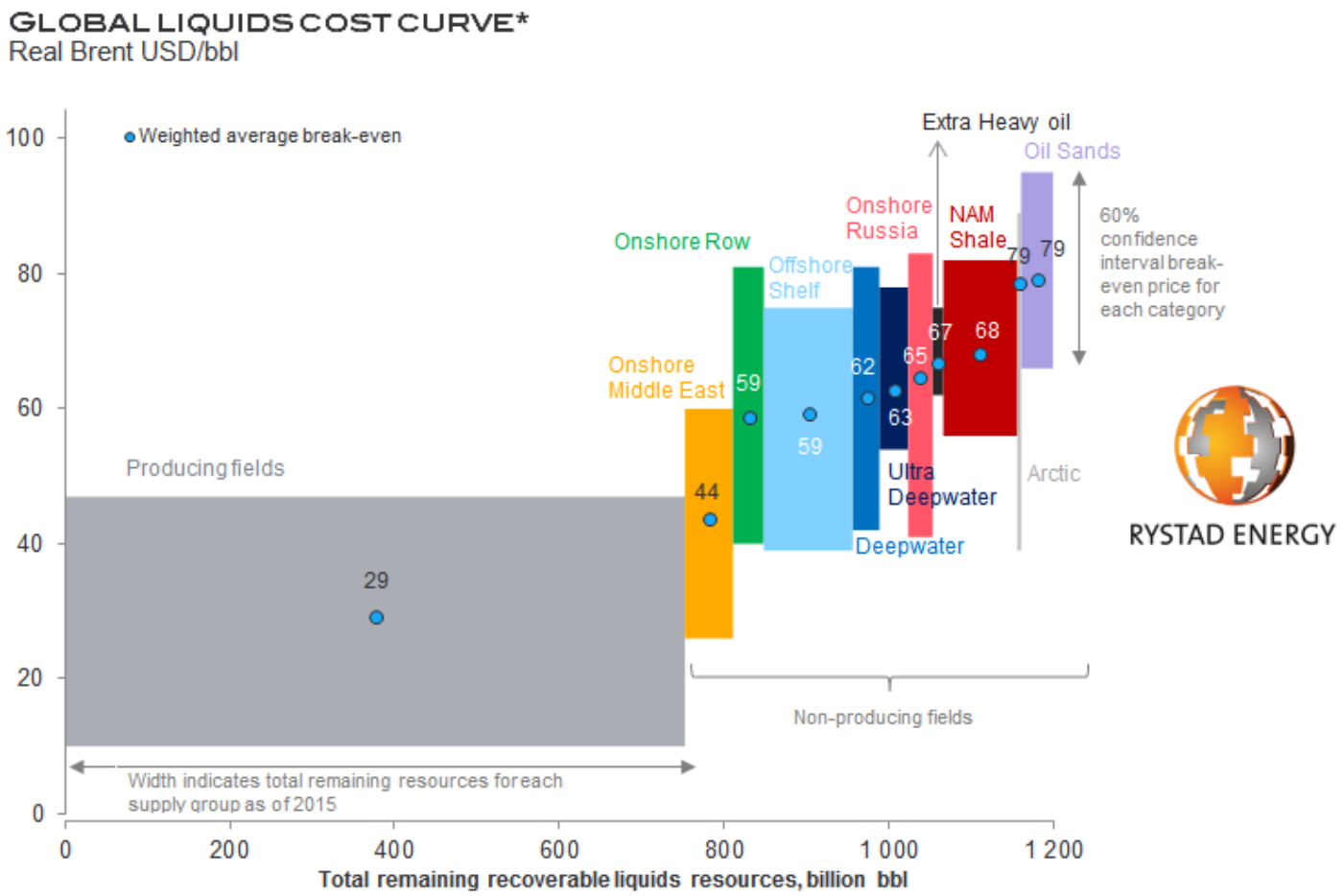
Oil Price – The Supply/Demand Balance



2015 World Oil Production 91.7 MMbbl/d

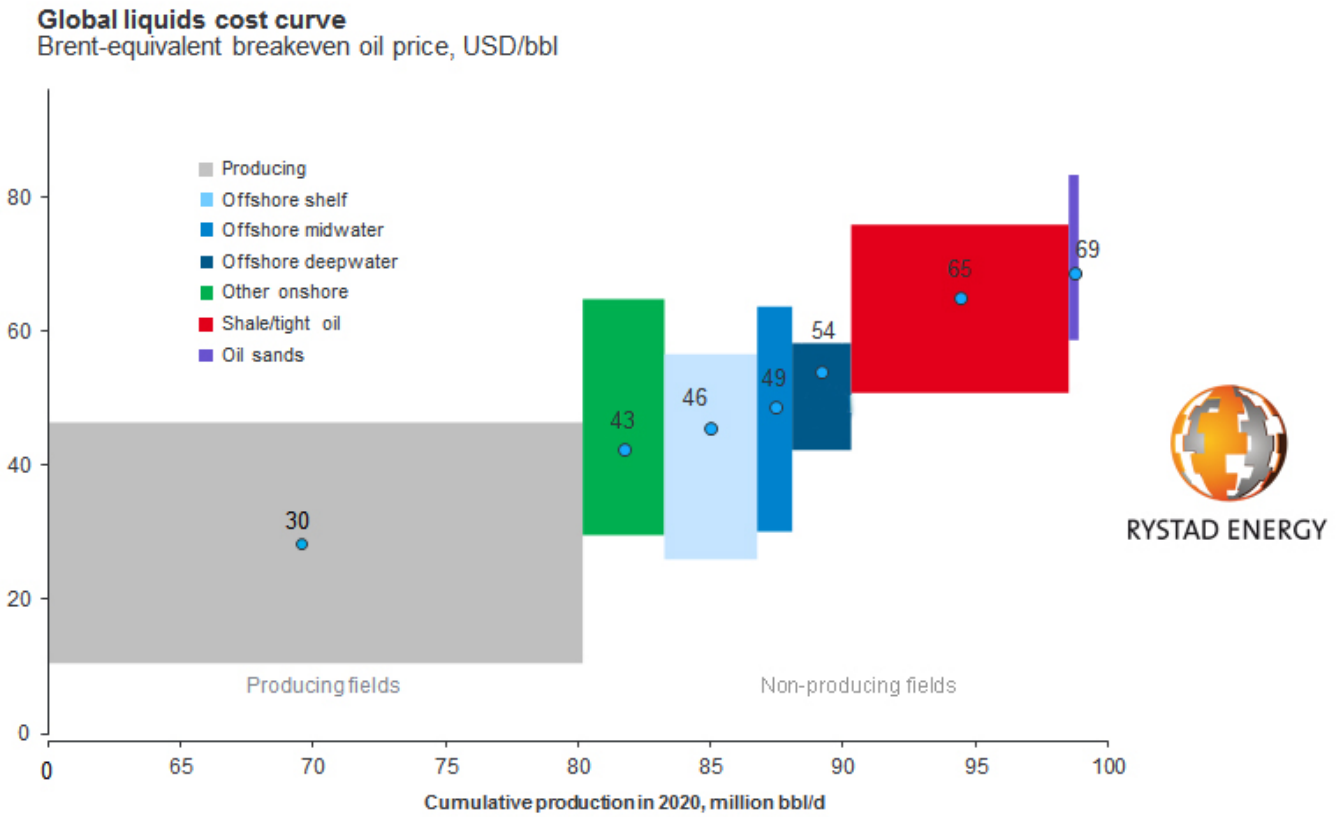
- **U.S. 12.7**
- **Saudi Arabia 12.0**
- **Russia 11.0**
- **Iran 3.9**

Global Liquids Cost Curve - 2015



*The break-even price is the Brent oil price at which NPV equals zero using a real discount rate of 7.5%. Resources are split into two life cycle categories: producing and non-producing (under development and discoveries). The latter is further split into several supply segment groups. The curve is made up of more than 20,000 unique assets based on each asset's break-even price and remaining liquids resources in 2015.
Source: Rystad Energy UCube September 2015

Global Liquids Cost Curve - 2016

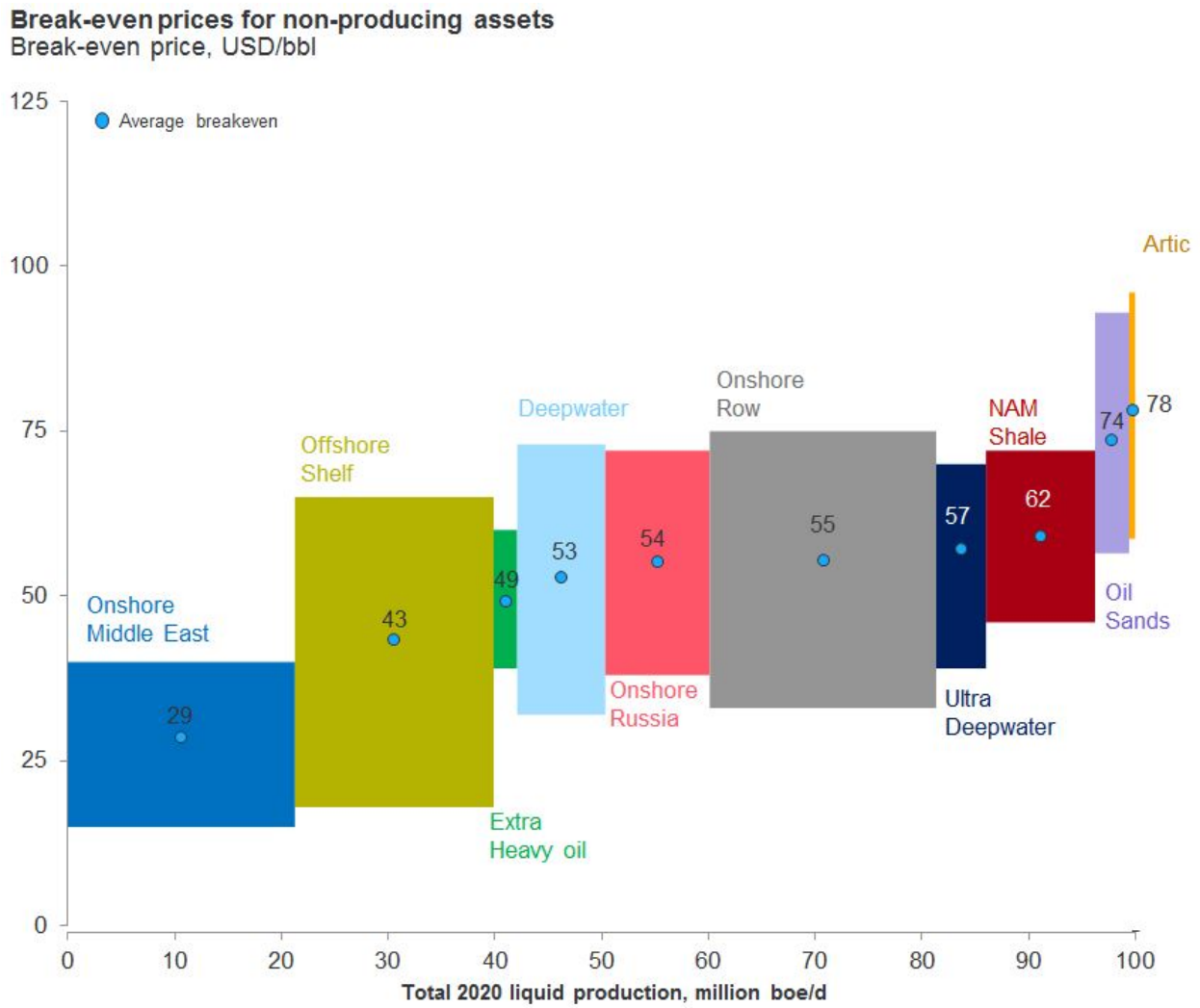


Producing fields are the cheapest supply source, as opposed to the most expensive – non producing oil sands – with 69 USD/bbl. The producing fields' low breakeven price is due to past capex that we consider as sunk, cheap Middle East and shale production. Non-producing shale and oil sands are the marginal sources of supply in 2020, with high drilling/completion costs for the former and high capex/opex for the latter.

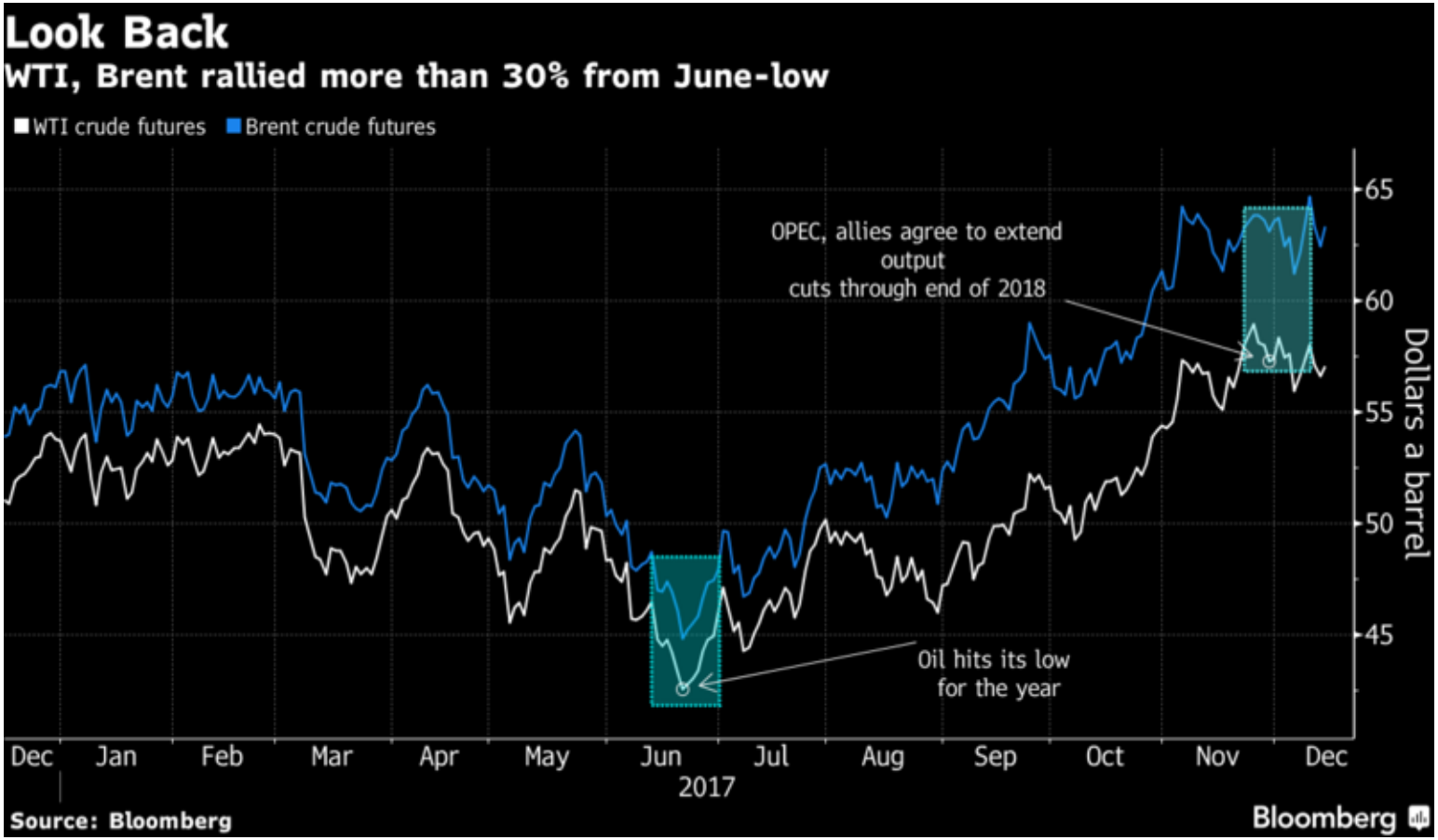
Rystad Energy's liquids cost curve is made up of nearly 20,000 unique assets by considering each asset's breakeven oil price and potential production in 2020. The breakeven price is the Brent oil price at which NPV equals zero, considering all future cash flows using a real discount rate of 7.5%.

Source: Rystad Energy research and analysis; UCube March 2016

Global Liquids Cost Curve - 2020



Bloomberg -2017



Primary Energy Consumption by Fuel - Mtoe

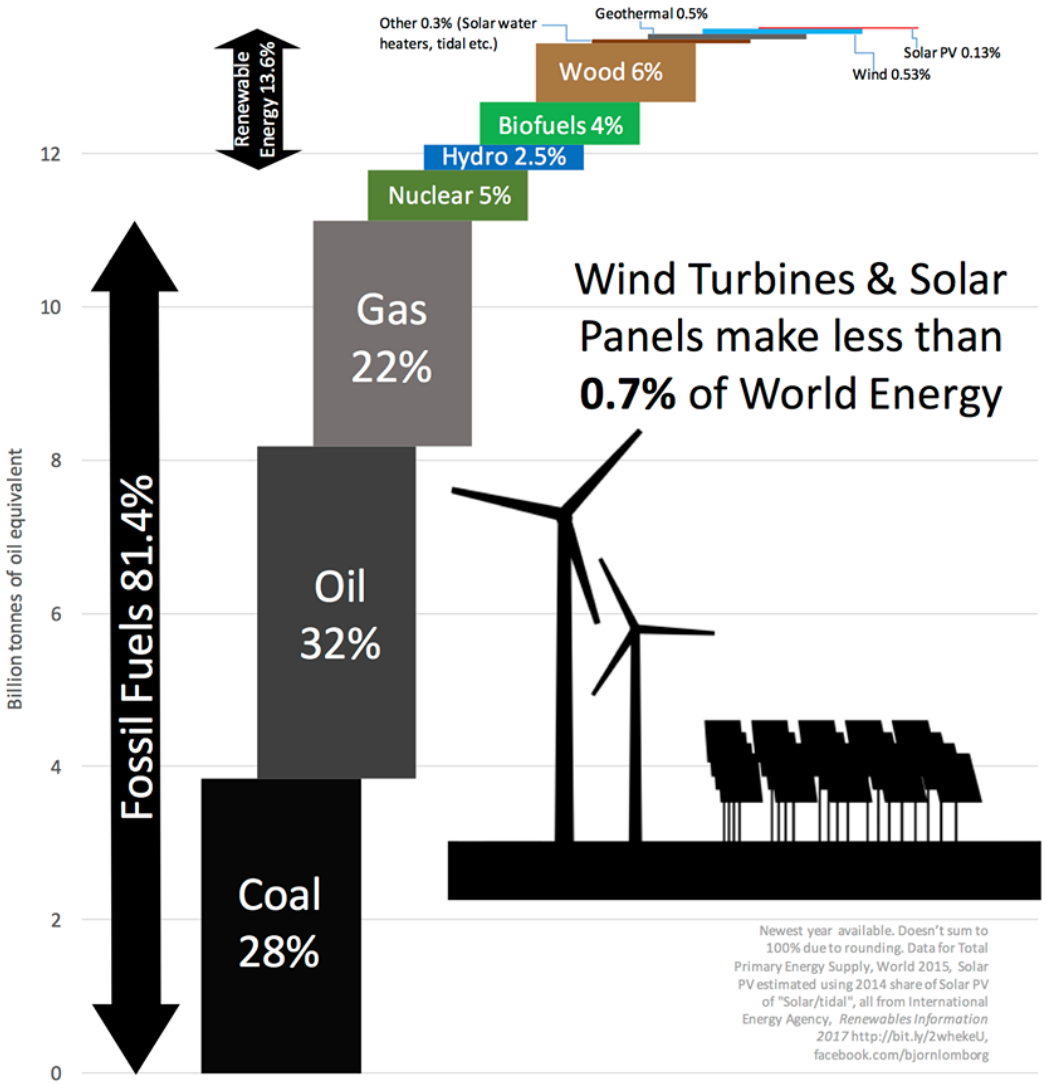
U.S. = 90.12 Quads

Million tonnes oil equivalent	2015 Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Renew-ables	Total	2016 Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Renew-ables	Total	Percent of 2016 Total
US	856.5	710.5	391.8	189.9	55.8	71.5	2275.9	863.1	716.3	358.4	191.8	59.2	83.8	**2272.7**	17.1%
Canada	99.1	92.2	19.6	22.8	85.4	8.5	327.7	100.9	89.9	18.7	23.2	87.8	9.2	**329.7**	2.5%
Mexico	84.4	78.4	12.7	2.6	7.0	3.7	188.8	82.8	80.6	9.8	2.4	6.8	4.1	**186.5**	1.4%
Total North America	**1040.0**	**881.2**	**424.2**	**215.3**	**148.2**	**83.6**	**2792.4**	**1046.9**	**886.8**	**386.9**	**217.4**	**153.9**	**97.1**	**2788.9**	21.0%
Brazil	146.6	37.5	17.7	3.3	81.4	16.0	302.6	138.8	32.9	16.5	3.6	86.9	19.0	**297.8**	2.2%
Total S. & Cent. America	**334.4**	**158.3**	**35.9**	**5.0**	**152.9**	**24.0**	**710.4**	**326.2**	**154.7**	**34.7**	**5.5**	**156.0**	**28.2**	**705.3**	5.3%
France	76.8	35.1	8.4	99.0	12.3	7.9	239.4	76.4	38.3	8.3	91.2	13.5	8.2	**235.9**	1.8%
Germany	110.0	66.2	78.5	20.8	4.3	38.1	317.8	113.0	72.4	75.3	19.1	4.8	37.9	**322.5**	2.4%
Italy	57.6	55.3	12.3	-	10.3	14.3	149.9	58.1	58.1	10.9	-	9.3	15.0	**151.3**	1.1%
Russian Federation	144.2	362.5	92.2	44.2	38.5	0.2	681.7	148.0	351.8	87.3	44.5	42.2	0.2	**673.9**	5.1%
Spain	61.2	24.6	13.7	13.0	6.3	15.6	134.4	62.5	25.2	10.4	13.3	8.1	15.5	**135.0**	1.0%
Turkey	38.9	39.2	34.7	-	15.2	3.9	131.9	41.2	37.9	38.4	-	15.2	5.2	**137.9**	1.0%
United Kingdom	71.8	61.3	23.0	15.9	1.4	17.5	190.9	73.1	69.0	11.0	16.2	1.2	17.5	**188.1**	1.4%
Total Europe & Eurasia	**865.9**	**909.2**	**471.3**	**263.9**	**194.7**	**141.6**	**2846.6**	**884.6**	**926.9**	**451.6**	**258.2**	**201.8**	**144.0**	**2867.1**	21.6%
Iran	84.5	171.7	1.6	0.8	4.1	0.1	262.8	83.8	180.7	1.7	1.4	2.9	0.1	**270.7**	2.0%
Saudi Arabia	166.6	94.0	0.1	-	-	^	260.8	167.9	98.4	0.1	-	-	^	**266.5**	2.0%
United Arab Emirates	40.9	66.4	1.3	-	-	0.1	108.6	43.5	69.0	1.3	-	-	0.1	**113.8**	0.9%
Total Middle East	**412.8**	**444.3**	**10.2**	**0.8**	**5.9**	**0.5**	**874.6**	**417.8**	**461.1**	**9.3**	**1.4**	**4.7**	**0.7**	**895.1**	6.7%
South Africa	27.9	4.6	83.4	2.8	0.2	1.4	120.1	26.9	4.6	85.1	3.6	0.2	1.8	**122.3**	0.9%
Total Africa	**182.1**	**122.2**	**95.3**	**2.8**	**26.9**	**4.2**	**433.5**	**185.4**	**124.3**	**95.9**	**3.6**	**25.8**	**5.0**	**440.1**	3.3%
Australia	47.9	38.6	44.1	-	3.2	4.8	138.5	47.8	37.0	43.8	-	4.0	5.4	**138.0**	1.0%
China	561.8	175.3	1913.6	38.6	252.2	64.4	3005.9	578.7	189.3	1887.6	48.2	263.1	86.1	**3053.0**	23.0%
India	195.8	41.2	396.6	8.7	30.2	12.7	685.1	212.7	45.1	411.9	8.6	29.1	16.5	**723.9**	5.5%
Indonesia	71.8	36.4	51.2	-	3.1	2.4	164.8	72.6	33.9	62.7	-	3.3	2.6	**175.0**	1.3%
Japan	189.0	102.1	119.9	1.0	19.0	14.8	445.8	184.3	100.1	119.9	4.0	18.1	18.8	**445.3**	3.4%
South Korea	113.8	39.3	85.5	37.3	0.5	3.9	280.2	122.1	40.9	81.6	36.7	0.6	4.3	**286.2**	2.2%
Taiwan	46.5	16.5	37.8	8.3	1.0	1.0	111.1	46.7	17.2	38.6	7.2	1.5	1.0	**112.1**	0.8%
Thailand	57.3	43.8	17.6	-	0.9	2.3	121.8	59.0	43.5	17.7	-	0.8	2.8	**123.8**	0.9%
Total Asia Pacific	**1505.8**	**631.6**	**2747.7**	**95.0**	**354.7**	**112.7**	**5447.4**	**1557.3**	**650.3**	**2753.6**	**105.9**	**368.1**	**144.5**	**5579.7**	42.0%
Total World	**4341.0**	**3146.7**	**3784.7**	**582.7**	**883.2**	**366.7**	**13105.0**	**4418.2**	**3204.1**	**3732.0**	**592.1**	**910.3**	**419.6**	**13276.3**	
	33.1%	24.0%	28.9%	4.4%	6.7%	2.8%	100.0%	33.3%	24.1%	28.1%	4.5%	6.9%	3.2%	100.0%	100.0%

