Energy Part 1
Climate Change

Osher Lifelong Learning Institute

At Tufts University

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Peter Baldwin

617-306-7419

pete_baldwin@base-e.net

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

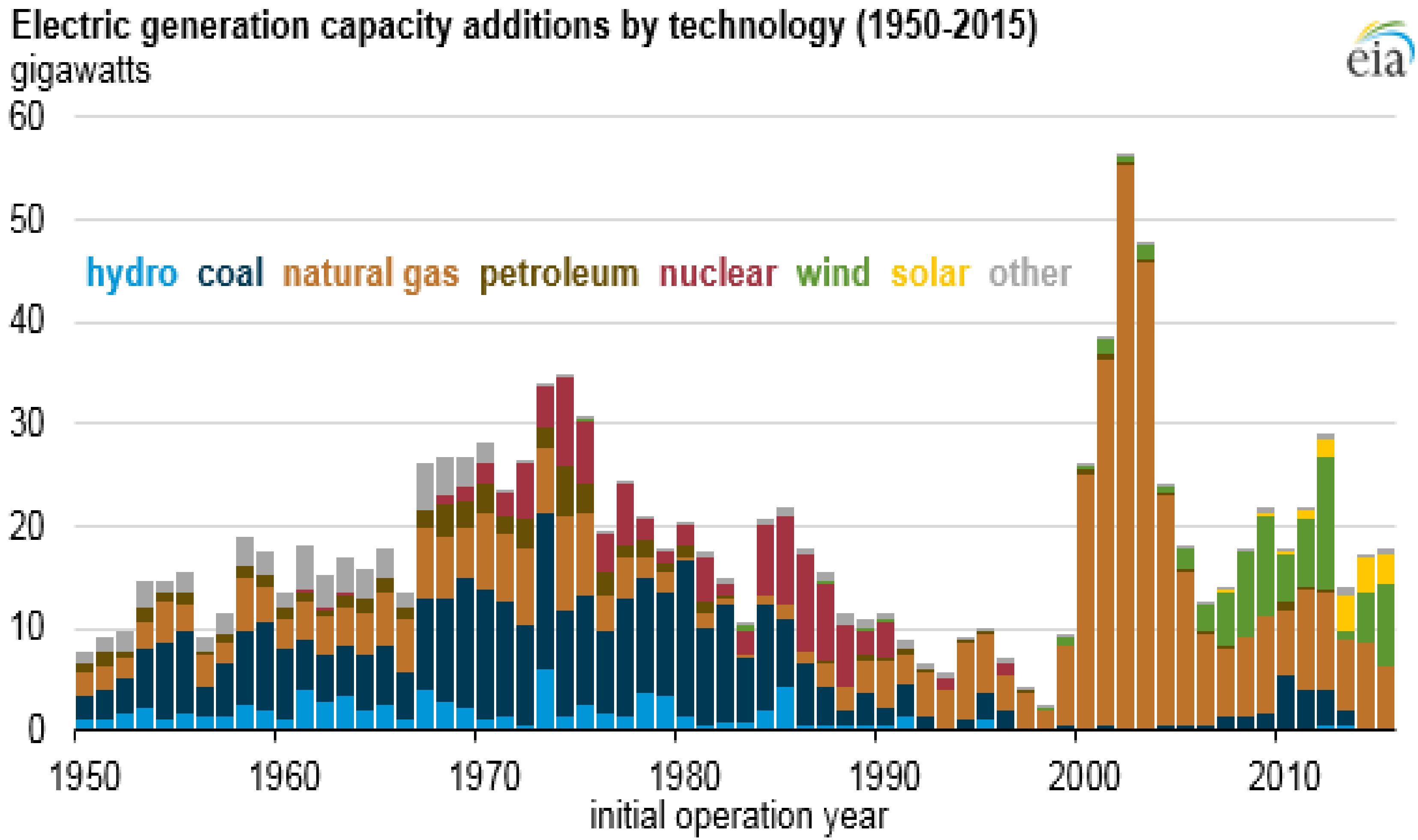
- The transport sector is set to change significantly, with electric vehicles, driverless - or autonomous - vehicles and new types of business.
- I think there is no forecast anywhere that does not expect demand for electricity to grow and for electricity to become a more important part of the energy mix. There is also a sort of consumer desirability for newer electric vehicles, like the current Tesla's, 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.

January 19, 2017 Source: BP

Electric Generation Capacity Additions



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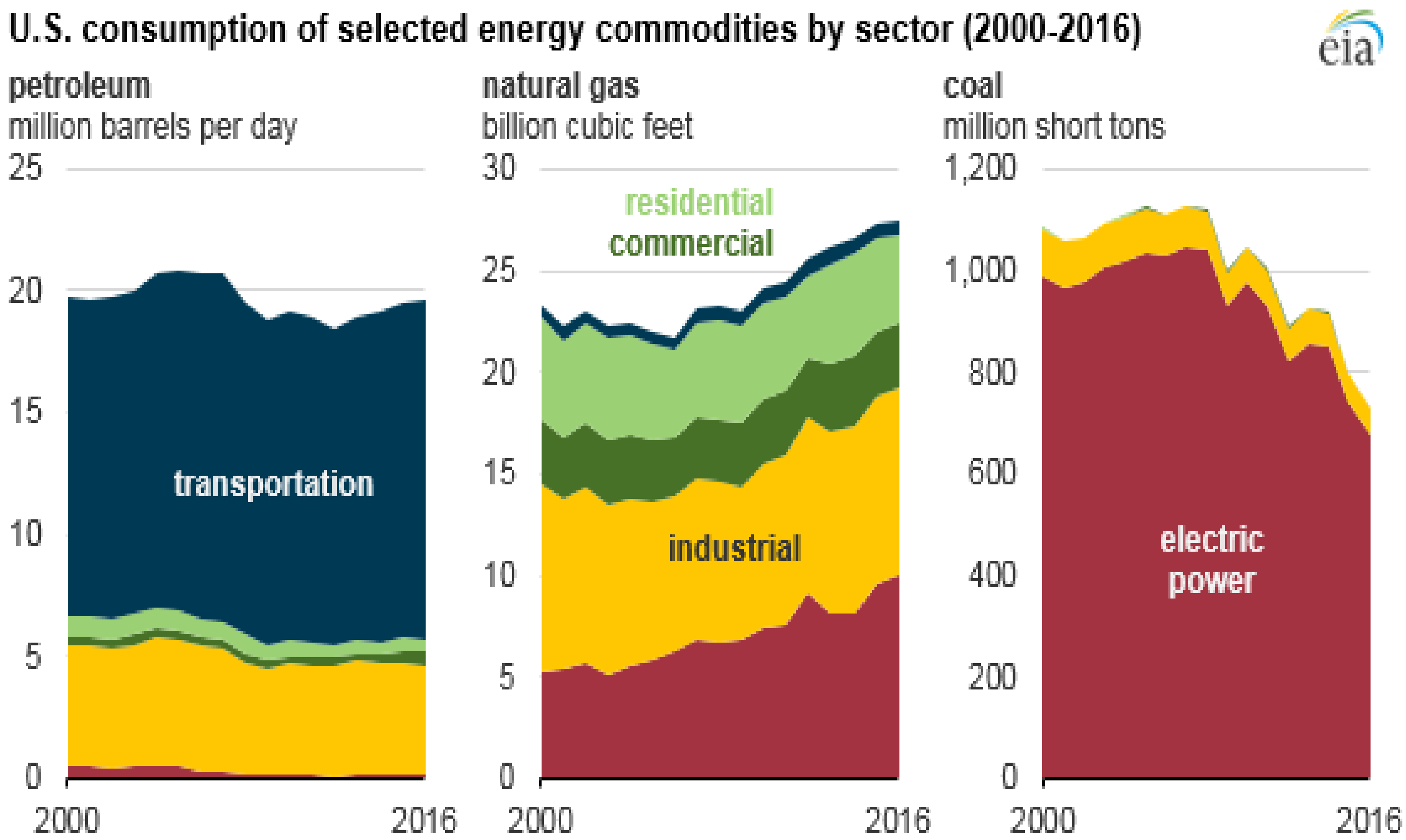
U.S. Energy Consumption by Sector



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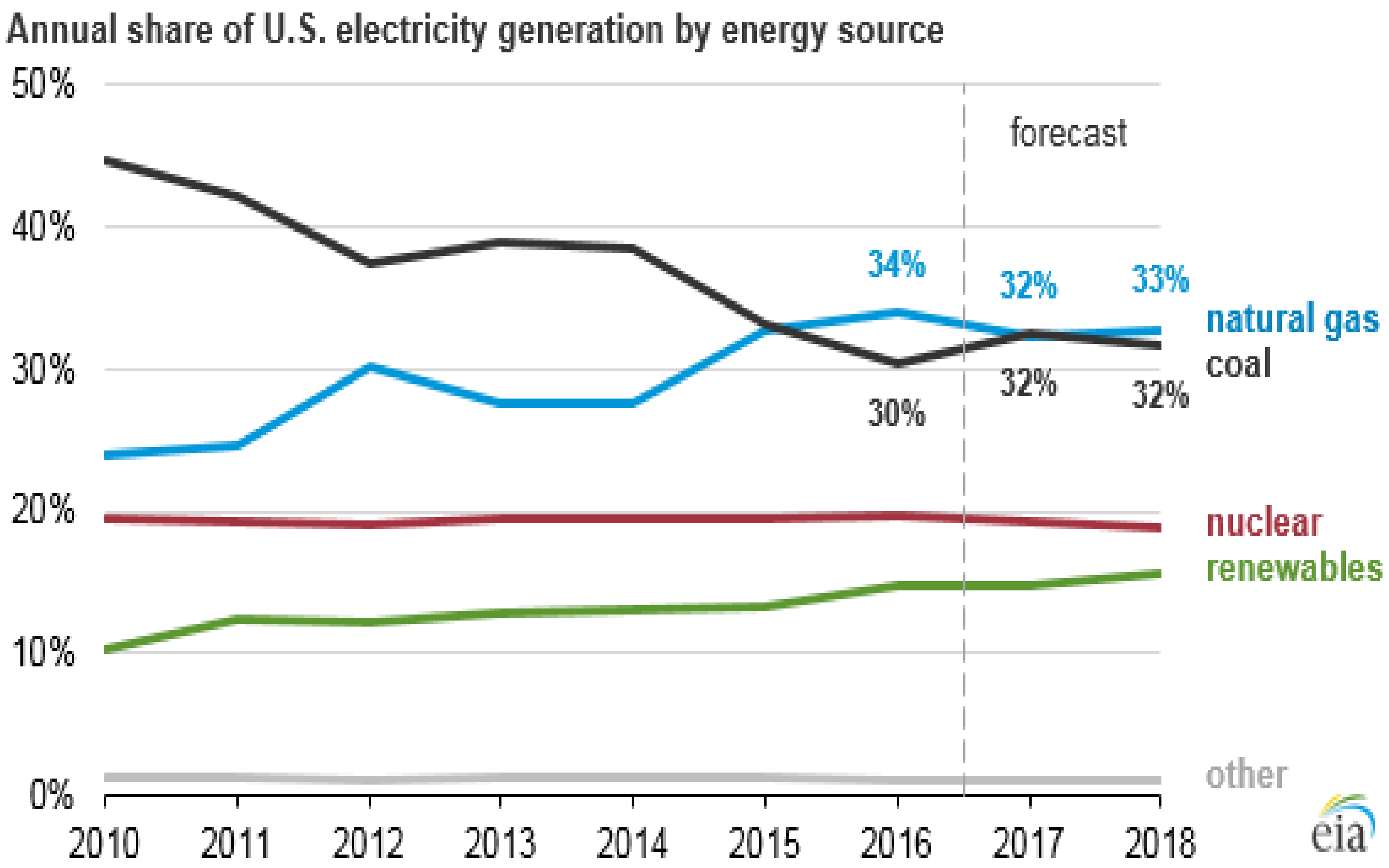
U.S. Power Generation Mix



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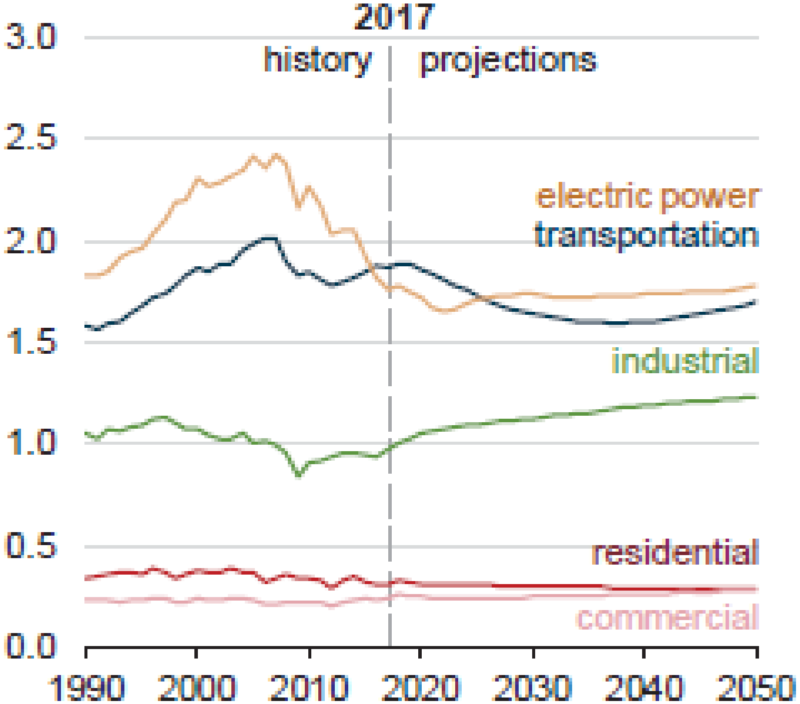
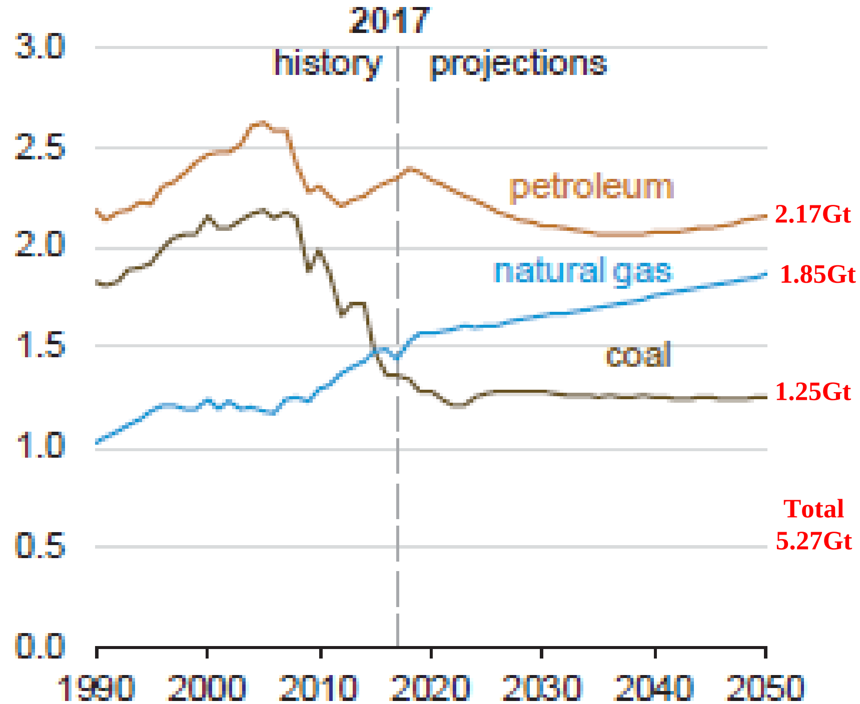
U.S. Energy Related CO_2 by Sector & Fuel

