CO_2 – By the Numbers

Winchester Unitarian Society

Speaker Series

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Without data you're just another person with an opinion.

W. Edwards Deming

Energy Policy = Choice of Fuel(s)

Global energy supply will be "plentiful" for years, BP exec says.

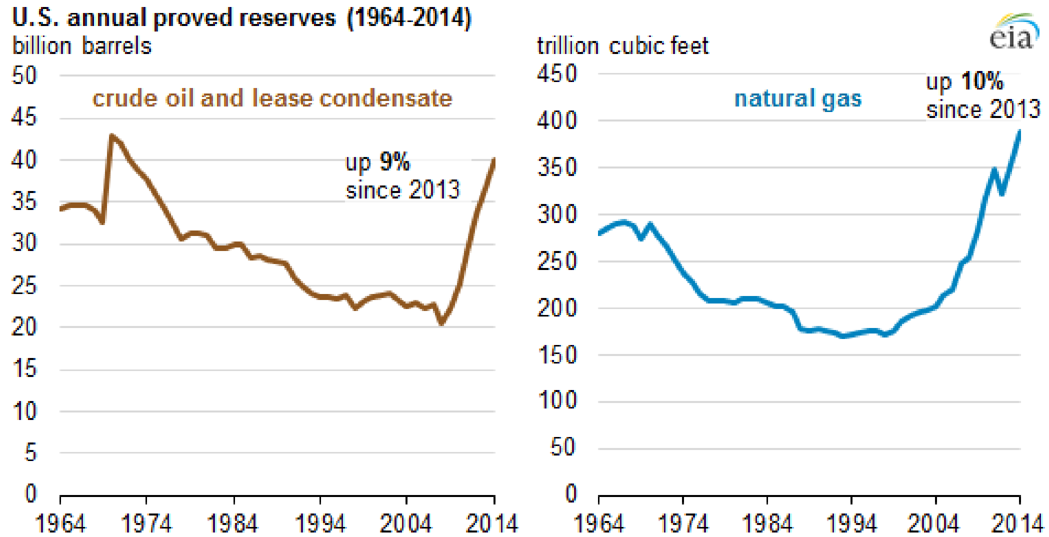
"The world will have no shortage of energy over the next 35 years, according to BP Group Head of Technology David Eyton. "Energy resources are plentiful.

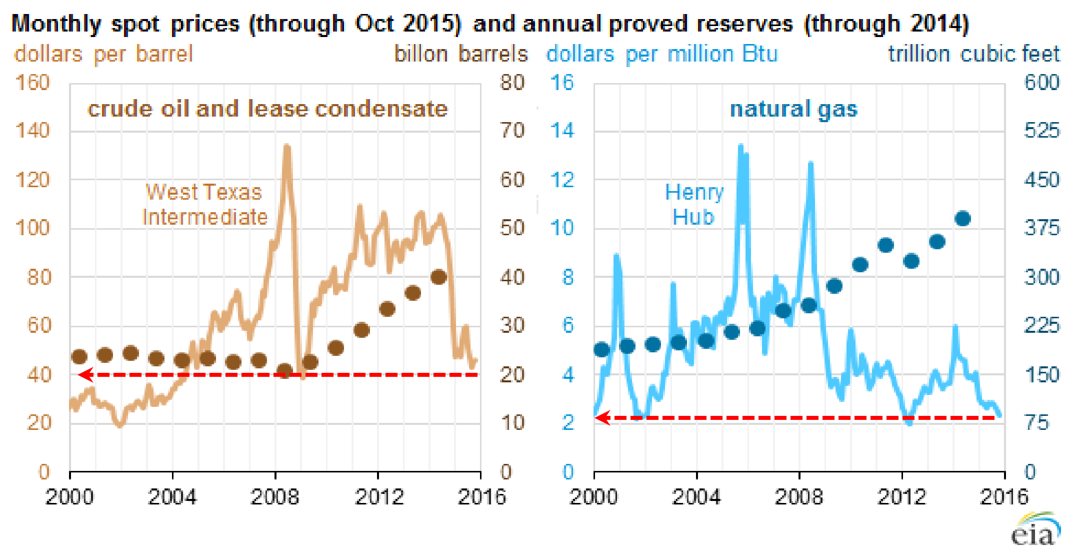
Concerns over running out of oil and gas have disappeared," he said.

Improved oil and natural gas industry technology means that government policies will be a greater determining factor in energy supply than availability of resources."

Reuters (11/2)

U.S. Proven Reserves & Price





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"Practical Strategies for Emerging Energy Technologies"

Fuel Value Chain Systemic Shocks

- **Oil**
  - Oil price
  - U.S. shale oil production
  - U.S. crude oil export restrictions
- **Natural Gas**
  - Oil-linked price indexing Asia & EU
  - Developing resource worldwide
  - LNG export
  - Russian gas to EU or China
- **Coal**
  - EPA New Source Performance Standard
  - EPA Clean Power Plan
- **Nuclear**
  - Continuing Fukushima effects
- **Technology**
  - Seismic & imaging tools
  - Horizontal drilling
  - Fracking
- **Environmental Issues**
  - Climate Change
  - Oil-Water nexus
  - Pipelines & tank cars
  - Fracking methods & produced water disposal
  - Canadian "Dirty Oil" resources
  - Nuclear waste disposal
- **Renewables**
  - System integration
  - Energy storage
  - Renewable Portfolio Standards (RPS)
  - Production Tax Credits (PTC)
- **Geo-Political Instabilities**
  - Russia/Ukraine
  - Iran Sanctions
  - Iraq/Syria/Yemen/Libya
  - Nigeria/Venezuela
  - Russia/Turkey
- **Supply Shortfalls**
  - UK
  - Mexico
  - Brazil
  - Iraq/Syria/Yemen/Libya
- **Territorial Disputes/Issues**
  - South China Sea
  - The Arctic

Basic Comparisons

	China	USA	India	Japan	Germany	Russia
Population - July 2015 est	1,367,485,388	321,368,864	1,251,695,584	126,919,659	80,854,408	142,423,773
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)	17.6	17.5	7.3	4.8	3.6	3.6
Installed Generating Capacity GW	1,505	1,053	223	287	178	240
% of World at 5,550 GW	27%	19%	4%	5%	3%	4%
Electric Production TWh	5,169	4,048	975	963	576	1,054
Electric Consumption TWh	4,831	3,883	758	860	583	1,037
Aggregate Load Factor	39.2%	43.9%	49.8%	38.3%	36.9%	50.2%
Natural Gas Production - BCM	117.1	687.6	36.0	3.2	11.8	668.0
Natural Gas Consumption - BCM	161.6	737.3	54.0	127.2	88.4	413.5
Refined Petroleum Products Production - mmbbl/d	9.6	18.5	4.4	3.6	2.2	4.8
Refined Petroleum Products Consumption - mmbbl/d	10.8	18.9	3.2	4.5	2.4	3.3
Coal Production - Million Tonnes Oil Equivalent	1844.6	507.8	243.5	0.7	43.8	170.9
Coal Consumption - Million Tonnes Oil Equivalent	1962.4	453.4	360.2	126.5	77.4	85.2

Source: CIA World Factbook

World Total Installed Electrical Generating Capacity 5,550 GW

Ps…….Total Value of Outstanding Student Loans - $1.3 trillion
U.S. health care cost 2014 – 3.0 trillion

World Energy Consumption Mtoe

Million tonnes oil equivalent	Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Renew - ables	Total 2014	Percent of 2014
US	836.1	695.3	453.4	189.8	59.1	65.0	**2298.7**	17.8%
Canada	103.0	93.8	21.2	24.0	85.7	4.9	**332.7**	2.6%
Mexico	85.2	77.2	14.4	2.2	8.6	3.7	**191.4**	1.5%
Total North America	**1024.4**	**866.3**	**488.9**	**216.1**	**153.5**	**73.6**	**2822.8**	21.8%
Brazil	142.5	35.7	15.3	3.5	83.6	15.4	**296.0**	2.3%
Total S. & Cent. America	**326.5**	**153.1**	**31.6**	**4.7**	**155.4**	**21.5**	**692.8**	5.4%
France	76.9	32.3	9.0	98.6	14.2	6.5	**237.5**	1.8%
Germany	111.5	63.8	77.4	22.0	4.6	31.7	**311.0**	2.4%
Italy	56.6	51.1	13.5	-	12.9	14.8	**148.9**	1.2%
Russian Federation	148.1	368.3	85.2	40.9	39.3	0.1	**681.9**	5.3%
Spain	59.5	23.7	12.0	13.0	8.9	16.0	**133.0**	1.0%
Turkey	33.8	43.7	35.9	-	9.1	2.8	**125.3**	1.0%
Ukraine	10.2	34.6	33.0	20.0	1.9	0.4	**100.1**	0.8%
United Kingdom	69.3	60.0	29.5	14.4	1.3	13.2	**187.9**	1.5%
Total Europe & Eurasia	**858.9**	**908.7**	**476.5**	**266.1**	**195.7**	**124.4**	**2830.3**	21.9%
Iran	93.2	153.2	1.1	1.0	3.4	0.1	**252.0**	1.9%
Saudi Arabia	142.0	97.4	0.1	-	-	^	**239.5**	1.9%
Other Middle East	76.0	40.4	0.1	-	1.8	^	**118.3**	0.9%
Total Middle East	**393.0**	**418.6**	**9.7**	**1.0**	**5.2**	**0.3**	**827.9**	6.4%
South Africa	29.1	3.7	89.4	3.6	0.3	0.6	**126.7**	1.0%
Other Africa	93.6	27.4	8.2	-	24.2	1.8	**155.3**	1.2%
Total Africa	**179.4**	**108.1**	**98.6**	**3.6**	**27.5**	**2.9**	**420.1**	3.2%
Australia	45.5	26.3	43.8	-	3.3	4.1	**122.9**	1.0%
China	520.3	166.9	1962.4	28.6	240.8	53.1	**2972.1**	23.0%
India	180.7	45.6	360.2	7.8	29.6	13.9	**637.8**	4.9%
Indonesia	73.9	34.5	60.8	-	3.4	2.2	**174.8**	1.4%
Japan	196.8	101.2	126.5	-	19.8	11.6	**456.1**	3.5%
South Korea	108.0	43.0	84.8	35.4	0.8	1.1	**273.2**	2.1%
Total Asia Pacific	**1428.9**	**610.7**	**2776.6**	**82.5**	**341.6**	**94.2**	**5334.6**	41.3%
Total World	**4211.1**	**3065.5**	**3881.8**	**574.0**	**879.0**	**316.9**	**12928.4**	100.0%
	32.6%	23.7%	30.0%	4.4%	6.8%	2.5%	100.0%	

U.S.
– 2.8% Renewables
– 2.6% Hydro

Renewables
– Germany 10.2%
– Spain 12.0%

Nuclear
– France 42%

Asia Pacific Represents >70% of Coal Consumption

53.7% Gas & Coal ⟷ **2.5% Renewables**

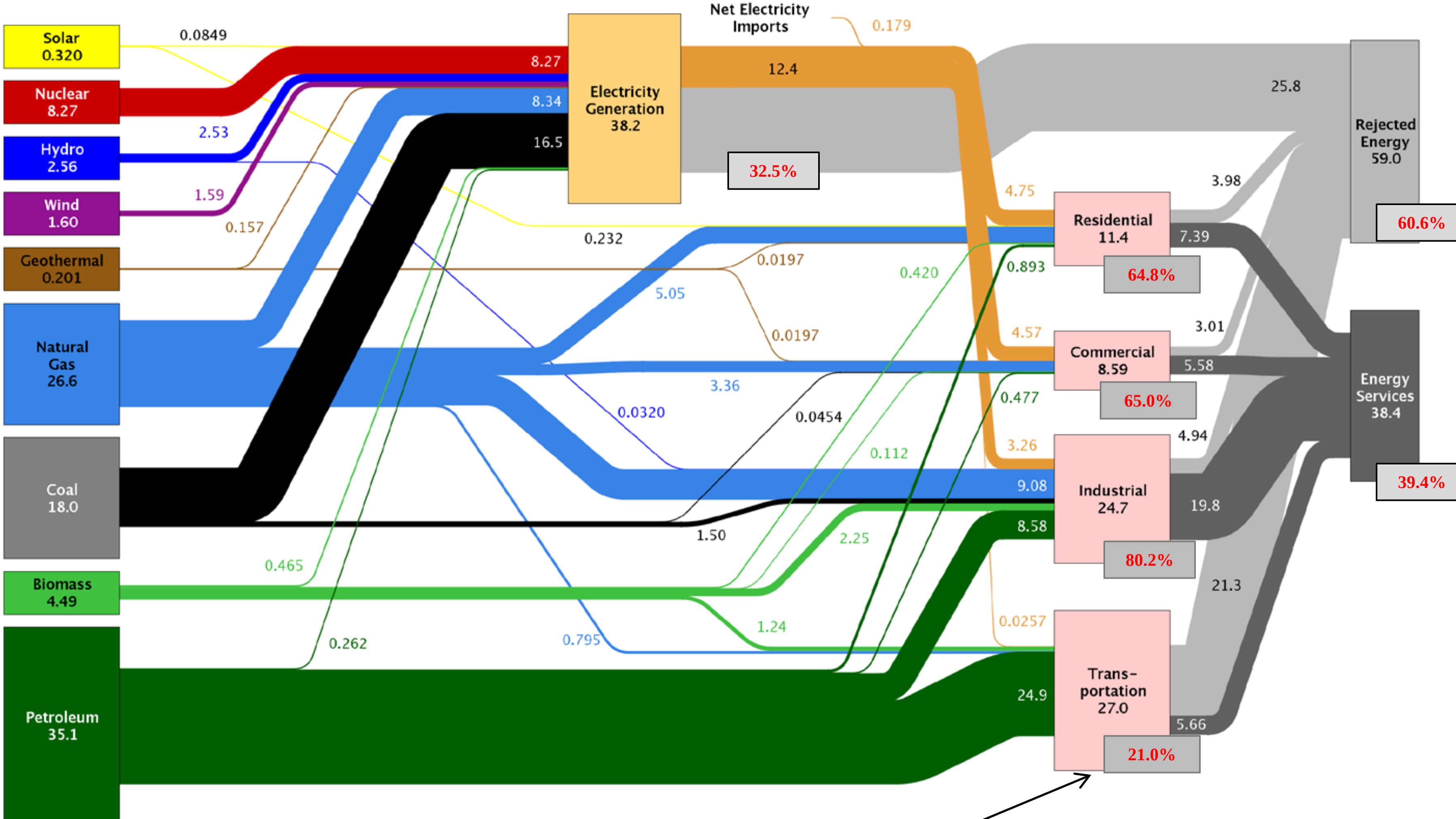
World Total Primary Energy Consumption - Quads