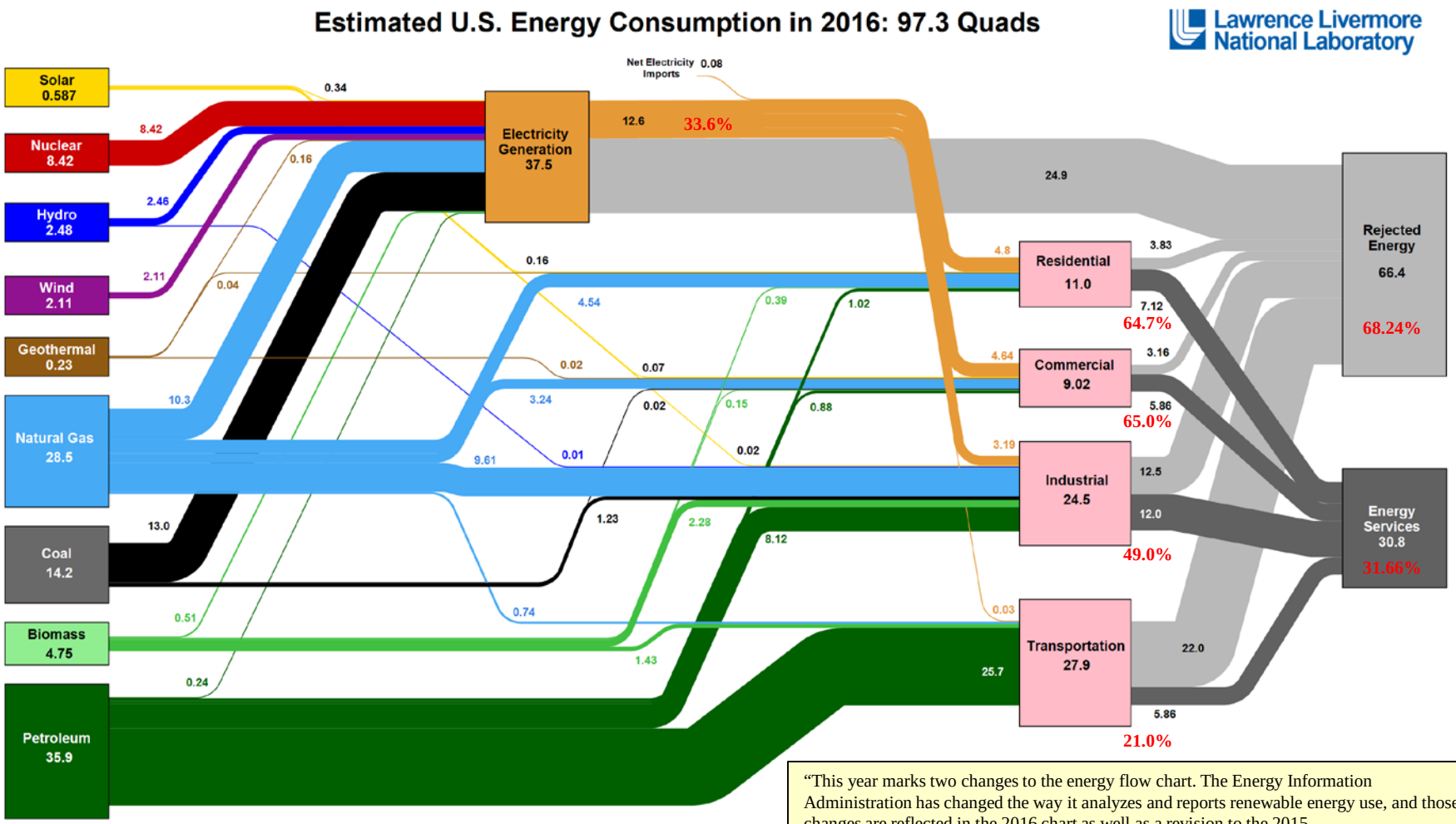
13,276.3 Mtoe = 545.7 Quads

Source: BP Statistical Review of World Energy 2017

World Energy Balance



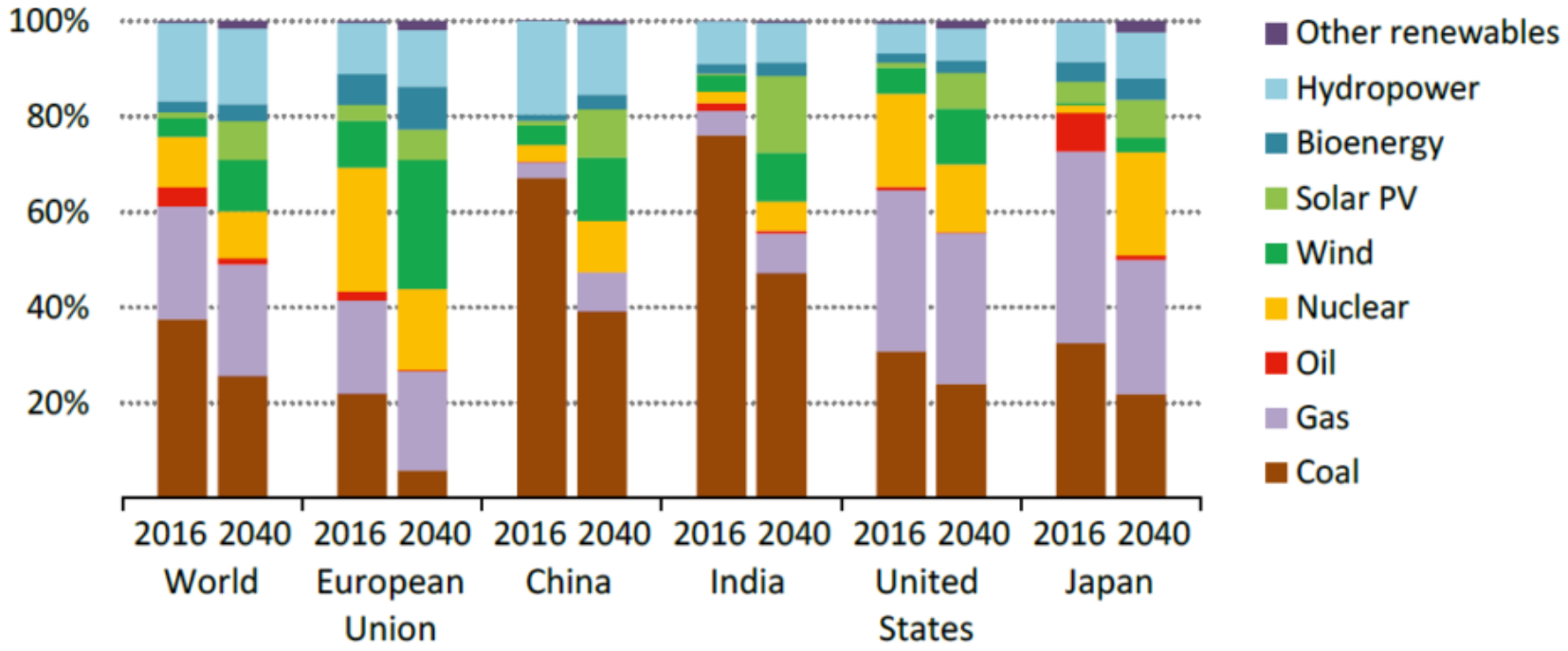
U.S. 2016 Energy Flow – 97.3Quads



"This year marks two changes to the energy flow chart. The Energy Information Administration has changed the way it analyzes and reports renewable energy use, and those changes are reflected in the 2016 chart as well as a revision to the 2015 analysis. Additionally, the estimate of efficiency of the industrial sector has been reduced from 80 percent to 49 percent to align with recent analysis at the DOE's Advanced Manufacturing Office. LLNL reports all year-over-year changes on a consistent basis with the new methodology."
https://energy.gov/eere/amo/energy-analysis-sector

World Energy Outlook 2017

Figure 6.14 ▷ Share of total generation by type worldwide and in selected regions in the New Policies Scenario



Current and proposed policies strongly reshape the power mix in the New Policies Scenario, nearly doubling the share of renewables and driving down coal's contribution

Crude Oil Consumption – 96.6 MMbbl/d

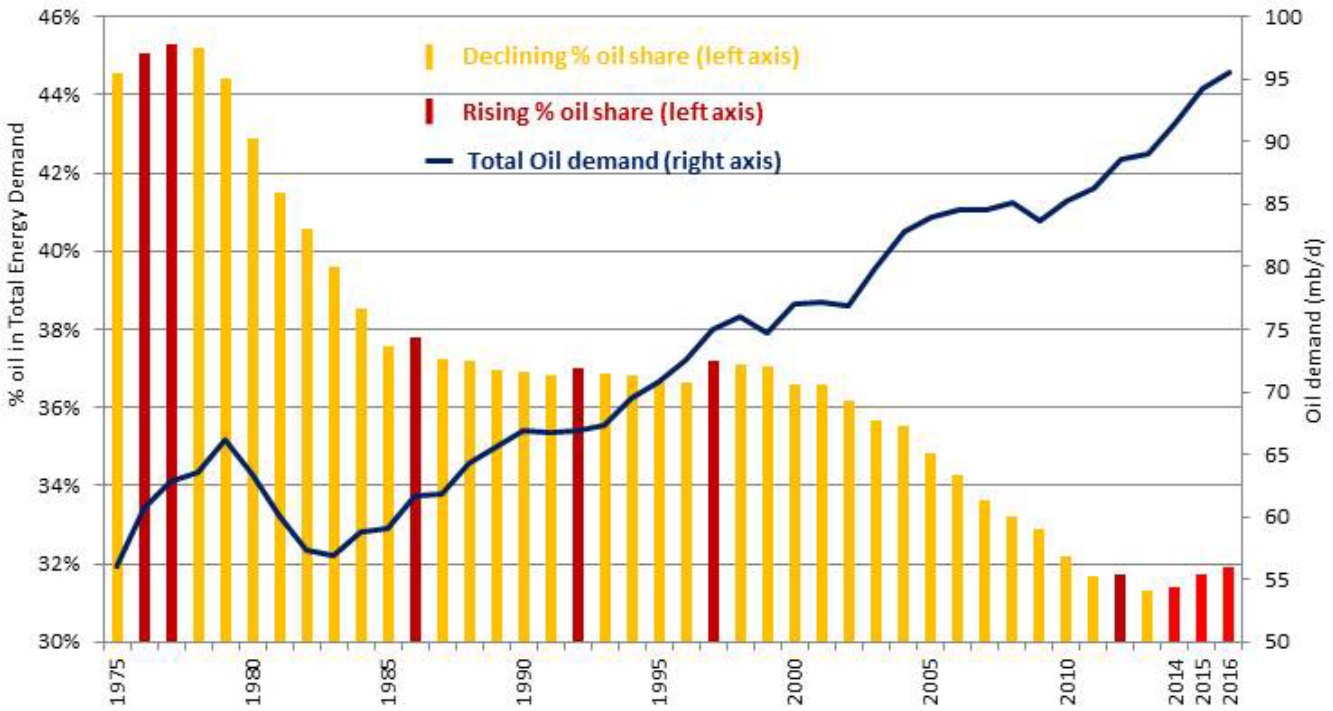
Oil: Consumption*

Thousand barrels daily	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Growth rate per annum 2016	Growth rate per annum 2005-15	Share 2016
US	20802	20687	20680	19490	18771	19180	18882	18490	18961	19106	19531	**19631**	0.5%	-0.6%	20.3%
Canada	2278	2275	2342	2295	2173	2305	2380	2340	2383	2372	2299	**2343**	1.9%	0.1%	2.4%
Mexico	2030	2019	2067	2054	1996	2014	2043	2063	2020	1943	1923	**1869**	-2.8%	-0.5%	1.9%
Total North America	**25110**	**24982**	**25089**	**23840**	**22940**	**23499**	**23305**	**22894**	**23364**	**23421**	**23753**	**23843**	**0.4%**	**-0.6%**	**24.7%**
Brazil	2123	2155	2313	2485	2502	2721	2839	2901	3110	3239	3170	**3018**	-4.8%	4.1%	3.1%
Total S. & Cent. America	**5373**	**5554**	**5831**	**6100**	**6094**	**6424**	**6666**	**6826**	**7073**	**7171**	**7139**	**6976**	**-2.3%**	**2.9%**	**7.2%**
France	1946	1942	1911	1889	1822	1763	1730	1676	1664	1616	1616	**1602**	-0.9%	-1.8%	1.7%
Germany	2592	2609	2380	2502	2409	2445	2369	2356	2408	2348	2340	**2394**	2.3%	-1.0%	2.5%
Italy	1798	1791	1740	1661	1563	1532	1475	1346	1260	1184	1222	**1232**	0.9%	-3.8%	1.3%
Russian Federation	2647	2762	2780	2861	2775	2878	3074	3119	3135	3299	3137	**3203**	2.1%	1.7%	3.3%
Spain	1593	1592	1613	1558	1473	1446	1378	1291	1195	1191	1237	**1268**	2.5%	-2.5%	1.3%
United Kingdom	1828	1813	1752	1720	1646	1623	1590	1533	1518	1511	1565	**1597**	2.1%	-1.5%	1.7%
Total Europe & Eurasia	**20229**	**20452**	**20202**	**20110**	**19300**	**19244**	**19064**	**18594**	**18370**	**18287**	**18450**	**18793**	**1.9%**	**-0.9%**	**19.5%**
Iran	1699	1851	1879	1954	1950	1817	1844	1854	2014	1961	1850	**1848**	-0.1%	0.9%	1.9%
Saudi Arabia	2203	2274	2407	2622	2914	3218	3295	3462	3470	3726	3868	**3906**	1.0%	5.8%	4.0%
Total Middle East	**6510**	**6726**	**6949**	**7418**	**7779**	**8102**	**8382**	**8760**	**8950**	**9180**	**9300**	**9431**	**1.4%**	**3.6%**	**9.8%**
Total Africa	**2900**	**2912**	**3042**	**3203**	**3316**	**3483**	**3393**	**3571**	**3720**	**3771**	**3866**	**3937**	**1.8%**	**2.9%**	**4.1%**
Australia	870	936	935	944	950	957	1006	1036	1046	1045	1039	**1036**	-0.3%	1.8%	1.1%
China	6900	7432	7808	7941	8278	9436	9796	10230	10734	11209	11986	**12381**	3.3%	5.7%	12.8%
India	2606	2737	2941	3077	3237	3319	3488	3685	3727	3849	4164	**4489**	7.8%	4.8%	4.6%
Indonesia	1303	1244	1318	1287	1317	1411	1589	1625	1639	1663	1592	**1615**	1.4%	2.0%	1.7%
Japan	5354	5174	5013	4846	4387	4442	4442	4702	4516	4303	4139	**4037**	-2.5%	-2.5%	4.2%
Singapore	796	848	921	973	1049	1157	1208	1202	1225	1268	1336	**1382**	3.4%	5.3%	1.4%
South Korea	2312	2320	2399	2308	2339	2370	2394	2458	2455	2454	2577	**2763**	7.2%	1.1%	2.9%
Taiwan	1052	1051	1110	1005	1020	1045	983	983	1010	1032	1040	**1046**	0.6%	-0.1%	1.1%
Thailand	1015	996	1030	1018	1065	1122	1185	1250	1298	1311	1355	**1382**	2.0%	2.9%	1.4%
Total Asia Pacific	**24556**	**25152**	**26047**	**25907**	**26262**	**27969**	**28920**	**30031**	**30636**	**31195**	**32494**	**33577**	**3.3%**	**2.8%**	**34.8%**
Total World	**84678**	**85777**	**87161**	**86578**	**85691**	**88722**	**89729**	**90675**	**92114**	**93025**	**95003**	**96558**	**1.6%**	**1.2%**	**100.0%**

+1,555 MMbbl/d

Source: BP Statistical Review of World Energy 2017

Oil Share of Total Energy Demand



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Coal Consumption – 3839.9 Mtoe

- Coal consumption declined by 1.8% in 2015
- India grew by 10.6%
- China declined by 1.5%
- Asia represents 72.9% of 2015

Coal: Consumption*

Million tonnes oil equivalent	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	**2015**	Change 2015 over 2014	2015 share of total
US	574.5	565.7	573.3	564.2	496.2	525.0	495.4	437.9	454.6	453.8	**396.3**	-12.7%	10.3%
Total North America	**616.9**	**608.1**	**615.8**	**604.5**	**530.7**	**563.0**	**532.3**	**472.0**	**488.1**	**487.9**	**429.0**	**-12.1%**	**11.2%**
Total S. & Cent. America	**21.0**	**24.5**	**25.7**	**28.6**	**23.7**	**28.7**	**30.6**	**32.1**	**34.8**	**36.7**	**37.1**	**1.2%**	**1.0%**
Czech Republic	20.2	21.0	21.4	19.7	17.6	18.4	18.1	17.2	16.4	15.9	**15.6**	-2.0%	0.4%
Germany	81.3	84.5	86.7	80.1	71.7	77.1	78.3	80.5	82.8	78.8	**78.3**	-0.6%	2.0%
Kazakhstan	26.9	28.3	31.1	33.8	30.9	33.4	36.3	36.5	36.3	35.5	**32.6**	-8.3%	0.8%
Poland	55.1	57.4	55.9	55.2	51.8	55.1	55.0	51.2	53.4	49.4	**49.8**	0.7%	1.3%
Russian Federation	94.6	97.0	93.9	100.7	92.2	90.5	94.0	98.4	90.5	87.6	**88.7**	1.3%	2.3%
Spain	20.5	17.9	20.0	13.5	9.4	6.9	12.8	15.5	11.4	11.6	**14.4**	23.9%	0.4%
Turkey	22.5	26.6	29.5	29.6	30.9	31.4	33.9	36.5	31.6	36.1	**34.4**	-4.7%	0.9%
Ukraine	37.5	39.8	39.8	41.8	35.9	38.3	41.5	42.5	41.6	35.6	**29.2**	-18.0%	0.8%
United Kingdom	37.4	40.9	38.4	35.6	29.8	30.9	31.4	39.0	37.1	29.9	**23.4**	-21.6%	0.6%
Other Europe & Eurasia	20.7	21.2	21.8	22.4	21.4	22.5	24.6	22.9	23.8	22.0	**23.4**	6.3%	0.6%
Total Europe & Eurasia	**514.9**	**536.3**	**540.2**	**528.0**	**475.4**	**491.6**	**514.1**	**527.4**	**507.2**	**481.0**	**467.9**	**-2.7%**	**12.2%**
Total Middle East	**9.8**	**9.8**	**9.9**	**9.7**	**9.9**	**10.1**	**11.1**	**12.3**	**10.8**	**10.7**	**10.5**	**-1.7%**	**0.3%**
South Africa	80.1	81.5	83.6	93.3	93.8	92.8	90.4	88.3	88.9	90.1	**85.0**	-5.6%	2.2%
Total Africa	**89.4**	**90.6**	**92.0**	**101.4**	**100.8**	**100.4**	**98.5**	**95.8**	**97.8**	**102.4**	**96.9**	**-5.4%**	**2.5%**
Australia	53.9	56.6	54.9	55.4	53.4	50.6	50.2	47.3	45.0	44.7	**46.6**	4.3%	1.2%
China	1318.2	1448.4	1576.9	1603.1	1680.4	1743.4	1899.0	1923.0	1964.4	1949.3	**1920.4**	-1.5%	50.0%
India	211.3	219.4	240.1	259.4	282.8	292.9	300.4	330.0	355.6	388.7	**407.2**	4.8%	10.6%
Indonesia	24.4	28.9	36.2	31.5	33.2	39.5	46.9	53.0	57.6	69.8	**80.3**	15.0%	2.1%
Japan	114.0	112.3	117.7	120.3	101.6	115.7	109.6	115.8	120.7	118.7	**119.4**	0.6%	3.1%
Malaysia	6.9	7.3	8.8	9.8	10.6	14.8	14.8	15.9	15.1	15.4	**17.6**	14.8%	0.5%
South Korea	54.8	54.8	59.7	66.1	68.6	75.9	83.6	81.0	81.9	84.6	**84.5**	-0.2%	2.2%
Taiw an	35.3	37.0	38.8	37.0	35.2	37.6	38.9	38.0	38.6	39.0	**37.8**	-3.1%	1.0%
Thailand	11.6	12.4	13.9	15.1	15.1	15.5	15.8	16.4	15.8	17.9	**17.6**	-1.8%	0.5%
Vietnam	9.0	5.3	5.8	11.4	10.7	14.0	16.5	15.0	15.8	19.3	**22.2**	15.4%	0.6%
Total Asia Pacific	**1878.6**	**2022.9**	**2192.3**	**2251.7**	**2333.2**	**2440.4**	**2613.5**	**2674.8**	**2752.0**	**2792.5**	**2798.5**	**0.2%**	**72.9%**
Total World	**3130.6**	**3292.2**	**3476.0**	**3523.9**	**3473.6**	**3634.3**	**3800.0**	**3814.4**	**3890.7**	**3911.2**	**3839.9**	**-1.8%**	**100.0%**

Source: BP Statistical Review of World Energy 2016

Coal Company Bankruptcies

Largest mines owned by companies recently in bankruptcy

Mine name*	Ultimate owner	Coal produced (tons) 2015	Q4'14	Q4'15
North Antelope Rochelle	Peabody Energy Corp.	109,343,913	30,671,497	28,153,722
Black Thunder	Arch Coal Inc.	99,450,689	26,506,223	22,502,481
Eagle Butte	Alpha Natural Resources Inc.	19,649,723	5,210,041	4,873,247
Belle Ayr	Alpha Natural Resources Inc.	18,318,629	4,625,701	3,775,390
Rawhide	Peabody Energy Corp.	15,167,996	3,959,328	3,784,091
Caballo	Peabody Energy Corp.	11,402,062	2,239,334	2,794,723
Bear Run	Peabody Energy Corp.	7,878,025	2,145,839	1,739,479
Coal Creek	Arch Coal Inc.	7,840,491	2,412,109	2,200,692
Cumberland	Alpha Natural Resources Inc.	7,490,061	2,008,118	2,086,848
El Segundo	Peabody Energy Corp.	7,476,237	2,173,207	1,866,494
Kayenta	Peabody Energy Corp.	6,804,555	2,071,901	1,375,829
Lively Grove	Multi-owned1	5,953,533	1,187,294	1,281,696
West Elk	Arch Coal Inc.	5,074,821	1,668,373	854,076
Foidel Creek	Peabody Energy Corp.	4,122,448	1,200,546	1,186,340
Leer	Arch Coal Inc.	3,383,885	898,667	655,893
Prairie Eagle - Underground	Arch Coal Inc.; CBR Investments LLC	3,353,038	879,050	769,690
No. 7	Walter Energy	3,035,681	1,110,442	362,666
Francisco Underground Pit	Peabody Energy Corp.	2,935,577	810,675	704,954
No. 4	Walter Energy	2,416,556	720,849	316,649
Coal-Mac Inc. Holden No. 22 Surface	Arch Coal Inc.	2,259,286	628,888	504,244
Viper	Arch Coal Inc.	2,155,473	467,453	491,455
Somerville Central	Peabody Energy Corp.	2,143,884	470,800	490,245
Wild Boar	Peabody Energy Corp.	2,041,888	544,416	509,813
Wildcat Hills - Underground	Peabody Energy Corp.	2,026,081	538,322	447,865
Mountaineer II	Arch Coal Inc.	1,923,968	560,493	373,767

As of March 1, 2016.
Includes coal production for bankrupt coal companies as operator, owner and ultimate owner of mines that have filed bankruptcy since 2012.
* Mines in bankruptcy are defined as mines owned by companies in bankruptcy since 2012 as tracked by S&P Global Market Intelligence compared to ownership and production data from the U.S. Mine Safety and Health Administration as of the end of the fourth quarter of 2015. Some mines may have since been transferred to solvent companies and some companies may have since emerged from bankruptcy.
1 Peabody Energy Corp.; Northern Illinois Municipal; Kentucky Muni Power Agency; Southern Illinois Power Coop; Prairie Power Inc.; MJMEUC; Indiana Municipal Power Agency; Illinois Municipal Elec Agency; American Mun Power Inc.
Source: S&P Global Market Intelligence

Source: SNL April 13, 2016

- 44.3% of the coal produced in the U.S. came from a company that has filed for bankruptcy court protection since 2012.
- More than 69% of the coal produced in the Powder River Basin came from coal companies recently filing bankruptcy.
- Three of every four tons mined in Wyoming came from a coal company on the bankruptcy list.
- 28.9% of coal from the Illinois Basin comes from a coal company recently filing for bankruptcy court protections.