Energy-related carbon dioxide emissions
by sector (Reference Case)
billion metric tons of carbon dioxide



Energy-related carbon dioxide emissions
by fuel (Reference case)
billion metric tons of carbon dioxide



1 billion metric ton(ne) = 1.0Gt

Primary Energy Consumption by Fuel 2017 - Mtoe

U.S. = 91.86 Quads

Primary Energy: Consumption by fuel*

Million tonnes oil equivalent	2016 Oil	2016 Natural Gas	2016 Coal	2016 Nuclear energy	2016 Hydro electric	2016 Renew-ables	2016 Total	2017 Oil	2017 Natural Gas	2017 Coal	2017 Nuclear energy	2017 Hydro electric	2017 Renew-ables	2017 Total	Percent of 2017 Total
US	907.6	645.1	340.6	191.9	59.7	83.1	2228.0	913.3	635.8	332.1	191.7	67.1	94.8	**2234.9**	16.5%
Canada	107.0	94.1	18.9	21.8	87.6	9.6	339.0	108.6	99.5	18.6	21.9	89.8	10.3	**348.7**	2.6%
Mexico	90.1	79.0	12.4	2.4	6.9	4.1	194.9	86.8	75.3	13.1	2.5	7.2	4.4	**189.3**	1.4%
Total North America	**1104.6**	**818.2**	**371.9**	**216.1**	**154.2**	**96.8**	**2761.9**	**1108.6**	**810.7**	**363.8**	**216.1**	**164.1**	**109.5**	**2772.8**	20.5%
Brazil	135.7	32.4	15.9	3.6	86.2	19.1	293.0	135.6	33.0	16.5	3.6	83.6	22.2	**294.4**	2.2%
Total S. & Cent. America	**320.8**	**150.6**	**34.9**	**5.5**	**156.4**	**28.6**	**696.8**	**318.8**	**149.1**	**32.7**	**5.0**	**162.3**	**32.6**	**700.6**	5.2%
France	79.2	38.3	8.2	91.2	13.6	8.4	238.9	79.7	38.5	9.1	90.1	11.1	9.4	**237.9**	1.8%
Germany	117.3	73.0	75.8	19.2	4.6	38.3	328.2	119.8	77.5	71.3	17.2	4.5	44.8	**335.1**	2.5%
Italy	59.8	58.5	11.0	-	9.6	14.8	153.8	60.6	62.0	9.8	-	8.2	15.5	**156.0**	1.2%
Spain	64.2	25.0	10.5	13.3	8.2	15.4	136.7	64.8	27.5	13.4	13.1	4.2	15.7	138.8	1.0%
Turkey	47.1	38.2	38.5	-	15.2	5.4	144.4	48.8	44.4	44.6	-	13.2	6.6	157.7	1.2%
United Kingdom	76.3	69.6	11.2	16.2	1.2	17.6	192.2	76.3	67.7	9.0	15.9	1.3	21.0	191.3	1.4%
Total Europe	**719.3**	**434.7**	**295.1**	**195.2**	**146.1**	**144.2**	**1934.6**	**731.2**	**457.2**	**296.4**	**192.5**	**130.4**	**161.8**	**1969.5**	14.6%
Russian Federation	152.5	361.3	89.2	44.5	41.8	0.3	689.6	153.0	365.2	92.3	46.0	41.5	0.3	**698.3**	5.2%
Total CIS	**202.8**	**492.6**	**156.2**	**63.3**	**56.3**	**0.8**	**972.0**	**203.4**	**494.1**	**157.0**	**65.9**	**56.7**	**0.9**	**978.0**	7.2%
Iran	80.7	173.1	0.9	1.5	3.5	0.1	259.8	84.6	184.4	0.9	1.6	3.7	0.1	**275.4**	2.0%
Saudi Arabia	173.8	90.6	0.1	-	-	^	264.5	172.4	95.8	0.1	-	-	^	**268.3**	2.0%
United Arab Emirates	45.7	62.3	1.5	-	-	0.1	109.6	45.0	62.1	1.6	-	-	0.1	**108.7**	0.8%
Total Middle East	**416.0**	**437.6**	**9.1**	**1.5**	**4.6**	**1.0**	**869.7**	**420.0**	**461.3**	**8.5**	**1.6**	**4.5**	**1.4**	**897.2**	6.6%
South Africa	28.7	4.0	84.7	3.6	0.2	1.8	123.0	28.8	3.9	82.2	3.6	0.2	2.0	**120.6**	0.9%
Total Africa	**192.6**	**114.5**	**94.9**	**3.6**	**27.1**	**5.2**	**438.0**	**196.3**	**121.9**	**93.1**	**3.6**	**29.1**	**5.5**	**449.5**	3.3%
Australia	50.5	35.9	43.6	-	4.0	5.4	139.5	52.4	36.0	42.3	-	3.1	5.7	**139.4**	1.0%
China	587.2	180.1	1889.1	48.3	261.0	81.7	3047.2	608.4	206.7	1892.6	56.2	261.5	106.7	**3132.2**	23.2%
India	217.1	43.7	405.6	8.6	29.0	18.3	722.3	222.1	46.6	424.0	8.5	30.7	21.8	**753.7**	5.6%
Indonesia	74.2	32.9	53.4	-	4.4	2.6	167.4	77.3	33.7	57.2	-	4.2	2.9	**175.2**	1.3%
Japan	191.4	100.1	118.8	4.0	18.1	18.8	451.2	188.3	100.7	120.5	6.6	17.9	22.4	**456.4**	3.4%
South Korea	128.9	41.0	81.9	36.7	0.6	3.1	292.2	129.3	42.4	86.3	33.6	0.7	3.6	**295.9**	2.2%
Taiw an	48.6	17.2	38.6	7.2	1.5	1.0	114.0	49.2	19.1	39.4	5.1	1.2	1.2	**115.1**	0.9%
Thailand	62.1	43.5	17.7	-	0.8	2.8	126.9	63.9	43.1	18.3	-	1.1	3.4	**129.7**	1.0%
Total Asia Pacific	**1601.1**	**625.1**	**2744.0**	**106.0**	**368.5**	**140.8**	**5585.5**	**1643.4**	**661.8**	**2780.0**	**111.7**	**371.6**	**175.1**	**5743.6**	42.5%
Total World	**4557.3**	**3073.2**	**3706.0**	**591.2**	**913.3**	**417.4**	**13258.5**	**4621.9**	**3156.0**	**3731.5**	**596.4**	**918.6**	**486.8**	**13511.2**	
	34.4%	23.2%	28.0%	4.5%	6.9%	3.1%	100.0%	34.2%	23.4%	27.6%	4.4%	6.8%	3.6%	100.0%	100.0%

13,511.2 Mtoe = 555.4 Quads

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Source: BP Statistical Review of World Energy 2018

Basic Comparisons 2017

	China	USA	India	Japan	Germany	Russia
Population - July 2014 est	1,379,302,771	326,525,791	1,281,935,911	126,451,398	80,594,017	142,257,519
Population Growth Rate	0.41%	0.81%	1.17%	-0.21%	-0.16%	-0.08%
Area - km^2	9,596,960	9,826,675	3,287,263	377,915	357,022	17,098,242
GDP - Purchasing Power Parity ($trillion)	23.1	19.4	9.4	5.4	4.2	4.0
Installed Generating Capacity GW	1,646	1,074	309	322	204	264
% of World at 6301GW	26%	17%	5%	5%	3%	4%
Electric Production TWh	6,142	4,088	1,289	976	559	1,008
Electric Consumption TWh	5,920	3,911	1,048	934	515	890
Aggregate Load Factor	42.6%	43.5%	47.6%	34.6%	31.3%	43.6%
Natural Gas Production - BCM	138.4	766.2	31.2	4.5	8.7	598.6
Natural Gas Consumption - BCM	210.3	773.2	102.3	123.6	79.2	418.9
Refined Petroleum Products Production - mmbbl/d	10.9	20.1	4.8	3.5	2.2	6.2
Refined Petroleum Products Consumption - mmbbl/d	11.8	19.7	4.1	4.0	2.4	3.6
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

Source: CIA World Factbook

World Total Installed Electrical Generating Capacity **6301GW**

Source: CIA World Factbook

PS… .Total Value of Outstanding Student Loans - $1.5 trillion
U.S. health care cost 2014 - $3.3 trillion
U.S. Household Debt 2017 - $13.2 trillion

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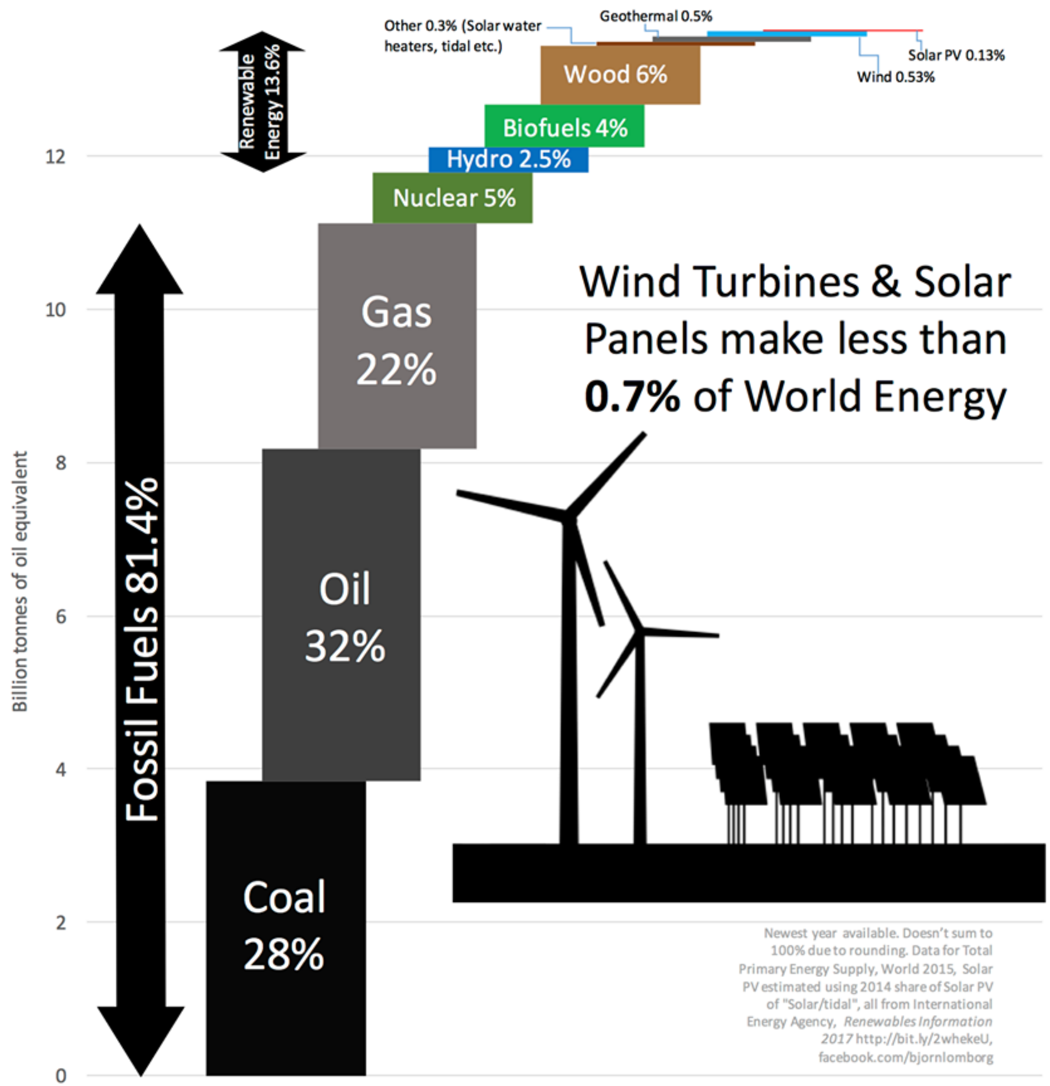
World Energy Balance



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Bjorn Lomborg
Presented at Copenhagen Consensus Center

Power – "Still in the Dark"

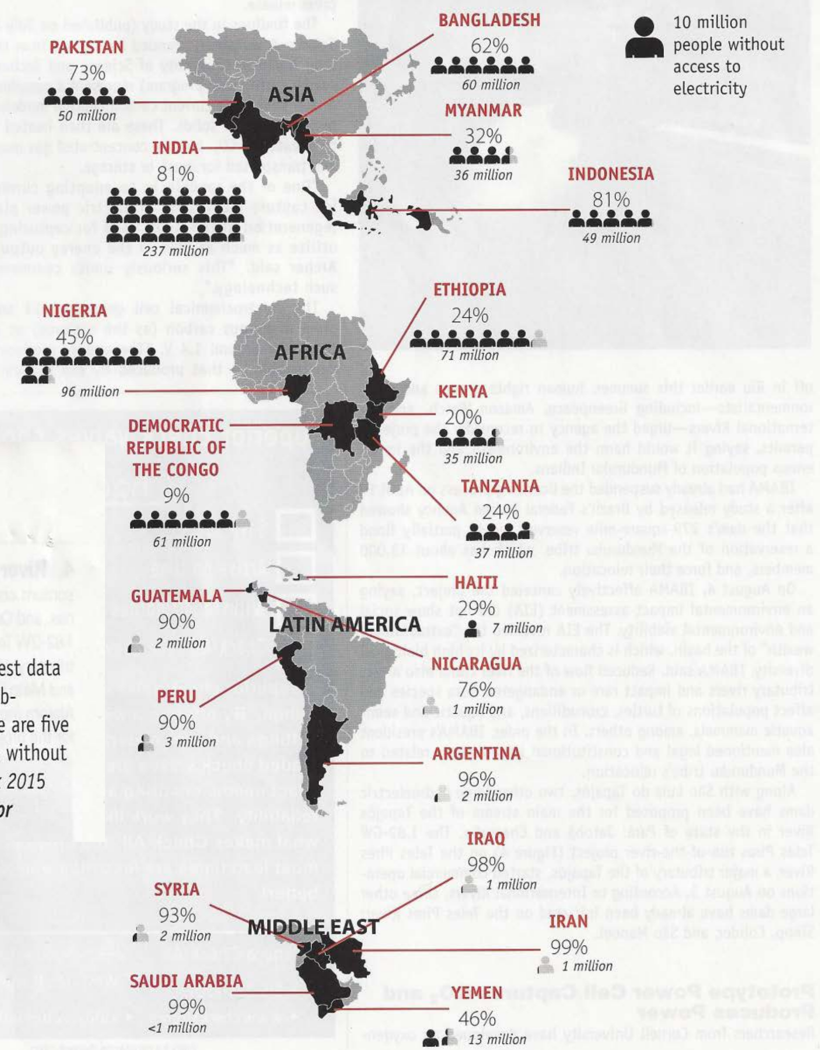
1.2 billion people 17% of Global Population do not have access to electricity