World total primary energy consumption by region, Reference case (Quadrillion Btu)								
Region/Country	2008	2011	2015	2020	2025	2030	2035	Growth Rate (2008-2035)
OECD								
OECD Americas	**122.9**	**121.3**	**126.1**	**131**	**135.9**	**141.6**	**147.7**	**0.70%**
United States	100.1	98.3	102	104.9	108	111	114.2	0.50%
Canada	14.3	14.3	14.6	15.7	16.4	17.6	18.8	1.00%
Mexico/Chile	8.5	8.7	9.5	10.4	11.5	13	14.7	2.10%
OECD Europe	**82.2**	**80.8**	**83.6**	**86.9**	**89.7**	**91.8**	**93.8**	**0.50%**
OECD Asia	**39.2**	**38.7**	**40.7**	**42.7**	**44.2**	**45.4**	**46.7**	**0.70%**
Japan	22.4	21.2	22.2	23.2	23.7	23.7	23.8	0.20%
South Korea	10	10.4	11.1	11.6	12.4	13.1	13.9	1.20%
Australia/New Zealand	6.8	7.1	7.4	7.8	8.1	8.5	8.9	1.00%
Total OECD	**244.3**	**240.7**	**250.4**	**260.6**	**269.8**	**278.7**	**288.2**	**0.60%**
Non-OECD								
Non-OECD Europe and Eurasia	**50.5**	**49.7**	**51.4**	**52.3**	**54**	**56**	**58.4**	**0.50%**
Russia	30.6	30.2	31.1	31.3	32.3	33.7	35.5	0.60%
Other	19.9	19.5	20.4	21	21.7	22.3	22.9	0.50%
Non-OECD Asia	**137.9**	**163.6**	**188.1**	**215**	**246.4**	**274.3**	**298.8**	**2.90%**
China	86.2	107	124.2	140.6	160.9	177.9	191.4	3.00%
India	21.1	24.4	27.8	33.1	38.9	44.3	49.2	3.20%
Other	30.7	32.2	36.2	41.3	46.7	52.1	58.2	2.40%
Middle East	**25.6**	**28.4**	**31**	**33.9**	**37.3**	**41.3**	**45.3**	**2.10%**
Africa	**18.8**	**20**	**21.5**	**23.6**	**25.9**	**28.5**	**31.4**	**1.90%**
Central and South America	**27.7**	**28.7**	**31**	**34.2**	**38**	**42.6**	**47.8**	**2.00%**
Brazil	12.7	13.8	15.5	17.3	19.9	23.2	26.9	2.80%
Other	15	14.9	15.6	16.9	18.1	19.5	20.8	1.20%
Total Non-OECD	**260.5**	**290.4**	**323.1**	**358.9**	**401.7**	**442.8**	**481.6**	**2.30%**
Total World	**504.7**	**531.2**	**573.5**	**619.5**	**671.5**	**721.5**	**769.8**	**1.60%**

Note ~3% Growth Rate

Overall 1.6% Growth Rate

U.S. Energy Consumption 2013 – 97.4 Quads



Numbers in red are input/output efficiencies

Source: DOE LLNL

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"Practical Strategies for Emerging Energy Technologies"

Where Does CO_2 Come From?

Worldwide CO_2 Emissions (million metric tonnes)

World carbon dioxide emissions by region, IEO2011 Reference case (Million metric tons carbon dioxide)									Growth Rate
Region/Country	2005	2008	2011	2015	2020	2025	2030	2035	(2008-2035)
OECD									
OECD Americas	**7079**	**6926**	**6665**	**6773**	**6924**	**7169**	**7431**	**7772**	**0.31%**
United States	5996	5838	5601	5680	5777	5938	6108	6311	0.17%
Canada	620	595	570	569	582	608	635	679	0.30%
Mexico/Chile	463	493	494	524	565	623	688	782	1.76%
OECD Europe	**4400**	**4345**	**4097**	**4115**	**4147**	**4156**	**4198**	**4257**	**-0.11%**
OECD Asia	**2172**	**2201**	**2112**	**2143**	**2181**	**2224**	**2253**	**2294**	**0.18%**
Japan	1241	1215	1114	1125	1142	1136	1110	1087	-0.44%
South Korea	494	522	539	553	562	597	634	678	1.06%
Australia/New Zealand	437	464	458	466	477	492	509	528	0.63%
Total OECD	**13651**	**13472**	**12873**	**13031**	**13252**	**13549**	**13882**	**14323**	**0.16%**
Non-OECD									
Non-OECD Europe and Eurasia	**2782**	**2832**	**2787**	**2803**	**2767**	**2782**	**2863**	**2964**	**0.21%**
Russia	1645	1663	1651	1648	1607	1603	1659	1747	0.20%
Other	1137	1169	1136	1154	1159	1179	1204	1217	0.23%
Non-OECD Asia	**8359**	**10100**	**11916**	**13238**	**14475**	**16475**	**18238**	**19688**	**2.90%**
China	5513	6801	8381	9386	10128	11492	12626	13441	3.02%
India	1182	1462	1633	1802	2056	2398	2728	3036	3.19%
Other	1665	1838	1901	2050	2291	2585	2884	3211	2.21%
Middle East	**1400**	**1581**	**1743**	**1889**	**2019**	**2199**	**2435**	**2659**	**2.16%**
Africa	**978**	**1078**	**1137**	**1209**	**1311**	**1430**	**1568**	**1735**	**1.93%**
Central and South America	**1011**	**1128**	**1184**	**1287**	**1386**	**1497**	**1654**	**1852**	**2.04%**
Brazil	365	423	468	528	579	644	739	874	2.95%
Other	646	705	716	759	807	853	916	978	1.39%
Total Non-OECD	**14530**	**16718**	**18766**	**20426**	**21958**	**24383**	**26758**	**28897**	**2.32%**
Total World	**28181**	**30190**	**31640**	**33457**	**35210**	**37932**	**40640**	**43220**	**1.44%**

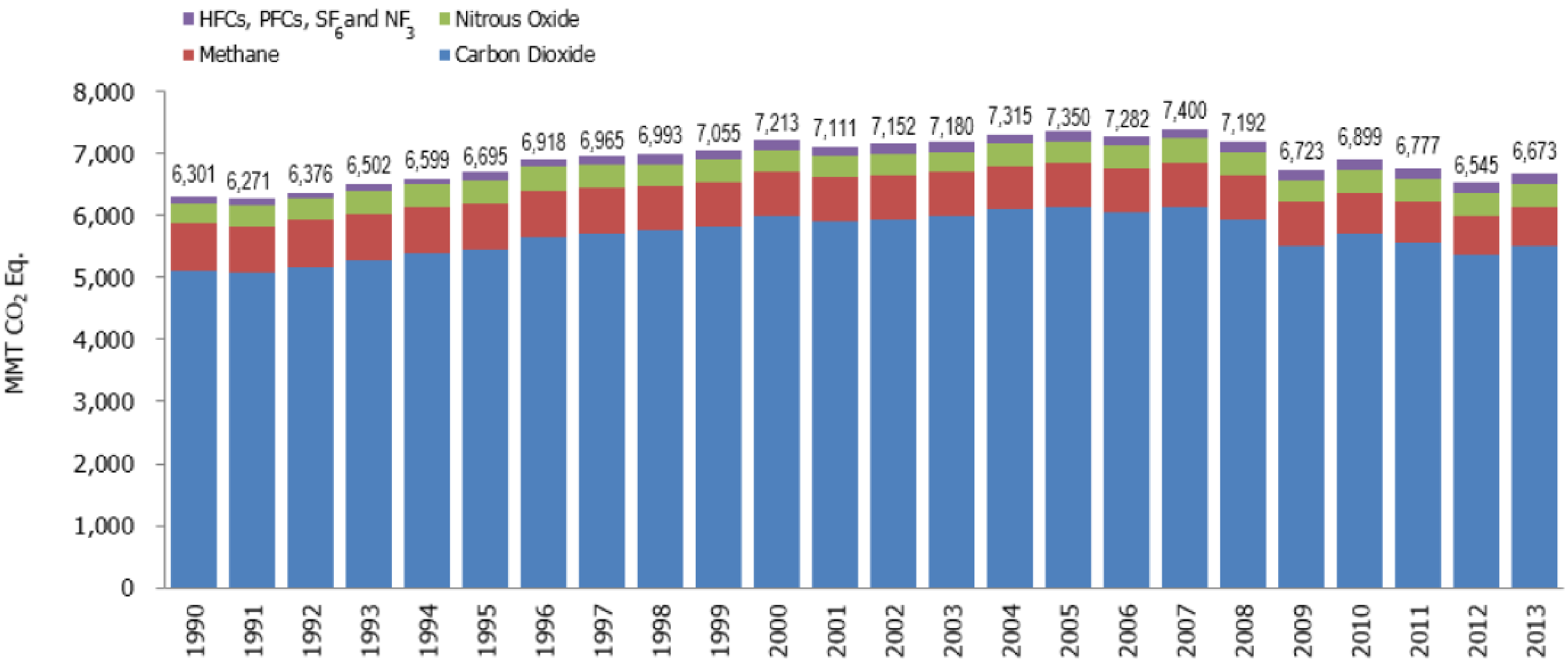
33.5 Gt

2015	
China	28.1%
U.S	17.0%
India	5.4%
Total	50.5%

CO_2 Equivalent Emissions – by Gas 1990-2013

Figure ES-1: U.S. Greenhouse Gas Emissions by Gas

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



EPA U.S GHG Emissions

U.S. GHG Gas Emissions & Sinks – CO_2

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**5,123.7**	**6,134.0**	**5,500.6**	**5,704.5**	**5,568.9**	**5,358.3**	**5,505.2**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Electricity Generation	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Transportation	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Industrial	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Residential	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Commercial	217.4	223.5	223.5	220.2	221.0	197.1	220.7
U.S. Territories	27.9	49.9	43.5	46.2	39.8	38.6	32.0
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Iron and Steel Production & Metallurgical Coke Production	99.8	66.7	43.0	55.7	60.0	54.3	52.3
Natural Gas Systems	37.6	30.0	32.2	32.3	35.6	34.8	37.8
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.6	28.1	23.7	27.4	26.4	26.5	26.5
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Petroleum Systems	4.4	4.9	4.7	4.2	4.5	5.1	6.0
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7

EPA GHG Inventory 1990-2013 Table ES-2 (page 1)

U.S. GHG Gas Emissions & Sinks – CO_2

Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Aluminum Production	6.8	4.1	3.0	2.7	3.3	3.4	3.3
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.1	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(775.8)*	*(911.9)*	*(870.9)*	*(871.6)*	*(881.0)*	*(880.4)*	*(881.7)*
Wood Biomass and Ethanol Consumption[b]	*219.4*	*229.8*	*250.5*	*265.1*	*268.1*	*267.7*	*283.3*
International Bunker Fuels[c]	*103.5*	*113.1*	*106.4*	*117.0*	*111.7*	*105.8*	*99.8*

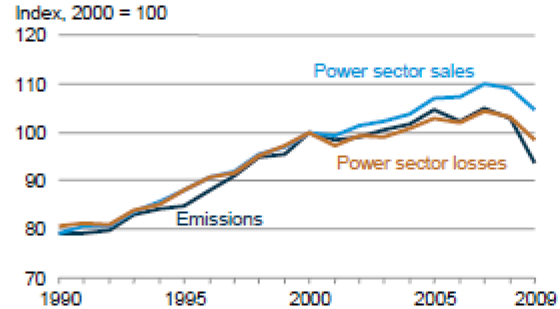
EPA GHG Inventory 1990-2013 Table ES-2 (page 2)

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



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.