Q4'15 coal production by major coal basins

Coal basin	Coal produced (tons) Total	From mines of companies recently in bankruptcy*	% production from companies recently in bankruptcy*
Powder River Basin	98,013,293	68,084,346	69.46
Illinois Basin	26,410,510	7,628,394	28.88
Northern Appalachia	27,356,159	3,772,808	13.79
Central Appalachia	18,699,925	6,364,752	34.04
Entire U.S.	207,355,826	91,946,261	44.34

As of March 1, 2016.
Includes coal production for bankrupt coal companies as operator, owner and ultimate owner of mines that have filed bankruptcy since 2012.
* Mines in bankruptcy are defined as mines owned by companies in bankruptcy since 2012 as tracked by S&P Global Market Intelligence compared to ownership and production data from the U.S. Mine Safety and Health Administration as of the end of the fourth quarter of 2015. Some mines may have since been transferred to solvent companies and some companies may have since emerged from bankruptcy.
Source: S&P Global Market Intelligence

Natural Gas Demand – 3542.9 BCM

Natural Gas: Consumption in billion cubic metres*

Billion cubic metres	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	**2016**	Growth rate per annum 2016	Growth rate per annum 2005-15	Share 2016
US	623.4	614.4	654.2	659.1	648.7	682.1	693.1	723.2	740.6	753.0	773.2	**778.6**	0.4%	2.2%	22.0%
Canada	97.8	96.9	96.2	96.1	94.9	95.0	100.9	100.2	103.9	104.2	102.5	**99.9**	-2.8%	0.5%	2.8%
Mexico	60.9	66.6	63.4	66.3	72.2	72.5	76.6	79.9	83.3	86.8	87.1	**89.5**	2.5%	3.6%	2.5%
Total North America	**782.1**	**778.0**	**813.8**	**821.5**	**815.9**	**849.6**	**870.6**	**903.3**	**927.8**	**944.1**	**962.8**	**968.0**	**0.3%**	**2.1%**	**27.3%**
Argentina	40.4	41.8	43.9	44.4	42.1	43.3	45.1	46.7	46.7	47.2	48.2	**49.6**	2.7%	1.8%	1.4%
Brazil	19.6	20.6	21.2	24.9	20.1	26.8	26.7	31.7	37.3	39.5	41.7	**36.6**	-12.5%	7.9%	1.0%
Venezuela	27.4	31.5	36.2	34.3	32.3	32.2	29.7	31.4	30.5	30.7	34.5	**35.6**	2.7%	2.3%	1.0%
Total S. & Cent. America	**123.4**	**135.5**	**142.6**	**143.4**	**136.7**	**150.2**	**150.5**	**159.6**	**165.2**	**168.9**	**175.8**	**171.9**	**-2.5%**	**3.6%**	**4.9%**
France	45.6	44.0	42.8	44.3	42.7	47.3	41.1	42.5	43.1	36.2	38.9	**42.6**	9.0%	-1.6%	1.2%
Germany	86.3	87.9	84.7	85.5	80.7	84.1	77.3	77.5	81.2	70.6	73.5	**80.5**	9.2%	-1.6%	2.3%
Italy	79.1	77.4	77.3	77.2	71.0	75.6	70.9	68.2	63.8	56.3	61.4	**64.5**	4.7%	-2.5%	1.8%
Netherlands	39.6	38.0	36.9	38.5	38.9	43.6	38.1	36.0	36.5	31.8	31.5	**33.6**	6.4%	-2.3%	0.9%
Russian Federation	394.0	415.0	422.0	416.0	389.6	414.1	424.6	416.2	413.5	409.7	402.8	**390.9**	-3.2%	0.2%	11.0%
Turkey	26.9	30.5	36.1	37.5	35.7	39.0	40.9	41.4	42.0	44.6	43.6	**42.1**	-3.7%	5.0%	1.2%
United Kingdom	94.9	90.0	91.0	93.8	87.0	94.2	78.1	73.9	73.0	66.7	68.1	**76.7**	12.2%	-3.3%	2.2%
Uzbekistan	42.7	41.9	45.9	48.7	39.9	40.8	47.6	47.2	46.8	48.8	50.2	**51.4**	2.0%	1.6%	1.4%
Total Europe & Eurasia	**1092.2**	**1114.8**	**1123.8**	**1132.2**	**1041.3**	**1118.4**	**1092.8**	**1074.0**	**1054.4**	**1005.6**	**1010.2**	**1029.9**	**1.7%**	**-0.8%**	**29.1%**
Iran	102.7	112.0	125.5	133.2	142.7	152.9	162.2	161.5	162.9	183.7	190.8	**200.8**	5.0%	6.4%	5.7%
Qatar	18.6	19.2	23.5	19.3	20.8	29.8	19.6	23.4	37.9	36.4	43.9	**41.7**	-5.4%	9.0%	1.2%
Saudi Arabia	71.2	73.5	74.4	80.4	78.5	87.7	92.3	99.3	100.0	102.4	104.5	**109.4**	4.4%	3.9%	3.1%
United Arab Emirates	42.1	43.4	49.2	59.5	59.1	60.8	63.2	65.6	66.9	65.9	73.8	**76.6**	3.6%	5.8%	2.2%
Total Middle East	**279.2**	**296.3**	**321.7**	**347.3**	**359.1**	**396.5**	**403.4**	**415.0**	**440.3**	**460.8**	**493.6**	**512.3**	**3.5%**	**5.9%**	**14.5%**
Algeria	23.2	23.7	24.3	25.4	27.2	26.3	27.8	31.0	33.4	37.5	39.4	**40.0**	1.2%	5.4%	1.1%
Egypt	31.6	36.5	38.4	40.8	42.5	45.1	49.6	52.6	51.4	48.0	47.8	**51.3**	7.0%	4.2%	1.4%
Total Africa	**85.0**	**89.6**	**96.7**	**100.7**	**99.5**	**106.4**	**113.3**	**120.6**	**123.2**	**127.0**	**135.8**	**138.2**	**1.4%**	**4.8%**	**3.9%**
Australia	22.5	25.1	28.1	27.9	29.1	31.1	33.7	33.8	35.5	38.3	42.9	**41.1**	-4.4%	6.6%	1.2%
China	48.2	59.3	73.0	84.1	92.6	111.2	137.1	150.9	171.9	188.4	194.8	**210.3**	7.7%	15.0%	5.9%
India	35.7	37.3	40.3	41.5	50.7	60.3	61.1	71.1	49.3	48.8	45.7	**50.1**	9.2%	2.5%	1.4%
Indonesia	35.9	36.6	34.1	39.1	41.5	43.4	42.1	42.2	40.8	40.9	40.4	**37.7**	-7.0%	1.2%	1.1%
Japan	78.6	83.7	90.2	93.7	87.4	94.5	105.5	116.9	116.9	118.0	113.4	**111.2**	-2.2%	3.7%	3.1%
Malaysia	34.9	35.3	35.5	39.2	35.4	29.6	34.8	35.5	40.3	42.2	41.8	**43.0**	2.7%	1.8%	1.2%
Pakistan	39.1	39.9	40.5	41.4	41.6	42.3	42.3	43.8	42.6	41.9	43.5	**45.5**	4.2%	1.1%	1.3%
South Korea	30.4	32.0	34.7	35.7	33.9	43.0	46.3	50.2	52.5	47.8	43.6	**45.5**	4.0%	3.7%	1.3%
Thailand	30.6	31.5	33.6	35.3	36.4	41.3	42.3	46.5	46.7	47.7	48.7	**48.3**	-1.0%	4.7%	1.4%
Total Asia Pacific	**406.5**	**436.5**	**468.7**	**499.8**	**513.3**	**566.4**	**615.4**	**665.1**	**672.9**	**694.4**	**701.8**	**722.5**	**2.7%**	**5.6%**	**20.4%**
Total World	**2768.4**	**2850.6**	**2967.3**	**3044.9**	**2965.9**	**3187.6**	**3245.9**	**3337.7**	**3383.8**	**3400.8**	**3480.1**	**3542.9**	**1.5%**	**2.3%**	**100.0%**

Source: BP Statistical Review of World Energy 2017

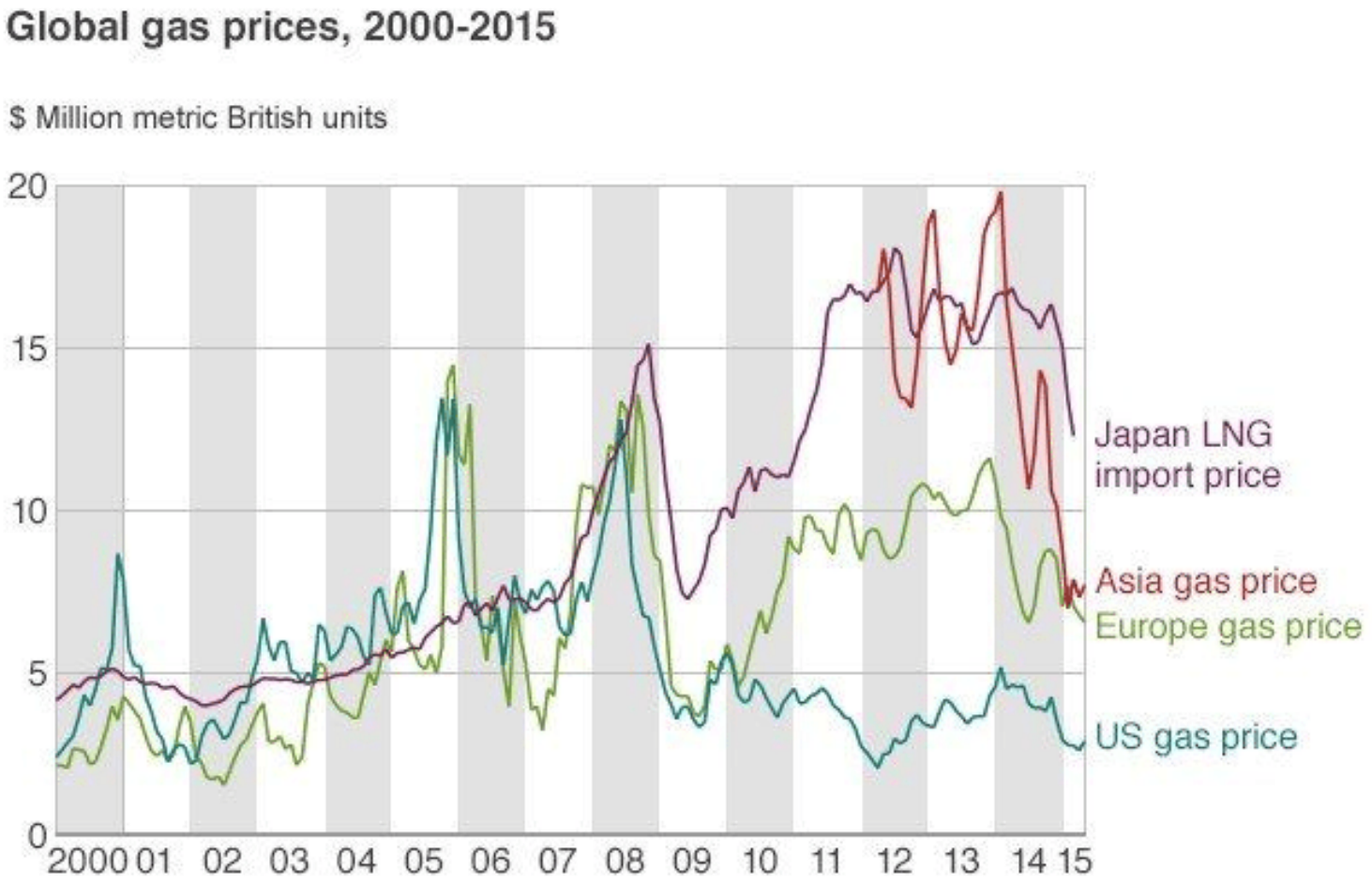
Natural Gas Production – 3551.6BCM

Natural Gas: Production*

Billion cubic metres	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	**2016**	Growth rate per annum 2016	Growth rate per annum 2005-15	Share 2016
US	511.1	524.0	545.6	570.8	584.0	603.6	648.5	680.5	685.4	733.1	766.2	**749.2**	-2.5%	4.1%	21.1%
Canada	170.7	171.7	165.5	159.3	147.6	144.5	144.4	141.1	141.4	147.2	149.1	**152.0**	1.7%	-1.3%	4.3%
Total North America	**734.1**	**753.0**	**764.6**	**783.5**	**790.9**	**805.7**	**851.2**	**878.9**	**885.0**	**937.3**	**969.4**	**948.4**	**-2.4%**	**2.8%**	**26.7%**
Argentina	45.6	46.1	44.8	44.1	41.4	40.1	38.8	37.7	35.5	35.5	36.5	**38.3**	4.6%	-2.2%	1.1%
Trinidad & Tobago	33.0	40.1	42.2	42.0	43.6	44.8	43.1	42.7	42.8	42.1	39.6	**34.5**	-13.2%	1.8%	1.0%
Venezuela	27.4	31.5	36.2	32.8	31.0	30.6	27.6	29.5	28.4	28.6	32.4	**34.3**	5.5%	1.7%	1.0%
Total S. & Cent. America	**140.5**	**154.1**	**162.1**	**163.0**	**157.8**	**166.2**	**166.9**	**173.4**	**175.6**	**176.9**	**178.0**	**177.0**	**-0.8%**	**2.4%**	**5.0%**
Netherlands	62.5	61.5	60.5	66.5	62.7	70.5	64.1	63.8	68.6	57.9	43.3	**40.2**	-7.6%	-3.6%	1.1%
Norway	85.8	88.7	90.3	100.1	104.4	107.3	101.3	114.7	108.7	108.8	117.2	**116.6**	-0.7%	3.2%	3.3%
Russian Federation	580.1	595.2	592.0	601.7	527.7	588.9	607.0	592.3	604.7	581.7	575.1	**579.4**	0.5%	-0.1%	16.3%
Turkmenistan	57.0	60.4	65.4	66.1	36.4	42.4	59.5	62.3	62.3	67.1	69.6	**66.8**	-4.3%	2.0%	1.9%
United Kingdom	88.2	80.0	72.1	69.6	59.7	57.1	45.2	38.9	36.5	36.8	39.6	**41.0**	3.3%	-7.7%	1.2%
Uzbekistan	54.0	56.6	58.2	57.8	55.6	54.4	57.0	56.9	56.9	57.3	57.7	**62.8**	8.4%	0.7%	1.8%
Total Europe & Eurasia	**1026.7**	**1042.2**	**1037.8**	**1066.7**	**947.9**	**1021.1**	**1032.5**	**1025.5**	**1032.7**	**1003.2**	**995.4**	**1000.1**	**0.2%**	**-0.3%**	**28.2%**
Iran	102.3	111.5	124.9	130.8	143.7	152.4	159.9	166.2	166.8	185.8	189.4	**202.4**	6.6%	6.4%	5.7%
Oman	22.1	25.8	26.1	26.0	27.0	29.3	30.9	32.2	34.8	33.3	34.7	**35.4**	1.7%	4.6%	1.0%
Qatar	45.8	50.7	63.2	77.0	89.3	131.2	145.3	157.0	177.6	174.1	178.5	**181.2**	1.3%	14.6%	5.1%
Saudi Arabia	71.2	73.5	74.4	80.4	78.5	87.7	92.3	99.3	100.0	102.4	104.5	**109.4**	4.4%	3.9%	3.1%
United Arab Emirates	47.8	48.8	50.3	50.2	48.8	51.3	52.3	54.3	54.6	54.2	60.2	**61.9**	2.5%	2.3%	1.7%
Total Middle East	**321.1**	**343.6**	**371.9**	**400.7**	**422.2**	**495.4**	**528.8**	**554.7**	**587.2**	**602.6**	**615.9**	**637.8**	**3.3%**	**6.7%**	**18.0%**
Algeria	88.2	84.5	84.8	85.8	79.6	80.4	82.7	81.5	82.4	83.3	84.6	**91.3**	7.6%	-0.4%	2.6%
Egypt	42.5	54.7	55.7	59.0	62.7	61.3	61.4	60.9	56.1	48.8	44.3	**41.8**	-5.7%	0.4%	1.2%
Nigeria	25.0	29.6	36.9	36.2	26.0	37.3	40.6	43.3	36.2	45.0	50.1	**44.9**	-10.6%	7.2%	1.3%
Total Africa	**177.0**	**192.6**	**203.4**	**212.0**	**199.7**	**213.2**	**209.4**	**214.4**	**206.3**	**207.1**	**210.0**	**208.3**	**-1.1%**	**1.7%**	**5.9%**
Australia	36.8	39.2	41.2	40.4	45.9	50.4	53.2	56.9	59.0	63.6	72.6	**91.2**	25.2%	7.0%	2.6%
China	51.0	60.6	71.6	83.1	88.2	99.1	109.0	111.8	122.2	131.6	136.1	**138.4**	1.4%	10.3%	3.9%
India	29.6	29.3	30.1	30.5	37.6	49.3	44.5	38.9	32.1	30.5	29.3	**27.6**	-6.0%	-0.1%	0.8%
Indonesia	75.1	74.3	71.5	73.7	76.9	85.7	81.5	77.1	76.5	75.3	75.0	**69.7**	-7.4%	♦	2.0%
Malaysia	63.9	62.7	61.5	63.8	61.1	56.2	62.2	61.5	67.3	68.4	71.2	**73.8**	3.4%	1.1%	2.1%
Pakistan	39.1	39.9	40.5	41.4	41.6	42.3	42.3	43.8	42.6	41.9	42.0	**41.5**	-1.3%	0.7%	1.2%
Thailand	23.4	24.0	25.7	28.5	30.6	35.8	36.6	41.0	41.3	41.6	39.3	**38.6**	-2.2%	5.3%	1.1%
Total Asia Pacific	**374.5**	**391.3**	**407.8**	**428.3**	**450.3**	**490.6**	**501.4**	**505.4**	**517.0**	**538.8**	**561.9**	**579.9**	**2.9%**	**4.1%**	**16.3%**
Total World	**2774.0**	**2876.7**	**2947.5**	**3054.2**	**2968.8**	**3192.2**	**3290.2**	**3352.3**	**3403.9**	**3465.9**	**3530.6**	**3551.6**	**0.3%**	**2.4%**	**100.0%**

Source: BP Statistical Review of World Energy 2017

Natural Gas Prices



Source: Bloomberg, Argus LNG

BBC

Natural Gas Trade – 1034.5 BCM

Pipeline trade grew 4.0%
LNG trade grew 6.5%
Consumption grew 1.5%

Gas Trade in 2015 and 2016 in billion cubic metres

Billion cubic metres	2015				2016			
	Pipeline imports	LNG imports	Pipeline exports	LNG exports	Pipeline imports	LNG imports	Pipeline exports	LNG exports
US	74.4	2.6	49.1	0.7	82.5	2.5	60.3	4.4
Canada	19.2	0.6	74.3	†	21.9	0.3	82.4	†
Mexico	29.9	7.3	†	-	38.4	5.9	†	-
Trinidad and Tobago	-	-	-	16.9	-	-	-	14.3
Other S. & Cent. America	19.9	19.8	19.9	5.1	16.8	15.5	16.8	6.1
France	31.8	6.8	-	0.6	32.3	9.7	-	1.5
Germany	102.3	-	32.7	-	99.3	-	19.3	-
Italy	55.7	5.4	0.2	-	59.4	5.7	-	-
Netherlands	33.6	2.1	47.1	1.3	38.0	1.5	52.3	0.7
Norw ay	†	-	109.6	5.9	†	-	109.8	6.3
Spain	15.2	13.1	0.5	1.8	15.0	13.2	0.6	0.2
Turkey	38.4	7.7	0.6	-	37.4	7.7	0.6	-
United Kingdom	29.0	13.1	13.4	0.3	34.1	10.5	10.0	0.5
Other Europe	94.7	6.9	13.8	1.5	100.2	8.2	15.0	1.3
Russian Federation	21.8	-	179.1	14.0	21.7	-	190.8	14.0
Ukraine	17.3	-	-	-	11.1	-	-	-
Other CIS	27.0	-	72.3	-	27.9	-	74.0	-
Qatar	-	-	20.0	101.8	-	-	20.0	104.4
Other Middle East	29.6	10.2	8.4	18.8	26.9	14.2	8.4	18.1
Algeria	-	-	26.3	16.6	-	-	37.1	15.9
Other Africa	9.0	3.7	11.0	30.0	8.8	10.2	8.5	29.6
Australia	6.4	-	-	38.1	8.3	0.1	-	56.8
China	33.6	25.8	-	-	38.0	34.3	-	-
Japan	-	110.7	-	-	-	108.5	-	-
Indonesia	-	-	9.3	20.7	-	-	8.8	21.2
South Korea	-	43.8	-	0.2	-	43.9	-	0.1
Other Asia Pacific	20.3	46.0	21.4	51.4	19.3	54.8	22.7	51.1
Total World	**709.0**	**325.5**	**709.0**	**325.5**	**737.5**	**346.6**	**737.5**	**346.6**

BCM Change 2016 vs. 2015

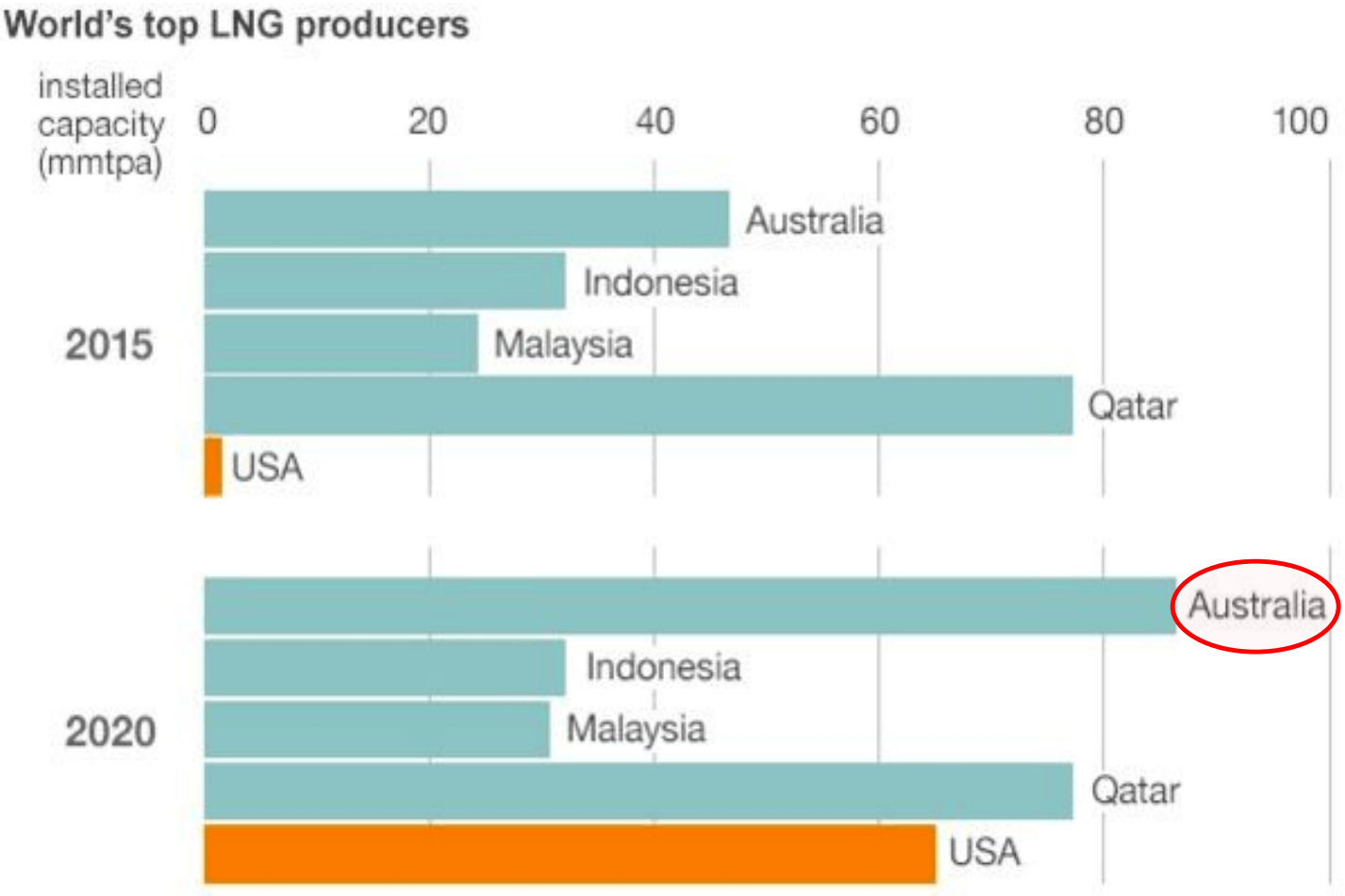
	Imports		exports	
	Pipeline imports	LNG imports	Pipeline exports	LNG exports
US	8.1	-†	11.3	3.7
Canada	2.7	-†	8.1	†
Mexico	8.6	-†	-†	-
Trinidad and Tobago	-	-	-	-†
Other S. & Cent. America	-†	-†	-†	0.9
France	0.5	2.8	-	0.9
Germany	-†	-	-†	-
Italy	3.7	0.2	-†	-
Netherlands	4.5	-†	5.3	-†
Norw ay	-†	-	0.1	0.4
Spain	-†	0.1	0.1	-†
Turkey	-†	†	†	-
United Kingdom	5.2	-†	-†	0.3
Other Europe	5.5	1.3	1.2	-†
Russian Federation	-†	-	11.7	-†
Ukraine	-†	-	-	-
Other CIS	0.9	-	1.7	-
Qatar	-	-	-†	2.7
Other Middle East	-†	3.9	-†	-†
Algeria	-	-	10.8	-†
Other Africa	-†	6.5	-†	-†
Australia	1.9	0.1	-	18.7
China	4.5	8.5	-	-
Japan	-	-†	-	-
Indonesia	-	-	-†	0.5
South Korea	-	0.2	-	-†
Other Asia Pacific	-†	8.8	1.4	-†
Total World	**28.5**	**21.1**	**28.5**	**21.1**

† Less than 0.05. Source: Includes data from FGE MENAgas service, GIIGNL, IHS Waterborne, PIRA Energy Group, Wood Mackenzie.