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



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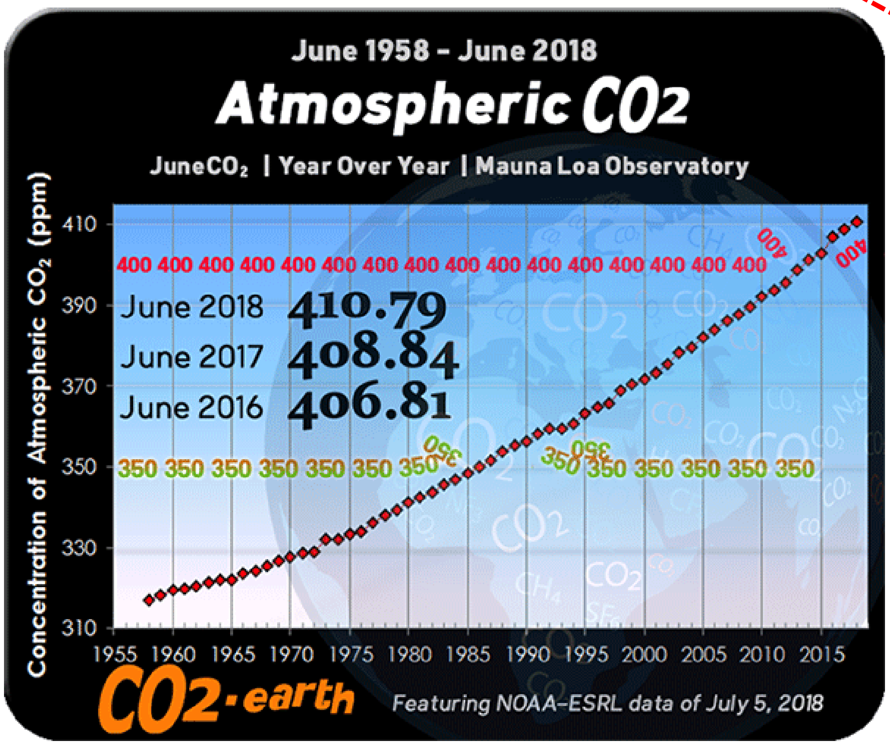
Climate Change

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



Gas	Ratio compared to Dry Air (%) By volume	By weight	Molecular Mass - M - (kg/kmol)	Chemical Symbol
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

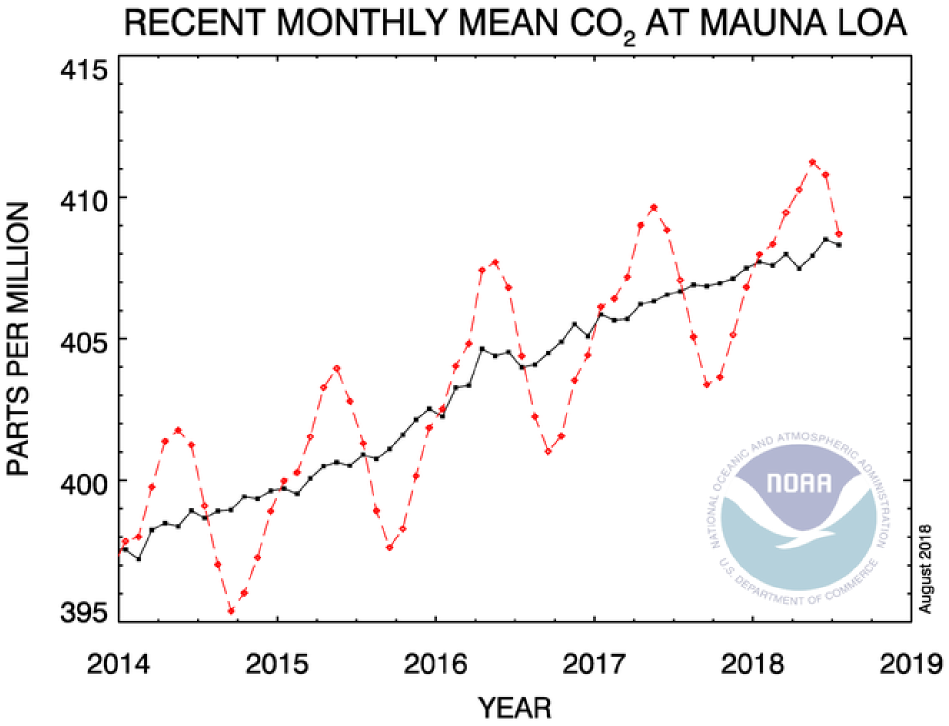
0.0300% = 300 ppm(v)

Value June 2018 at Mauna Loa was 410.79ppm(v)

Recent Monthly Mean CO_2 Measurements Mauna Loa

Recent Monthly Average Mauna Loa CO_2

July 2018: 408.71 ppm
July 2017: 407.07 ppm
Last updated: August 7, 2018



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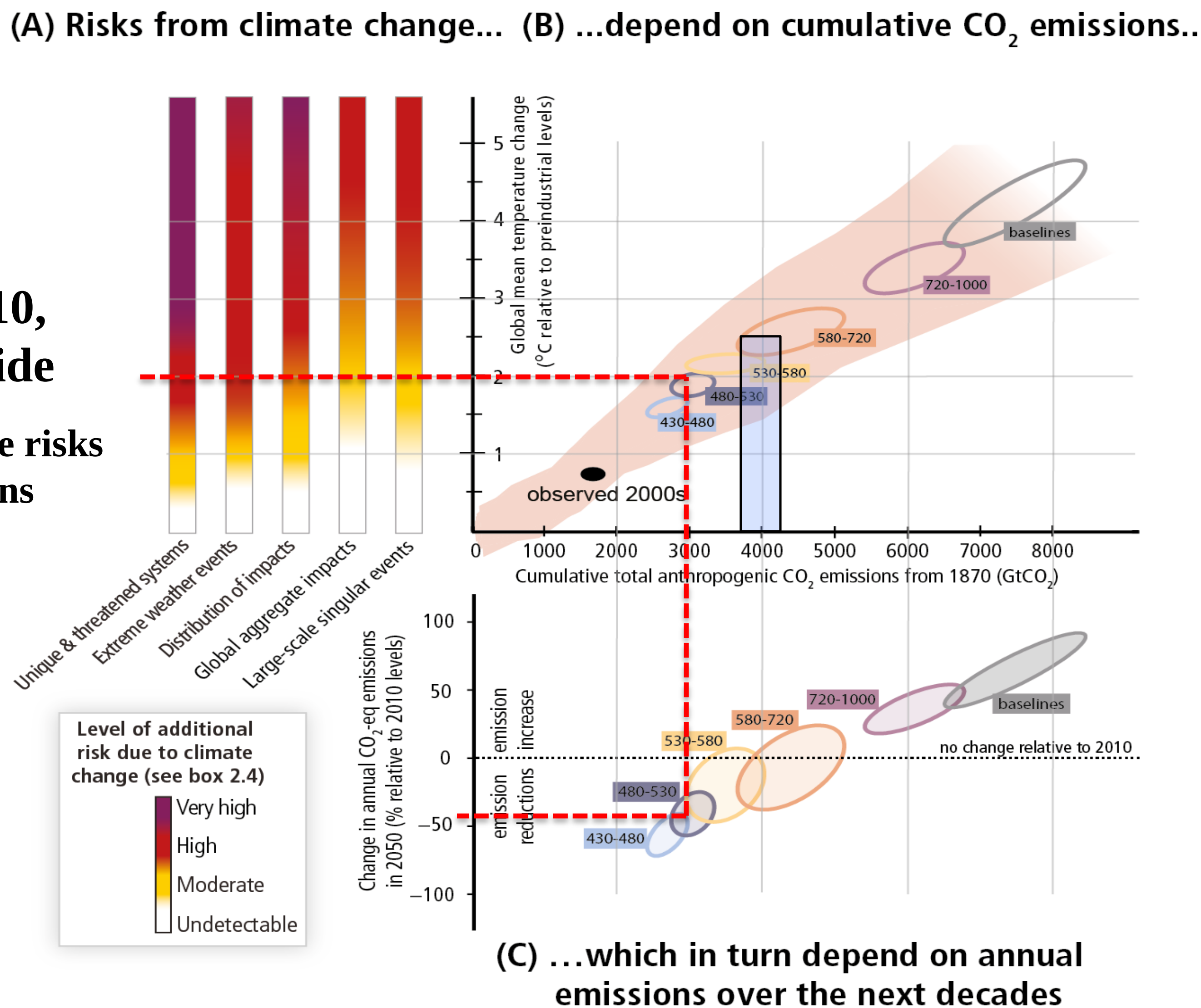
This is the "Science Bit"

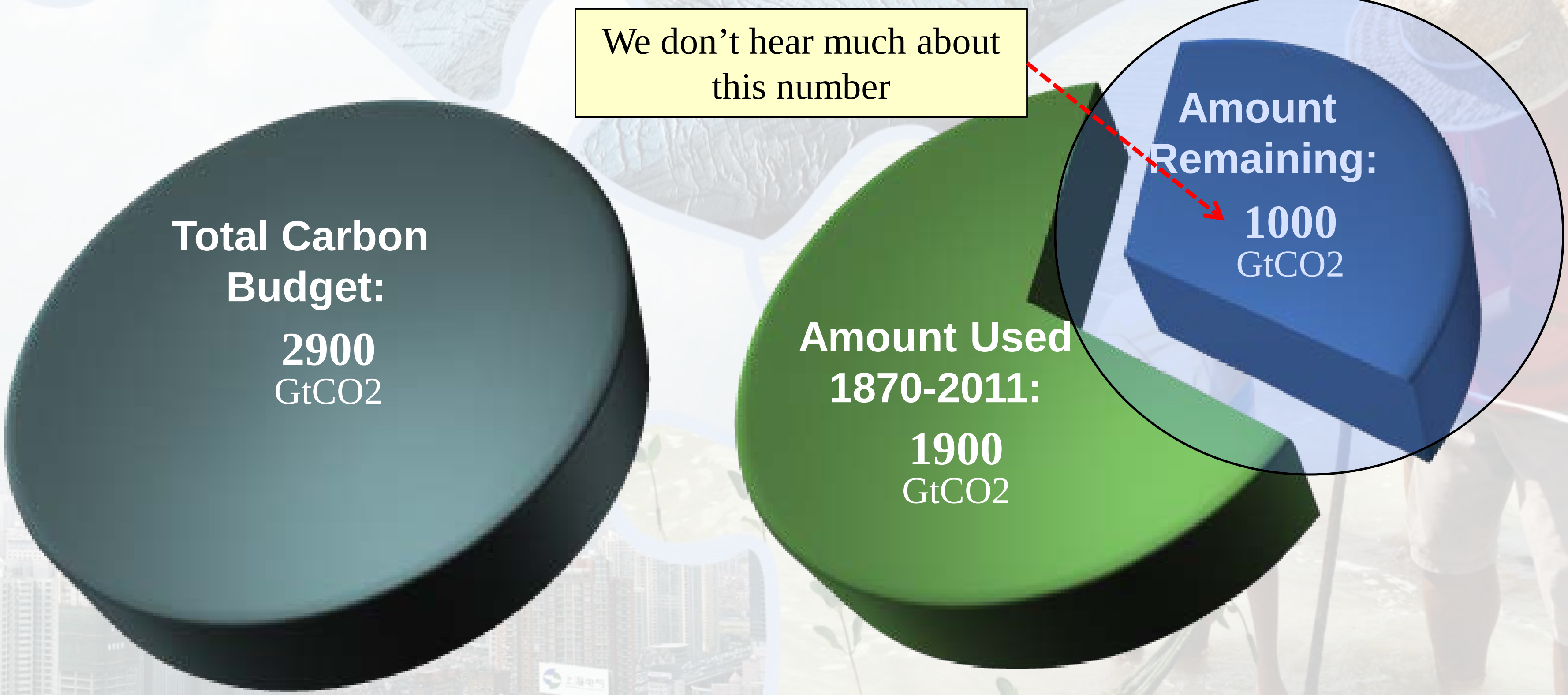
Figure SPM.10, A reader's guide

From climate change risks to GHG emissions



The window for action is rapidly closing

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



AR5 WGI SPM

EIA WW Annual Energy Outlook 2017

Reference Case includes CPP

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)

34519.2 MMt = 34.5 Gt

U.S. EIA Annual Energy Outlook 2018

10 Cases
Sorted High-Low, 2050

Energy-Related Carbon Dioxide Emissions by Sector and Source (MMmt)	2016	2020	2025	2030	2035	2040	2045	2050	Growth (2017-2050)
High economic growth	5174	5207	5138	5170	5225	5372	5568	5814	0.40%
Low oil price	5174	5170	5163	5156	5165	5234	5365	5521	0.20%
High economic growth with Clean Power Plan	5174	5204	5041	4927	4943	5057	5234	5424	0.20%
High oil and gas resource and technology	5174	5132	4999	5014	5020	5069	5152	5307	0.10%
Reference case	5174	5187	5079	5053	5024	5080	5159	5279	0.10%
Low oil and gas resource and technology	5174	5300	5114	4984	4954	4968	5030	5103	0.00%
High oil price	5174	5141	4926	4937	4950	4950	4987	5061	-0.10%
Reference case with Clean Power Plan	5174	5179	4997	4840	4822	4852	4915	5013	-0.10%
Low economic growth	5174	5110	4919	4856	4780	4743	4728	4742	-0.20%
Low economic growth with Clean Power Plan	5174	5115	4861	4697	4611	4586	4561	4562	-0.40%
CPP Impact Ref Case	0	24	43	87	121	205	319	266	

~6°C Trajectory

Clean Power Plan Effect is tiny

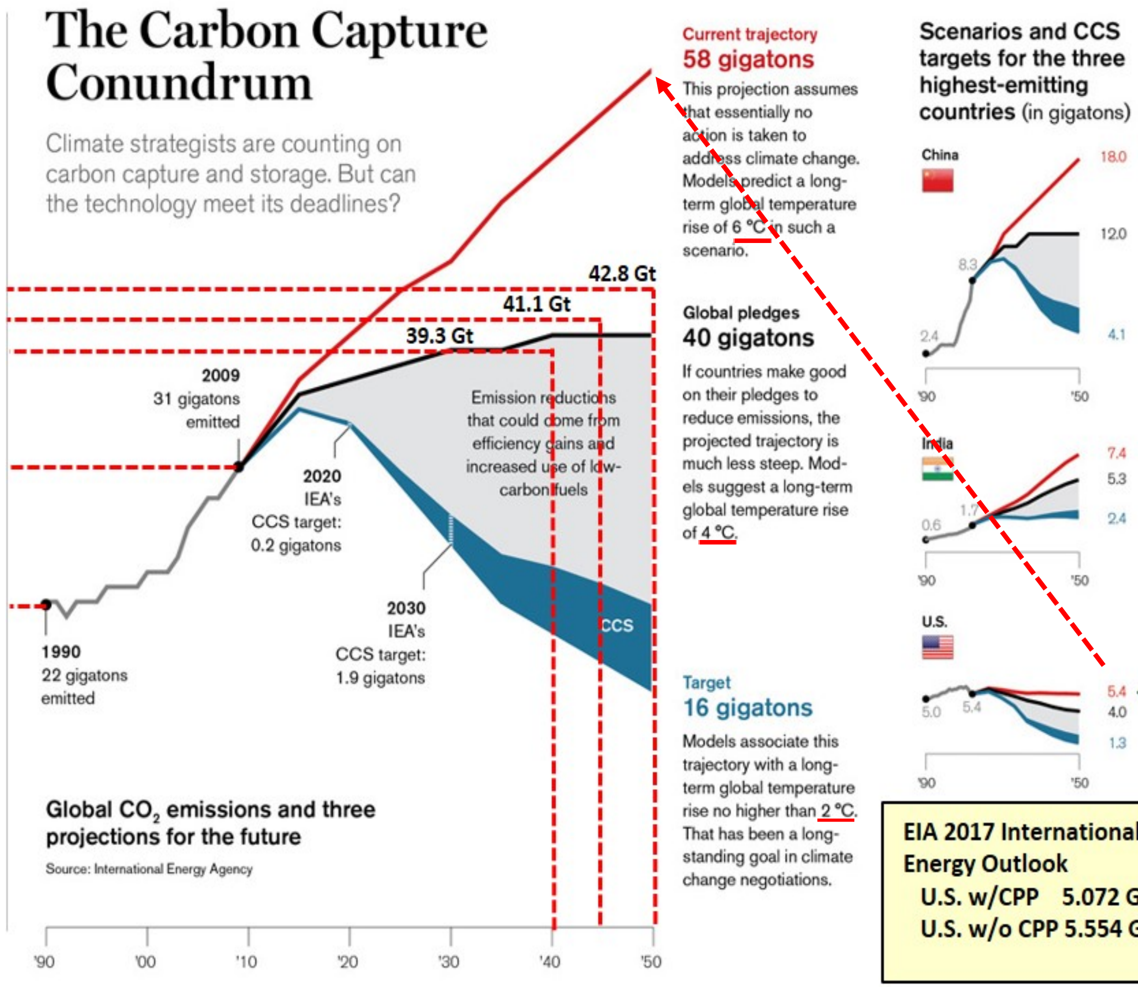
Energy-Related Carbon Dioxide Emissions Intensity by Sector and Source (MMmtCO2/capita)									
Reference case	16.0	15.5	14.7	14.1	13.6	13.4	13.3	13.3	-0.50%
Reference case with Clean Power Plan	16.0	15.5	14.4	13.5	13.0	12.8	12.6	12.6	-0.70%