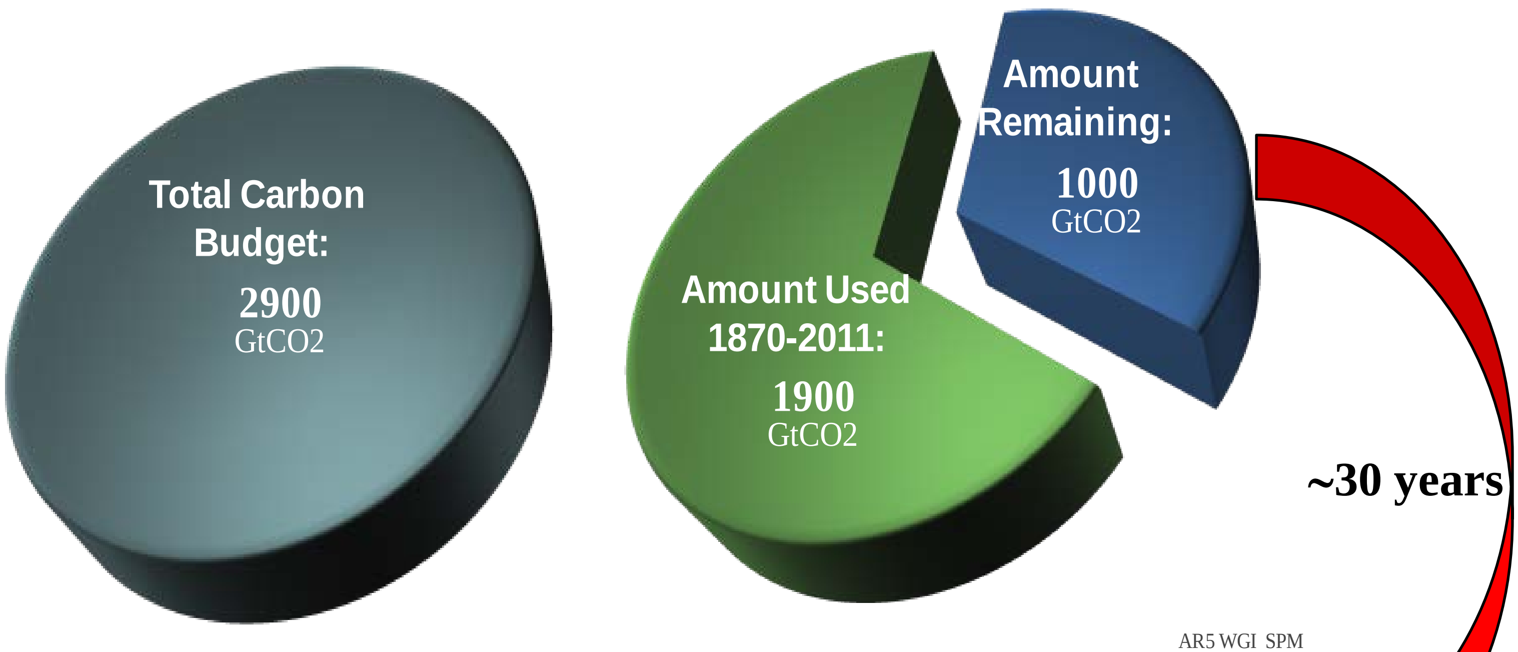
2,302.9 total in 2005

2005 @ 2416 Mt is benchmark for CPP (until EPA changes it again)

What's Our Target?

The CO_2 Budget

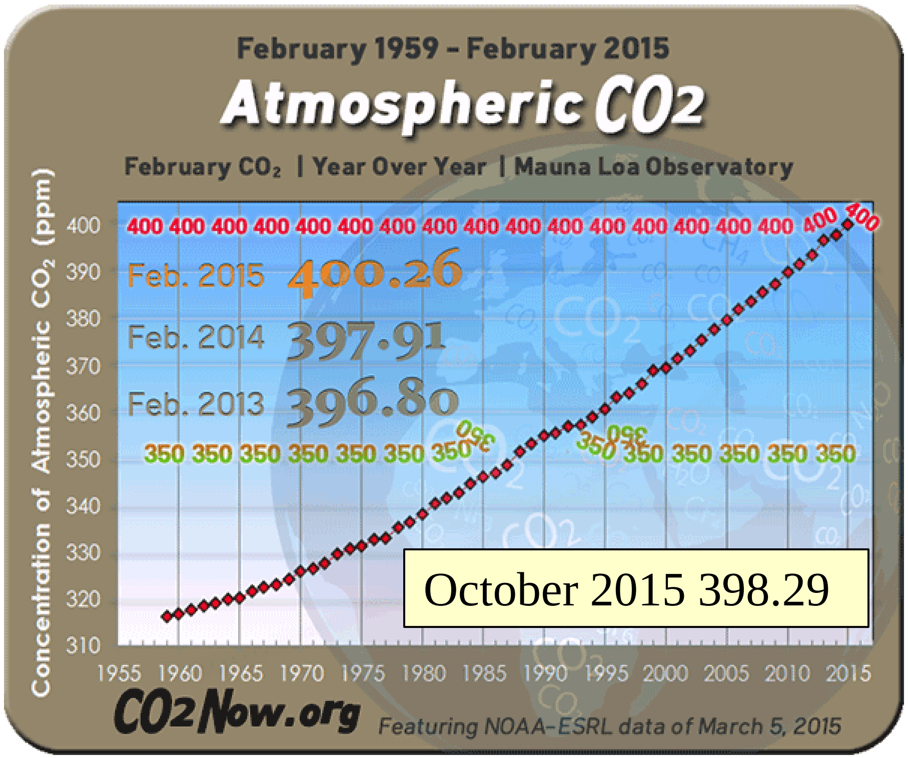
65% of our carbon budget compatible with a 2°C goal already used



Intergovernmental Panel on Climate Change - IPCC AR5

2014 CO2 Emissions ~34Gt Worldwide

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

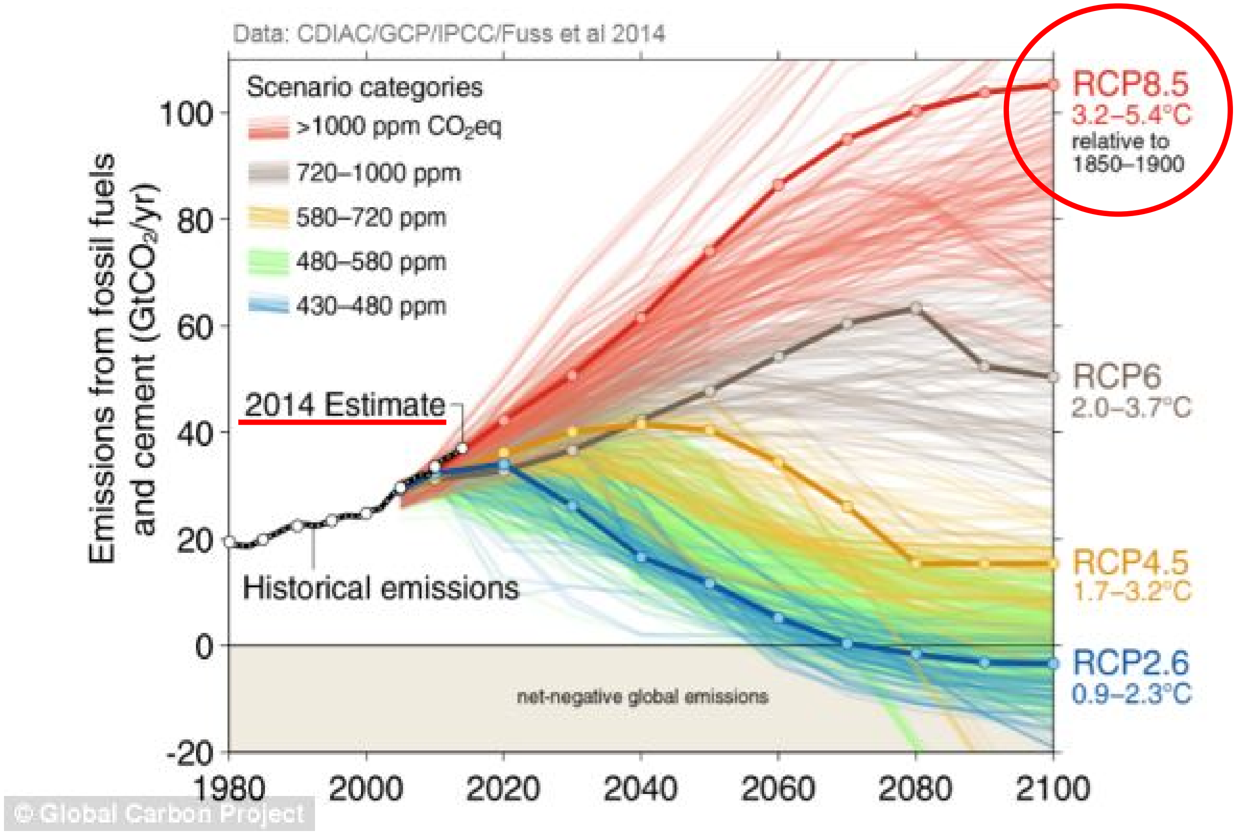
0.0300% = 300 ppm(v)

Value March 5, 2015 at Mauna Loa was 400.26 ppm(v)

"Busted"

– The world pumped 36.1 Gt of carbon dioxide into the air last year by burning coal, oil and gas.
– That is 0.706 Gt or 2.3 per cent more than the previous year, despite increasingly urgent warnings over the need to curb greenhouse gases

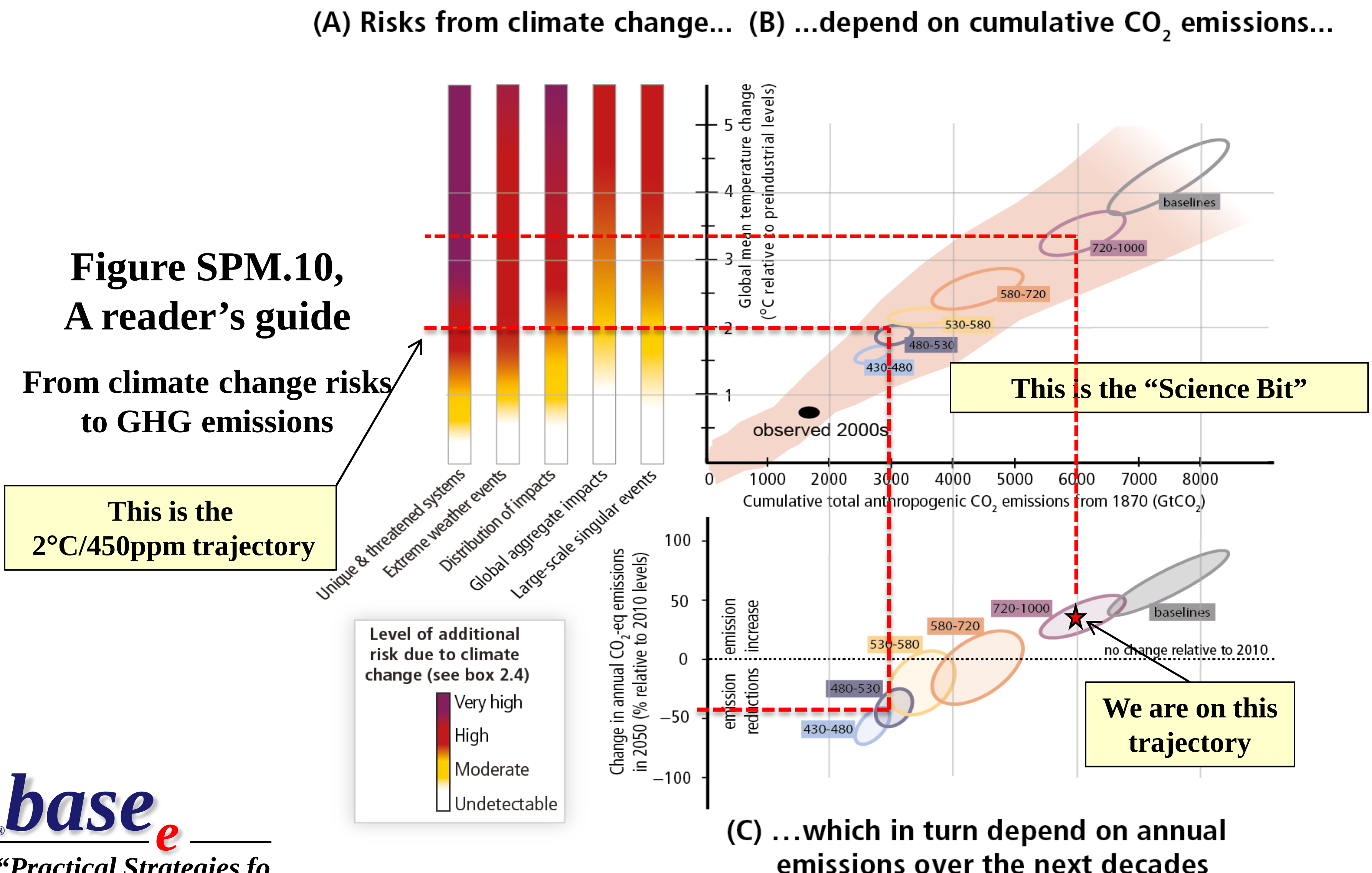
The world appears to be on the >1000 ppm path



This is the “Science Bit”