Trade represents approximately 30% of the consumption
Japan & Korea represent almost half of all LNG Imports

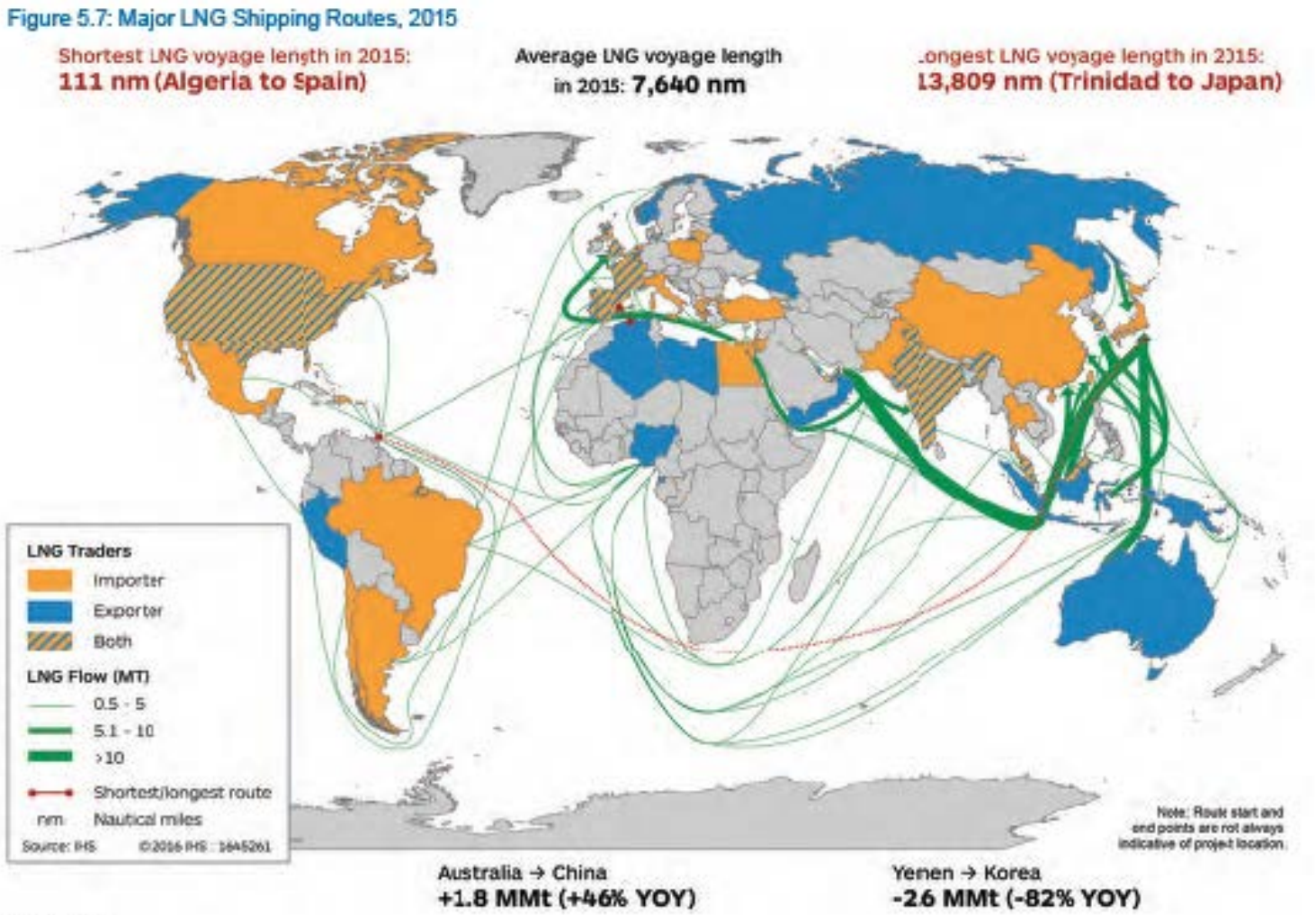
Source: BP Statistical Review of World Energy 2017

Top LNG Producers



Source: Poyry Management Consulting

Major LNG Shipping Routes



Source: IHS.

Russian Gas - 607 BCM Production

44,600 BCM Reserves
Reserves/Production Ratio - 73.5

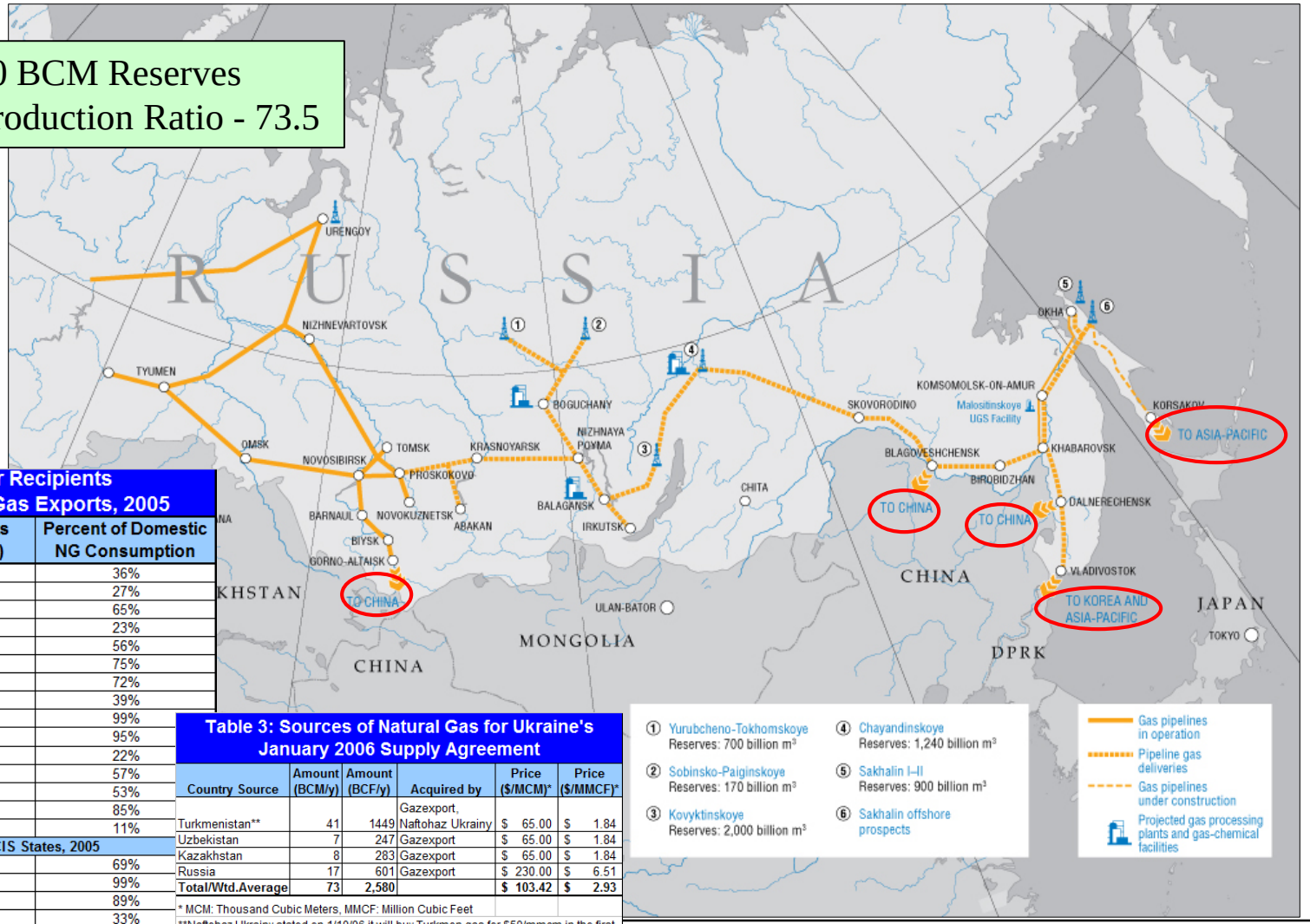


Table 2: Major Recipients of Russian Natural Gas Exports, 2005

Rank	Country	Imports (bcf/y)	Percent of Domestic NG Consumption
1	Germany	1,291	36%
2	Italy	824	27%
3	Turkey	630	65%
4	France	406	23%
5	Hungary	294	56%
6	Czech Republic	252	75%
7	Austria	246	72%
8	Poland	226	39%
9	Slovakia	226	99%
10	Finland	148	95%
11	Romania	140	22%
12	Fmr Yugoslavia	134	57%
13	Bulgaria	101	53%
14	Greece	85	85%
15	Switzerland	13	11%
Sales to Baltic & CIS States, 2005			
	Ukraine	2,113	69%
	Belarus	710	99%
	Baltic States	205	89%
	Azerbaijan	120	33%
	Georgia	46	88%

Sources: Domestic Consumption: EIA International Energy Annual, 2005; Imports: Cedigaz 2006 and BP Statistical Review 2007.

Table 3: Sources of Natural Gas for Ukraine's January 2006 Supply Agreement

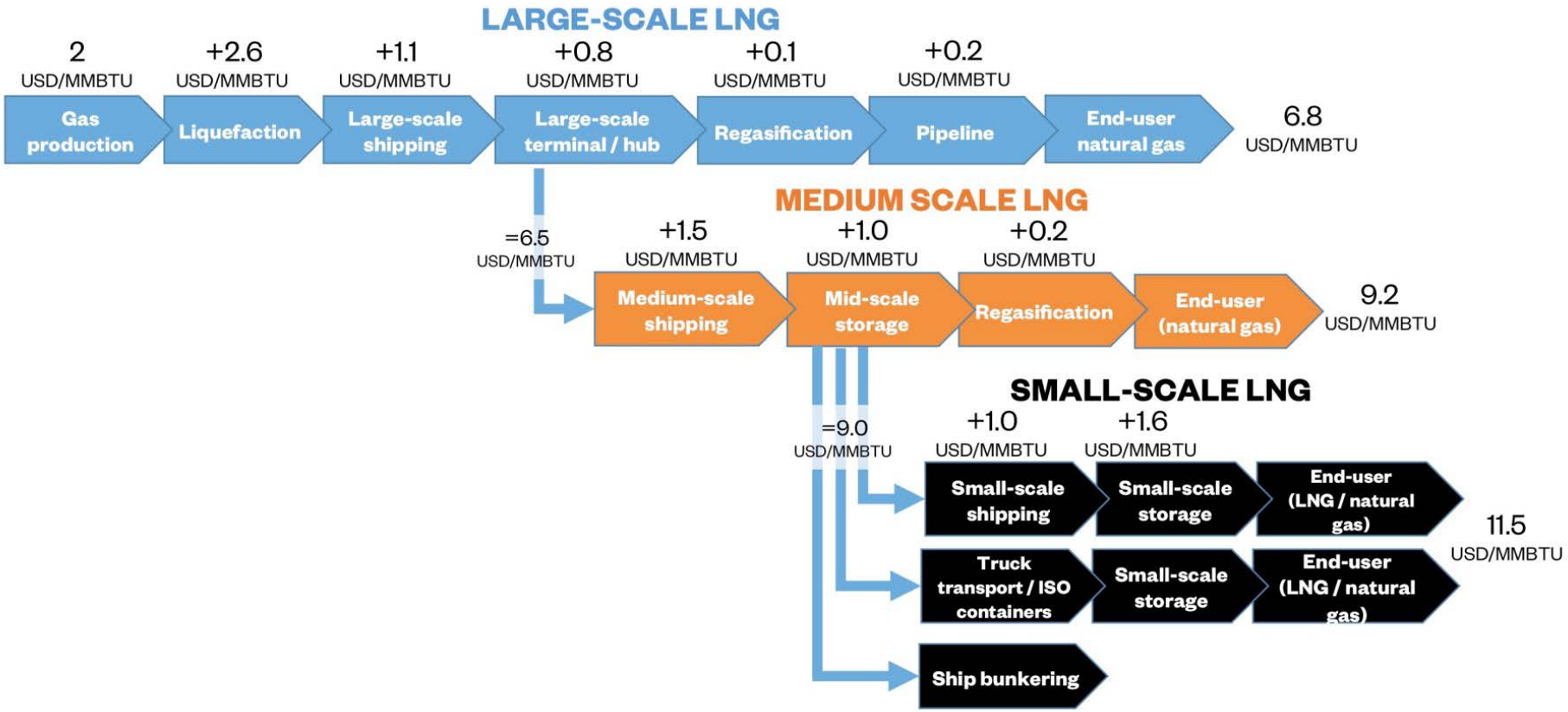
Country Source	Amount (BCM/y)	Amount (BCF/y)	Acquired by	Price ($/MCM)*	Price ($/MMCF)*
Turkmenistan**	41	1449	Gazexport, Naftohaz Ukrainy	$ 65.00	$ 1.84
Uzbekistan	7	247	Gazexport	$ 65.00	$ 1.84
Kazakhstan	8	283	Gazexport	$ 65.00	$ 1.84
Russia	17	601	Gazexport	$ 230.00	$ 6.51
Total/Wtd.Average	**73**	**2,580**		**$ 103.42**	**$ 2.93**

* MCM: Thousand Cubic Meters, MMCF: Million Cubic Feet

**Naftohaz Ukrainy stated on 1/10/06 it will buy Turkmen gas for $50/mmcm in the first half of 2006 and $60 during the second half, but the final agreement's price was higher. Using the lower price for Turkmen gas, the wtd. average price is $97.8/MCM.

Source: Russian Energy Monthly, January 2006

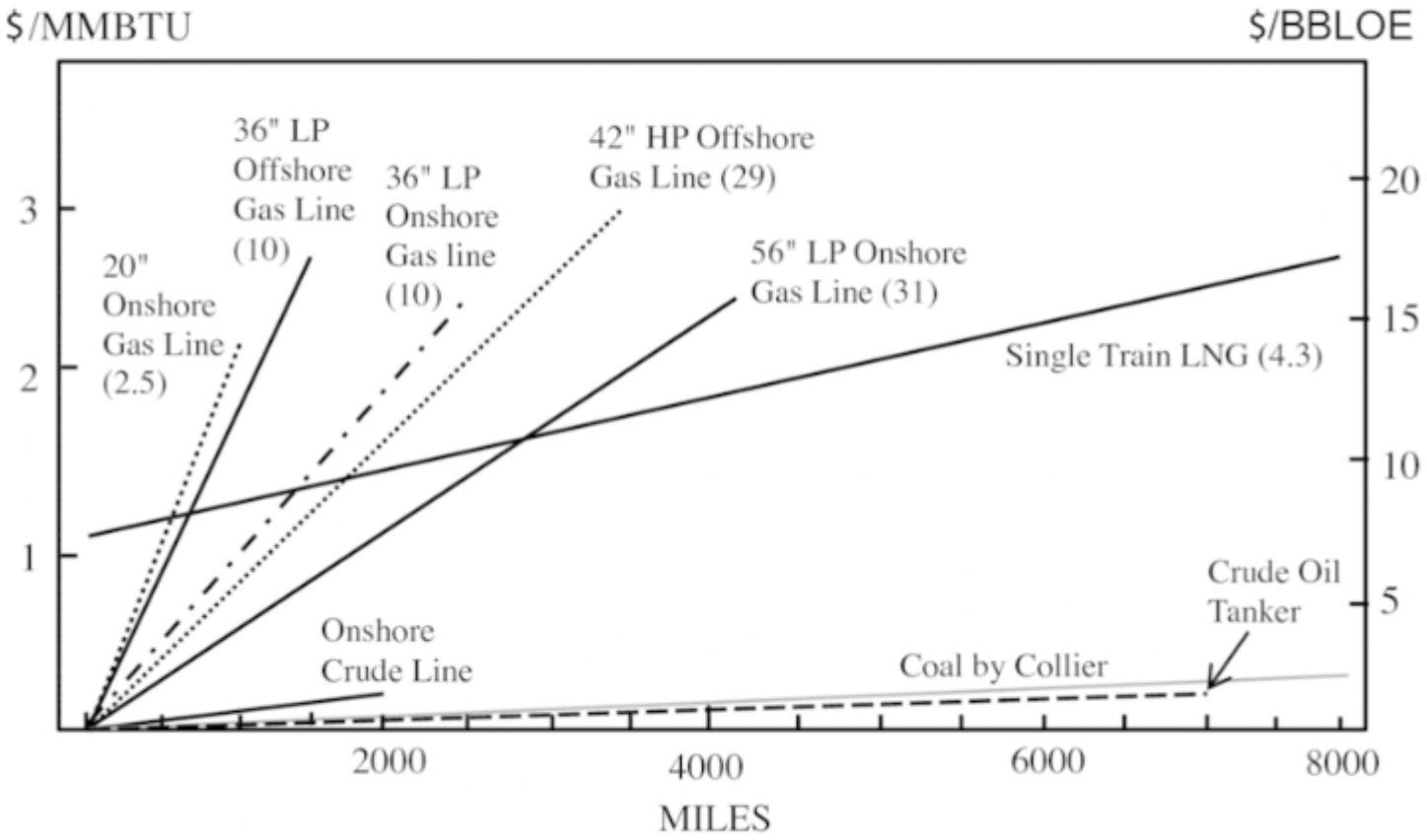
LNG Value Chain



Wärtsilä Technical Journal October 20, 2016

Jensen 2004 Break-even Points

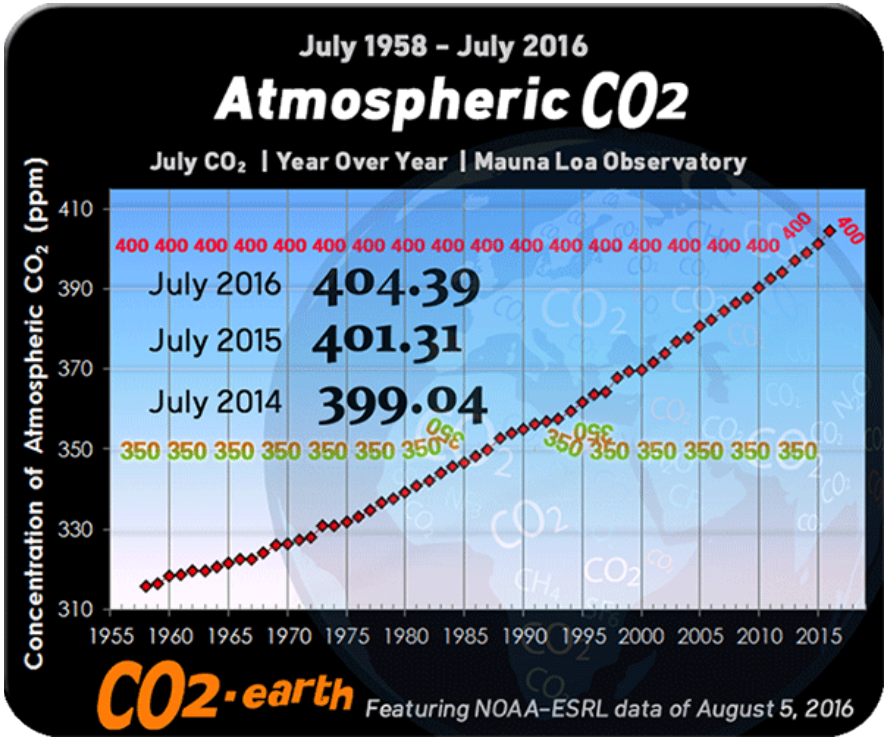
Figure 1 Break-even points. Source of data: [6]6. Jensen , J. 2004. The Development of a Global LNG Market. Is it Likely? If So, When?, Oxford: Oxford Institute for Energy Studies. View all references.



Note: Figures in brackets show gas delivery capability in BCM

Climate Change

What does "450 ppm(v) CO_2" Mean?



Gas	Ratio compared to Dry Air *(%)*		Molecular Mass *- M -* *(kg/kmol)*	Chemical Symbol
	By volume	By weight		
Oxygen	20.9500	23.2	32.00	O_2
Nitrogen	78.0900	75.47	28.02	N_2
Carbon Dioxide	0.0300	0.046	44.01	CO_2
Hydrogen	0.0001	~ 0	2.02	H_2
Argon	0.9330	1.28	39.94	Ar
Neon	0.0018	0.0012	20.18	Ne
Helium	0.0005	0.00007	4.00	He
Krypton	0.0001	0.0003	83.80	Kr
Xenon	$9\ 10^{-6}$	0.00004	131.29	Xe

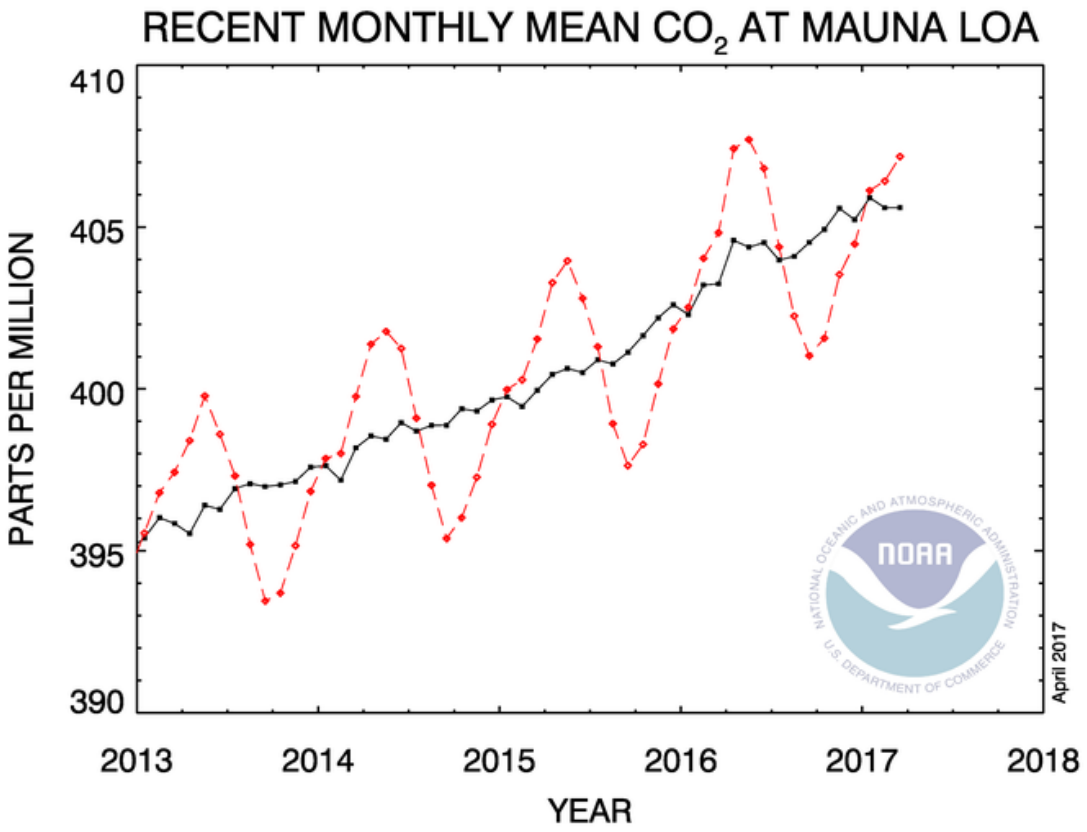
Standard assumptions on the chemical composition of Air

0.0300% = 300 ppm(v)

Value July 2016 at Mauna Loa was 404.30ppm(v)