Real Gross Domestic Product ($billion)									
Reference case	16716	18335	20221	22421	24802	27356	30204	33205	2.00%
Reference case with Clean Power Plan	16716	18319	20195	22380	24775	27341	30177	33161	2.00%

Population (millions)									
Reference case	323.7	333.8	346.6	358.6	369.5	379.4	388.6	397.5	0.60%
Reference case with Clean Power Plan	323.7	333.8	346.6	358.6	369.5	379.4	388.6	397.5	0.60%

EIA Annual Energy Outlook 2018

Values from EIA WW Annual Energy Outlook 2017 (slide 19)



The U.S. is on the 6°C trajectory

EIA 2017 International Energy Outlook
U.S. w/CPP 5.072 Gt
U.S. w/o CPP 5.554 Gt

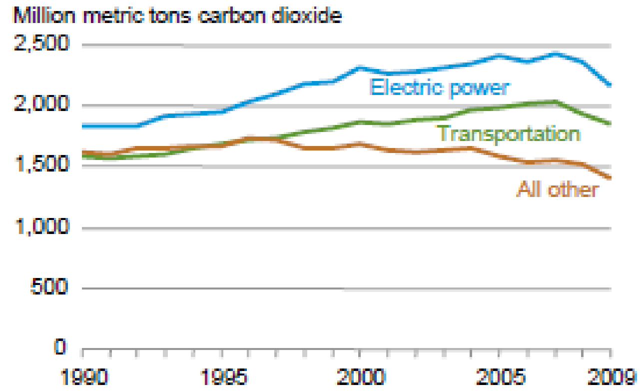
EIA 2018 International Energy Outlook
U.S. w/ CPP 5.013 Gt
U.S. w/o CPP 5.279 Gt
High Growth 5.815 Gt

CO_2 Emissions by End-Use Sector

U.S. energy-related carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	5,038.7	5,996.4	5,838.0	5,425.6
Change from 1990 (million metric tons)		957.7	799.2	386.9
(percent)		*19.0%*	*15.9%*	*7.7%*
Average annual change from 1990 *(percent)*		*1.2%*	*0.8%*	*0.4%*
Change from 2005 (million metric tons)			-158.4	-570.8
(percent)			*-2.6%*	*-9.5%*
Change from 2008 (million metric tons)				-412.4
(percent)				*-7.1%*

Figure 10. Energy-related carbon dioxide emissions for selected sectors, 1990-2009



2005 is the "Baseline" for the Obama initiative

Table 7. U.S. energy-related carbon dioxide emissions by end-use sector, 1990-2009 (million metric tons carbon dioxide)

Sector	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Residential	963.4	1,039.1	1,185.1	1,230.1	1,227.8	1,261.5	1,192.0	1,242.0	1,229.0	1,162.2
Commercial	792.6	851.4	1,022.0	1,036.0	1,053.5	1,069.0	1,043.4	1,078.6	1,073.5	1,003.6
Industrial	1,695.1	1,742.8	1,788.1	1,691.9	1,731.1	1,675.2	1,661.1	1,661.6	1,597.6	1,405.4
Transportation	1,587.7	1,681.0	1,872.0	1,898.9	1,962.3	1,990.7	2,021.9	2,039.6	1,937.9	1,854.5
Total	**5,038.7**	**5,314.3**	**5,867.2**	**5,856.9**	**5,974.7**	**5,996.4**	**5,918.3**	**6,021.8**	**5,838.0**	**5,425.6**
Electricity generation[a]	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

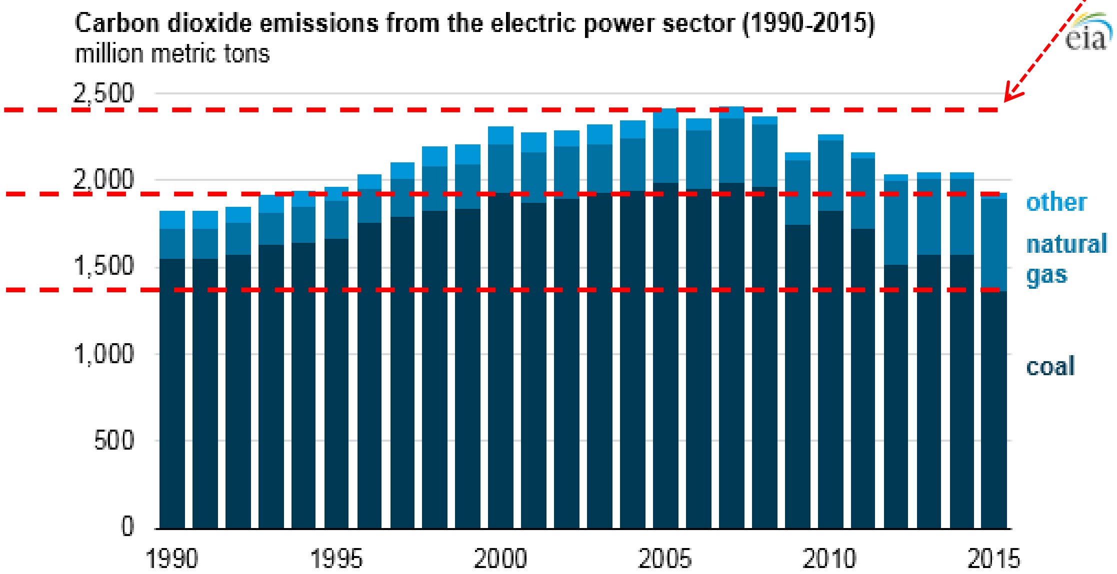
[a]Electric power sector emissions are distributed across the end-use sectors. Emissions allocated to sectors are unadjusted for U.S. Territories and international bunker fuels. Adjustments are made to total emissions only.
Note: Totals may not equal sum of components due to independent rounding.

EIA 2009 Emissions of Greenhouse Gases

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 = (Goal 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, always a good place to start!



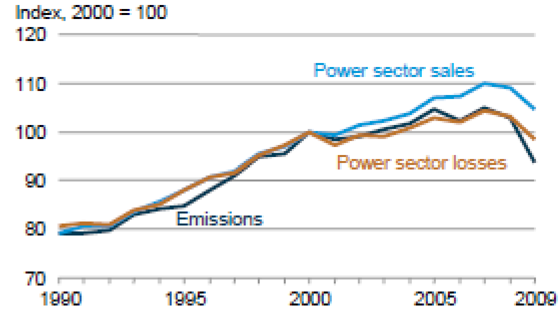
CO_2 Emission from Electric Power

EIA 2009 Emissions of Greenhouse Gases

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



38.5% from Fossil Fuel PowerGen

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	11.6
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.

2,302.9 total in 2005

2005 @ 2416 MMt is benchmark for CPP
2,416 x 0.68 = 1643 MMt (1.643Gt)

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

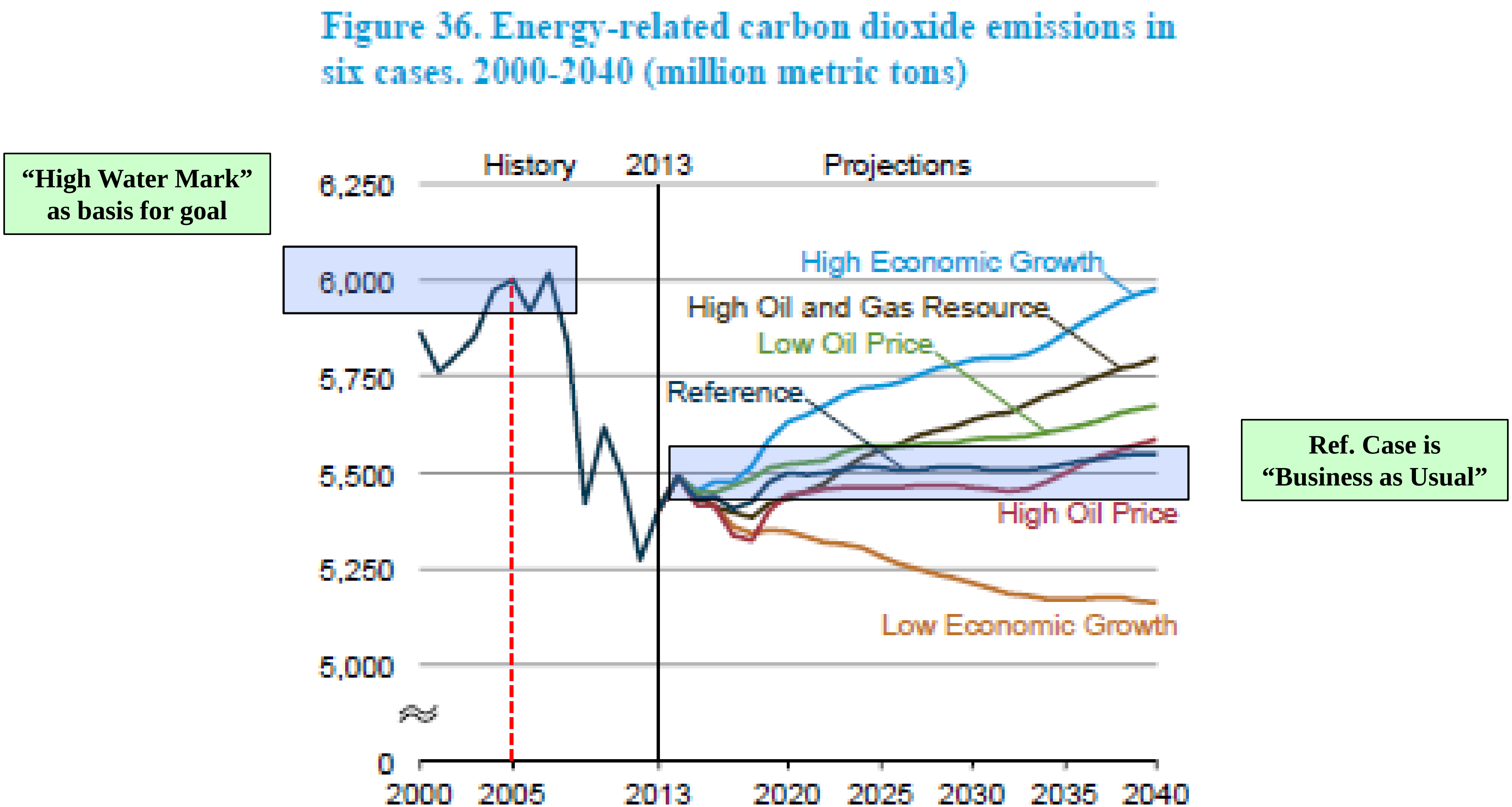
"32% reduction in 2005 power plant CO_2 emissions by 2030"

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.
- 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
- The goal appears to be set based on:
  - 70% Combined Cycle Natural Gas
  - 30% Renewables
- States then develop and implement plans that ensure that the power plants in their 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.

EIA Energy Related CO2 Forecast



Coal-to-Gas Shift – nature.com

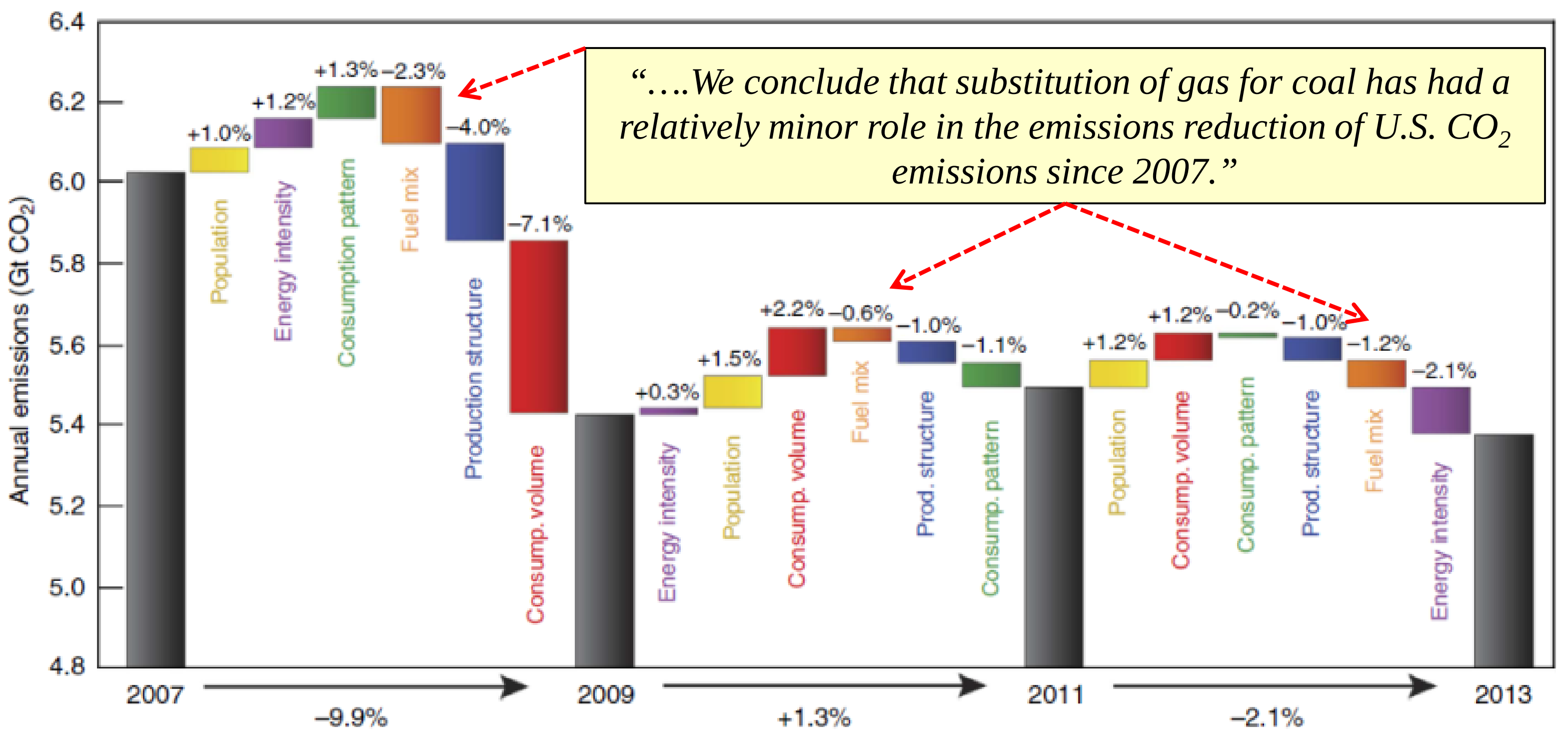


Figure 3 | Contributions of different factors to the decline in US CO_2 emissions 2007-2009 and 2009-2011 and 2011-2013. Between 2007 and 2009, decreases in the volume of goods and services consumed during the economic recession (red) was the primary contributor to the nearly 10% drop in emissions. But 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"