Figure SPM.10, A reader’s guide

From climate change risks to GHG emissions



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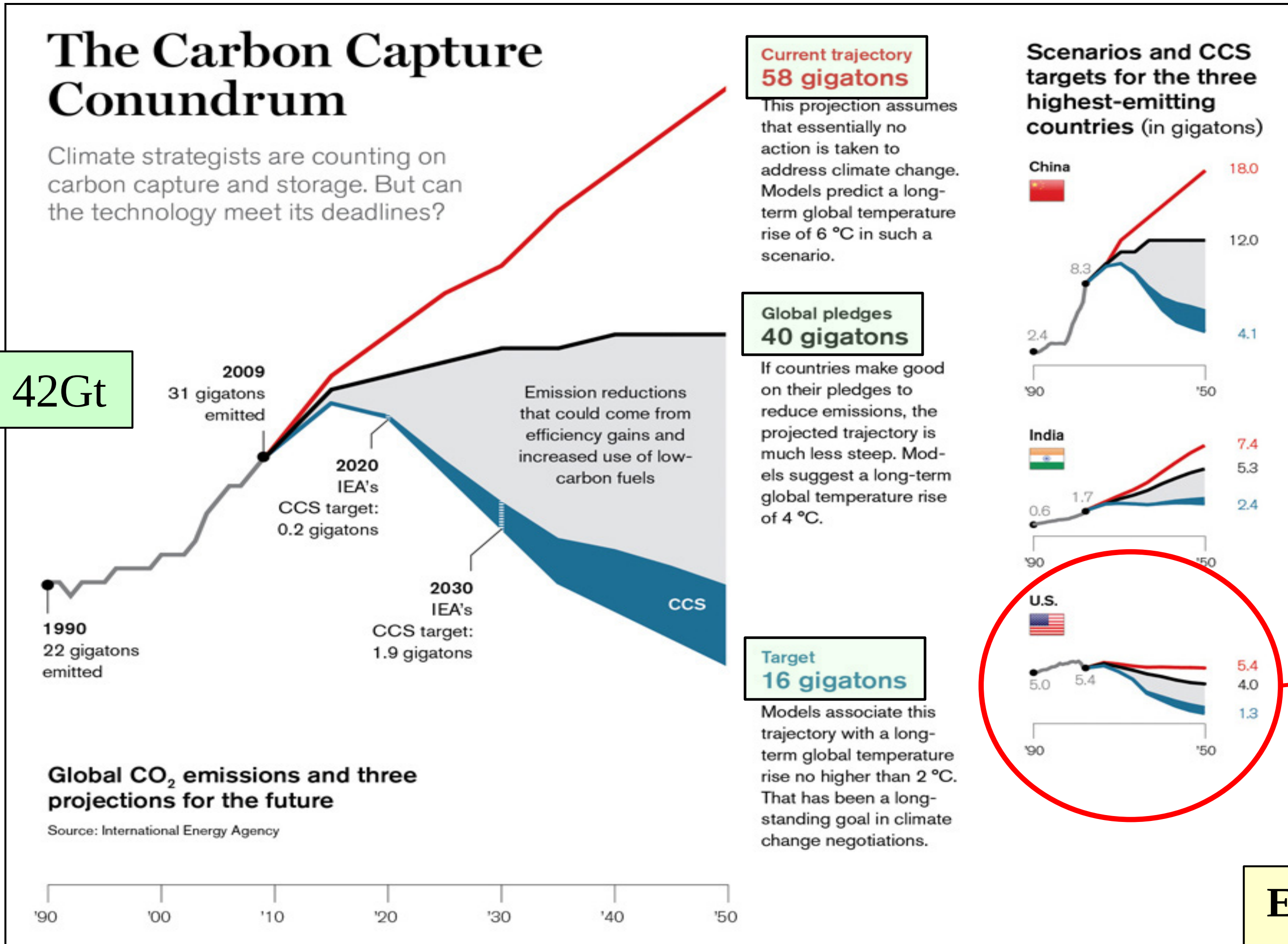
“Practical Strategies fo

The Carbon Conundrum

58-16 = 42Gt



MIT Technology Review – Mike Orcott

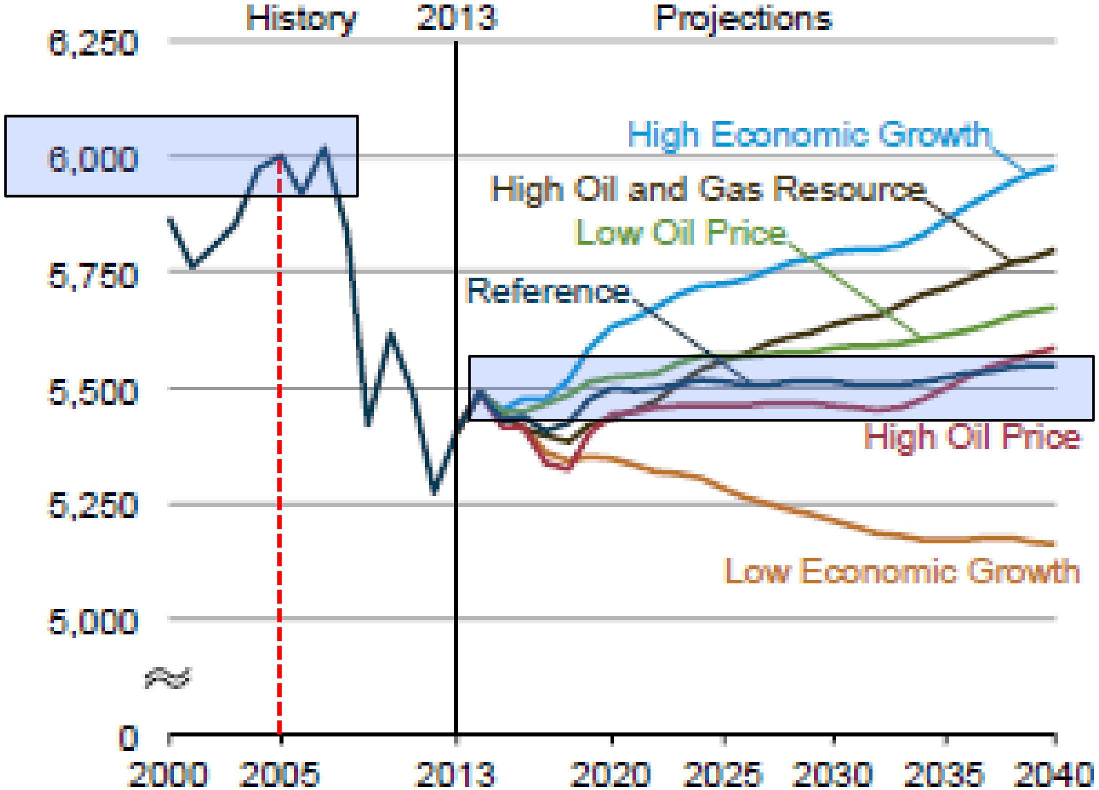
@38.5% for PowerGen:
5.4 = 2,079Mt
4.0 = 1,540Mt
1.3 = 500Mt

EPA CPP goal 2030
1,643Mt (~4°C)

EIA Energy Related CO_2 Forecast

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

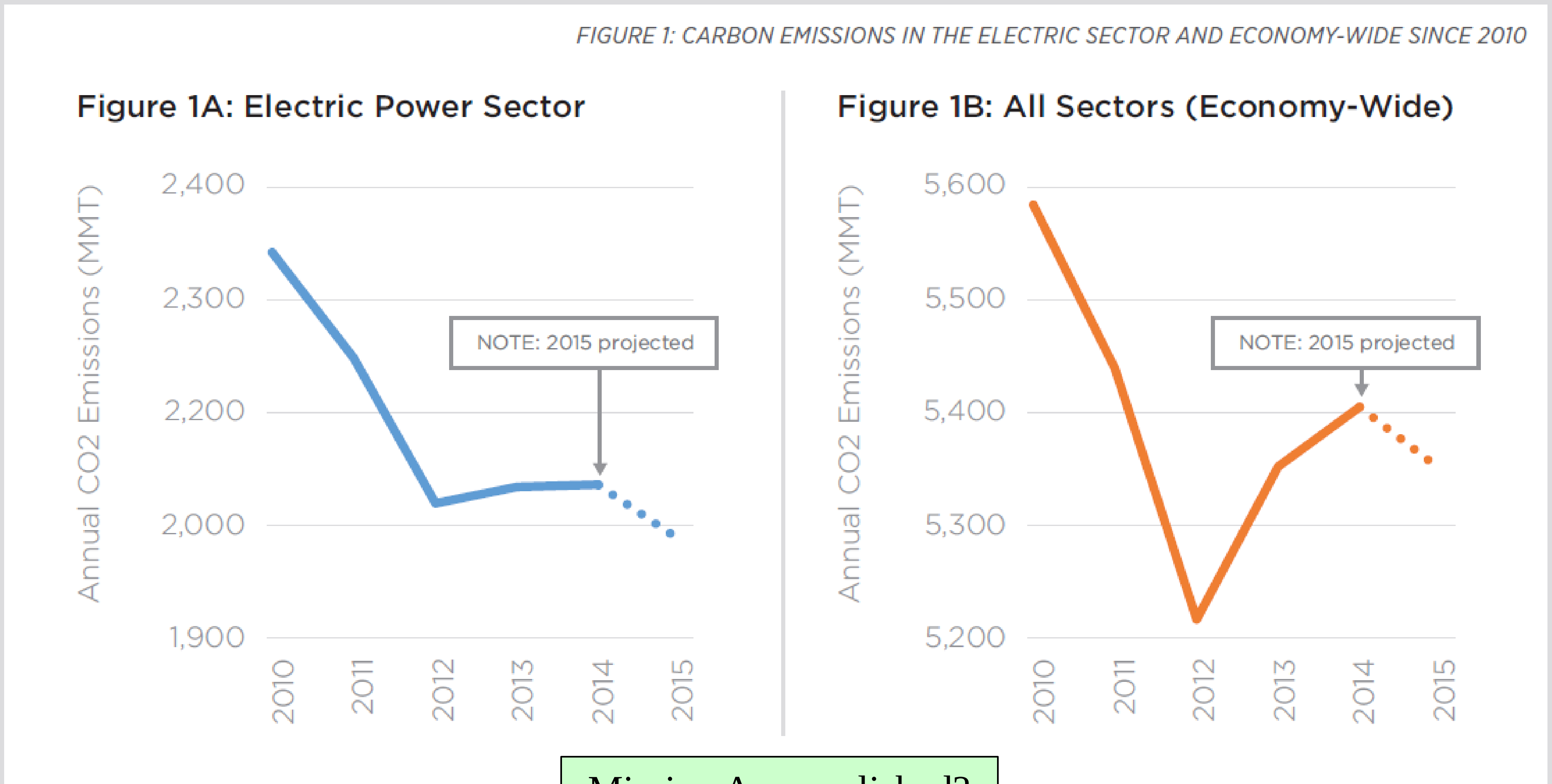
"High Water Mark" as basis for goal



Reference Case is: "Business as Usual"

There is no case presented that combines High O&G Resource with High Economic Growth

Sierra Club Fact Sheet – November 3, 2015



Mission Accomplished?

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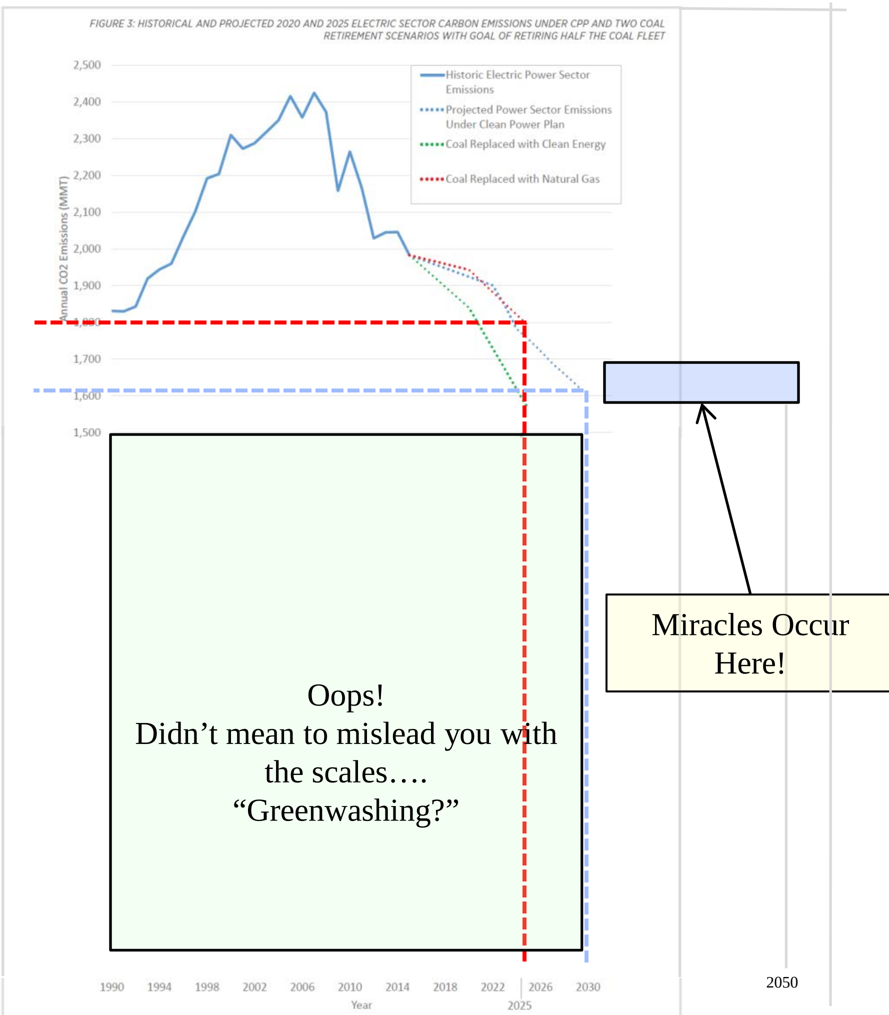
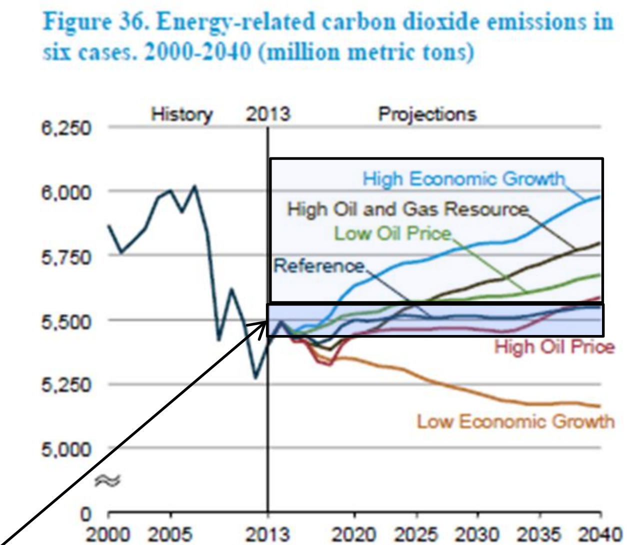
Sierra Club Fact Sheet – November 3, 2015 (Re-scaled)