Recent Monthly Mean CO_2 at Mauna Loa

March 2017: 407.18 ppm
March 2016: 404.83 ppm
Last updated: April 5, 2017

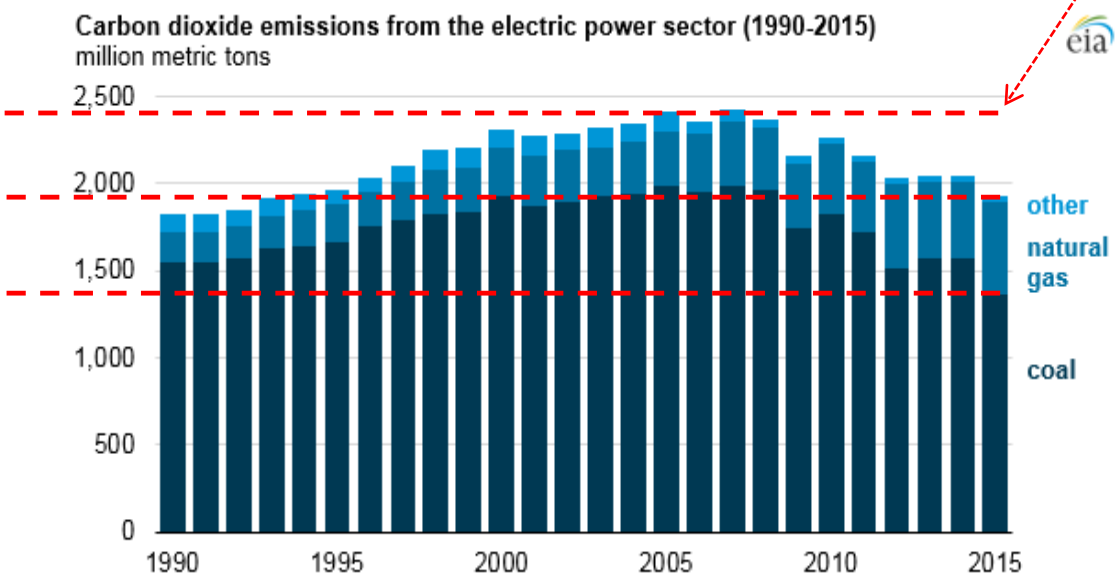


CO_2 Emission from the Power Sector

- **CO_2 emissions from electricity generation**
  - 2,416 million metric tonnes in 2005
  - 1,925 million metric tonnes in 2015 = (20.3%)
  - 1,643 million metric tonnes in 2030 = (32.0% lower than 2005)

- **The Clean Power Plan - CPP**
  - A shift on the electricity generation mix, with generation from natural gas and renewables displacing coal-fired power, drove the reductions in emissions.
  - Total carbon dioxide emissions from the electric power sector declined even as demand for electricity remained relatively flat over the previous decade

Note:
2005 was close to the all time high



CO_2 Emission from Electric Power

Electric power sector carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	1,831.0	2,416.9	2,373.7	2,160.3
Change from 1990 (million metric tons)		585.8	542.7	329.3
(percent)		*32.0%*	*29.6%*	*18.0%*
Average annual change from 1990 *(percent)*		*1.9%*	*1.5%*	*0.9%*
Change from 2005 (million metric tons)			-43.1	-256.5
(percent)			*-1.8%*	*-10.6%*
Change from 2008 (million metric tons)				-213.4
(percent)				*-9.0%*

Figure 15. U.S. electric power sector energy sales and losses and carbon dioxide emissions from primary fuel combustion, 1990-2009

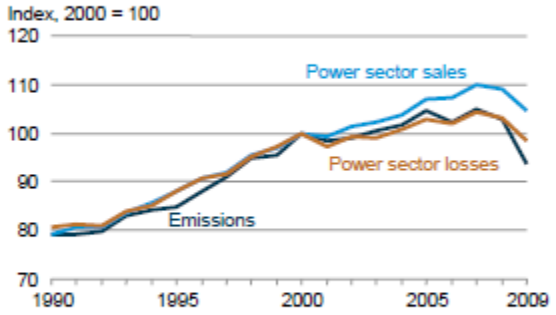


Table 12. U.S. carbon dioxide emissions from electric power sector energy consumption, 1990-2009 (million metric tons carbon dioxide)

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Petroleum										
Residual fuel oil	91.6	44.6	68.6	68.5	69.3	69.1	28.4	31.3	18.9	14.3
Distillate fuel oil	7.1	7.9	12.8	11.8	8.1	8.4	5.4	6.5	5.3	5.1
Petroleum coke	3.1	8.2	10.1	17.8	22.7	24.9	21.8	17.5	15.7	14.2
Petroleum subtotal	*101.8*	*60.7*	*91.5*	*98.1*	*100.1*	*102.3*	*55.6*	*55.3*	*40.0*	*33.6*
Coal	1,547.6	1,660.7	1,927.4	1,931.0	1,943.1	1,983.8	1,953.7	1,987.3	1,959.4	1,742.2
Natural gas	175.5	228.2	280.9	278.3	296.8	319.1	338.2	371.7	362.3	372.6
Municipal solid waste[a]	5.8	10.0	10.1	11.4	11.2	11.2	11.5	11.3	11.6	11.8
Geothermal	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total	**1,831.0**	**1,960.1**	**2,310.2**	**2,319.2**	**2,351.5**	**2,416.9**	**2,359.5**	**2,425.9**	**2,373.7**	**2,160.3**

[a]Emissions from nonbiogenic sources, including fuels derived from recycled tires.
Notes: Emissions for total fuel consumption are allocated to end-use sectors in proportion to electricity sales. Totals may not equal sum of components due to independent rounding.

38.5% from Fossil Fuel PowerGen

2,302.9 total in 2005

base e®

"Practical Strategies for Emerging Energy Technologies"

2005 @ 2416 Mt is benchmark for CPP
Was 2,416 x 0.68 = 1643 mmt

EPA Clean Power Plan - 2015

2030

O&G Resource		Economic Growth: Ref Case	Economic Growth: High EG
Ref Case			
	2005 Ref	2416	
	AEO2015	2177	2262
	CPP	1596	1727
	CPPEXT	1553	
	Obama 2015?	1643	
High OGR			
	AEO2015	2089	2171
	CPP	1606	1738

2040

O&G Resource		Economic Growth: Ref Case	Economic Growth: High EG
Ref Case			
	2005 Ref	2416	
	AEO2015	2195	2266
	CPP	1691	1827
	CPPEXT	1329	
High OGR			
	AEO2015	2179	2249
	CPP	1701	1838

"32% reduction in 2005 power plant CO_2 emissions by 2030"

What does that really mean?
It's time for those pesky numbers again!

How the Clean Power Plan Works

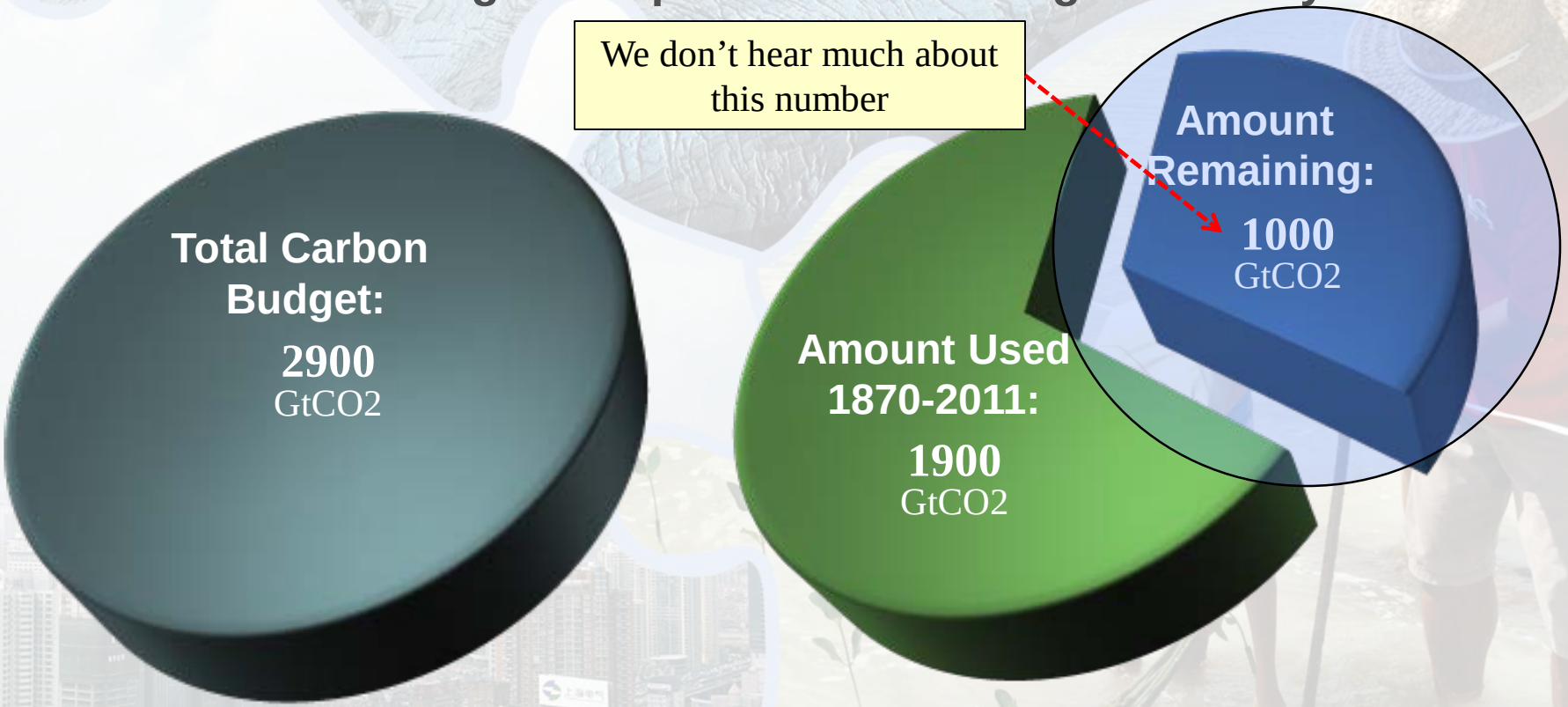
- The Clean Air Act creates a partnership between EPA, states, tribes and U.S. territories – with EPA setting a goal and states and tribes choosing how they will meet it.
- The final Clean Power Plan follows that approach. EPA is establishing interim and final carbon dioxide (CO_2) emission performance rates for two subcategories of fossil fuel-fired electric generating units (EGUs):
  - Fossil fuel-fired electric steam generating units (generally, coal- and oil-fired power plants)
  - Natural gas-fired combined cycle generating units
- To maximize the range of choices available to states in implementing the standards and to utilities in meeting them, EPA is establishing interim and final statewide goals in three forms:
  - A rate-based state goal measured in pounds per megawatt hour (lb/MWh);
  - A mass-based state goal measured in total short tons of CO_2;
  - A mass-based state goal with a new source complement measured in total short tons of CO_2.
- States then develop and implement plans that ensure that the power plants in their state – either individually, together or in combination with other measures – achieve the interim CO_2 emissions performance rates over the period of 2022 to 2029 and the final CO_2 emission performance rates, rate-based goals or mass-based goals by 2030.
- These final guidelines are consistent with the law and align with the approach that Congress and EPA have always taken to regulate emissions from this and all other industrial sectors – setting source-level, source category-wide standards that sources can meet through a variety of technologies and measures.

EPA State Goals appear to be based on 70% Natural Gas and 30% Renewables

The window for action is rapidly closing

65% of our carbon budget compatible with a 2°C goal already used

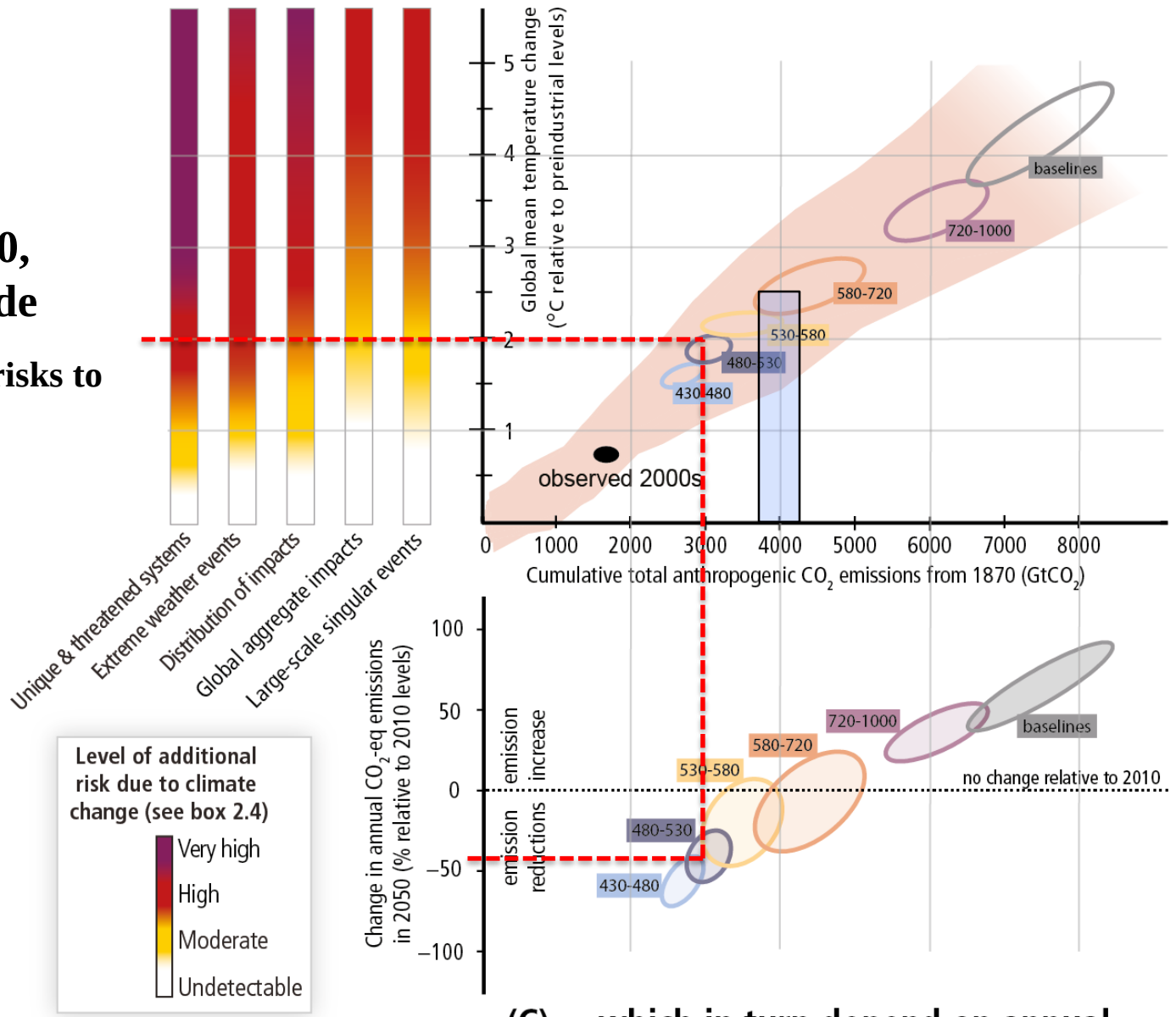
We don't hear much about this number



AR5 WGI SPM

Figure SPM.10, A reader's guide

From climate change risks to GHG emissions



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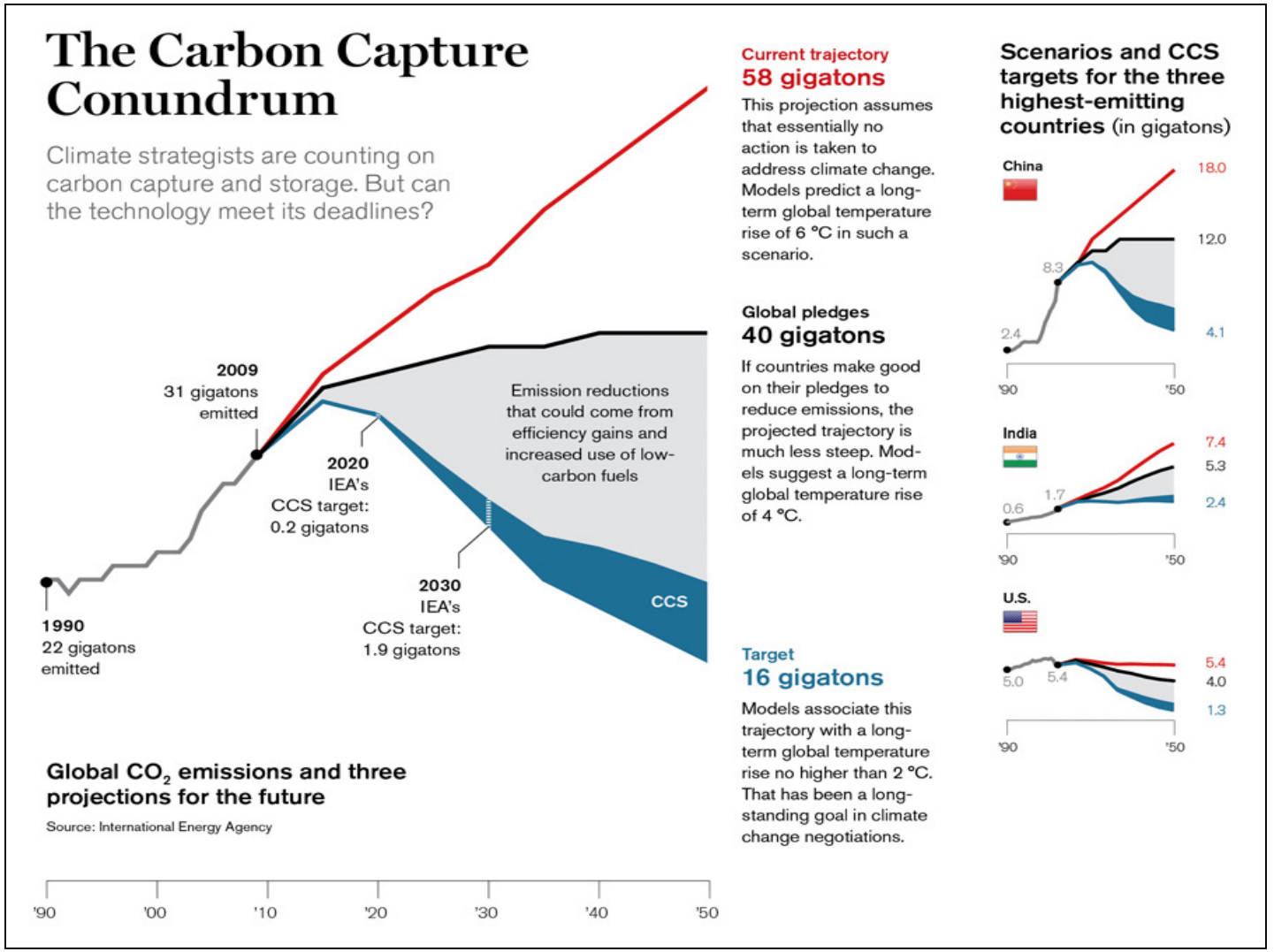
"Practical Strategies

The Carbon Conundrum



MIT Technology Review – Mike Orcott

EIA U.S. Annual Energy Outlook 2017

Annual U.S. Emissions (Mmt CO2)

	Case ID	2015	2020	2025	2030	2035	2040	2045	2050
Total Electric Power	Ref Case without CPP	1918.5	1835.9	1849.8	1885.5	1906.6	1940.6	1979.1	2018.7
U.S. Energy-Related		5259.1	5287.8	5267.6	5210.5	5208.2	5297.2	5419.4	5565.4
Electric Power	High Economic Growth	1918.5	1846.3	1661.1	1541.5	1539.4	1544.0	1552.0	1561.2
U.S. Energy-Related		5259.1	5328.6	5118.9	4947.7	5000.6	5128.3	5292.9	5481.3
Electric Power	Low Oil Price	1918.5	1824.0	1661.8	1540.1	1540.3	1536.6	1541.7	1553.6
U.S. Energy-Related		5259.1	5336.6	5154.6	4979.4	5018.5	5101.0	5225.0	5380.9
Electric Power	High O&G Res & Tech	1918.5	1743.3	1616.2	1532.7	1528.3	1523.9	1523.0	1551.3
U.S. Energy-Related		5259.1	5216.1	5079.2	4929.0	4928.2	4981.9	5073.9	5217.2
Electric Power	Ref Case with CPP	1918.5	1820.5	1658.9	1537.0	1532.0	1530.8	1536.3	1546.8
U.S. Energy-Related		5259.1	5271.7	5068.6	4850.9	4827.1	4878.4	4968.3	5084.2
Electric Power	High Oil Price	1918.5	1678.1	1641.2	1533.6	1528.8	1531.1	1537.0	1545.1
U.S. Energy-Related		5259.1	5044.7	4960.2	4806.1	4819.9	4880.4	4918.8	5018.5
Electric Power	Low O&G Res & Tech	1918.5	1870.2	1660.0	1528.4	1531.5	1522.0	1510.2	1505.0
U.S. Energy-Related		5259.1	5303.8	4982.2	4710.9	4685.3	4704.0	4777.5	4862.6
Electric Power	Low Economic Growth	1918.5	1787.9	1644.2	1530.2	1531.3	1534.3	1537.9	1539.9
U.S. Energy-Related		5259.1	5203.1	4964.9	4708.8	4639.7	4616.4	4624.4	4647.5

No impact for Coal-to-Gas shift after 2030
CPP contributes 400-500 Mt

EIA U.S. Annual Energy Outlook 2017

- The Impact of the Clean Power Plan is 400-500 mmt

	Case ID	2015	2020	2025	2030	2035	2040	2045	2050
Impact of CPP	Electric Power	0.0	15.4	190.9	348.5	374.6	409.8	442.8	471.9
Impact of CPP	U.S. Energy Related	0.0	16.1	199.0	359.6	381.1	418.8	451.0	481.2

- The U.S. would represent 10.4% or 11.4% of worldwide CO2 emission, depending on whether CPP is in or is out of the plan.