Gas Bridge to Renewables Already Built

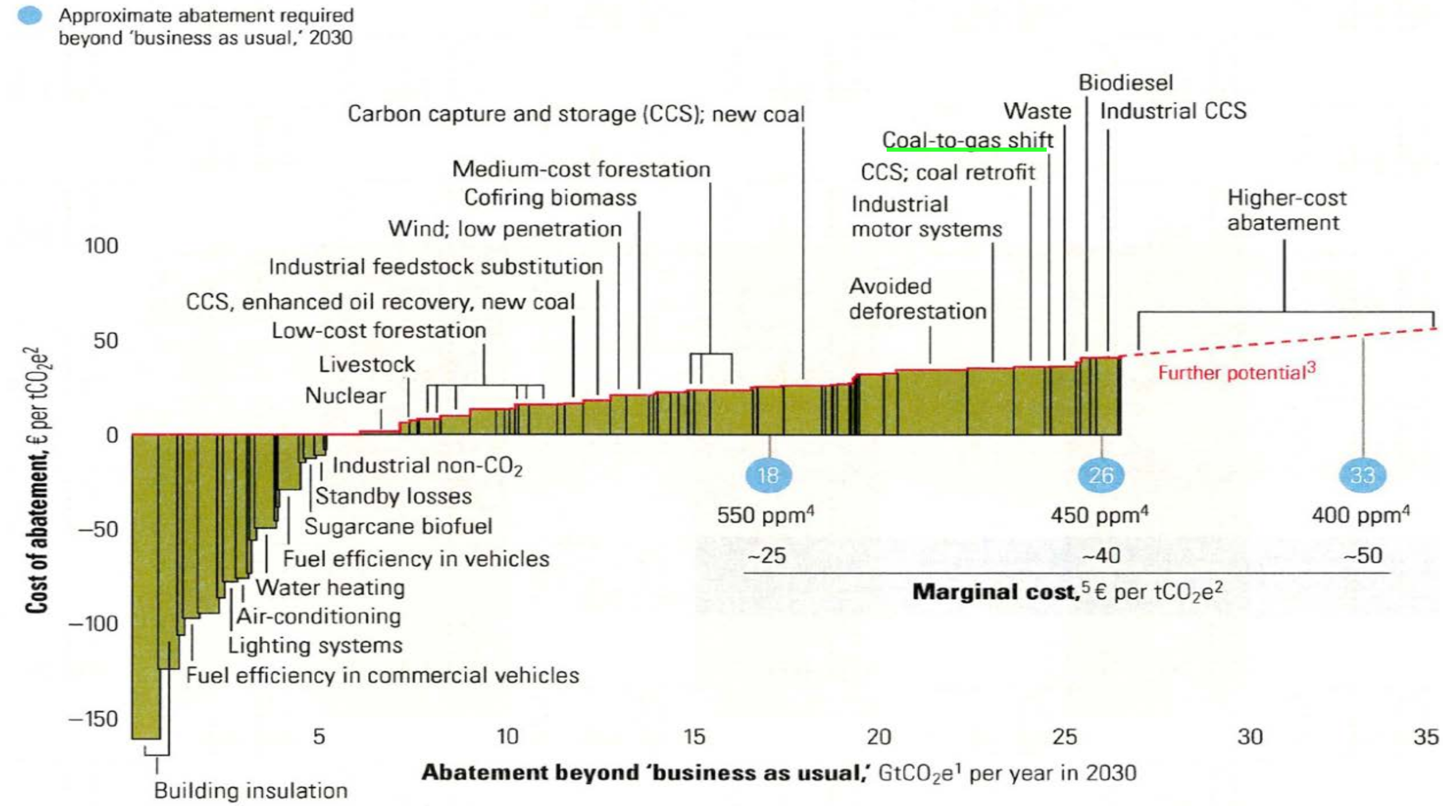
- For the U.S. to reach its climate goals, the deadline for constructing the last gas-fired power plant is coming up shortly — if not already past
- Gas has a significant near-term role in reducing dependence on coal-fired power and helping the transition to intermittent renewable sources. But, to reduce 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.
- 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

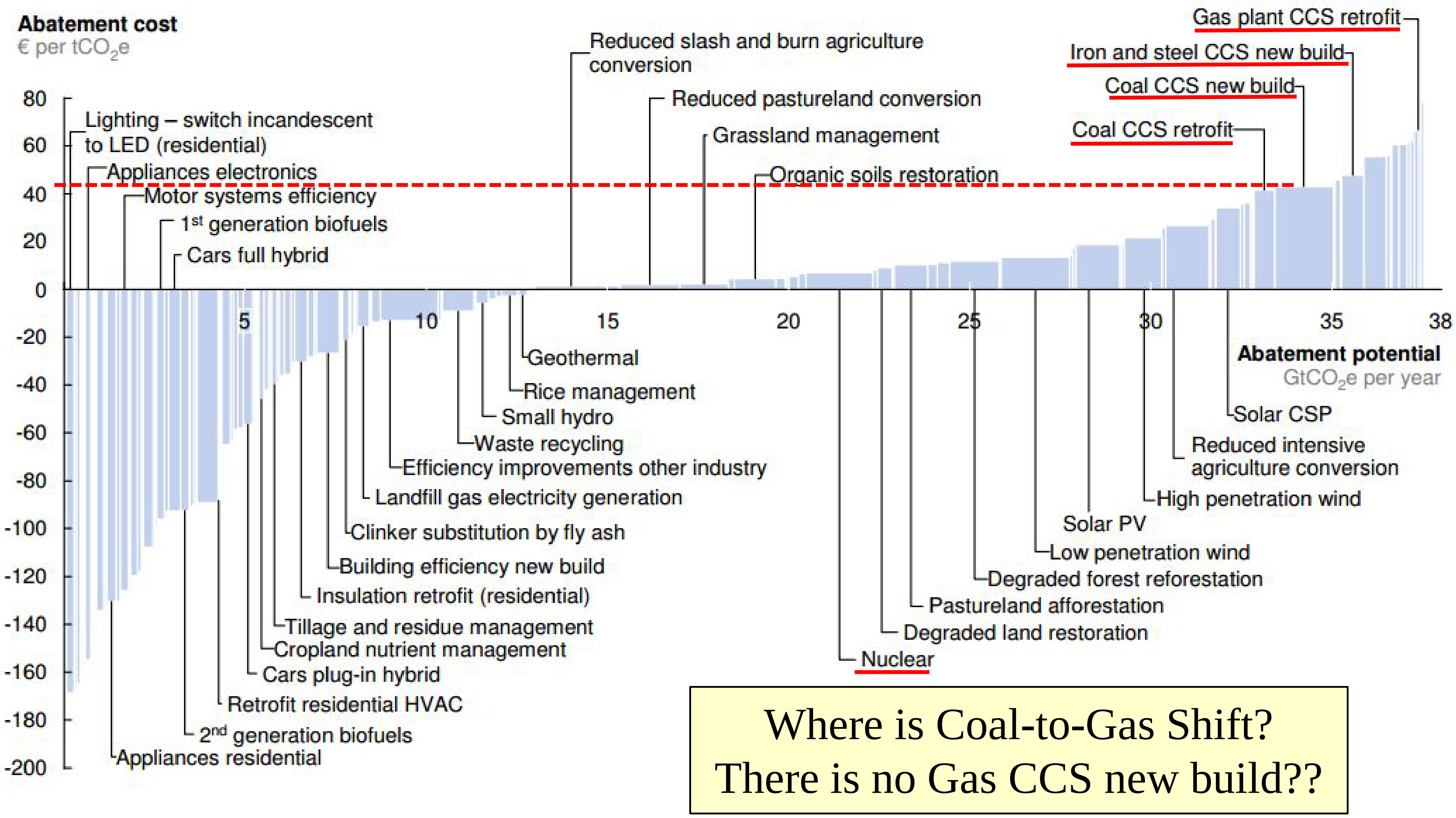
McKinsey CO_2 Cost Curve V1.0

Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in $GtCO_2e^1$



[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.

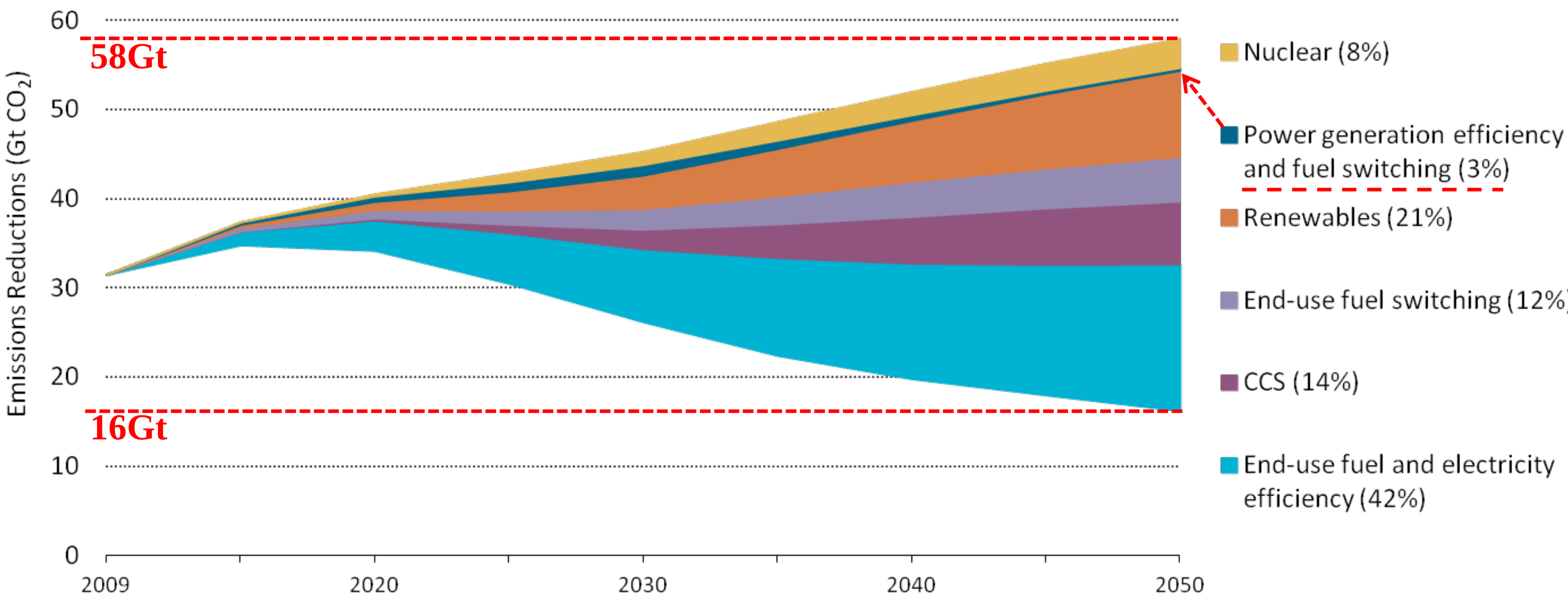
McKinsey Global GHG Cost Curve V2.1



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

IEA Vision May 2013

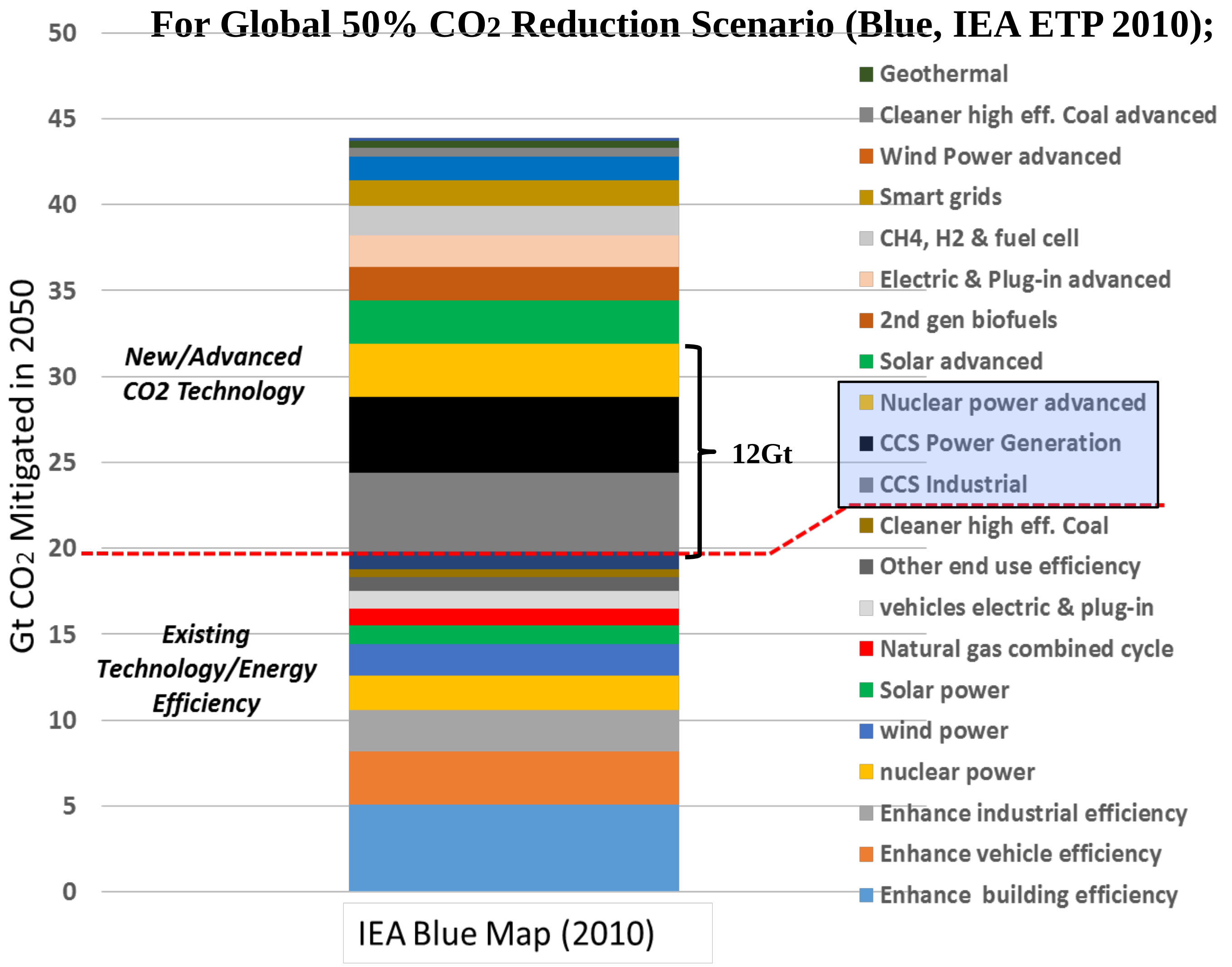


Nuclear and CCS technologies currently on "life support"