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"

Coal-to-Gas Shift – nature.com

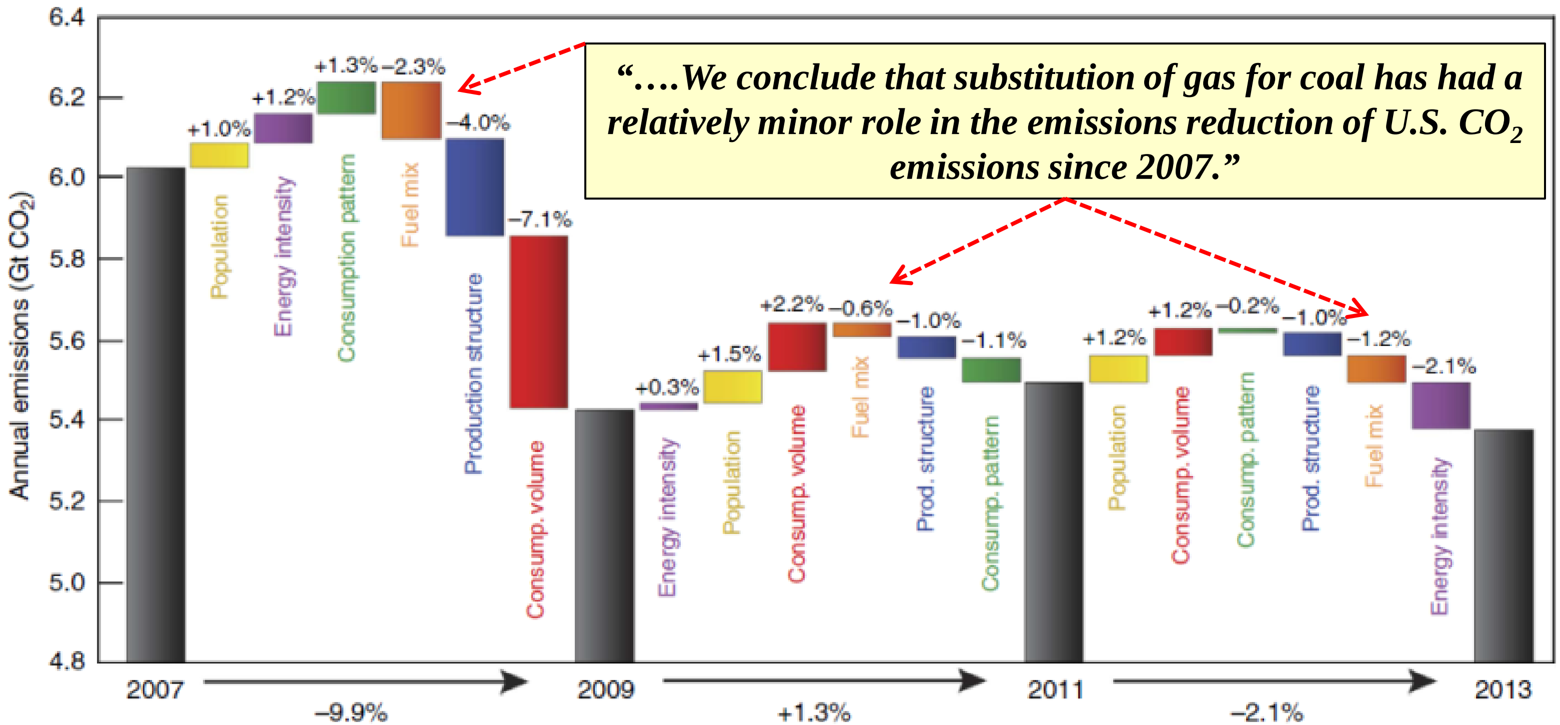


Figure 3 | Contributions of different factors to the decline in US CO_2 emissions 2007-2009 and 2009-2011 and 2011-2013. Between 2007 and 2009, decreases in the volume of goods and services consumed during the economic recession (red) was the primary contributor to the nearly 10% drop in emissions. But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

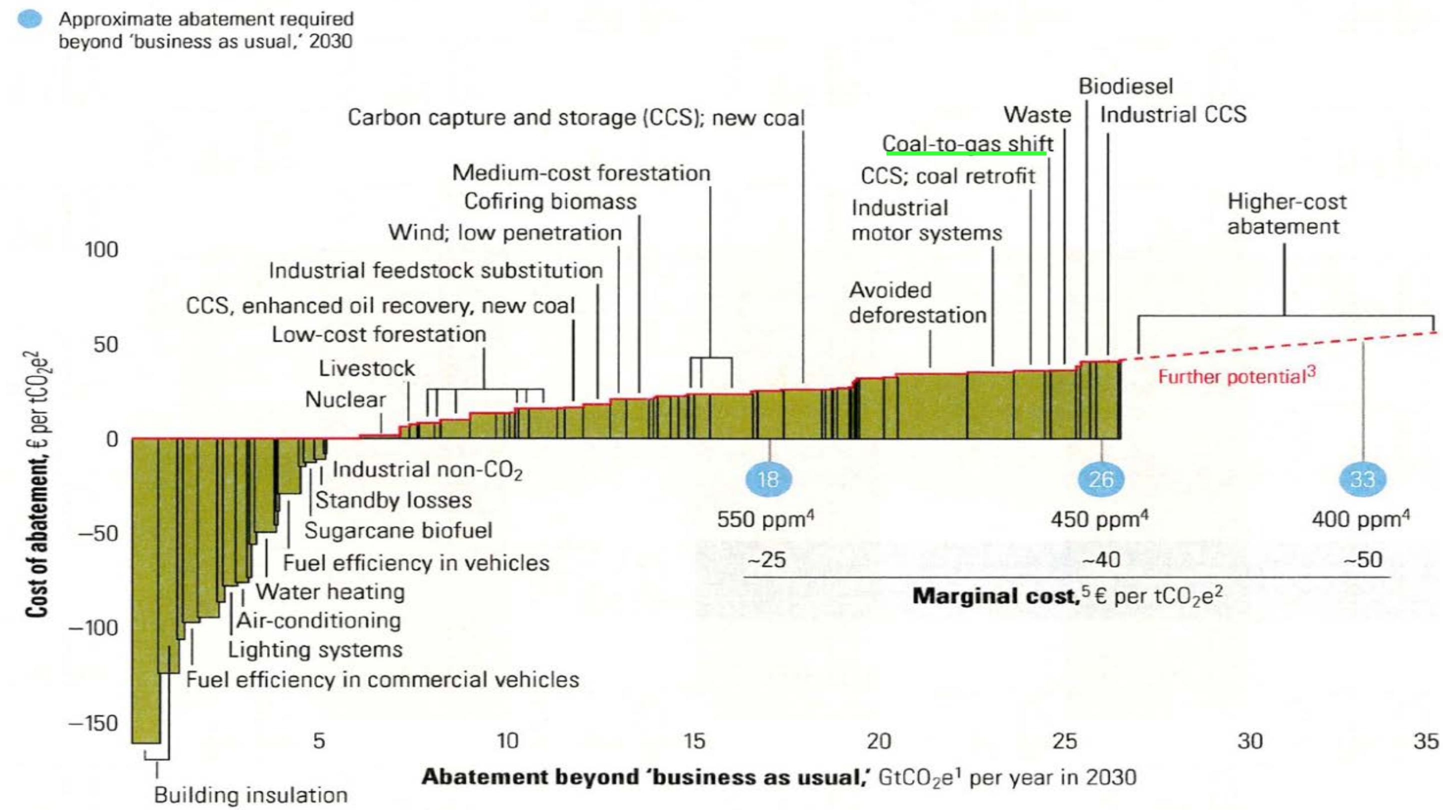
"The new EPA Clean Power Plan is largely built on fuel switching and renewables deployment"

What Can We Do?

- **Stop producing or produce less CO_2**
  - – "Switch to Renewables"
  - – Fuel Switching
- **Use the CO_2**
  - – As a Fuel
  - – Chemical Feedstock
  - – Biomass Nutrient
  - – Carbon(ate) - Based Product
  - – Enhanced Oil Recovery (EOR)
- **Put the CO_2 back**
  - – Carbon Capture & Storage
- **Adapt to its effects**
  - – Build seawalls
  - – Harden vulnerable assets

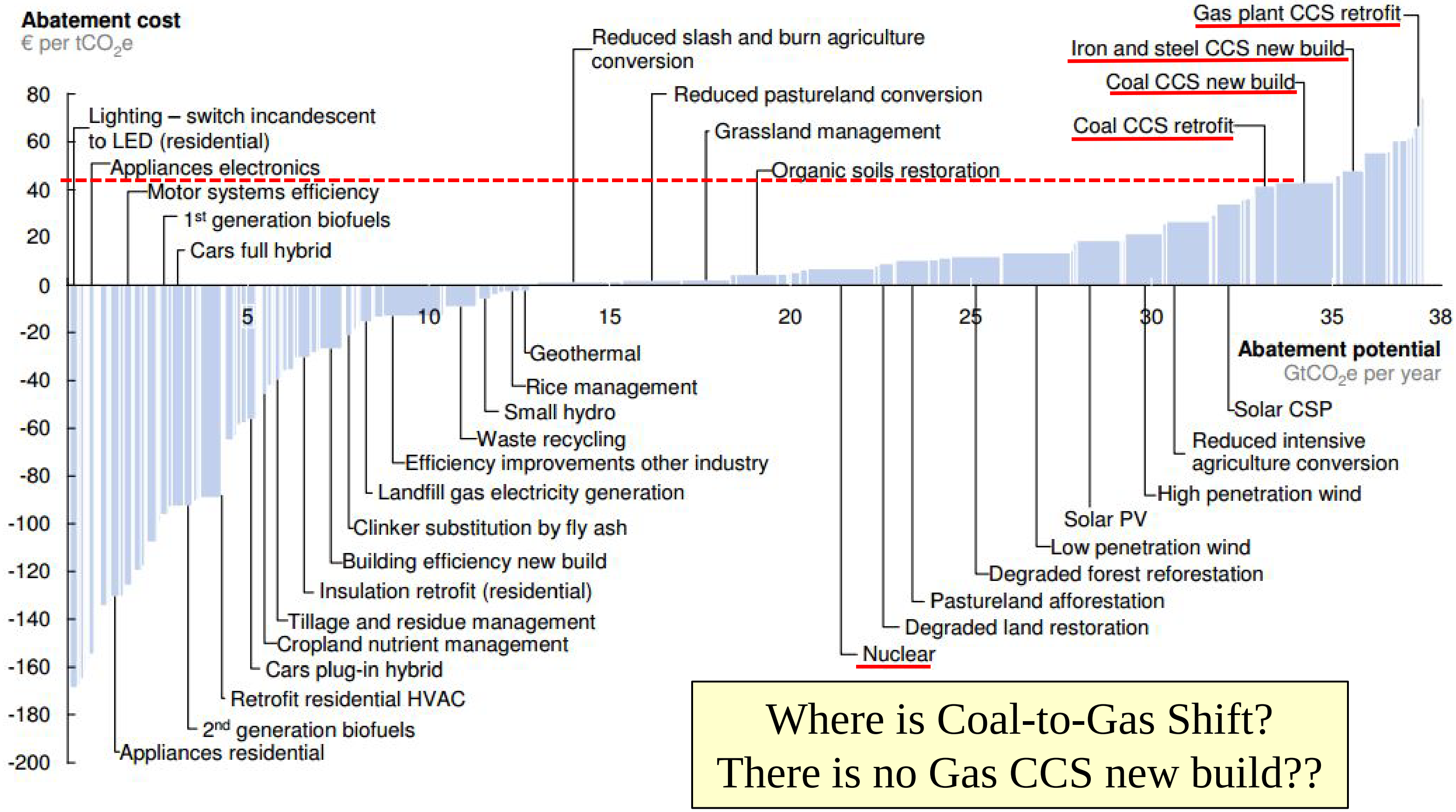
McKinsey CO_2 Cost Curve V1.0

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.