	Case ID	2015	2020	2025	2030	2035	2040	2045	2050
WW Emissions AEO2016	U.S. Energy Related	33.5	35.6	37.432	39.1	41.1	43.2		
U.S. % of WW	without CPP	15.7%	14.8%	14.1%	13.3%	12.7%	12.3%	11.8%	11.4%
U.S. % of WW	With CPP	15.7%	14.8%	13.5%	12.4%	11.7%	11.3%	10.8%	10.4%

- The AEO2017 Reference Case Worldwide in 2050:

  Worldwide Forecast with CPP = 48.8 Gt

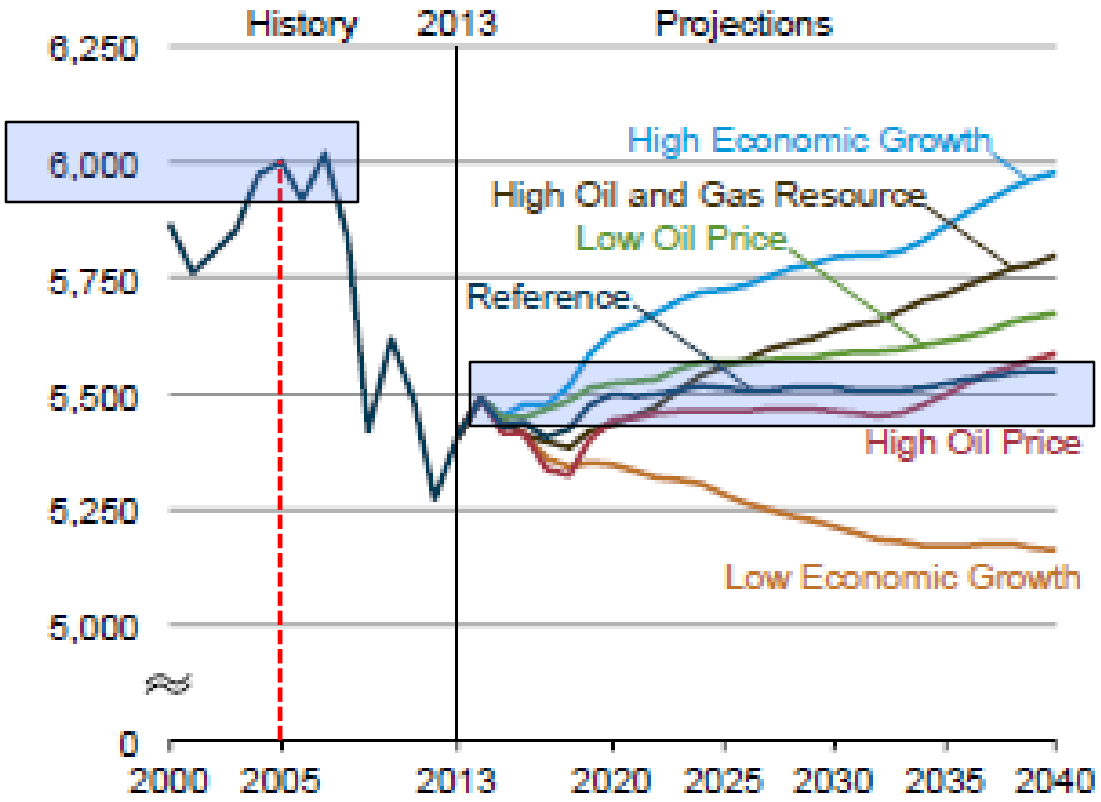
  Worldwide Forecast without CPP = 57.0 Gt

- The World reaches the cumulative 2900Gt, 2C/450 ppm in ~2037/38

EIA Energy Related CO2 Forecast

"High Water Mark" as basis for goal

Figure 36. Energy-related carbon dioxide emissions in six cases, 2000-2040 (million metric tons)



Ref. Case is "Business as Usual"

Sierra Club Fact Sheet – November 3, 2015

FIGURE 1: CARBON EMISSIONS IN THE ELECTRIC SECTOR AND ECONOMY-WIDE SINCE 2010

Figure 1A: Electric Power Sector

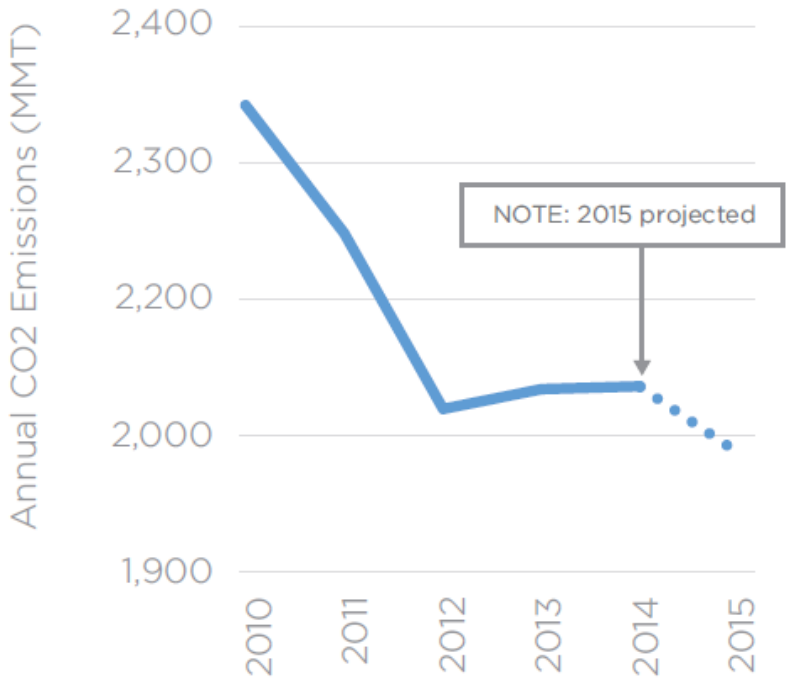
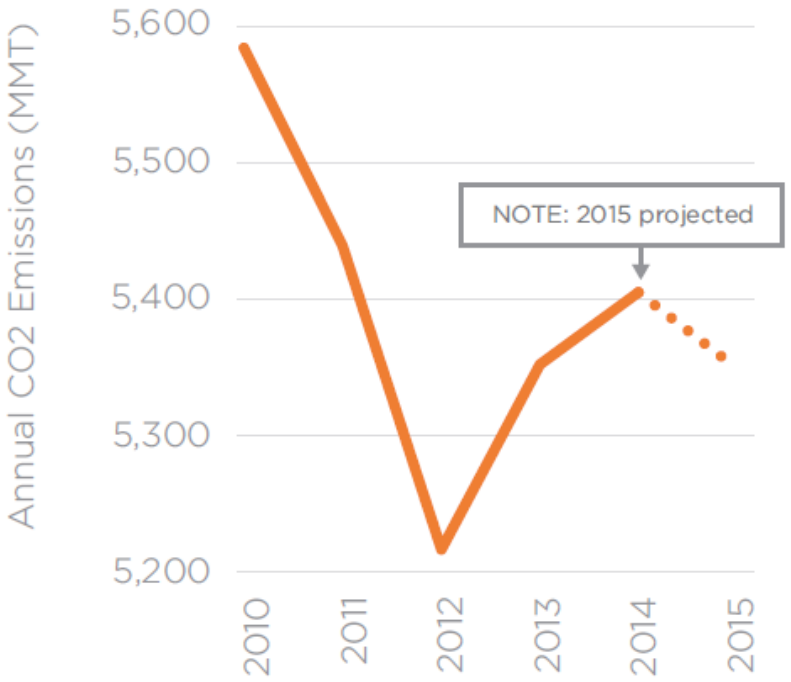


Figure 1B: All Sectors (Economy-Wide)

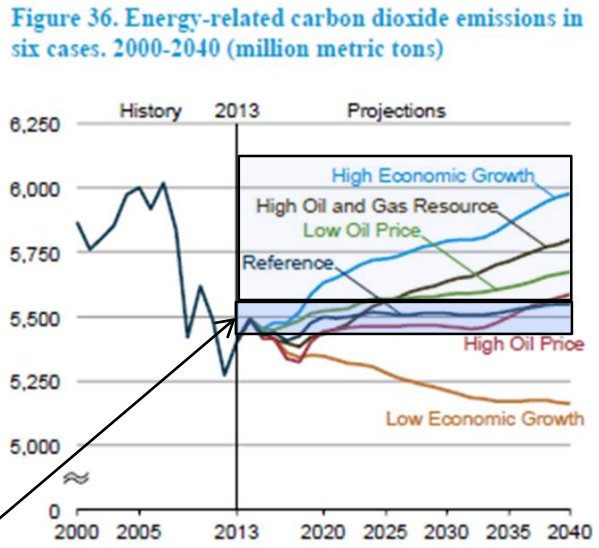


Mission Accomplished?

Sierra Club Fact Sheet – November 3, 2015 (Re-scaled)

Oops!
Didn't mean to mislead you with the scales….
"Greenwashing?"

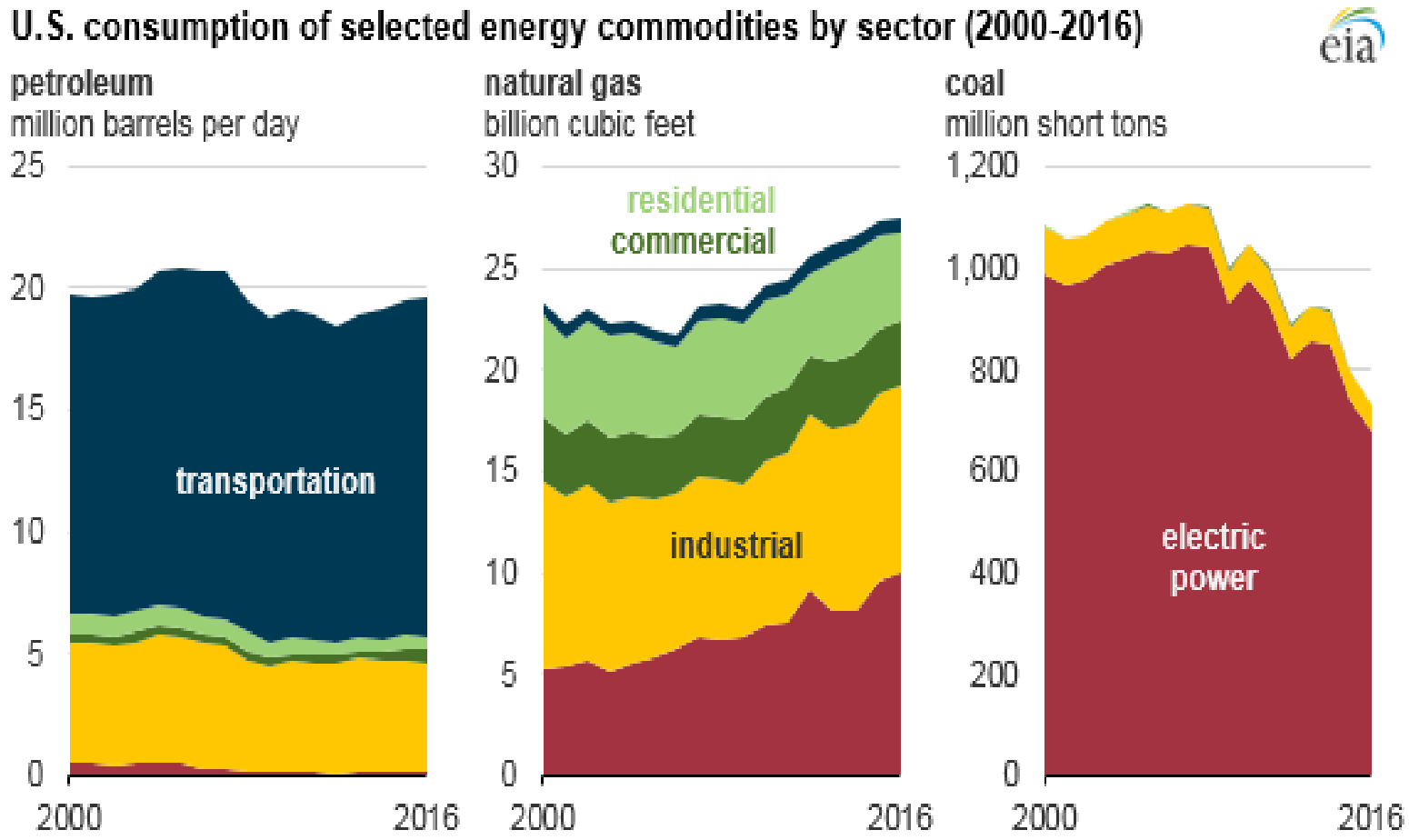
Miracles Occur Here!



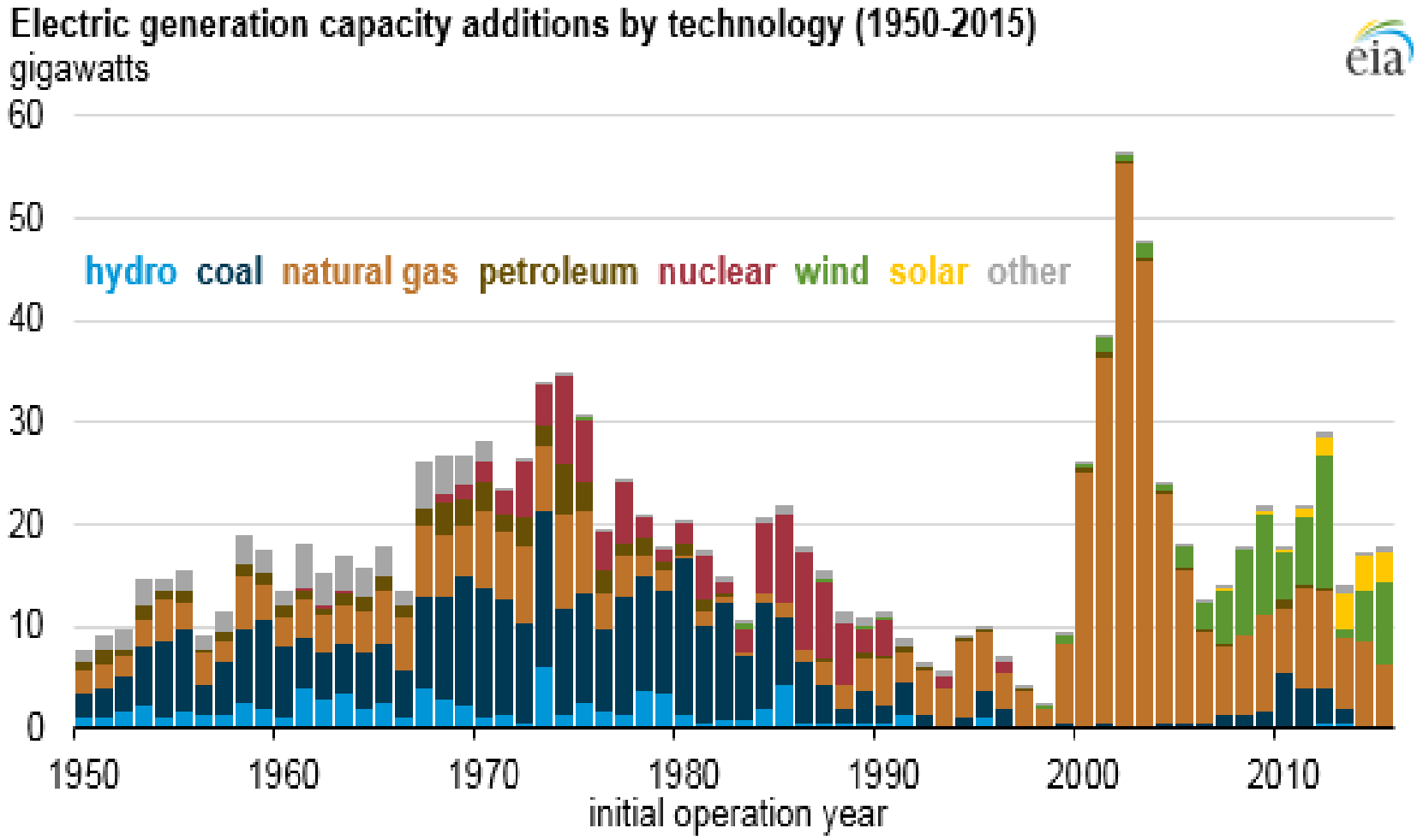
OBTW - The Sierra Club has admitted to accepting $27 million contribution from the natural gas industry, presumably to fund their "Beyond Coal" initiative, but only after the facts became known.

Mission defined as "eliminating coal", vs. "eliminating emissions from coal"

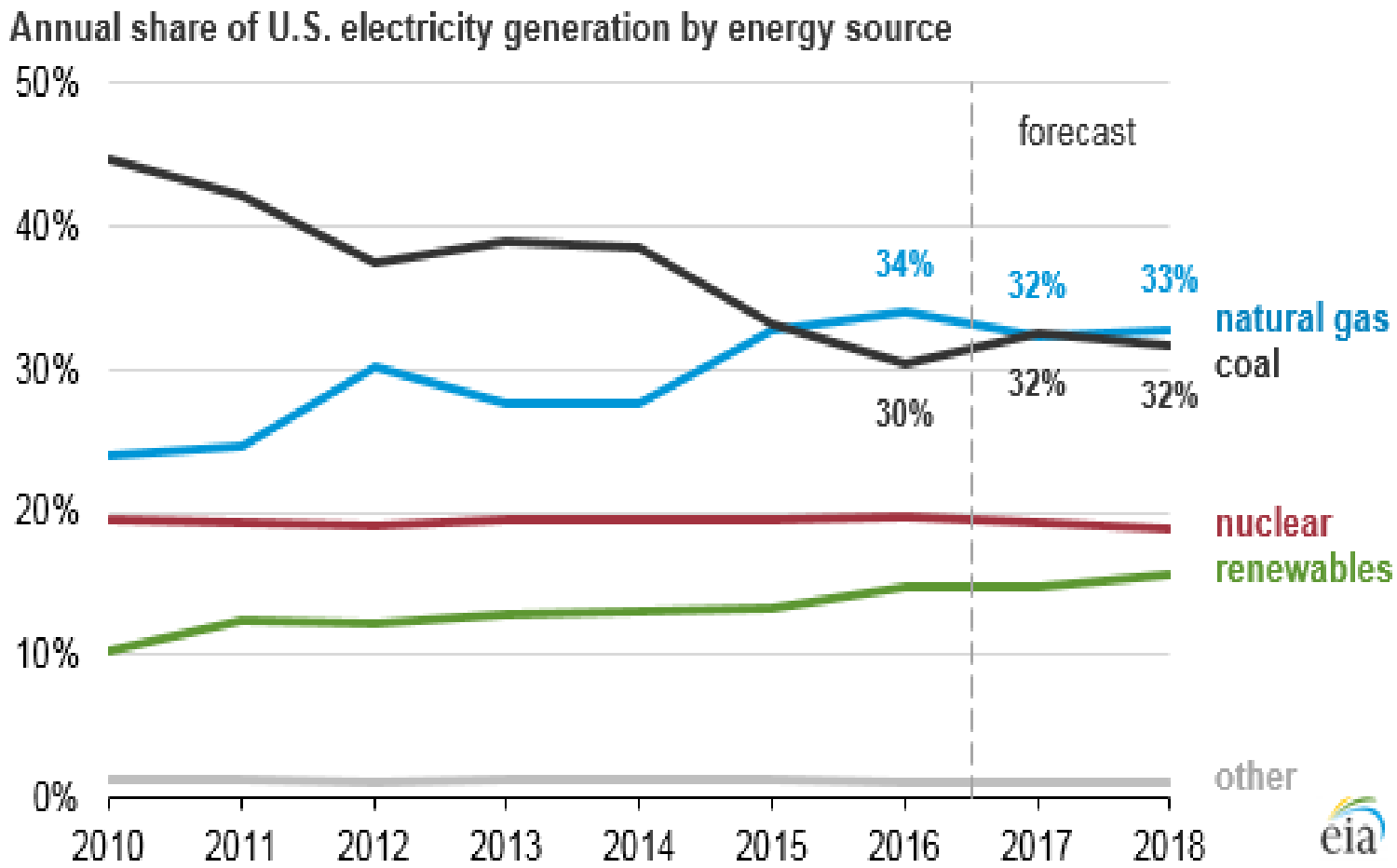
U.S. Energy Consumption by Sector



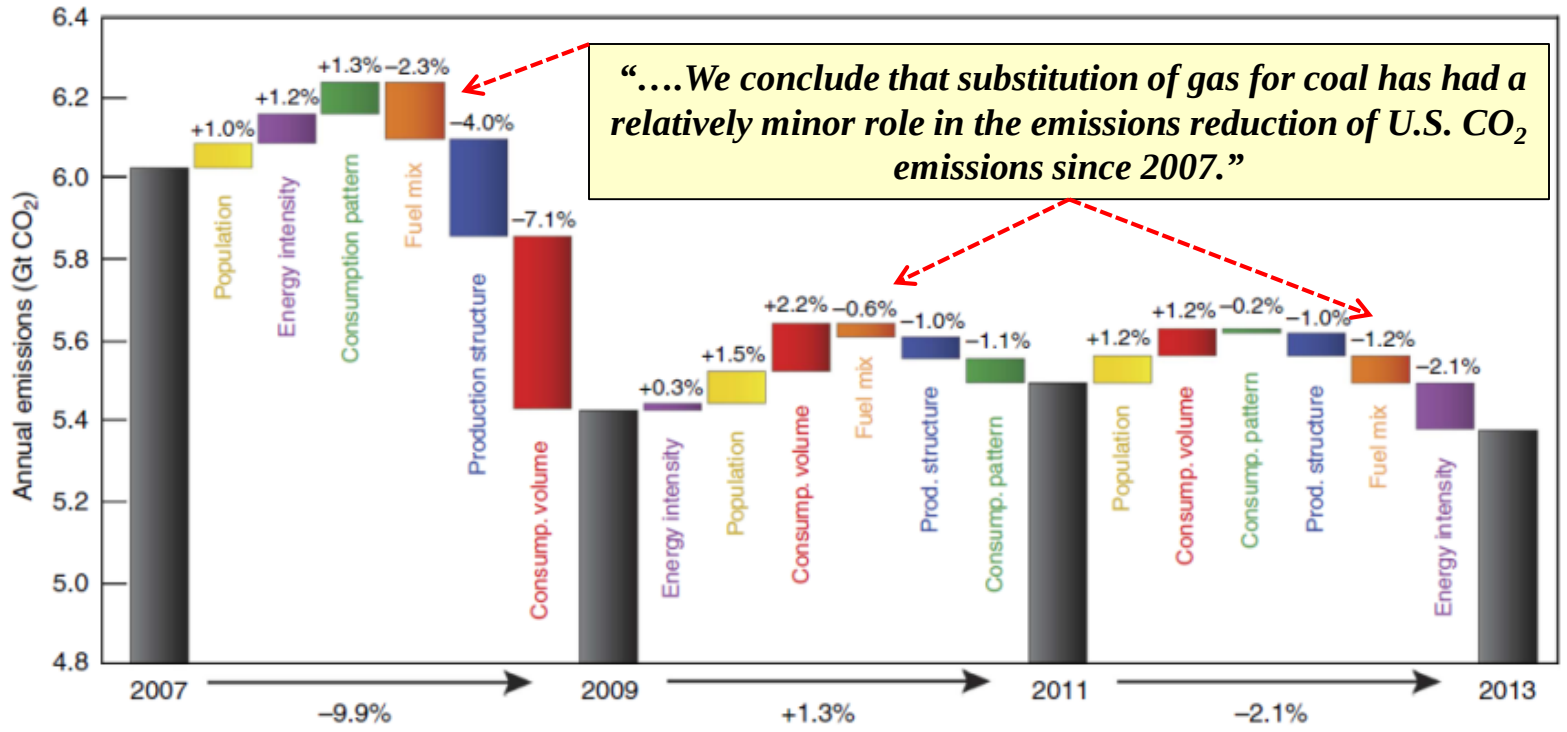
Electric Generation Capacity Additions



U.S. Power Generation Mix



Coal-to-Gas Shift – nature.com



"….We conclude that substitution of gas for coal has had a relatively minor role in the emissions reduction of U.S. CO_2 emissions since 2007."

Figure 3 | Contributions of different factors to the decline in US CO_2 emissions 2007–2009 and 2009–2011 and 2011–2013. Between 2007 and 2009, decreases in the volume of goods and services consumed during the economic recession (red) was the primary contributor to the nearly 10% drop in emissions. But between 2009 and 2011, consumption (consump.) volume rebounded, population grew and the energy intensity of output increased, driving up emissions by 1.3% against modest decreases in the carbon intensity of the fuel mix and shifts in production structure and consumption patterns. Between 2011 and 2013, increases in population and consumption volume again pushed emissions upward, but overall emissions decreased by 2.1% due to further changes in production (prod.) structure, consumption patterns, decreasing use of coal and decreases in energy intensity of output. Not shown here, emissions increased by 1.7% between 2012 and 2013, driven primarily by increases in consumption volume.

"The new EPA Clean Power Plan is largely built on fuel switching and renewables deployment"

http://www.nature.com/ncomms/2015/150721/ncomms8714/full/ncomms8714.html

Gas Bridge to Renewables Already Built

- For the U.S. to reach its climate goals, the deadline for constructing the last gas-fired power plant is coming up shortly — if not already past
- Gas has a significant near-term role in reducing dependence on coal-fired power and helping the transition to intermittent renewable sources. But, to reduce greenhouse gas emissions to a target of 80% below 1990 levels by 2050, the nation must ultimately eliminate almost all use of fossil fuels, including natural gas
- "A power plant on the drawing boards today could still be operational in 2050 and well beyond. With each passing year, the likely life span of new natural gas power plants moves further beyond 2050 ".
- **The U.S. EPA's Clean Power Plan might do more harm than good** because substituting gas-fired power for coal capacity is one of the options for complying with the rules requirements. Rather, lawmakers should consider setting a final date beyond which no new natural gas power plants can be approved, Weissman advised.
- To make that possible while maintaining grid reliability, policymakers would have to require strategic adoption of renewable power, trying to match the types and locations for maximum impact.
- Lawmakers and regulators would also need to deploy a wide range of demand-response tools, focus on energy efficiency measures and better structure regional power markets to manage shifting demand.
- Almost 237 GW of gas-fired generation capacity was added between 2000 and 2010, making up 81% of all the generation capacity added in that decade. This momentum could increasingly complicate efforts to cut back on gas use.
- **"As more people and institutions invest in natural gas, political pressure to sustain its use grows. It will become more and more difficult to achieve long-range greenhouse gas reduction goals". "Natural gas cannot play a long-term role in creating our desired carbon-constrained future, as its benefits are not enough to support our carbon reduction goals"**

Steve Weissman – Senior Policy Advisor, Center for Sustainable Energy

Source: Sarah Smith SNL Thursday, March 31, 2016 12:56 PM ET

EIA Analysis of the Clean Power Plan – 5/22/2015

	2005	2013	2020				2030				2040			
			AEO HOGR	CPP HOGR	AEO HEG	CPP HEG	AEO HOGR	CPP HOGR	AEO HEG	CPP HEG	AEO HOGR	CPP HOGR	AEO HEG	CPP HEG
ELECTRIC GENERATION (billion kWh)														
Coal	2,013	1,586	1,443	1,212	1,733	1,415	1,441	898	1,733	1,293	1,440	910	1,744	1,421
Natural Gas	761	1,118	1,450	1,610	1,204	1,377	1,832	2,092	1,573	1,422	2,200	2,439	1,705	1,475
Nuclear	782	789	804	804	804	804	808	808	818	808	808	808	911	863
Hydro	270	267	289	294	294	305	290	295	297	305	290	295	298	308
Wind	18	168	229	263	243	315	232	407	301	634	234	412	489	725
Solar	1	19	51	59	52	70	65	85	80	247	85	106	160	420
Other renewables	69	76	107	110	106	117	146	128	158	161	175	145	222	207
Oil/other	142	47	44	41	43	42	42	39	43	41	42	40	43	42
Total	4,055	4,070	4,417	4,392	4,480	4,445	4,854	4,753	5,003	4,912	5,274	5,154	5,574	5,461
ELECTRIC GENERATION CAPACITY (GW)														
Coal	313	304	245	201	265	230	242	173	263	223	242	173	264	223
Natural gas / Oil	442	470	497	516	490	497	573	607	564	540	674	704	657	629
Nuclear	100	99	101	101	101	101	101	101	103	102	101	101	115	109
Hydro	78	79	79	80	80	82	79	80	80	82	79	80	81	83
Wind	9	61	82	97	87	115	83	142	105	216	84	144	165	245
Solar	0	13	27	32	28	38	36	45	44	121	48	58	82	200
Other renewables	12	15	17	18	18	19	20	21	23	26	22	23	32	31
Other	24	25	26	26	26	26	26	26	26	26	26	26	26	26
Total	978	1,065	1,075	1,070	1,094	1,108	1,159	1,196	1,207	1,335	1,275	1,309	1,422	1,546
ELECTRICITY-RELATED CARBON DIOXIDE EMISSIONS (million metric tons)														
Power sector	2,416	2,053	1,973	1,789	2,165	1,886	2,089	1,605	2,262	1,727	2,179	1,701	2,266	1,827

- Reference (AEO)
- Base Policy (CPP)
- Policy with High Oil & Gas Resource (CPPHOGR)

There is no mention of Climate Change in the report and…
There is no mention of CO2 concentration…
Let alone a target of 2C/450 ppm!