12th Annual CCUS Conference
Pittsburgh, 15 May 2013

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

New & Advanced Technologies Needed

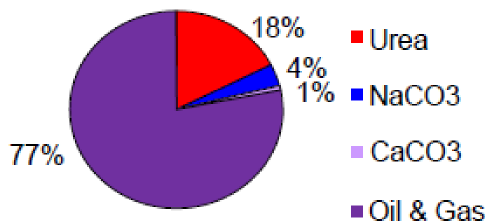


Source: DOE SCO2 Conference 2014, as presented by EPA

Annual U.S. CO_2 Utilization vs. Emissions

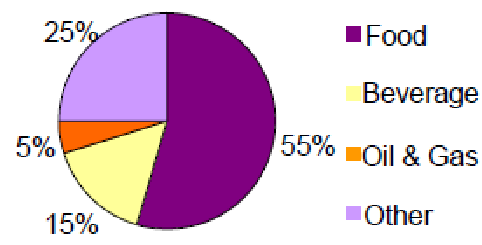
Gaseous Consumption

Mainly enhanced oil recovery



Liquid/Solid Consumption

Mainly Food



Total Utilization ~ 100 Mt

Sources: SRI Consulting, MIT, UT Austin

5 Largest CO_2 Emitters in 2009

	Plant	Location	CO_2, Mt/yr	GWe
1	Scherer	Juliette, GA	25.0	3.56
2	Bowen	Cartersville, GA	20.8	3.50
3	Miller	Quinton, AL	23.3	2.82
4	Martin Lake	Tatum, TX	26.0	2.38
5	Gibson	Owensville, IN	22.2	3.34
		Total	**117.3**	**15.6**

U.S. Utilization = 100 Mt
= Emissions 5 large plants
U.S. Emissions = 2400 Mt from utility
= 6000 Mt total

Sources: EPA, IEA

DOE estimates ~25% of coal power CO_2 emissions could be used for EOR, if ~$30/t

EPRI ELECTRIC POWER RESEARCH INSTITUTE

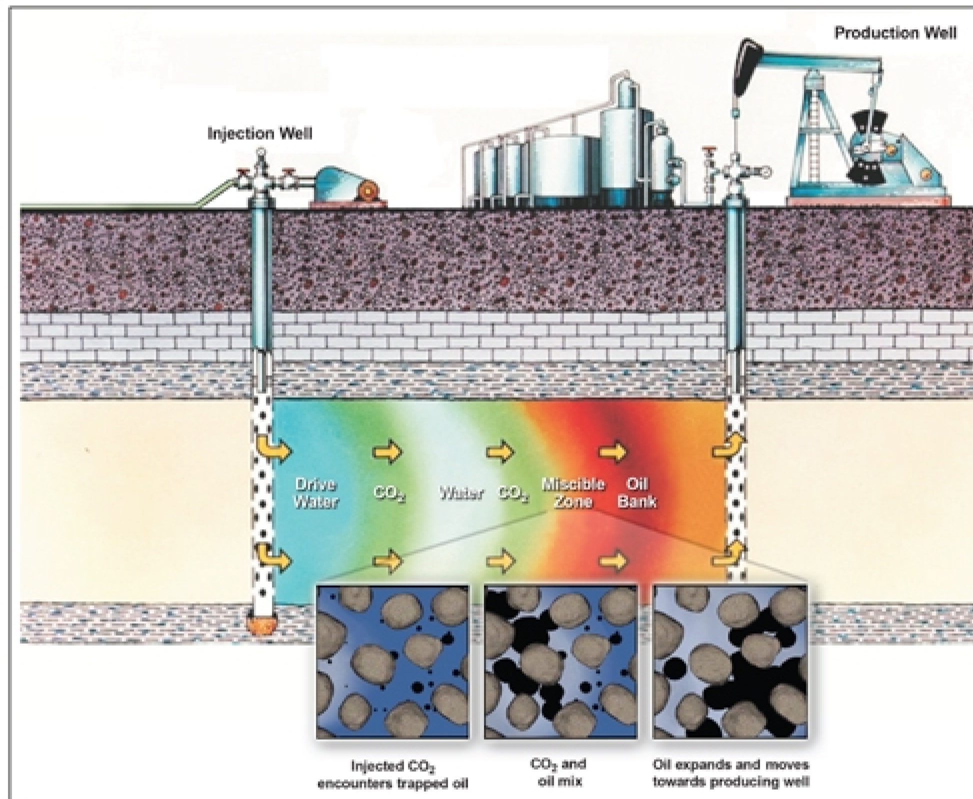
We do not grasp the scale of the problem!

EPRI CO_2 Utilization

- CO_2 chemical conversion to fuels
  - Requires ~6-15 times more energy produced
  - Uses CO_2 as energy storage – other options much better
- CO_2 conversion to other chemicals
  - Requires more energy and/or reactants than produced
  - Scale mismatch - CO_2 production dwarfs other chemicals
- Mineralization
  - Emits >50% of carbon captured at low capture efficiency
  - Scale of reactants, energy needed, low conversion
- Biological conversion
  - Land use requirement: size of Ohio for US coal fleet
  - Significant energy cost: EROI <2

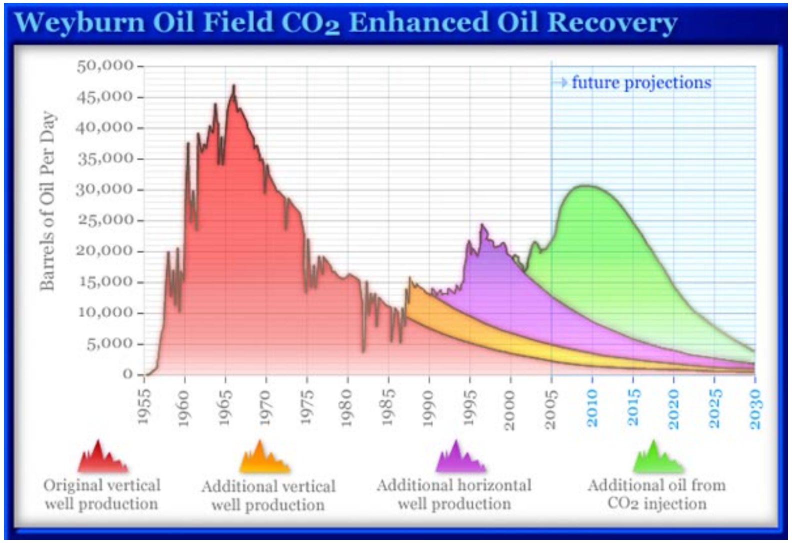
Enhanced Oil Recovery (EOR)

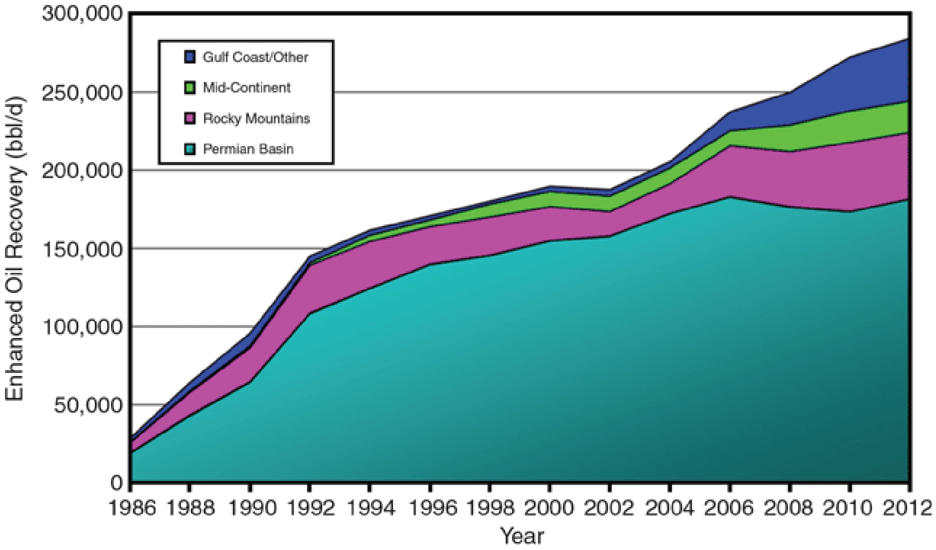
EOR Economic Payback
(1) Mt CO_2 Produces (3) Barrels of Oil



Enhanced Oil Recovery

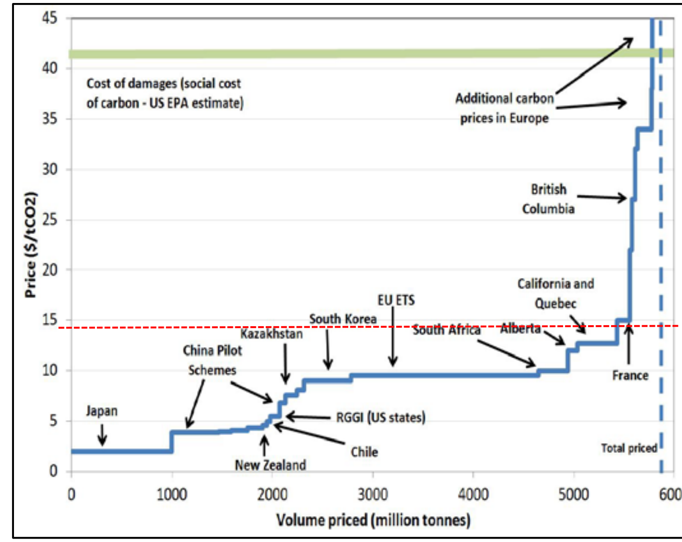
- **Enhance Oil Recovery (EOR)**
  - Near term application
  - Recover up to 15% more oil from existing reservoirs
  - Extend useful life by 25 years
  - Substitute for natural gas re-injection
  - $800 million annual market potential
- **Enhanced Coal Bed Methane**
  - R&D efforts focused on similar use and effects
- **Oil Shale & Tar Sands**
  - 1 trillion bbl oil equivalent
  - In-situ methods under investigation
  - Potential CO_2 use
    - Stimulate production
    - Moderate in-situ combustion





CO_2 Pricing

Source: On Climate Change Policy



Carbon pricing is spreading

– Prices are far too low to price emissions efficiently

– The vast majority of priced emissions – about 90% of the total – are priced below $14/tCO_2$

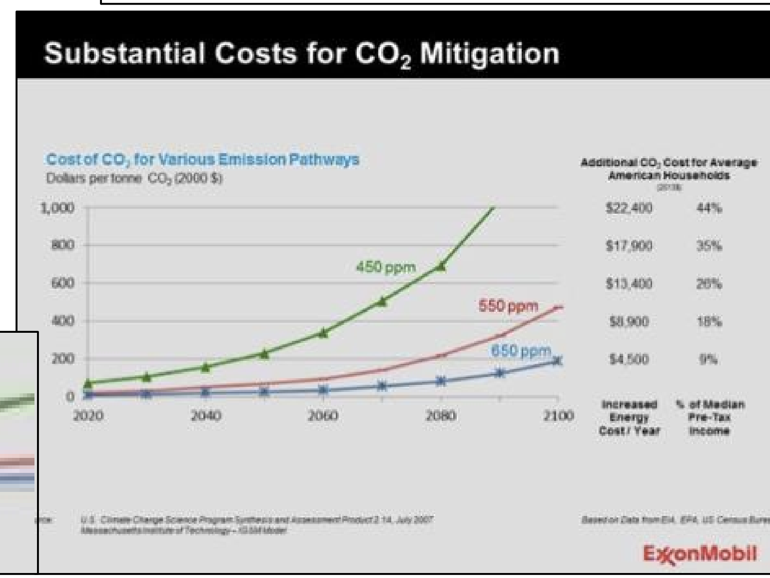
– Higher carbon prices are invariably for small volumes, and are found in Europe, British Columbia and Alberta

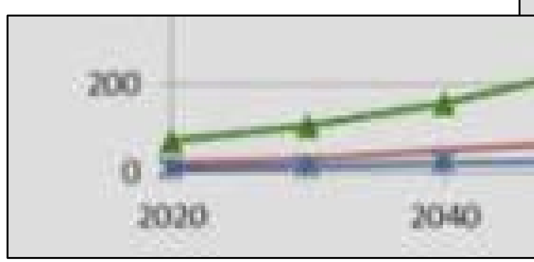
– The environmental damage caused by emissions – as estimated the US EPA

– Carbon prices are too low even compared with a likely underestimate of the cost of emissions

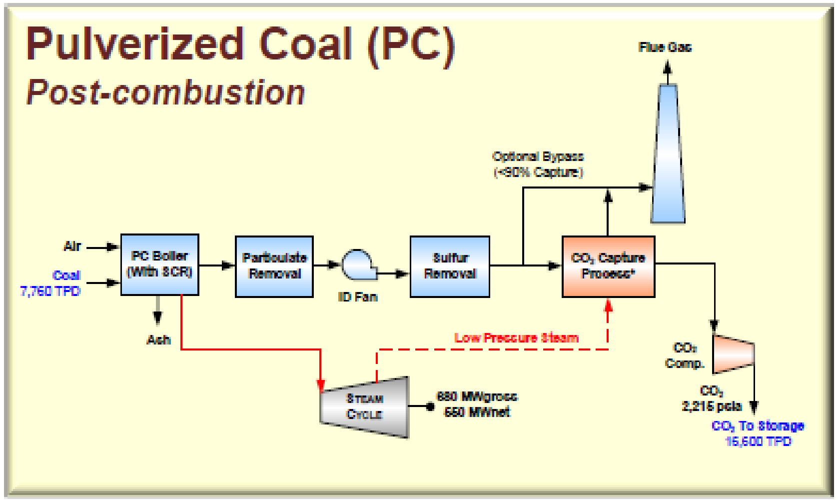
– Taxes are too low and caps are too loose to price carbon adequately

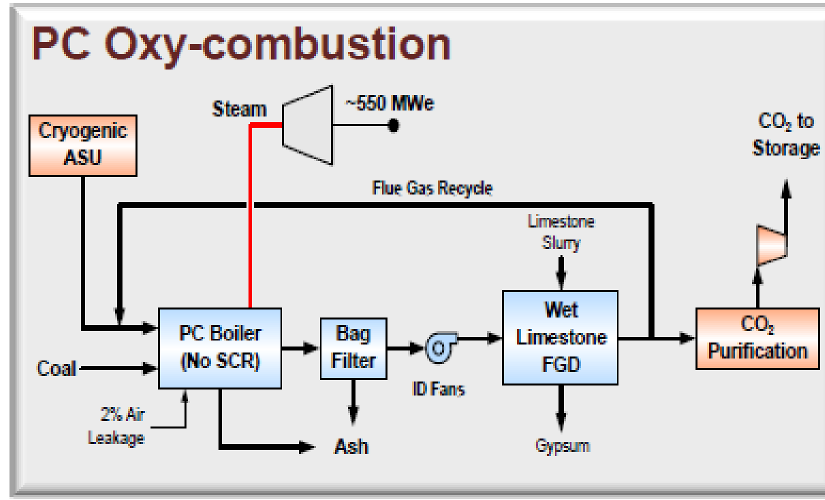
– Consequently efficient abatement is not happening.