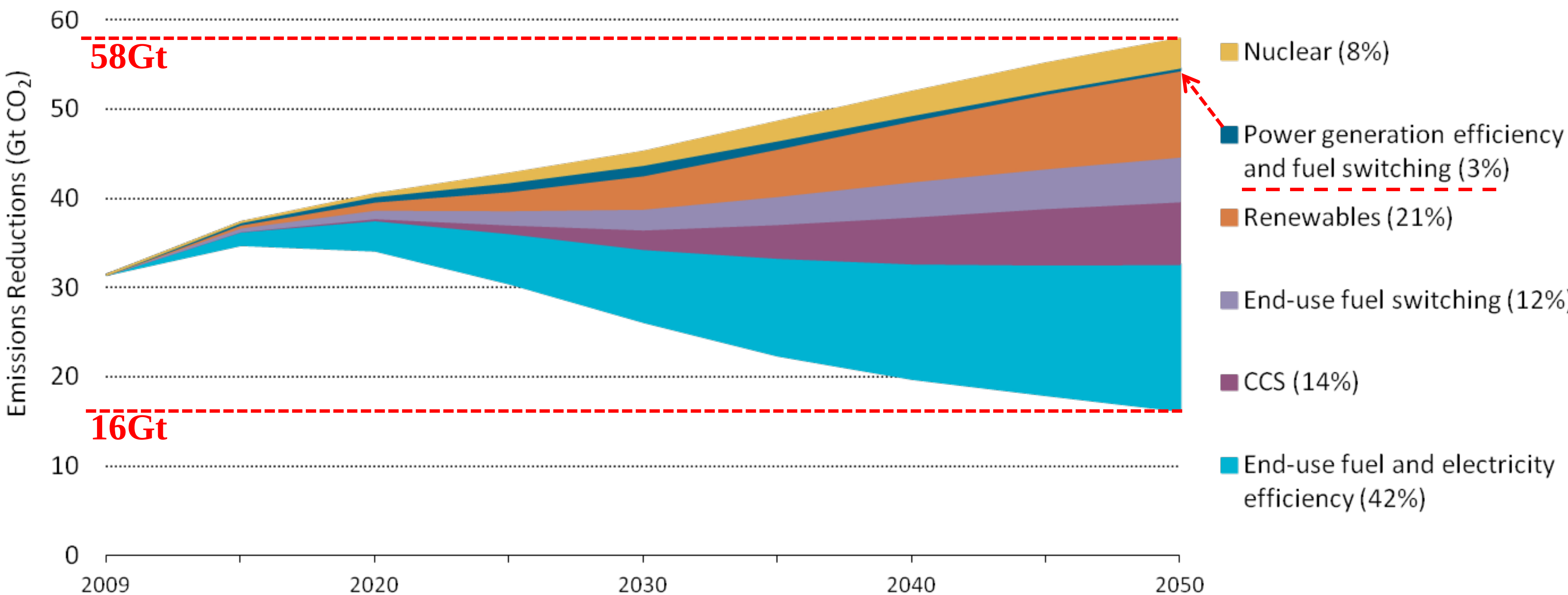
McKinsey Global GHG Cost Curve V2.1



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

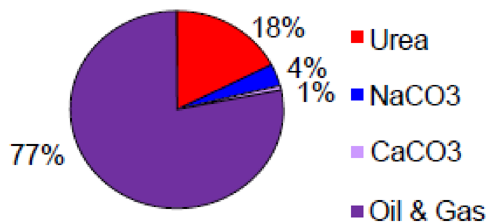
Juho Lipponen
Head of Unit, Carbon Capture and Storage
International Energy Agency

OK….Let’s Use the Stuff!

Annual U.S. CO_2 Utilization vs. Emissions

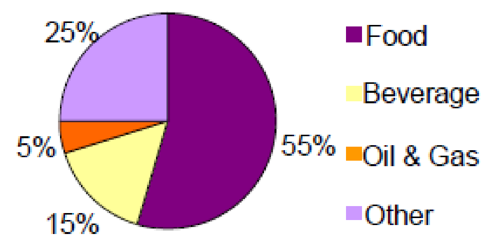
Gaseous Consumption

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

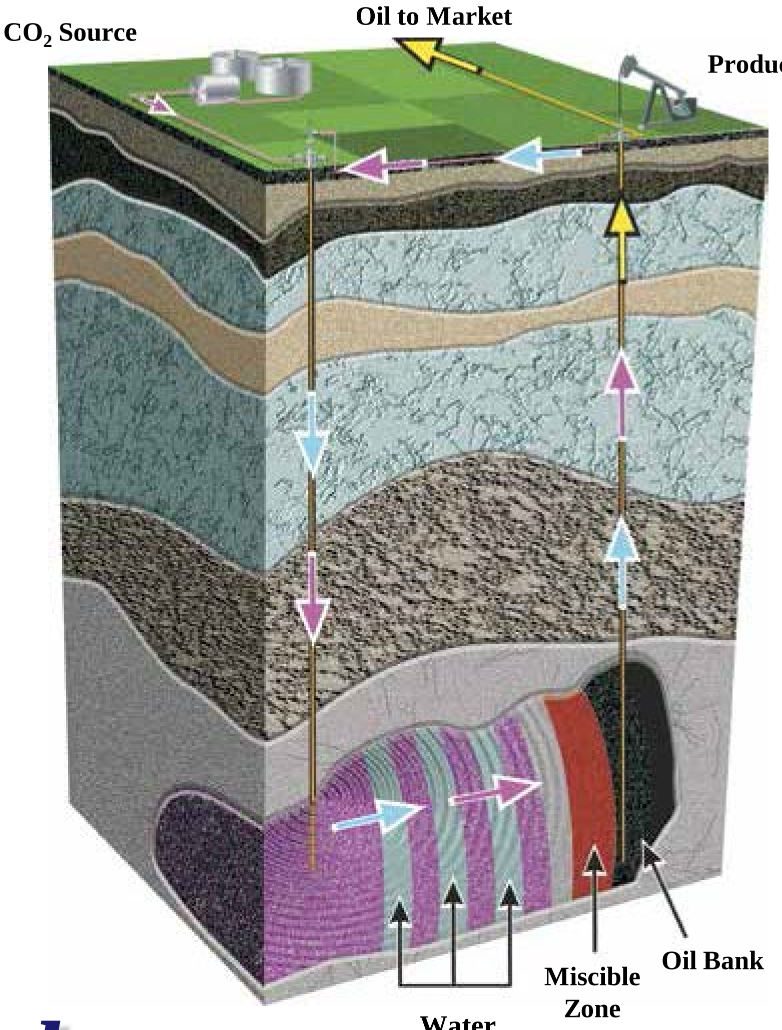
DOE estimates ~25% of coal power CO_2 emissions could be used for EOR, if ~\$30/t

5

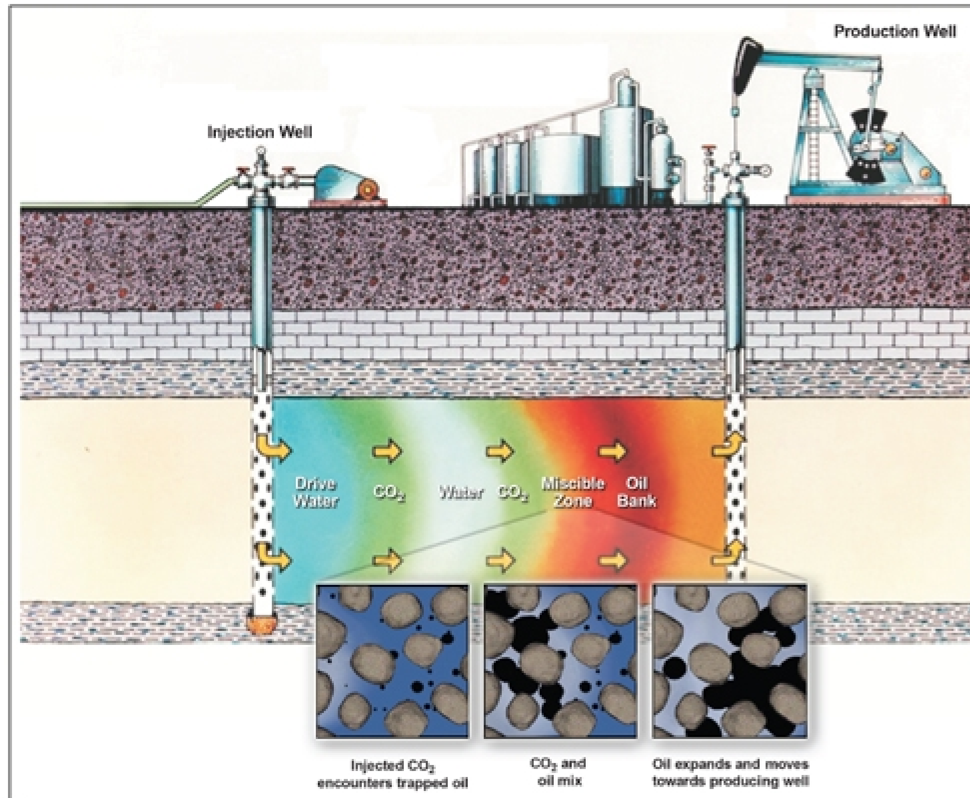
EPRI ELECTRIC POWER RESEARCH INSTITUTE

We do not grasp the scale of the problem

Enhanced Oil Recovery



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



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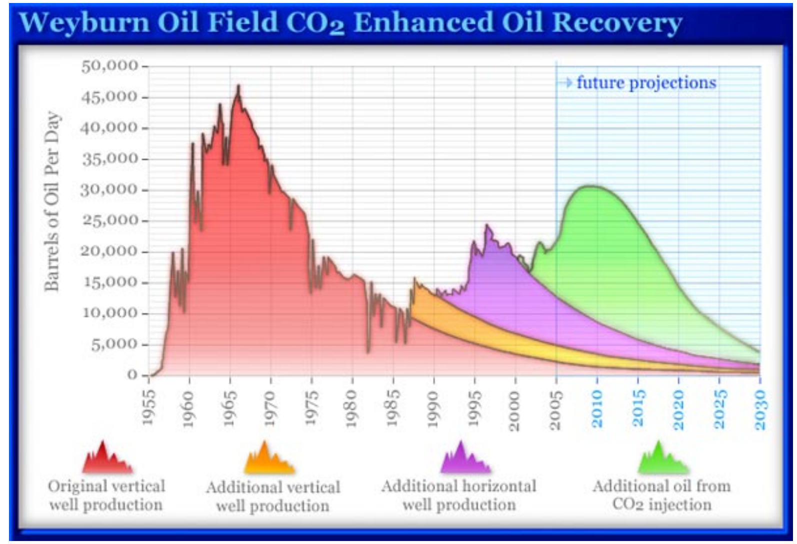
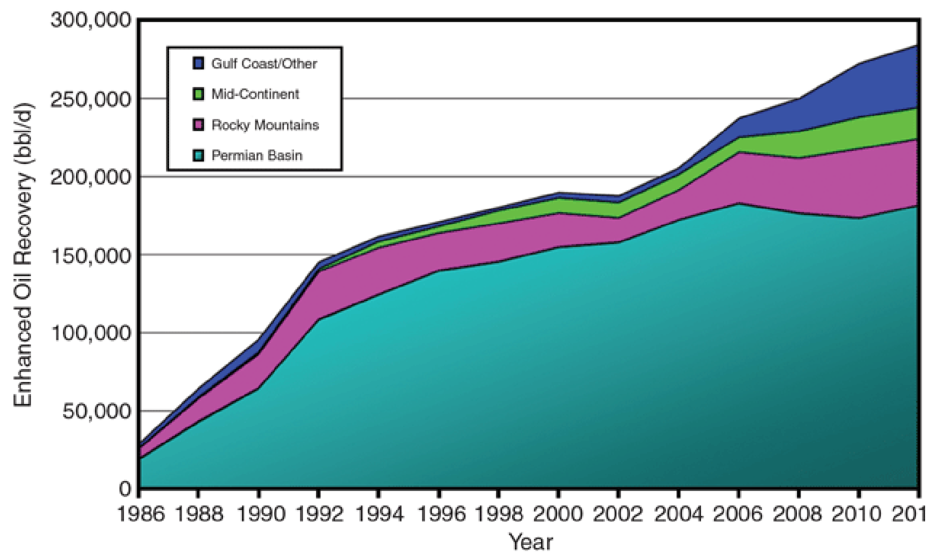
Enhanced Oil Recovery

- **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





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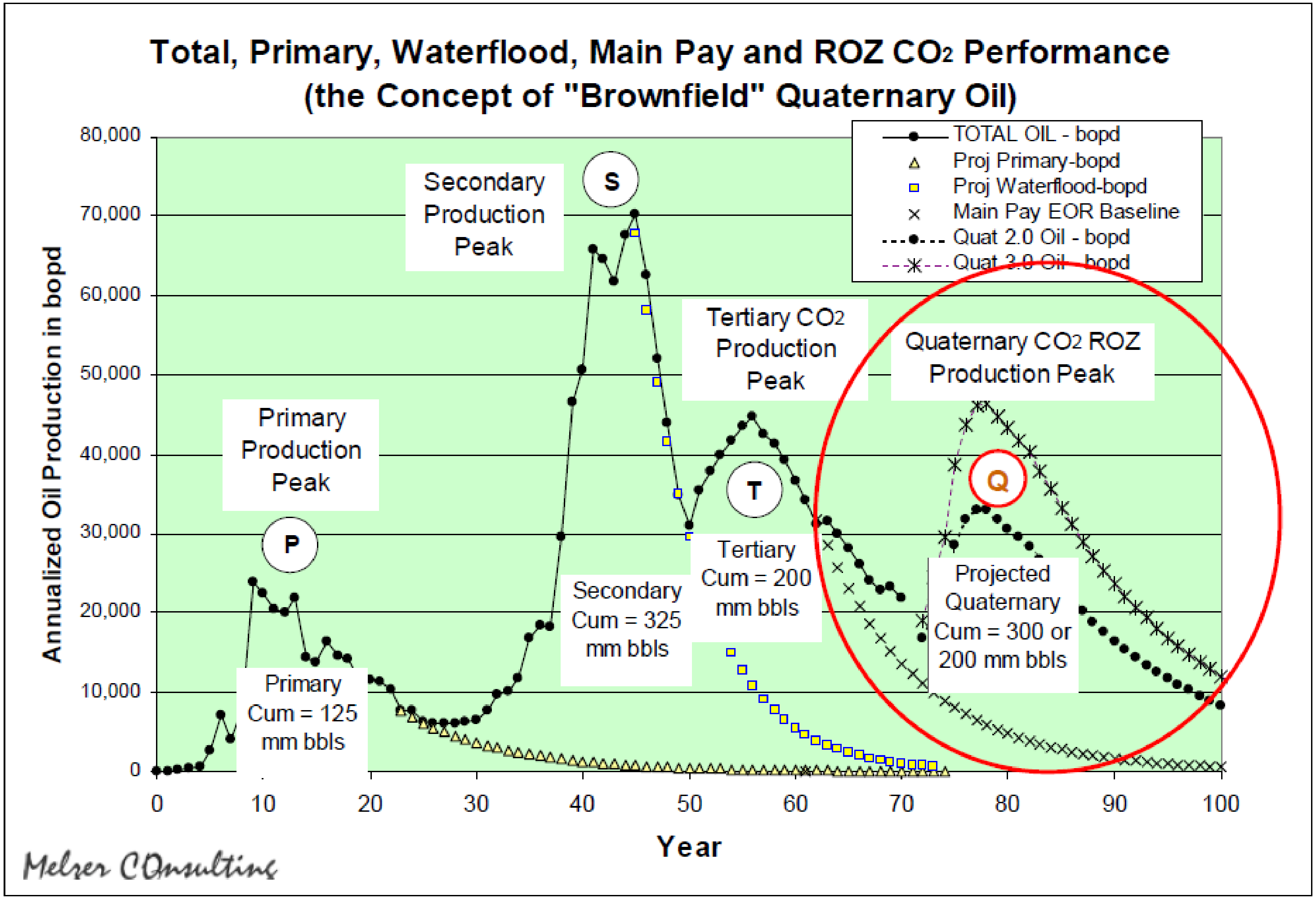
Residual Oil Zones - ROZ