Page 18; Para (4) "…..and static CPP targets in the post-2030 period in the CPP case allow existing coal-fired plants to operate at a higher utilization rate which rises from a low of 60% in 2024 to 71% in 2040."

OBTW - Natural Gas Reserves

44.7% w/out Qatar

3. Top 20 countries with largest proved reserves (in trillion cubic feet and as equivalent % of total world share)

1.	IRAN	1183.0	18%
2.	RUSSIA	1139.6	17.3%
3.	QATAR	858.1	13%
4.	TURKMENISTAN	617.3	9.4%
5.	US	307.7	4.7%
6.	SAUDI ARABIA	297.6	4.5%
7.	UAE	215.1	3.3%
8.	VENEZUELA	201.3	3.1%
9.	CHINA	189.5	2.9%
10.	NIGERIA	186.6	2.8%

11.	ALGERIA	159.1 (2.4%)
12.	IRAQ	130.5 (2.0%)
13.	AUSTRALIA	122.6 (1.9%)
14.	INDONESIA	101.2 (1.5%)
15.	CANADA	76.7 (1.2%)
16.	EGYPT	65.2 (1.0%)
17.	KUWAIT	63.0 (1.0%)
18.	NORWAY	62.3 (0.9%)
19.	LIBYA	53.1 (0.8%)
20.	INDIA	43.3 (0.7%)

At more than 6,588 trillion cubic feet recorded in 2016, global proved gas reserves are sufficient to meet more than 52 years of current production. As a region, the Middle East holds the largest reserves with 42.5% of the global total, while Iran holds the most proved gas resources as a country.

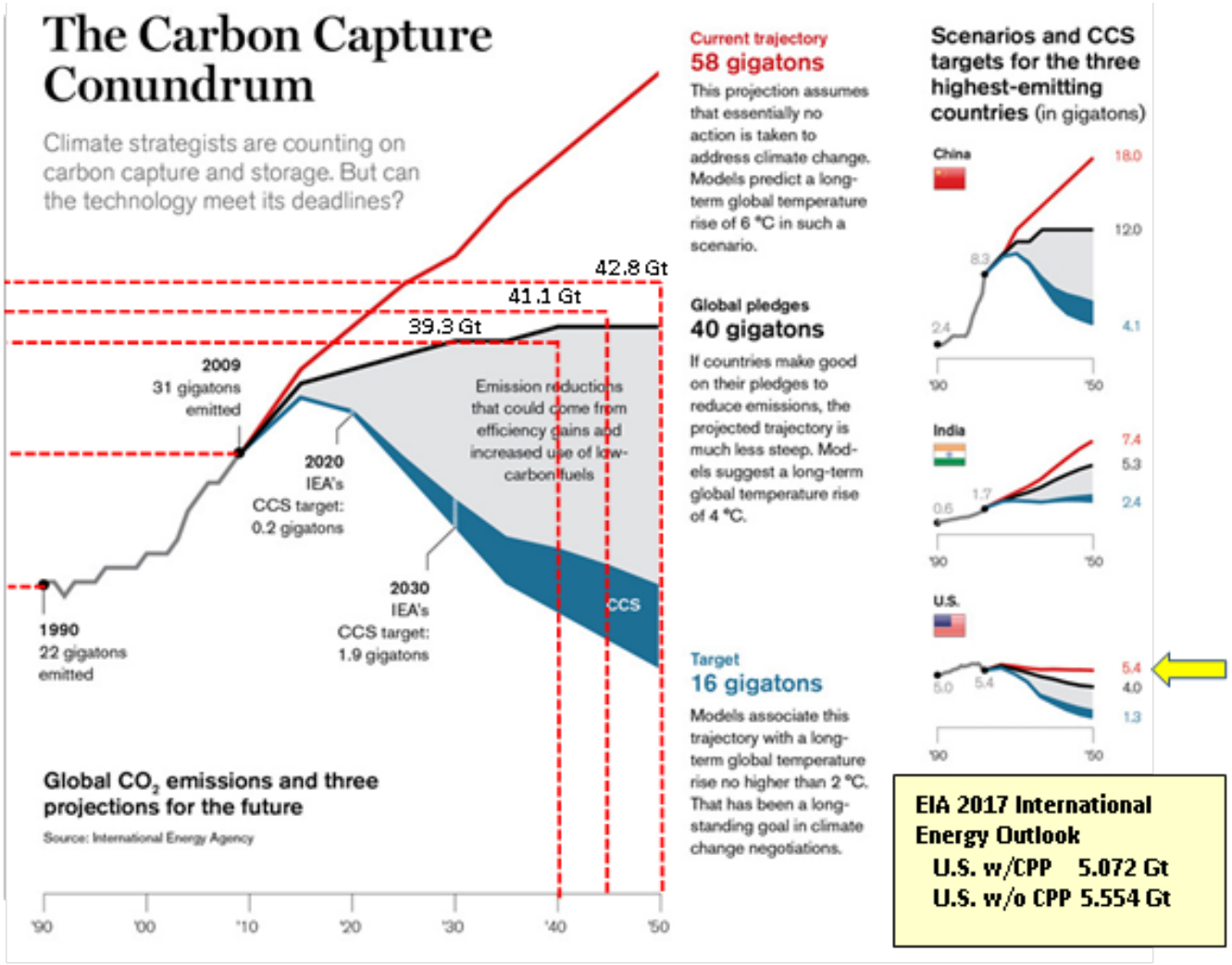
EIA WW Annual Energy Outlook 2017

Carbon dioxide emissions (Mmt): Reference Case	2010	2015	2016	2017	2020	2025	2030	2035	2040	2045	2050	Growth (2015-2050)
OECD Americas	6622.5	6341.5	6237.4	6271.3	6341.1	6175.4	5966.9	5970.4	6074.2	6217.4	6384.6	0.00%
United States	5570.5	5247.6	5145.5	5171.3	5260.2	5057.0	4839.4	4815.6	4866.8	4956.8	5072.6	-0.10%
Canada	555.0	590.3	592.6	603.8	586.8	600.6	595.7	607.6	626.3	649.2	671.8	0.40%
Mexico/Chile	497.0	503.7	499.2	496.3	494.2	517.8	531.8	547.2	581.0	611.3	640.1	0.70%
OECD Europe	4159.8	3858.0	3930.0	3962.6	3922.6	3814.0	3798.1	3902.6	3988.2	4096.9	4260.6	0.30%
OECD Asia	2093.9	2233.6	2240.6	2228.4	2185.8	2209.0	2243.1	2284.3	2332.5	2389.0	2466.2	0.30%
Japan	1108.0	1154.1	1139.6	1132.8	1072.6	1058.4	1038.2	1014.2	987.1	961.3	944.5	-0.60%
South Korea	563.0	663.0	687.8	683.4	702.3	720.9	751.3	791.0	835.2	881.2	930.2	1.00%
Australia/New Zealand	422.9	416.5	413.3	412.3	410.9	429.7	453.7	479.1	510.1	546.5	591.5	1.00%
Total OECD	12876.2	12433.1	12408.0	12462.4	12449.5	12198.4	12008.1	12157.4	12394.9	12703.2	13111.4	0.20%
Non-OECD Europe and Eurasia	2646.7	2691.8	2661.9	2665.1	2630.4	2582.8	2570.0	2616.9	2624.6	2599.8	2574.1	-0.10%
Russia	1620.0	1675.8	1636.5	1632.9	1609.8	1583.3	1587.1	1615.8	1615.0	1582.3	1540.9	-0.20%
Other	1026.7	1016.0	1025.3	1032.3	1020.6	999.4	983.0	1001.1	1009.6	1017.5	1033.3	0.00%
Non-OECD Asia	11320.1	14293.8	14546.9	14819.4	15167.5	16050.0	16589.1	17384.2	18285.7	19226.4	20056.6	1.00%
China	7746.0	9923.6	10009.5	10157.3	10205.1	10464.0	10421.8	10298.1	10161.1	10017.6	9792.9	0.00%
India	1612.0	2001.8	2108.3	2160.7	2305.3	2552.1	2883.6	3388.8	3959.2	4544.9	5043.1	2.70%
Other	1962.1	2368.4	2429.1	2501.3	2657.1	3033.8	3283.6	3697.3	4165.4	4663.9	5220.6	2.30%
Middle East	1730.4	1959.1	1966.1	2020.3	2085.0	2192.3	2315.6	2495.1	2691.8	2923.3	3117.4	1.30%
Africa	1067.3	1251.4	1274.6	1319.7	1370.4	1444.2	1505.5	1591.5	1739.8	1905.7	2100.1	1.50%
Non-OECD Americas	1193.7	1272.4	1237.9	1232.3	1269.6	1354.9	1409.5	1472.8	1580.8	1693.7	1811.7	1.00%
Brazil	457.0	482.3	459.8	452.1	470.0	513.7	540.2	561.1	595.8	633.2	668.4	0.90%
Other	736.7	790.2	778.1	780.2	799.7	841.2	869.3	911.7	985.0	1060.5	1143.3	1.10%
Total Non-OECD	17958.2	21468.6	21687.3	22056.8	22522.9	23624.1	24389.7	25560.6	26922.7	28349.0	29660.0	0.90%
Total World	30834.4	33901.8	34095.3	34519.2	34972.4	35822.5	36397.8	37717.9	39317.6	41052.2	42771.4	0.70%

Source: U.S. Energy Information Administration
https://www.eia.gov/outlooks/aeo/data/browser/#/?id=10-IEO2017&region=0-0&cases=Reference&start=2010&end=2050&f=A&linechart=Reference-d082317.2-10-IEO2017&sourcekey=0
Wed Sep 20 2017 12:46:07 GMT-0400 (Eastern Daylight Time)

Reference Case includes CPP

EIA 2017 International Energy Outlook

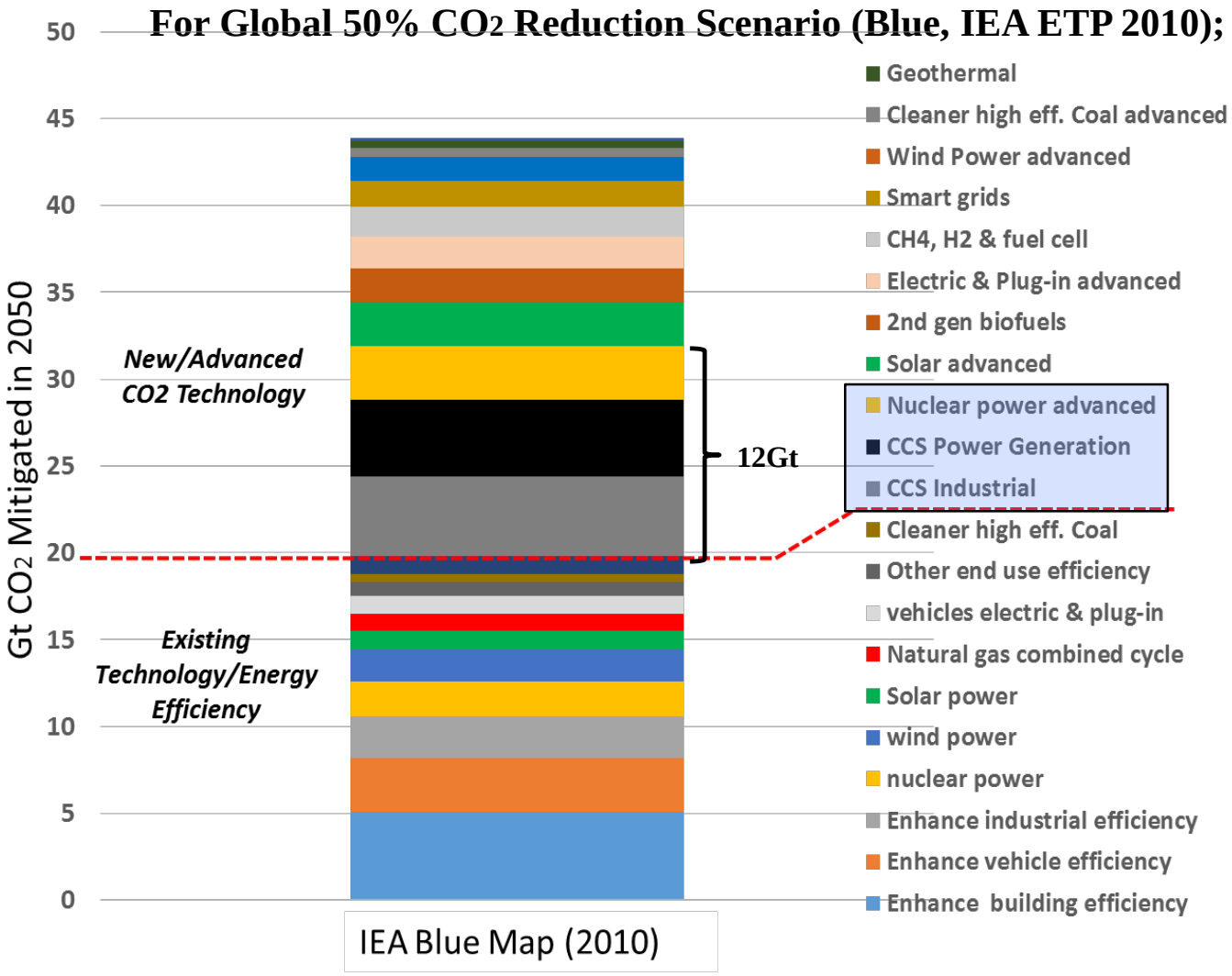


EIA 2017 International Energy Outlook

U.S. w/CPP 5.072 Gt

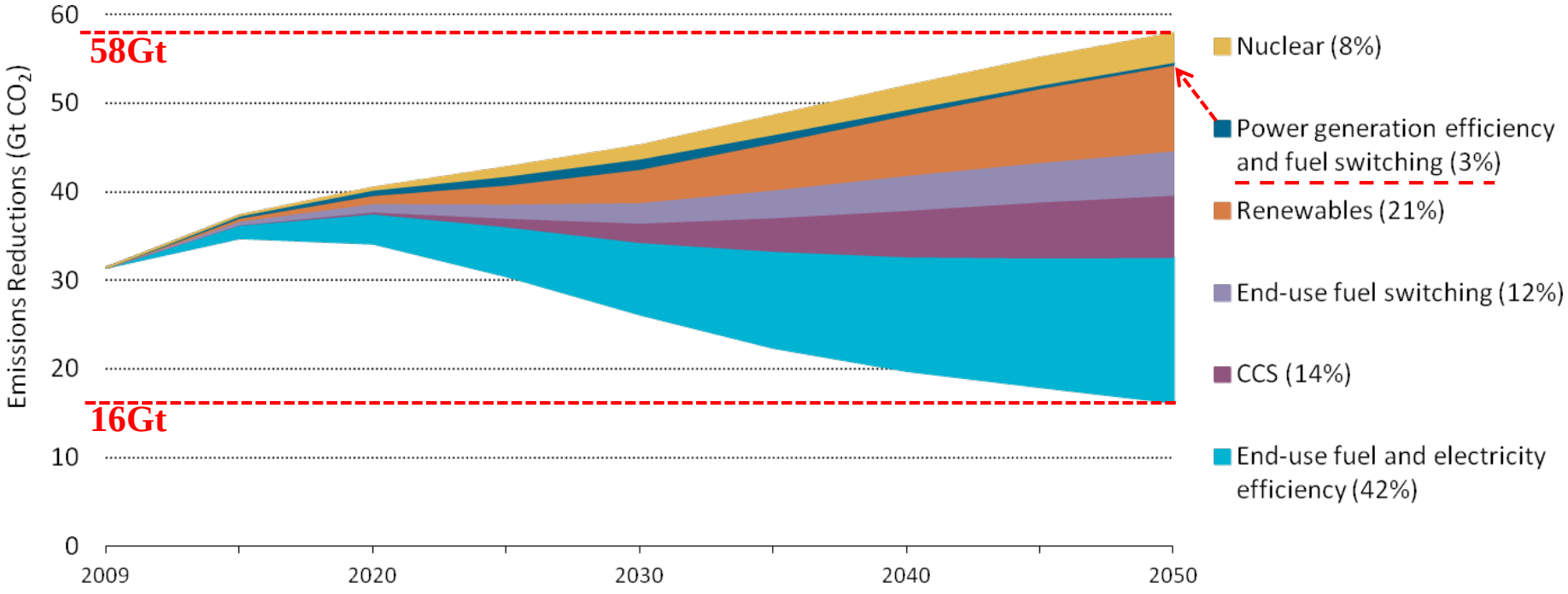
U.S. w/o CPP 5.554 Gt

New & Advanced Technologies Needed



Source: DOE SCO2 Conference 2014, as presented by EPA

IEA Vision May 2013



Nuclear and CCS technologies currently on "life support"

12th Annual CCUS Conference
Pittsburgh, 15 May 2013

Juho Lipponen
Head of Unit, Carbon Capture and Storage
International Energy Agency

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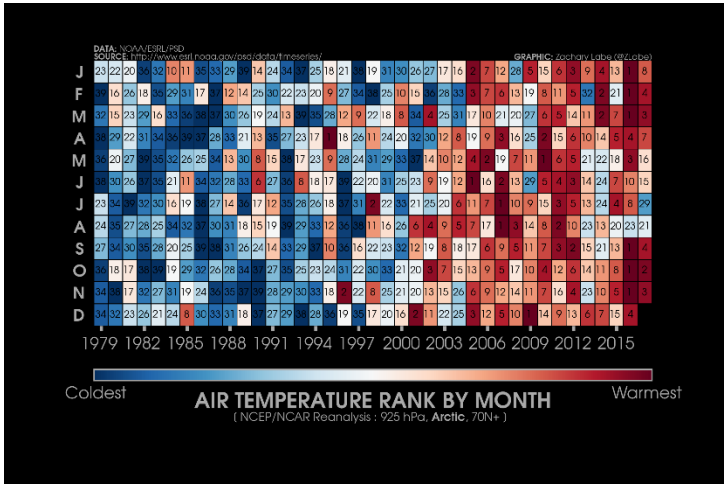
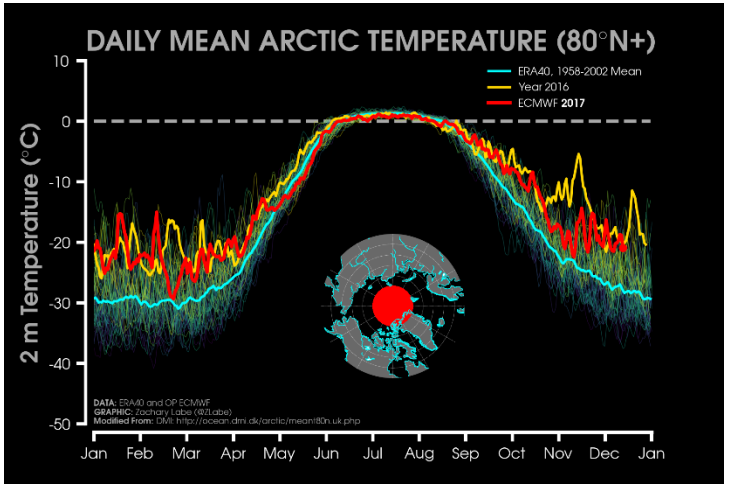
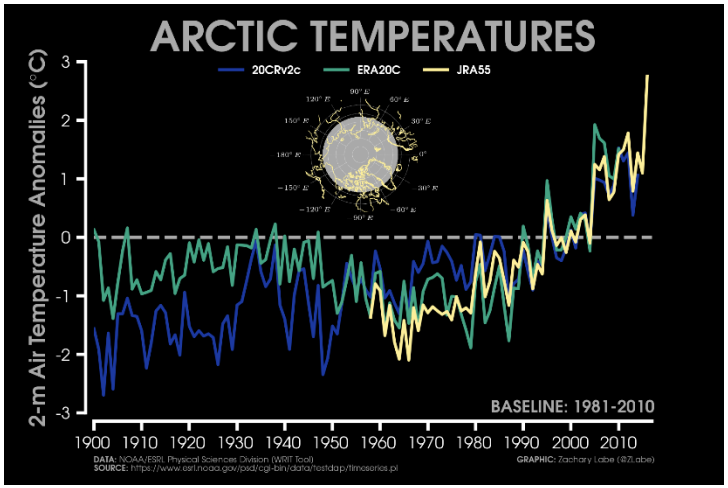
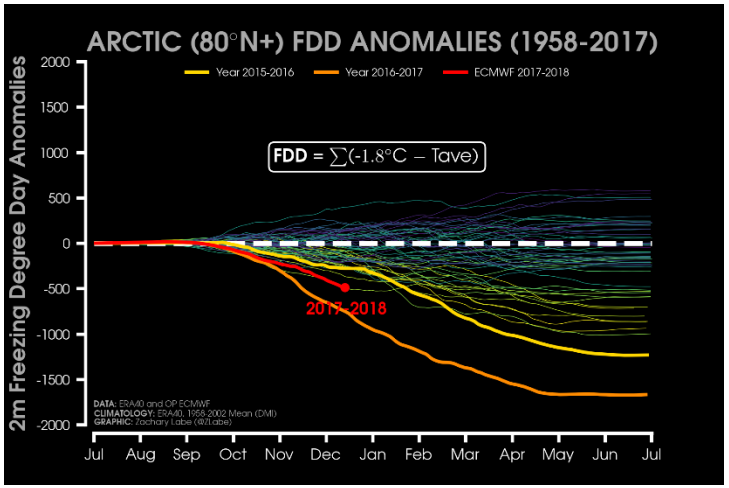
"Practical Strategies for Emerging Energy Technologies"

The Arctic Will Never Be Frozen Again









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http://sites.uci.edu/zlabe/arctic-temperatures/ ...