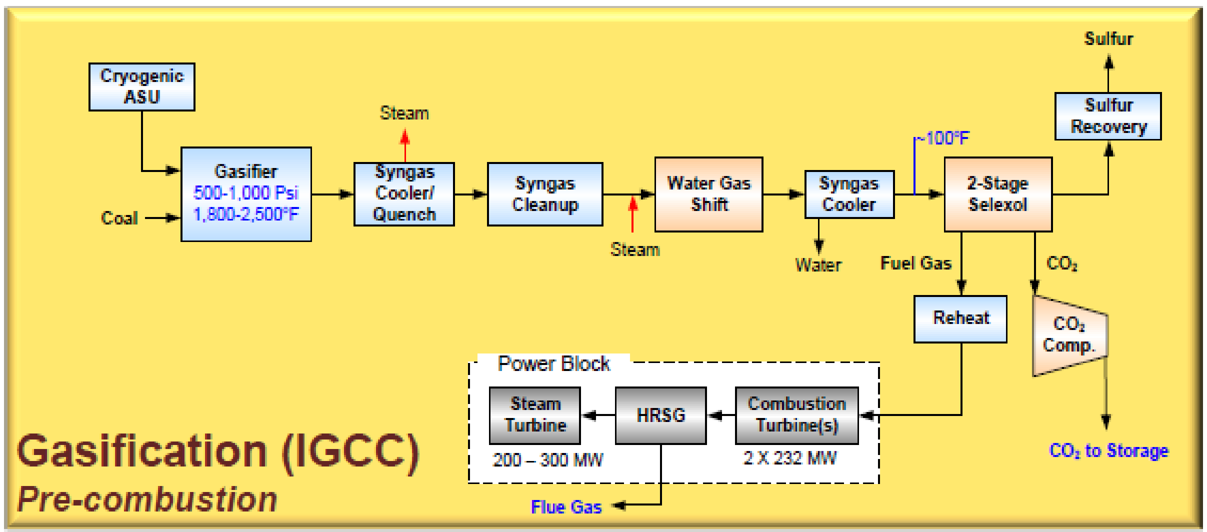




CO_2 Power Plant/Capture Options

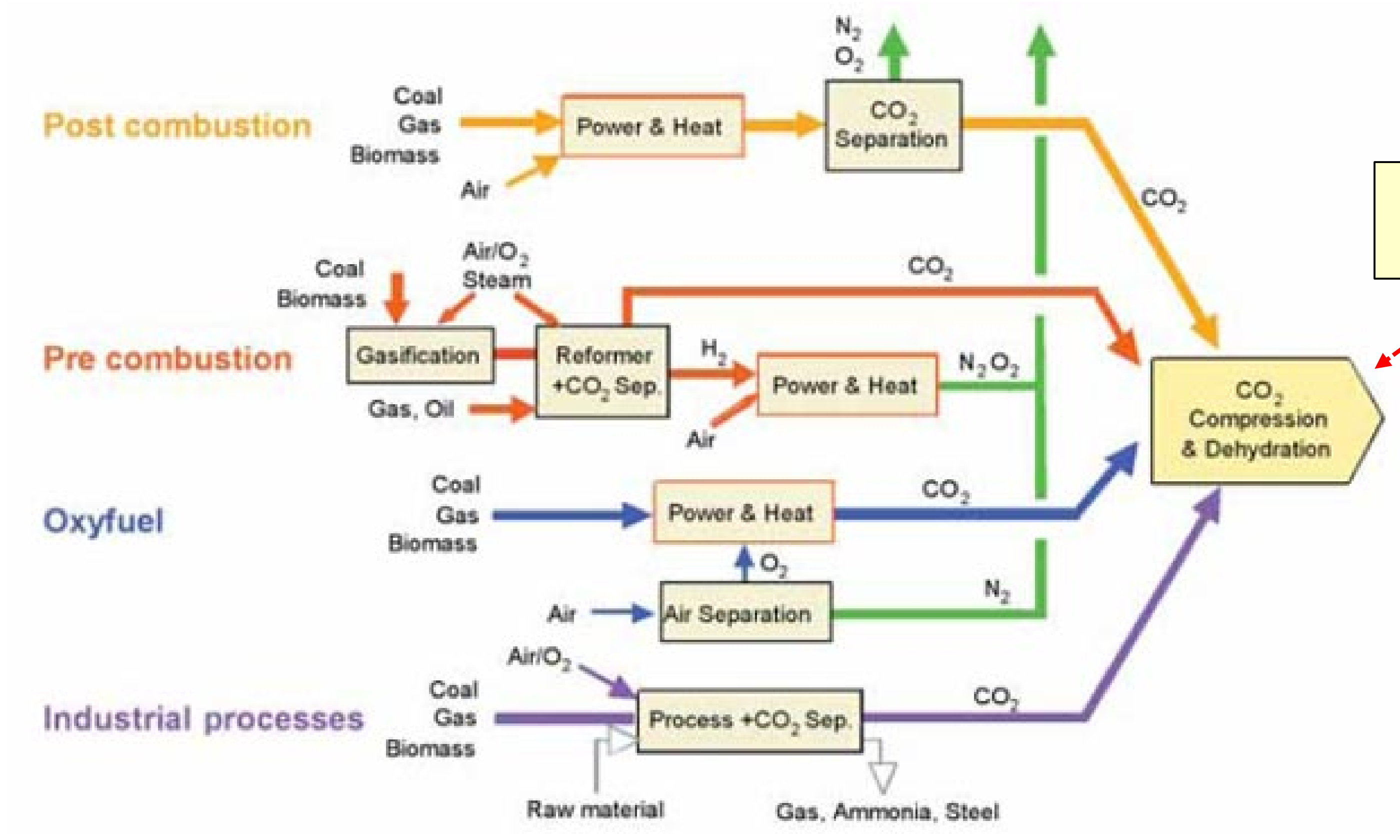






Source: Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity; NETL, May 2007.

Carbon Capture Processes



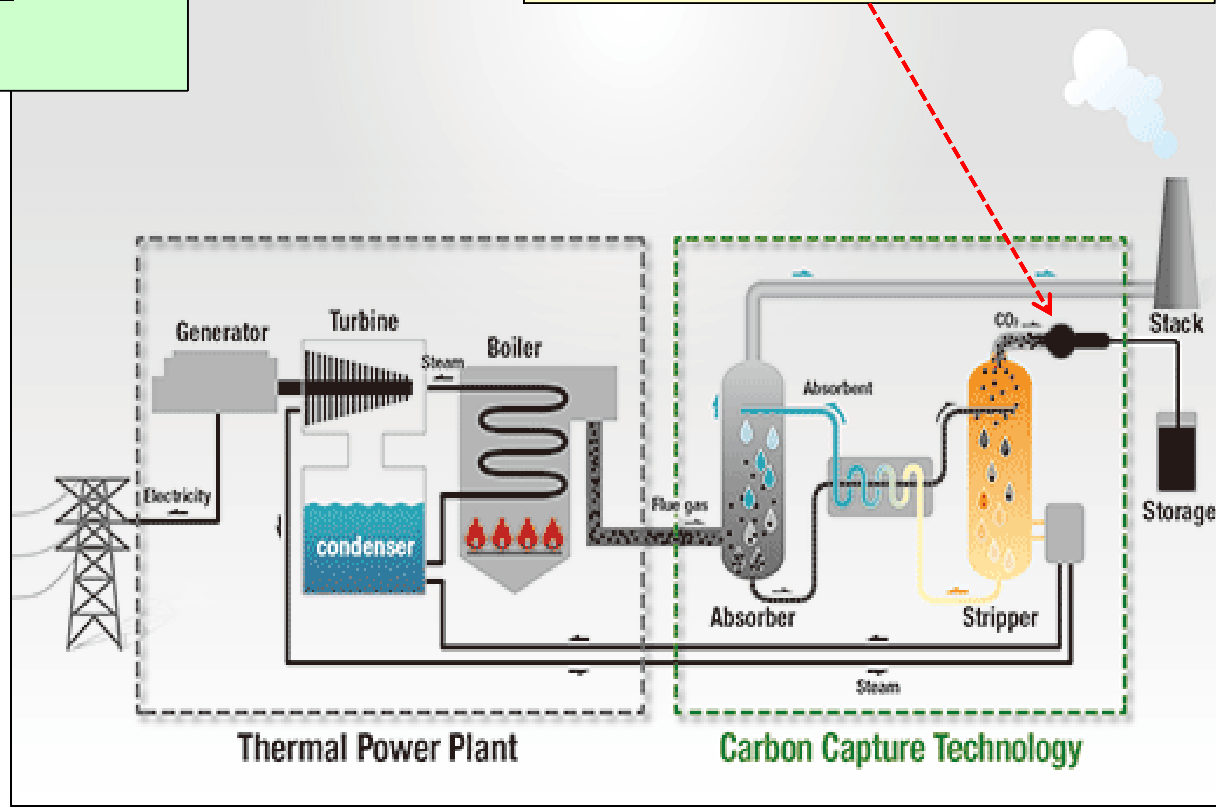
They all end up here in one form or another!

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O$$

Fossil Fuel Power Plant – CC&S

All fossil fuel power plants produce CO_2

This is the compressor(s)



CO_2 Compressor Power

- **Advanced pulverize coal – 8-12%**
  - **600MW ⇨70MW ⇨93,000 hp**
- **IGCC - 5%**
  - **600MW ⇨30MW ⇨40,000 hp**
- **NGCC – 8%**
  - **400MW ⇨32MW ⇨43,000 hp**

Compression Costs are 36% of Total Cost/Mt of CO_2

This is what 6000 hp Compressor Really Looks Like

Pr 200:1
1.70 Pr per stage
10-stage
6000 hp
$8.0 million
$1350/hp

NETL U.S. Carbon Storage Atlas V

Estimates of CO_2 Stationary Source Emissions and Estimates of CO_2 Storage Resources for Geologic Storage Sites

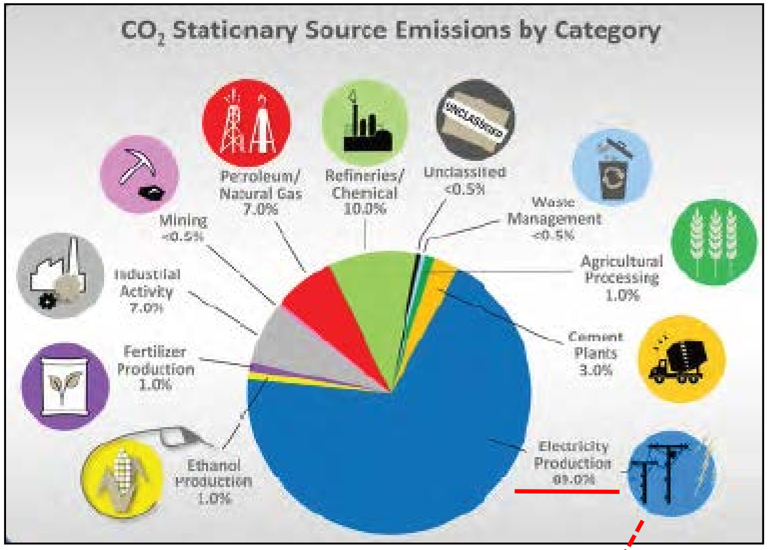
RCSP or Geographic Region	CO_2 Stationary Sources		CO_2 Storage Resource Estimates (billion metric tons of CO_2)								
	CO_2 Emissions (million metric tons per year)	Number of Sources	Saline Formations			Oil and Gas Reservoirs			Unmineable Coal Areas		
			Low	Med***	High	Low	Med***	High	Low	Med***	High
BSCSP	115	301	211	805	2,152	<1	<1	1	<1	<1	<1
MGSC	267	380	41	163	421	<1	<1	<1	2	3	3
MRCSP	604	1,308	108	122	143	9	14	26	<1	<1	<1
PCOR*	522	946	305	583	1,012	2	4	9	7	7	7
SECARB	1,022	1,857	1,376	5,257	14,089	27	34	41	33	51	75
SWP	326	779	256	1,000	2,693	144	147	148	<1	1	2
WESTCARB*	162	555	82	398	1,124	4	5	7	11	17	25
Non-RCSP**	53	232	--	--	--	--	--	--	--	--	--
Total	3,071	6,358	2,379	8,328	21,633	186	205	232	54	80	113

Source: U.S. Carbon Storage Atlas – Fifth Edition (Atlas V); data current as of November 2014

* Totals include Canadian sources identified by the RCSP

** As of November 2014, "U.S. Non-RCSP" includes Connecticut, Delaware, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, and Puerto Rico

*** Medium = p50



Sources >25,000 tonnes

Electricity Production 69%

2005 = 2416 Mt

2012 = 0.69 x 3,071 = 2,119 Mt

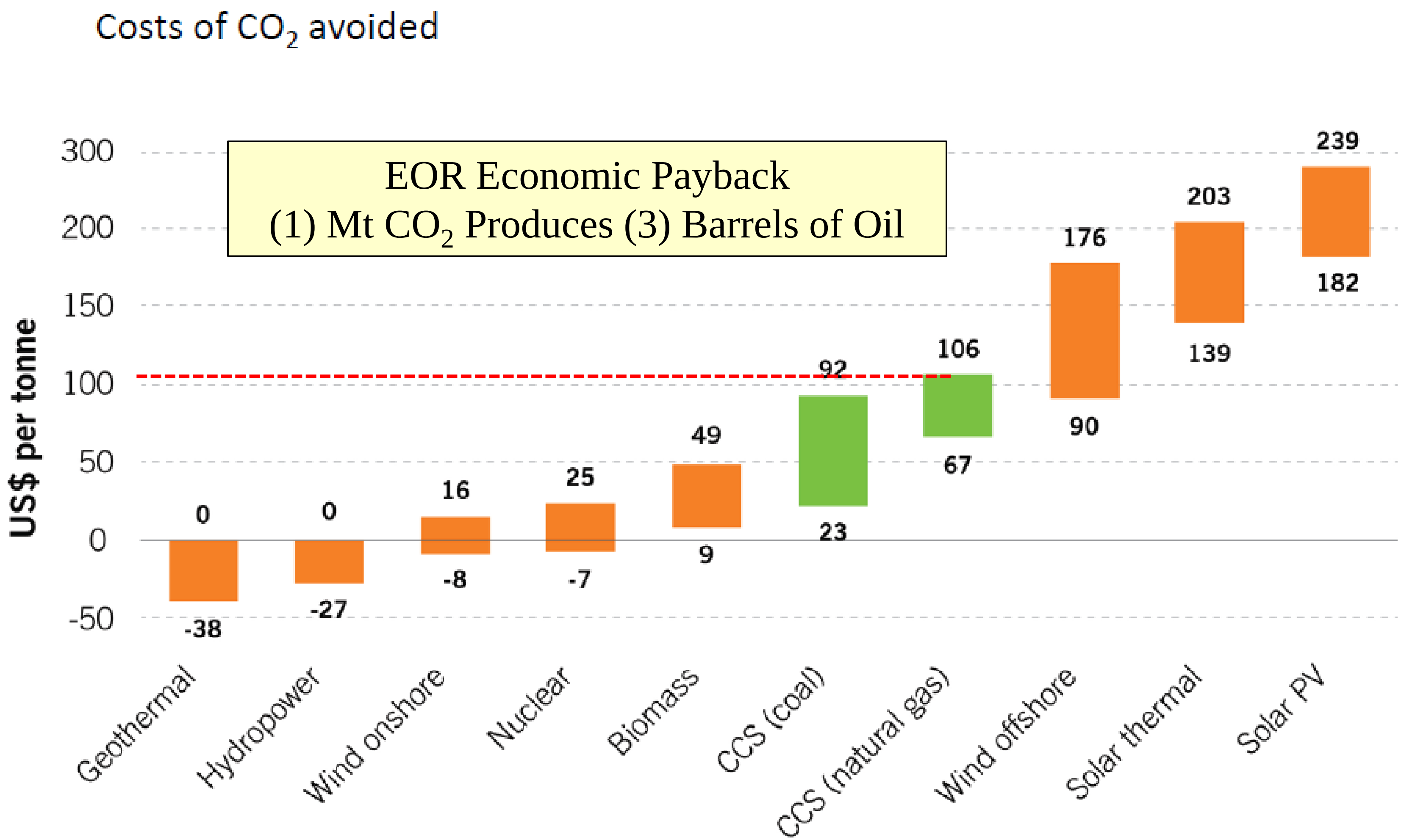
U.S. Totals

2011 = 5601 (37.6%)

2015 = 5680 (37.3%)

http://www.netl.doe.gov/research/coal/carbon-storage/natcarb-atlas

Costs of CO_2 Avoided



Source: Global CCS Institute Victor Der July 2013

US - 45Q Tax Credit (Price on Carbon)

- The 45Q CCUS tax credit was originally passed in 2008 and provided $10/metric ton for CO_2 used for EOR and $20/metric ton for CO_2 injected into saline storage
- The reformed 45Q tax credit provides:
  - **$35/metric ton CO2 for beneficial use, including EOR**
  - **$50/metric ton CO2 for saline aquifer storage**
  - 12-year window for receiving tax credits
  - Construction must begin by Jan 1, 2024
  - Minimum capture rate: 500,000 metric tons per year for power plants and 100,000 tpy for industry.
  - Transferrable, which means that non-profits such as cooperatives can use the tax credit.
- Not all power companies pay enough in taxes to directly use the tax credits that would be generated.
- Due to the recent US tax legislation, overall national and corporate tax rates are lower, resulting in fewer opportunities use and/or monetize the 45Q credits.
- Providing new, tangible examples that CCUS is real and provides substantial emission reductions from multiple industries.
- These projects may result in the states, US federal government, and possibly even inter-governmental (for example, the US and Canada) developing standards for CO_2 storage monitoring, verification, and well-closure rules. This would represent a major advancement for CCUS.
- They will lead to real infrastructure investments, including pipelines, which is especially important for CO_2 transport.