'Quaternary' Oil at the Seminole Field (Given Access to Needed CO_2 Supplies)



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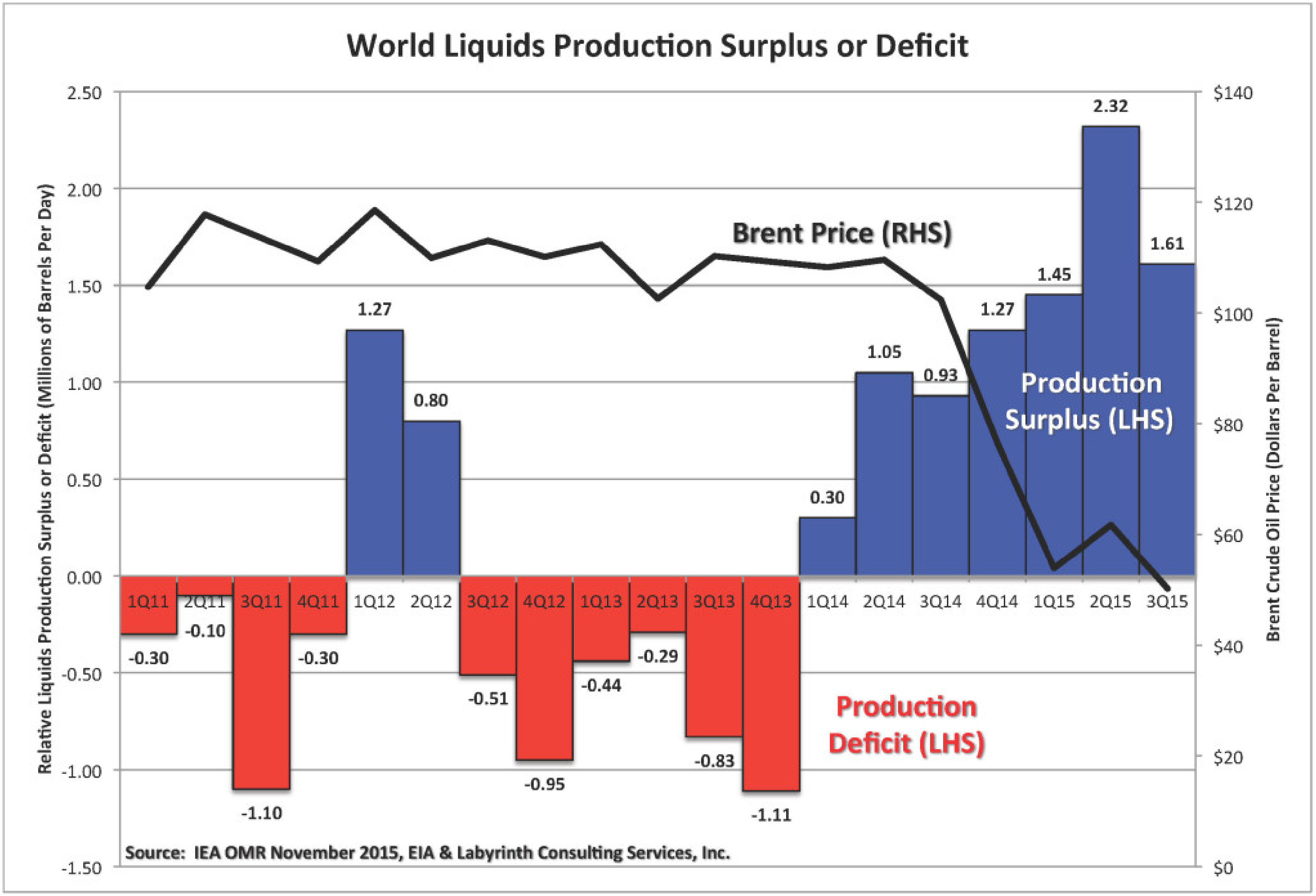
Oil Price



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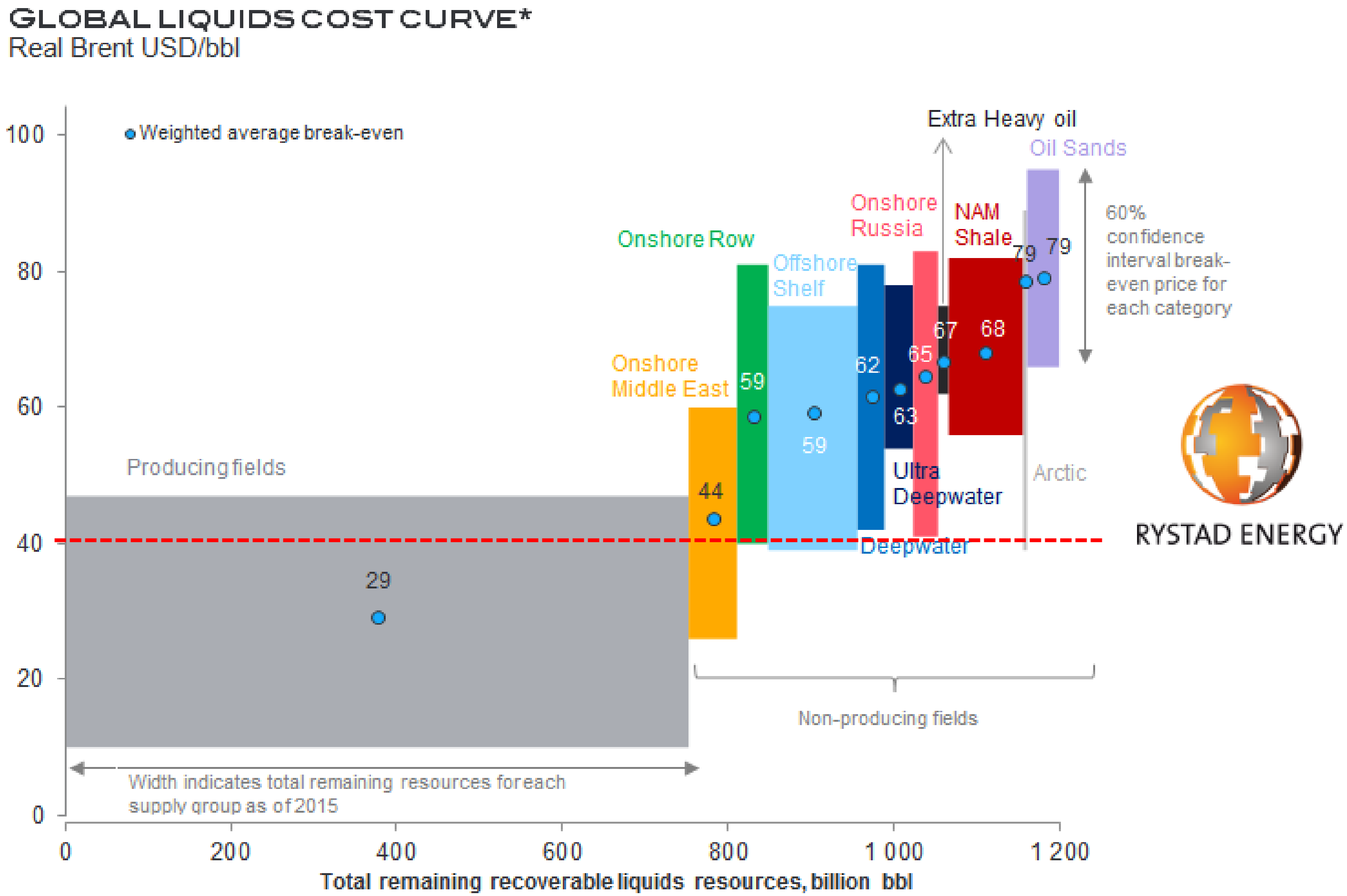
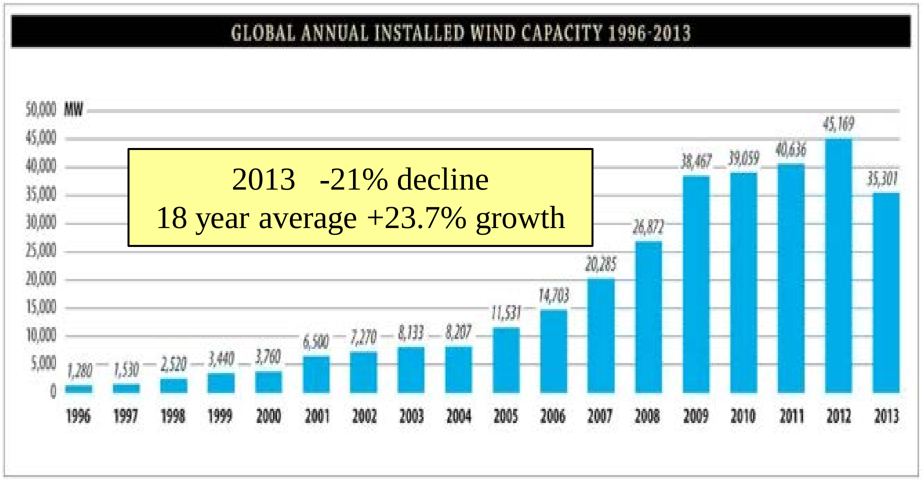
Global Liquids Cost Curve



*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

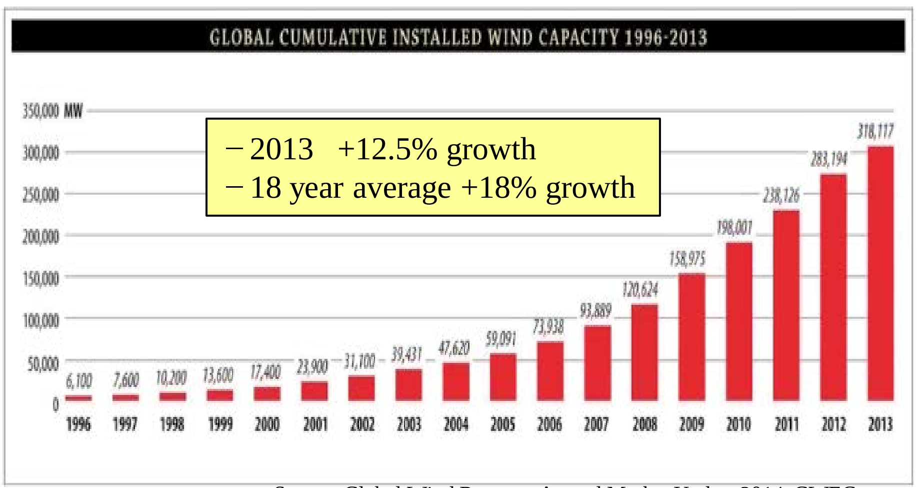
Renewables

Wind Installed Capacity & Load Factors (2012)



Average Load Factor is 21.5%

- High 28.3% - Denmark
  26.8% - USA
  17.9% - China
- Low 16.8% - Germany



Source: Global Wind Report – Annual Market Update 2014, GWEC

Top windpower electricity producing countries in 2012 (TWh)

Country	Windpower Production	% of World Total	Nameplate GW	Nameplate TWh	Load Factor
United States	140.9	26.40%	60.0	526	26.8%
China	118.1	22.10%	75.3	660	17.9%
Spain	49.1	9.20%	22.8	200	24.6%
Germany	46.0	8.60%	31.3	274	16.8%
India	30.0	5.60%	18.4	161	18.6%
United Kingdom	19.6	3.70%	8.4	74	26.6%
France	14.9	2.80%	7.6	67	22.4%
Italy	13.4	2.00%	8.1	71	18.9%
Canada	11.8	2.20%	6.2	54	21.7%
Denmark	10.3	1.90%	4.2	36	28.3%
Rest of World	80.2	15.00%	40.9	358	22.4%
World Total	534.3	100.00%	283.1	2480	21.5%

Production Tax Credit - PTC

- In December 2014, The Tax Increase Prevention Act of 2014 extended the expiration date for this tax credit to December 31, 2014.
- Projects that are not under construction prior to January 1, 2015, are ineligible for this credit.
- In March 2015, IRS Notice 2015-25 extended the Continuous Construction Test and Continuous Efforts Test (used to determine if a project commencing construction before the end of 2014 is eligible for the PTC) by 1 year to January 1, 2017.
- **Generally applies to first 10 years of operation**

Resource Type	Credit Amount
Wind	$0.023/kWh
Closed-Loop Biomass	$0.023/kWh
Geothermal Energy	$0.023/kWh
Open-Loop Biomass	$0.011/kWh
Landfill Gas	$0.011/kWh
Municipal Solid Waste	$0.011/kWh
Qualified Hydroelectric	$0.011/kWh
Marine and Hydrokinetic	$0.011/kWh

Economic Merit Order Dispatch

Total capacity by technology | Total capacity by owner | Plant age distribution | Under construction | **Merit order**