"Practical Strategies for Emerging Energy Technologies"

Making Electricity - The Terminology

- **Prime Movers** extract power from energy level differentials
  - Sources are the high side
  - Sinks are the low side
- Most Prime Movers are **Heat Engines**
- **Working Fluids** are the media used to
  - Extract the heat from the source/high side at a high pressure & temperature
  - Expand thru the Prime Mover, causing equipment rotation
  - Recover remaining heat & pressure on the low side
    - Return Working Fluid to the system a **closed cycle**
    - Exhaust Working Fluid to the atmosphere in an **open cycle**
- The prime mover drives
  - An Electric Generator, or
  - Mechanical devices such as compressor and pumps
- The higher the energy differentials , the smaller the equipment
- The smaller the equipment the faster it runs and the lower the cost
- The equipment used in heat cycles are
  - Turbines
  - Reciprocating engines
  - The equipment used in heat cycles are
- **Cycle Efficiency** improves with greater high side pressure and temperature

Working Fluids

- **Steam**
  - Supercritical (SCPC)
  - Ultra-supercritical Pulverized Coal (USCPC)
  - Nuclear
  - Geothermal
  - Concentrated Solar
- **Air/Vitiated Air**
  - Gas Turbine
  - Wind Turbine
- **Organic Fluid**
  - Organic Rankine Cycle (ORC)
  - Ocean Thermal–Ammonia
  - Geothermal

Water

- Hydroelectric
- Wave
- Tidal

- **Helium**
  - Pebble Bed Modular Reactor (PBMR)
  - Molten Salt Reactor (MSR)
- **CO_2**
  - Allam Cycle
  - Molten Salt Reactor
  - Super-critical CO2

Units of Measure

Units of Mass

- Ton (short) = 2000 lb
- tonne (metric) = 1000 kg = 2205 lb
- Mt = mmt = million metric tonnes
- Gigatonne (Gt) = 1000 Mt

Units of Cost

- Plant Cost ($/kW)
- LCOE – Levelized Cost of Electricity (mils/kWh)

Utilization Rate

- Capacity Factor % = kWh produced/kWh rated
  - 85% Pulverized Coal
  - 75% NGCC
  - 20-30% Wind

Measures of Efficiency

- Power Plant Heat Rate
  - Btu/kWh
- Power Plant Efficiency
  - 3412 Btu/kWh/Plant Heat Rate
- LHV & HHV Fuel Heat Content
  - The gas company sells HHV
  - Utilities normally use HHV
  - Gas Turbine Industry advertises/uses LLV
  - Natural Gas
    - LHV = 23,860 Btu/lb
    - HHV = 21,501 Btu/lb
  - The effect is a 10% difference in claimed efficiency
- Net Output vs. Gross Output

Each fuel has:
– An energy content - Btu/lb
– A carbon content – lb-CO_2/mmBtu
Each Power Plant (type) has efficiency or "heat rate" – Btu/kWh

Hydrocarbon Fuels Energy Content

Energy Source	Unit	Energy Content (*Btu*)	Btu/lb
Electricity	1 Kilowatt-hour	3412	-
Butane	1 Cubic Foot (cu.ft.)	3200	20,185
Coal	1 Ton	28000000	14,000
Crude Oil	1 Barrel - 42 gallons	5800000	19,153
Fuel Oil no.1	1 Gallon	137400	16,756
Fuel Oil no.2	1 Gallon	139600	19,579
Fuel Oil no.4	1 Gallon	145100	18,918
Fuel Oil no.5	1 Gallon	148800	18,859
Fuel Oil no.6	1 Gallon	152400	18,815
Diesel Fuel	1 Gallon	139000	20,020
Gasoline	1 Gallon	124000	20,418
Natural Gas	1 Cubic Foot (cu.ft.)	950 - 1150	23,623
Heating Oil	1 Gallon	139000	16,951
Kerosene	1 Gallon	135000	19,795
Pellets	1 Ton	16500000	8,250
Propane LPG	1 Gallon	91330	21,745
Propane gas 60^{o}F	1 Cubic Foot (cu.ft.)	2550	21,544

Coal: $C_{137}H_{97}O_9NS$

Natural Gas: CH_4

"Natural Gas is ½ of Coal"

Stationary Combustion Emission Factors

Fuel Type	Heating Value	CO_2 Factor	CH_4 Factor	N_2O Factor	CO_2 Factor	CH_4 Factor	N_2O Factor	Unit
	mmBtu per short ton	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per short ton	g CH_4 per short ton	g N_2O per short ton	
Coal and Coke								
Anthracite Coal	25.09	103.54	11	1.6	2,598	276	40	short tons
Bituminous Coal	24.93	93.40	11	1.6	2,328	274	40	short tons
Sub-bituminous Coal	17.25	97.02	11	1.6	1,674	190	28	short tons
Lignite Coal	14.21	96.36	11	1.6	1,369	156	23	short tons
Mixed (Commercial Sector)	21.39	95.26	11	1.6	2,038	235	34	short tons
Mixed (Electric Power Sector)	19.73	94.38	11	1.6	1,862	217	32	short tons
Mixed (Industrial Coking)	26.28	93.65	11	1.6	2,461	289	42	short tons
Mixed (Industrial Sector)	22.35	93.91	11	1.6	2,099	246	36	short tons
Coke	24.80	102.04	11	1.6	2,531	273	40	short tons
Fossil Fuel-derived Fuels (Solid)								
Municipal Solid Waste	9.95	90.70	32	4.2	902	318	42	short tons
Petroleum Coke (Solid)	30.00	102.41	32	4.2	3,072	960	126	short tons
Plastics	38.00	75.00	32	4.2	2,850	1,216	160	short tons
Tires	26.87	85.97	32	4.2	2,310	860	113	short tons
Biomass Fuels (Solid)								
Agricultural Byproducts	8.25	118.17	32	4.2	975	264	35	short tons
Peat	8.00	111.84	32	4.2	895	256	34	short tons
Solid Byproducts	25.83	105.51	32	4.2	2,725	827	108	short tons
Wood and Wood Residuals	15.38	93.80	32	4.2	1,443	492	65	short tons
	mmBtu per scf	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per scf	g CH_4 per scf	g N_2O per scf	
Natural Gas								
Natural Gas (per scf)	0.001028	53.02	1.0	0.10	0.05450	0.001028	0.000103	scf
Fossil-derived Fuels (Gaseous)								
Blast Furnace Gas	0.000092	274.32	0.022	0.10	0.02524	0.000002	0.000009	scf
Coke Oven Gas	0.000599	46.85	0.480	0.10	0.02806	0.000288	0.000060	scf
Fuel Gas	0.001388	59.00	0.022	0.10	0.08189	0.000031	0.000139	scf
Propane Gas	0.002516	61.46	0.022	0.10	0.15463	0.000055	0.000252	scf
Biomass Fuels (Gaseous)								
Biogas (Captured Methane)	0.000841	52.07	3.200	0.630	0.04379	0.002691	0.000530	scf

Sub-Bituminous Coal = 97.02 kg/mmBtu x 2.20462 lb/kg = 213.9 lb-CO_2/mmBtu
Lignite = 96.36 = 212.44
Bituminous Coal = 93.40 = 205.91
Natural Gas = 53.02 = 116.88

AEO2017 Cost & Performance New Generating Tech

Technology	First available year[1]	Size (MW)	Lead time (years)	Base overnight cost in 2016 (2016 $/kW)	Project Contin-gency Factor[2]	Techno-logical Optimism Factor[3]	Total overnight cost in 2016[4,10] (2016 $/kW)	Variable O&M[5] (2016 $/MWh)	Fixed O&M (2016$/ kW/yr)	Heat rate[6] in 2016 (Btu/kWh)	nth-of-a-kind heat rate (Btu/kWh)	
Coal with 30% carbon sequestration	2020	650	4	4,586	1.07	1.03	5,030	7.06	69.56	9,750	9,221	37.0%
Coal with 90% carbon sequestration	2020	650	4	5,072	1.07	1.03	5,562	9.54	80.78	11,650	9,257	36.8 %
Conv Gas/Oil Comb Cycle	2019	702	3	923	1.05	1.00	969	3.48	10.93	6,600	6,350	53.7%
Adv Gas/Oil Comb Cycle (CC)	2019	429	3	1,013	1.08	1.00	1,094	1.99	9.94	6,300	6,200	55.0%
Adv CC with carbon sequestration	2019	340	3	1,917	1.08	1.04	2,153	7.08	33.21	7,525	7,493	45.5%
Conv Comb Turbine[7]	2018	100	2	1,040	1.05	1.00	1,092	3.48	17.39	9,920	9,600	35.5%
Adv Comb Turbine	2018	237	2	640	1.05	1.00	672	10.63	6.76	9,800	8,550	39.9%
Fuel Cells	2019	10	3	6,252	1.05	1.10	7,221	44.91	0.00	9,500	6,960	49.0%
Adv Nuclear	2022	2,234	6	5,091	1.10	1.05	5,880	2.29	99.65	10,459	10,459	32.6%
Distributed Generation - Base	2019	2	3	1,463	1.05	1.00	1,536	8.10	18.23	8,981	8,900	38.3%
Distributed Generation - Peak	2018	1	2	1,757	1.05	1.00	1,845	8.10	18.23	9,975	9,880	34.5%
Biomass	2020	50	4	3,540	1.07	1.00	3,790	5.49	110.34	13,500	13,500	25.2%
Geothermal[8,9]	2020	50	4	2,586	1.05	1.00	2,715	0.00	117.95	9,510	9,510	35.8%
MSW - Landfill Gas	2019	50	3	8,059	1.07	1.00	8,623	9.14	410.32	18,000	18,000	19.0%
Conventional Hydropower[9]	2020	500	4	2,220	1.10	1.00	2,442	2.66	14.93	9,510	9,510	35.8%
Wind[10]	2019	100	3	1,576	1.07	1.00	1,686	0.00	46.71	9,510	9,510	
Wind Offshore	2020	400	4	4,648	1.10	1.25	6,391	0.00	77.30	9,510	9,510	
Solar Thermal[8]	2019	100	3	3,908	1.07	1.00	4,182	0.00	70.26	9,510	9,510	
Photovoltaic[4,10,11]	2018	150	2	2,169	1.05	1.00	2,277	0.00	21.66	9,510	9,510	

Power Plant Conversion Efficiency (and Cost)

"The Calculations"

30% Capture is 1330 lb-CO_2/MWh…Wonder Why?

Coal w/90% CCS

$$\frac{205.44lb-CO_2}{mmBtu}*\frac{9257Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{1902lb-CO_2}{MWh}*(1-90\%)=\frac{190lb-CO_2}{MWh}$$

Gas without CCS

Combined Cycle

$$\frac{116.38lb-CO_2}{mmBtu}*\frac{6200Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{722lb-CO_2}{MWh}$$

Simple Cycle

$$\frac{116.38lb-CO_2}{mmBtu}*\frac{9600Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{1117lb-CO_2}{MWh}$$

Gas w/CCS

$$\frac{116.38lb-CO_2}{mmBtu}*\frac{6200Btu}{kWh}*\frac{1000kW}{MW}*\frac{mmBtu}{10^6Btu}=\frac{722lb-CO_2}{MWh}*(1-90\%)=\frac{72lb-CO_2}{MWh}$$

Competitive Positioning Based on EPA NSPS-2014

Case 12 vs. Case 13
- 5X first cost
- ½ the efficiency
- Coal cost up 44% since 2010
- Coal cost up 80% since original 2007 baseline

		Supercritical PC			NGCC
Case		11	12	13	14
CO2 Capture		No	Yes	No	Yes
Gross Power Output - kWe		580,400	662,800	564,700	511,000
Auxilliary Power Requirements - kWe		30,410	112,830	9,620	37,430
Report Net Power Output - kWe		549,990	549,970	555,080	473,570
Net Plant HHV Efficiency - %		39.30%	28.40%	50.20%	42.80%
Net Plant HHV Heat Rate - Btu/kWh		8,687	12,002	6,798	7,968
Total Plant Cost - $/kW		1995	3583	725	1509
Total Overnight Cost - $/kW		2452	4391	891	1842
Total as Spent Cost - $/kW		2782	5006	957	1986
LCOE - mils/kWh		80.95	137.28	59.59	86.58
CO2 Emissions - lb/MWh		1768	244	804	94
$/MMBtu		2.94	2.94	6.13	6.13
Load Factor		85%	85%	85%	85%
kW Nominal Gross		580,411	662,836	559,532	593,471
550,000	kW Nominal Net	550,000	550,000	550,000	550,000
Total as Spent Capital		$1,529,834,783	$2,753,292,297	$526,223,607	$1,092,280,160
Cost Premium vs. NGCC Case 13		1,003,611,175	2,227,068,690	–	566,056,553
kWh/year		4,095,300,000	4,095,300,000	4,095,300,000	4,095,300,000
MMBtu/year		35,575,871	49,151,791	27,839,849	32,631,350
Annual Fuel		$104,593,061	$144,506,264	$170,658,277	$200,030,178
Fuel Cost vs. NGCC Case 13		($66,065,216)	($26,152,012)	–	$29,371,901
LCOE		$331,514,535	$562,202,784	$244,038,927	$354,571,074
Fuel%		31.6%	25.7%	69.9%	56.4%
$60.00	per tonne	$197,051	$27,194	$90,438	$9,021
CO2 Cost vs. NGCC Case 13		$106,612	($63,244)	–	($81,417)
tonnes-CO2/year		3,284	453	1,507	150

Source data:
DOE/NETL- Baseline
341/082312
August 2012

DOE/NETL- Baseline
2010/1397
November 2010

base e

"Practical Strategies for Emerging Energy Technologies"

At $4.00/mmBtu gas
LCOE for NGCC is 1/3 of Coal w/CCS

The War on Coal Begins in 2014

8740 w/o CCS
12000 w/CCS

AEO 2014 Cost & Performance New Generating Technologies

	Size (MW)	Thermal Input mmBtu	Total Overnight Cost in 2013 $/kW	nth of a Kind Heat Rate Btu/kWh	Fuel Heating Value Btu/lb	Carbon Factor lb-CO2/mmBtu	lb-CO2/MWh
Scrubbed Coal New	1300	11362	2925	8740	8940	205.44	1796
Advanced Combustion Turbine	210	1796	673	8550	21501	116.38	995
Advanced NGCC w/CCS	340	2548	2084	7493	21501	116.38	872
Conventional NGCC	620	4216	915	6800	21501	116.38	791
Advanced NGCC	400	2533	1021	6333	21501	116.38	737
Conventional Combustion Turbine	85	888	971	10450	21501	116.38	1216

NSPS 2014 Threshold

CCS Required

CCS Not Required

- Coal with CCS
  - First Cost $/kW is ~5x
  - Levelized Cost of Electricity is 2.3x
  - Efficiency is ~1/2
  - w/Natural Gas at $6.13

Updated Estimates of Power Plant Capital and Operating Costs

Plant Type	Plant Cost (2012$)/kW	
	Without CCS	With CCS
Single Advanced Pulverized Coal	$3,246	$5,227
Dual Advanced Pulverized Coal	$2,934	$4,724
Single IGCC	$4,400	$6,599
Advanced Combined Cycle	$1,023	$2,095

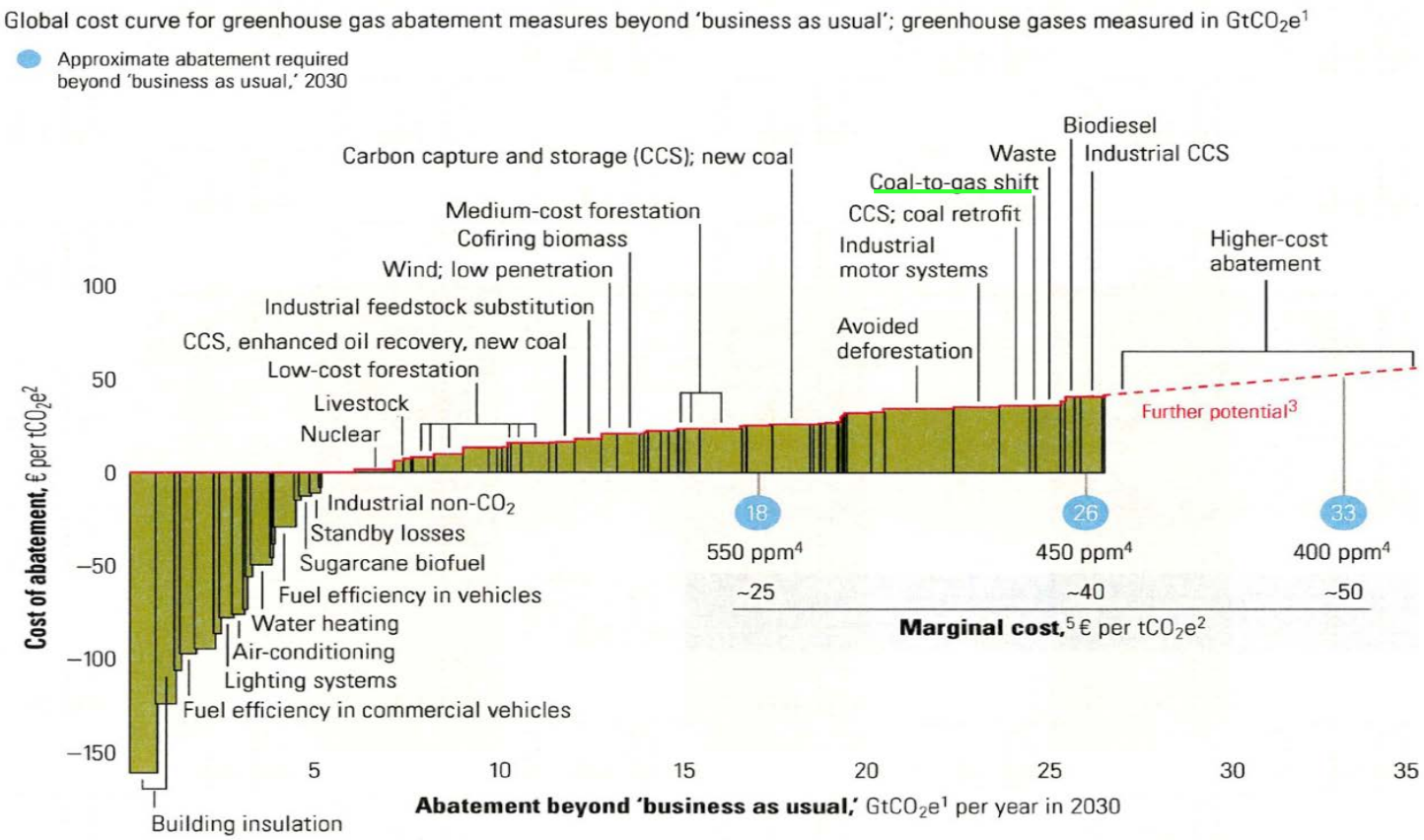
Source: U.S. Department of Energy, U.S. Energy Information Administration, Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants (April 2013) (DOE Report).

EPA Output Ratings 2015 – lb-CO_2/MWh

			Baseline Report				
Fuel	Natural Gas			Bituminous Coal			
Carbon Factor - lb-CO2/mmBtu	116.4	116.4	116.4	203.3	203.3	203.3	203.3
Power Plant							
- Type	SC	NGCC	NGCC	PC	SCPC	USCPC	USCPC
- Heat Rate (HHV) - Btu/kWh	9885	6602	7162	8795	8268	7975	7187
- Efficiency - HHV%	34.5%	51.7%	47.6%	38.8%	41.3%	42.8%	47.5%
- Efficiency - LHV%	38.3%	57.3%	52.9%	43.1%	45.8%	47.5%	52.7%
- Thermal Input - mmBtu	850	850	850	850	850	850	850
- Rating - MW@850 mmBtu/hr	85.99	128.74	118.68	96.65	102.80	106.58	118.28
Emissions - lb-CO2/MWh							
- Unabated	1150.4	768.4	833.5	1788	1681	1622	1461
- Applicable Threshold							
- Interim	1150	832	832	1534	1534	1534	1534
- Final	1150	771	771	1305	1305	1305	1305
CCS % required to meet final threshold	0.04%	0.00%	7.50%	27.02%	22.37%	19.52%	10.69%

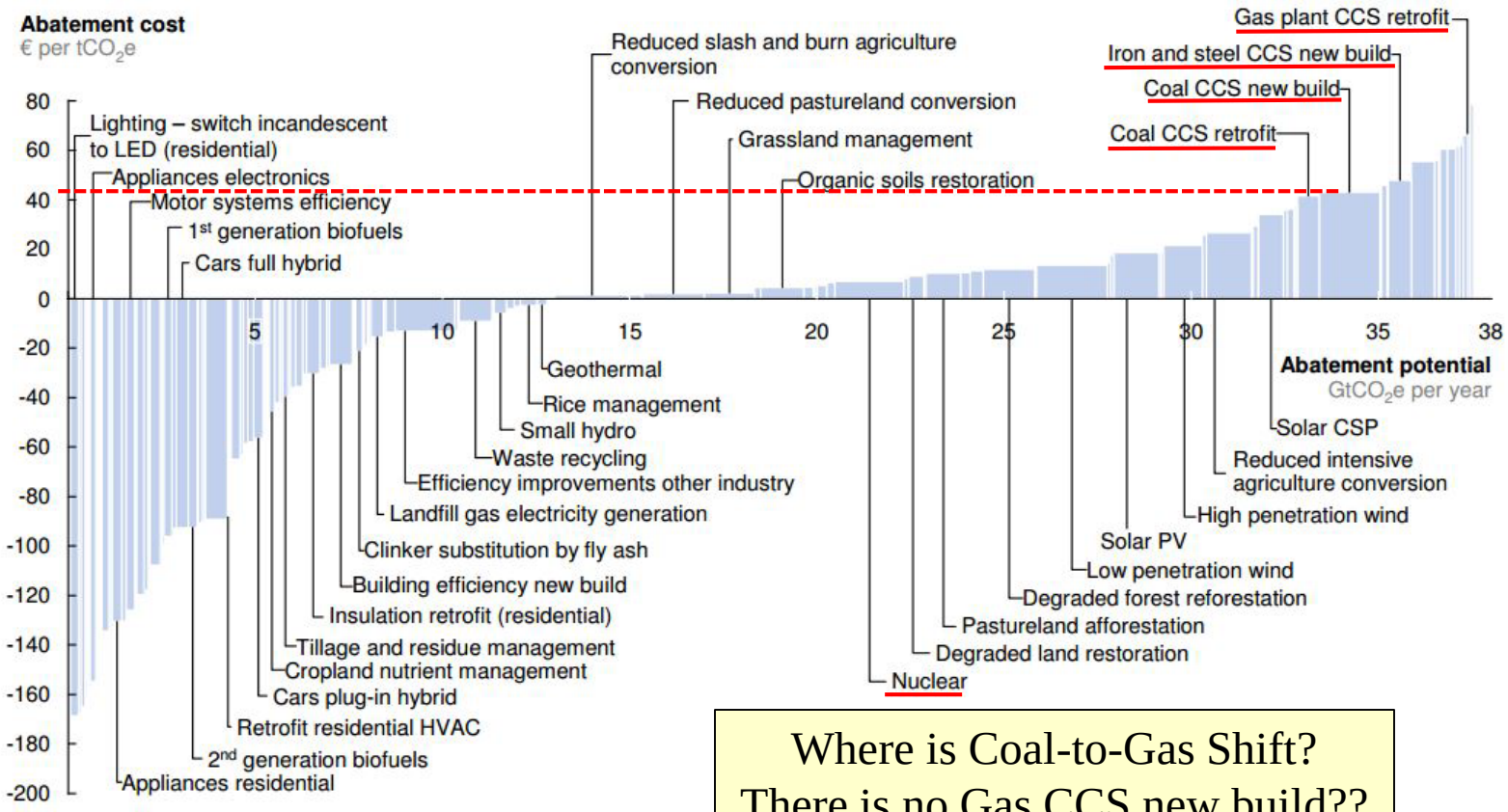
Do you notice a theme here???

McKinsey CO_2 Cost Curve V1.0



[1]$GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2]tCO_2e = ton of carbon dioxide equivalent.
[3]Measures costing more than €40 a ton were not the focus of this study.
[4]Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5]Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

McKinsey Global GHG Cost Curve V2.1



Where is Coal-to-Gas Shift?
There is no Gas CCS new build??

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.1

Appendix 1

BP Conversion Factors

Approximate conversion factors

Crude oil*

From	To				
	tonnes (metric)	kilolitres	barrels	US gallons	tonnes per year
	Multiply by				
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
US gallons	0.00325	0.0038	0.0238	1	–
Barrels per day	–	–	–	–	49.8

*Based on worldwide average gravity.

Products

	To convert			
	barrels to tonnes	tonnes to barrels	kilolitres to tonnes	tonnes to kilolitres
	Multiply by			
Liquefied petroleum gas (LPG)	0.086	11.60	0.542	1.844
Gasoline	0.120	8.35	0.753	1.328
Kerosene	0.127	7.88	0.798	1.253
Gas oil/diesel	0.134	7.46	0.843	1.186
Residual fuel oil	0.157	6.35	0.991	1.010
Product basket	0.125	7.98	0.788	1.269

Natural gas (NG) and liquefied natural gas (LNG)

From	To					
	billion cubic metres NG	billion cubic feet NG	million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
	Multiply by					
1 billion cubic metres NG	1	35.3	0.90	0.74	35.7	6.60
1 billion cubic feet NG	0.028	1	0.025	0.021	1.01	0.19
1 million tonnes oil equivalent	1.11	39.2	1	0.82	39.7	7.33
1 million tonnes LNG	1.36	48.0	1.22	1	48.6	8.97
1 trillion British thermal units	0.028	0.99	0.025	0.021	1	0.18
1 million barrels oil equivalent	0.15	5.35	0.14	0.11	5.41	1

Units

1 metric tonne	= 2204.62lb = 1.1023 short tons
1 kilolitre	= 6.2898 barrels = 1 cubic metre
1 kilocalorie (kcal)	= 4.187kJ = 3.968Btu
1 kilojoule (kJ)	= 0.239kcal = 0.948Btu
1 British thermal unit (Btu)	= 0.252kcal = 1.055kJ
1 kilowatt-hour (kWh)	= 860kcal = 3600kJ = 3412Btu

Calorific equivalents

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories 42 gigajoules 40 million British thermal units
Solid fuels	1.5 tonnes of hard coal 3 tonnes of lignite
Gaseous fuels	See Natural gas and liquefied natural gas table
Electricity	12 megawatt-hours

One million tonnes of oil or oil equivalent produces about 4400 gigawatt-hours (= 4.4 terawatt-hours) of electricity in a modern power station.

1 barrel of ethanol = 0.57 barrel of oil
1 barrel of biodiesel = 0.88 barrel of oil