Holly Krutka
Peabody Energy
April 19, 2018

Clean Power Plan Replacement

- The EPA proposed regulations will require only modest improvements in generator efficiency and could allow states to opt out of the rules altogether,
- The plan would aim for the power sector to cut emissions 0.7% to 1.5% from 2005 levels by 2030, the Washington Post reports, in contrast to the Obama administration's Clean Power Plan, which envisioned a 19% cut in power sector emissions.
- Greater efficiency at coal plants could allow them to run more often, however, potentially erasing even the more modest emissions reductions.
- Replacement of the Clean Power Plan (CPP) represents a major step for Trump's deregulatory agenda and push to reinvigorate the domestic coal sector.
- The CPP, finalized in 2015, aimed to set minimum emission standards for power plants and allow states to decide how to meet them.
- The rule never went into effect. The Supreme Court put it on hold in 2016
- The EPA's replacement rule is expected to be more modest, only requiring minor improvements to generator efficiency that can be accomplished "inside the fenceline" of existing units.
- In some parts of the nation, like the windy Great Plains, the price of renewable energy has fallen below the cost utilities pay to keep large coal and nuclear facilities online. Researchers expect that situation to spread as wind, solar and batteries decline in price, which could speed utilities' transition away from coal.
- State policies to price carbon and mandate renewable energy will also counteract the Trump administration's deregulatory agenda, but the White House is aiming to stop some of those rules as well.
- When it is proposed, the Trump administration's CPP replacement will be subject to a 60 day comment period. Like the auto rule rollback, it will likely face court challenges from environmental groups and liberal states.

Follow Gavin Bade on Twitter

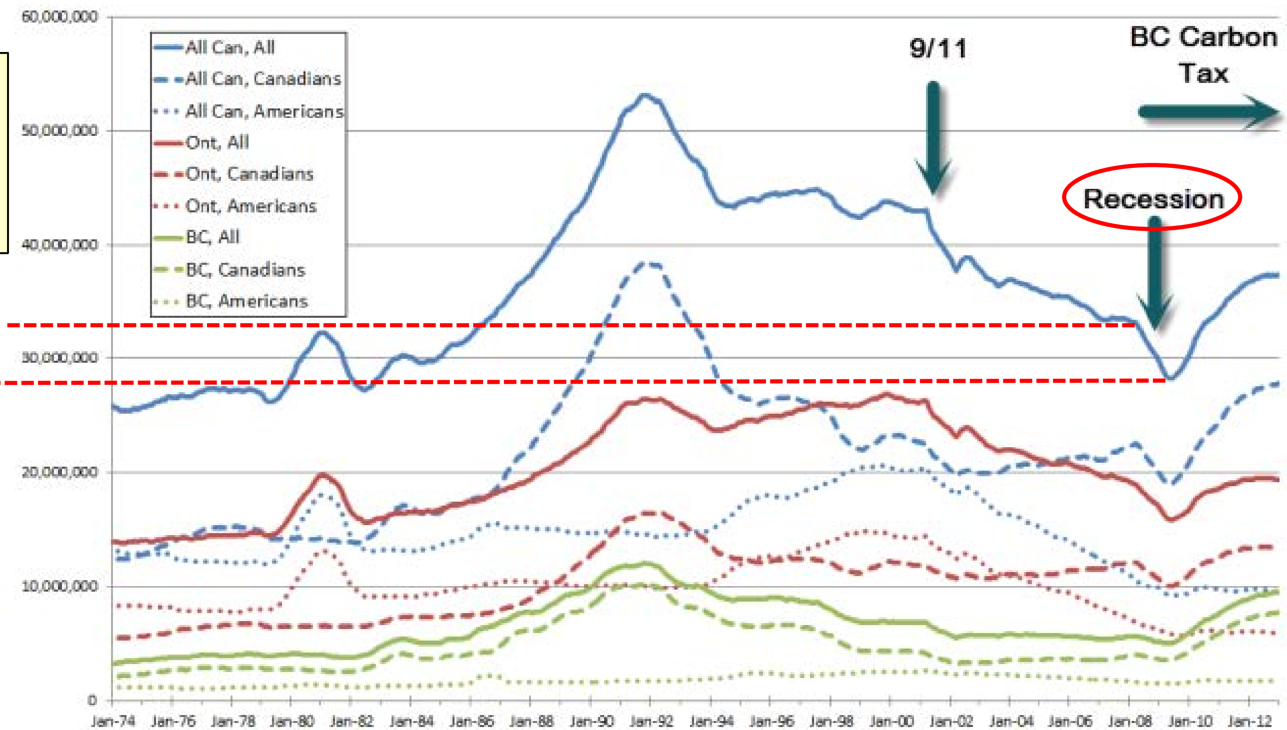
British Columbia Carbon Tax "Success"

- "Successful implementation"
  - 16% drop in consumption after introduction in 2008
- Initially $C10/tonne, increasing to current $C30/tonne
  - $C30/tonne = 7 cents/liter = 26.5 cents/gallon
- Use of ½ Carbon Tax funds for Regional Transit expansion denied
- A 2nd Carbon Tax is being discussed to fund the Region's Transit expansion

"The goal of the carbon tax, reducing carbon, is just completely synchronous with public transit funding and getting people out of cars," he said. "Regardless of what the minister has said, we still believe it's the best source."

Richard Walton, mayor of the District of North Vancouver

15,000 miles
20 mpg
750 gal
$200 @ $26.5/gal



19.64 lb-CO2/gal
750 gal
14,730 lb-CO2
6.68 tonnes
$200 @ $30/tonne

base e ®

Well-to-Wheels Comparison Electric vs. Gasoline

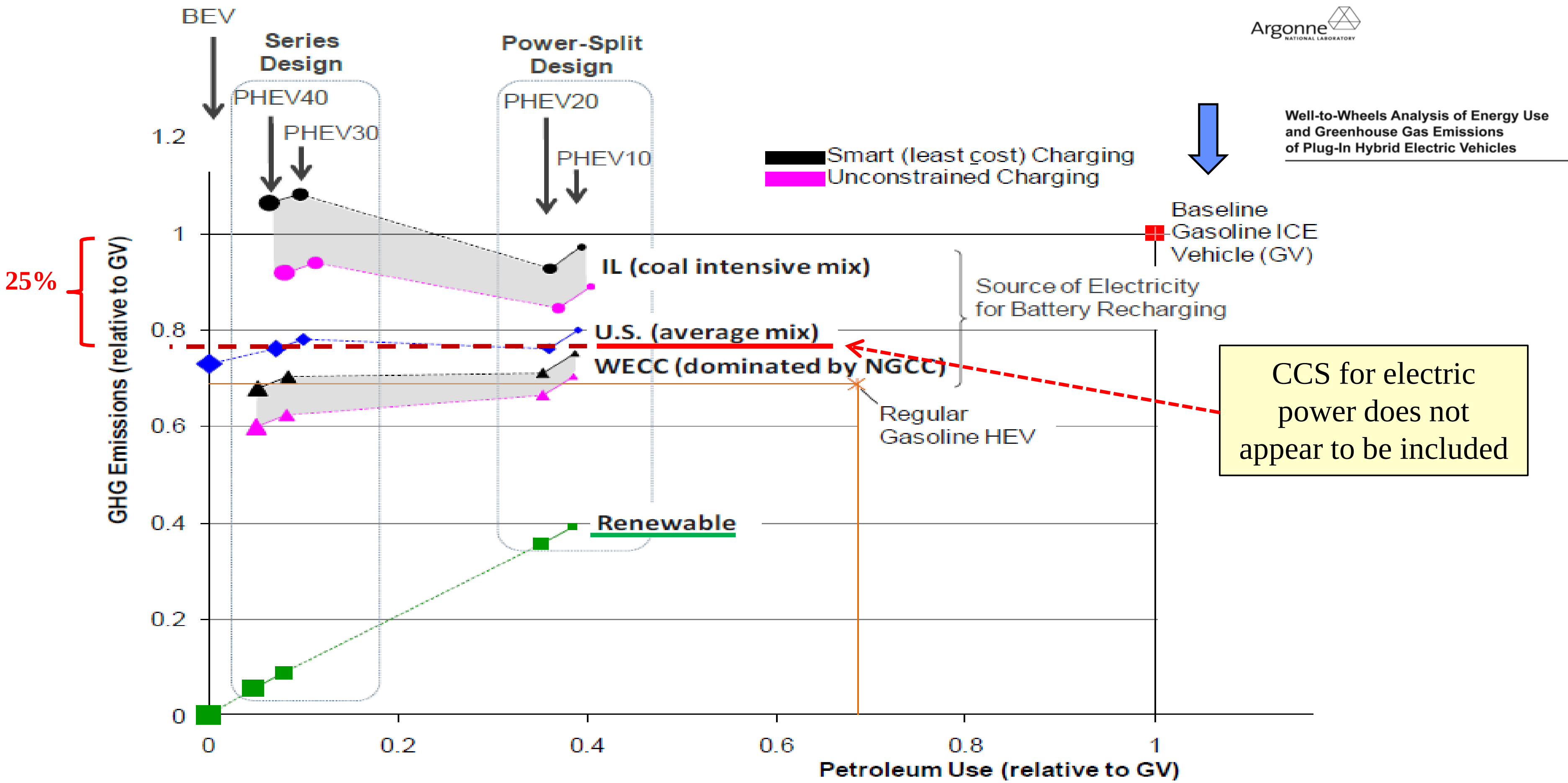
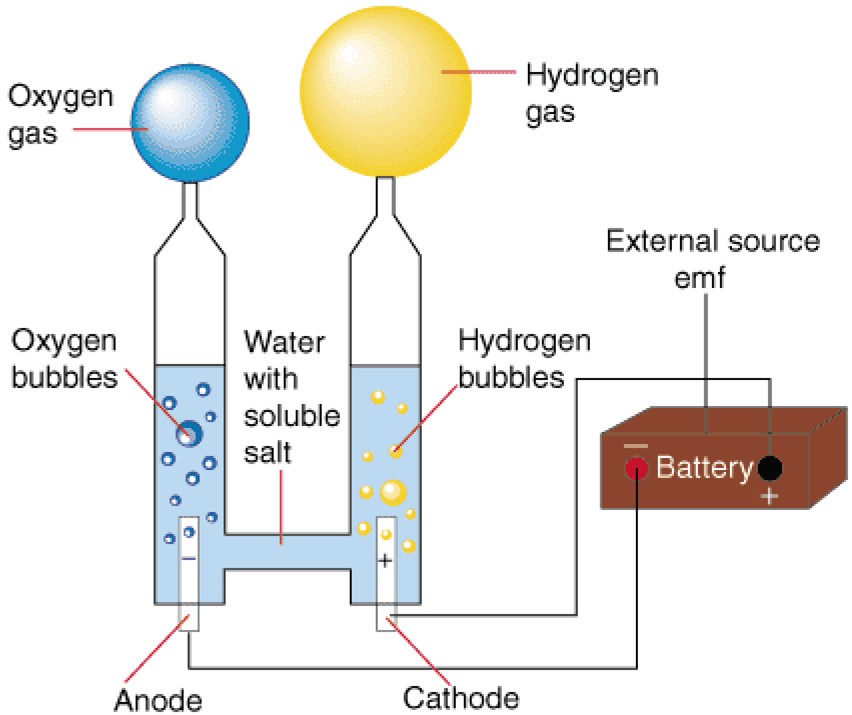
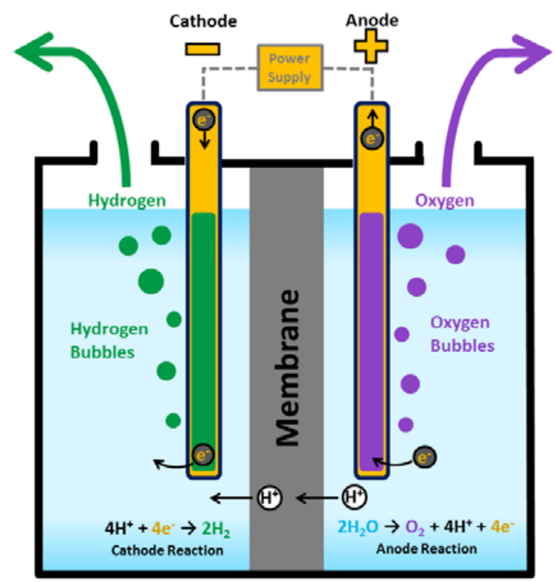


FIGURE ES.1 WTW Petroleum Use and GHG Emissions for CD Operation of Gasoline PHEVs and BEVs Compared with Baseline Gasoline ICEVs and Regular Gasoline HEVs

Hydrogen from Water





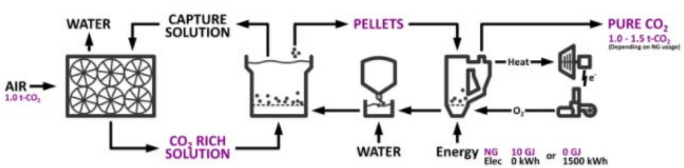
2H2O(l) = 2H2(g) + O2(g)

Solar PV + electrolyzer = Hydrogen

"Practical Strategies for Emerging Energy Technologies"

Air Capture

As we move to commercialization, we envision industrial-scale air capture facilities, sited outside of cities and on non-agricultural land, that supply CO2 for fuel synthesis, and eventually for direct sequestration to compensate for emissions that are too challenging or costly to eliminate at source. At this large scale, our technology will be able to achieve costs of $100-150 USD per tonne of CO2 captured, purified, and compressed to 150 bar.



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