Include plant:
☑ Operational

Fuel	Price	Units	Rating	
Gasoil	406.7	$/tonne	100	%
LSFO	258.7	$/tonne	100	%
Gas	19.15	€/MWh	100	%
Lignite	10.28	€/tonne	100	%
Coal	58.10	$/tonne	100	%
BF/Ref Gas	4.73	€/GJ	50	%
Waste Biomass	2.40	€/GJ	50	%
Biomass	2.80	€/GJ	100	%
Hydro	0.00	€/MWh(e)	40	%
Uranium	5.00	€/MWh(e)	100	%
Wind	0.00	€/MWh(e)	25	%
Solar	0.00	€/MWh(e)	10	%
CO2 price	7.16	Euro/t		
Dollars per Euro	1.16	$/Euro		

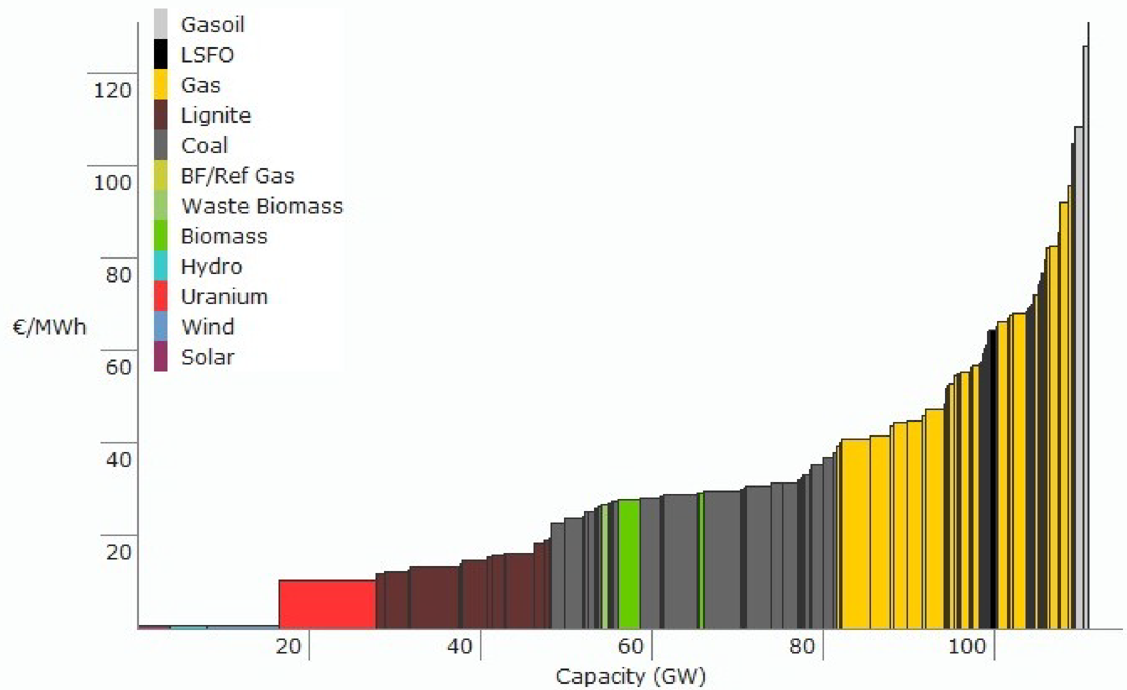
Group similar fuels ☐

Create chart by fuel

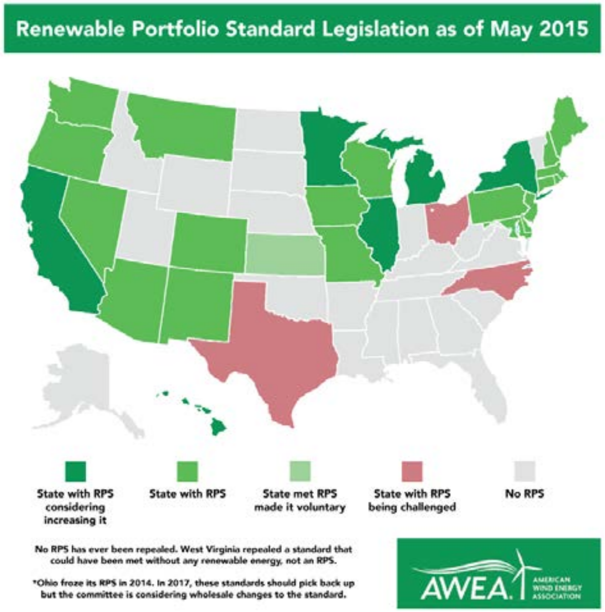
Max companies plotted

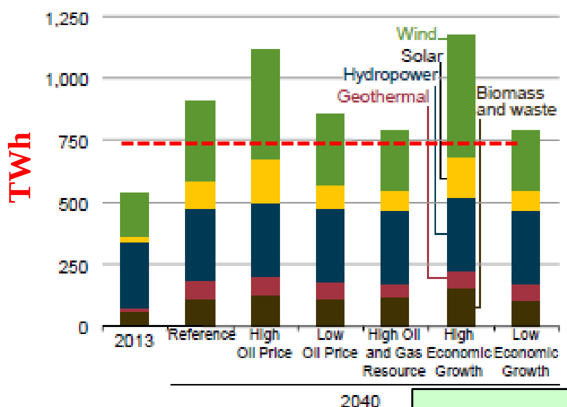
Create chart by company

Total charted capacity: 182 GW | To download: 21-01-2015 Daily



Renewable Portfolio Standards





U.S. Electrical Production
4,048 TWh

AEO 2015 Total U.S. renewable generation by fuel in 2013 & six 2040 cases (TWh)

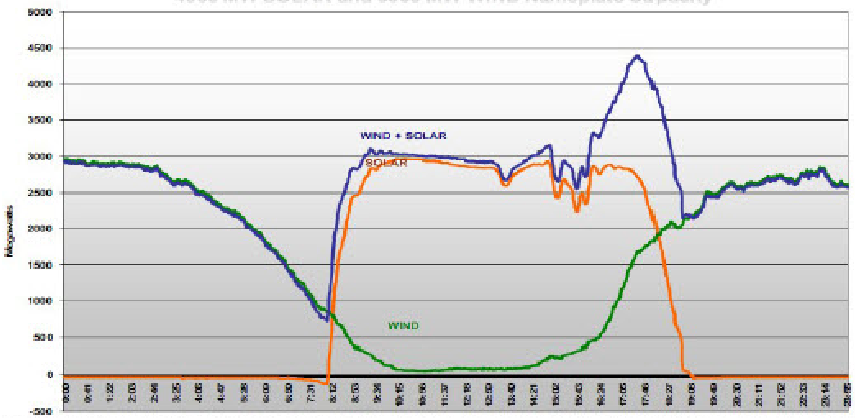
- **Seven states – Hawaii, California, Nevada, Colorado, Minnesota, Connecticut, and Oregon** – have effective RPS requirements of 25 percent or greater.
- **Six states – CA, MI, NY, MN, IL and VT** – are seriously debating an increase in their RPS this year.
- **Ohio** – With the signing of Senate Bill 310 in 2014, Ohio became the only state to "freeze" its RPS, effectively halting the state's mandates for efficiency and renewables until 2017. In 2017, these standards should pick up where they left off when the freeze occurred, however an Energy Mandates Study Committee is reviewing wholesale changes to the standard. In this context of policy uncertainty, renewable energy employment and investment is moving away, to more welcoming states.
- Legislators in **four states (CO, MT, CT, and NH)** have voted down proposals to diminish or repeal RPS policies this year.

Source: American Wind Energy Association (AWEA)

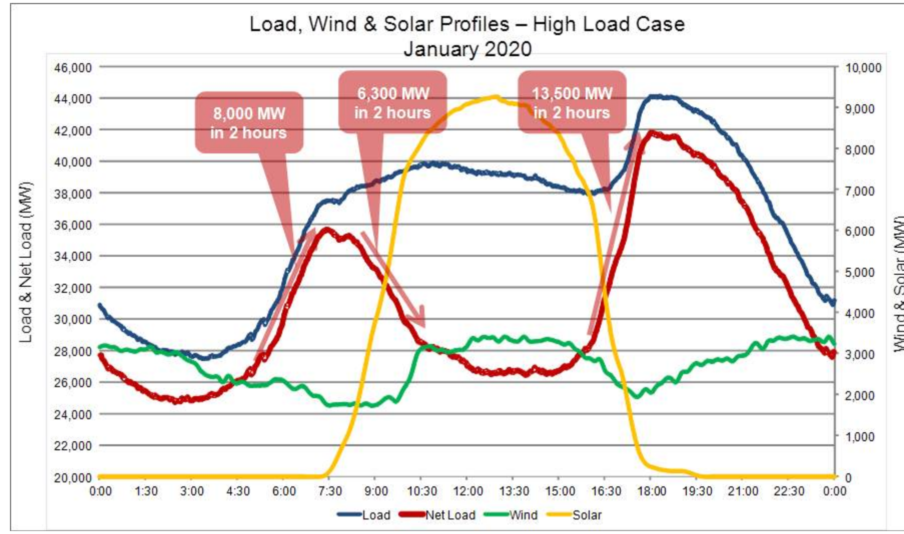
Integrating Renewables “Dealing with The Duck”

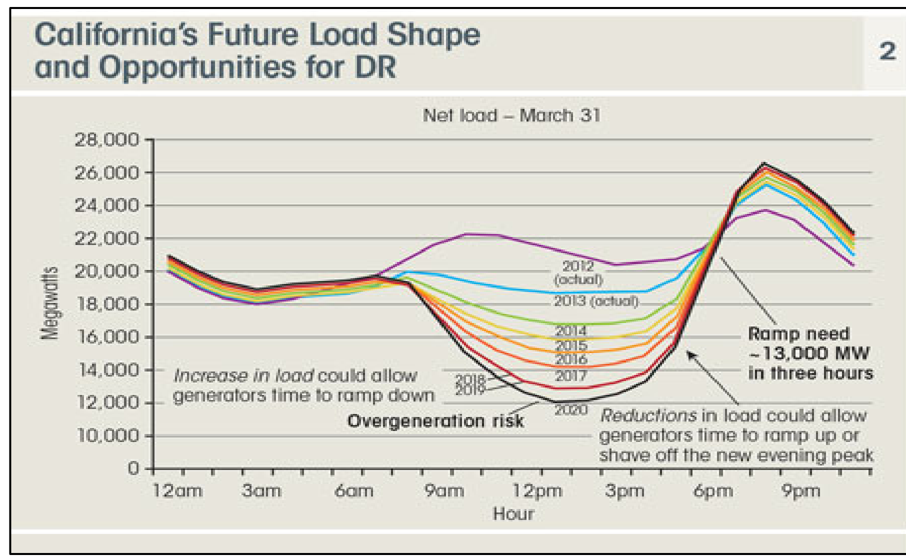
All about correlation

Example of typical wind and solar generation in California with 20% RPS

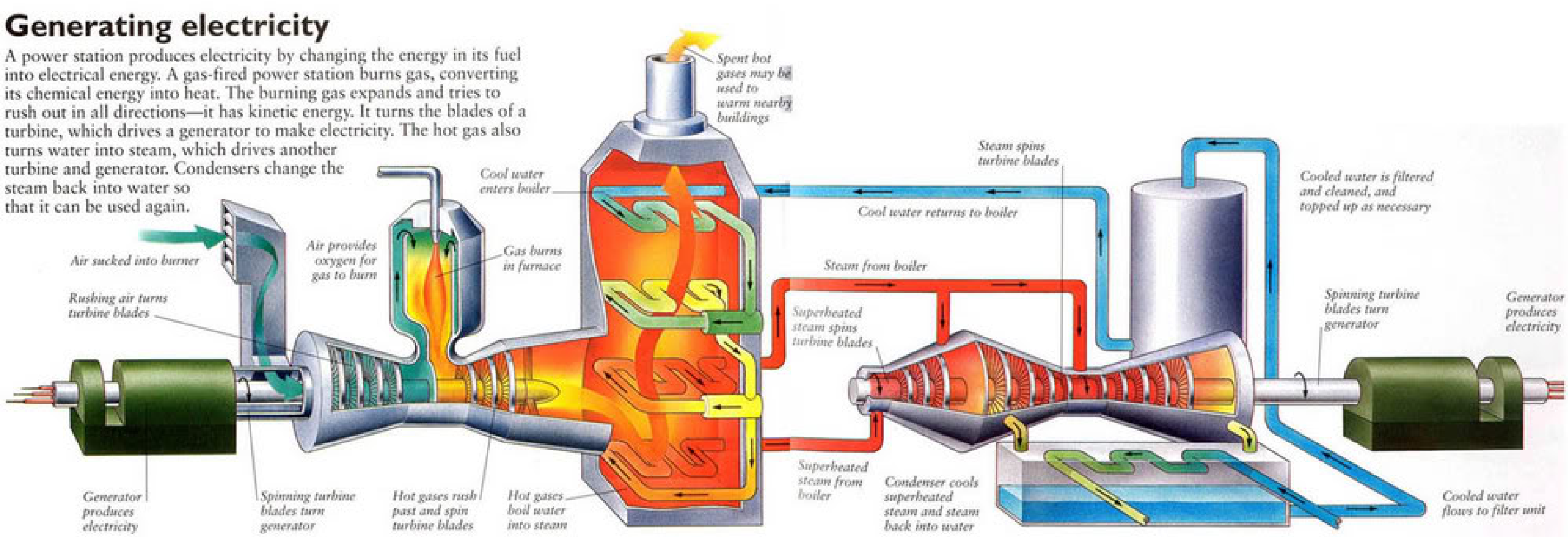


Source: Source: Discussion paper on Renewable Integration: Market & Product Review, CAISO, 8 July 2010 available at http://www.caiso.com/27cd/27cdeb8548450.pdf





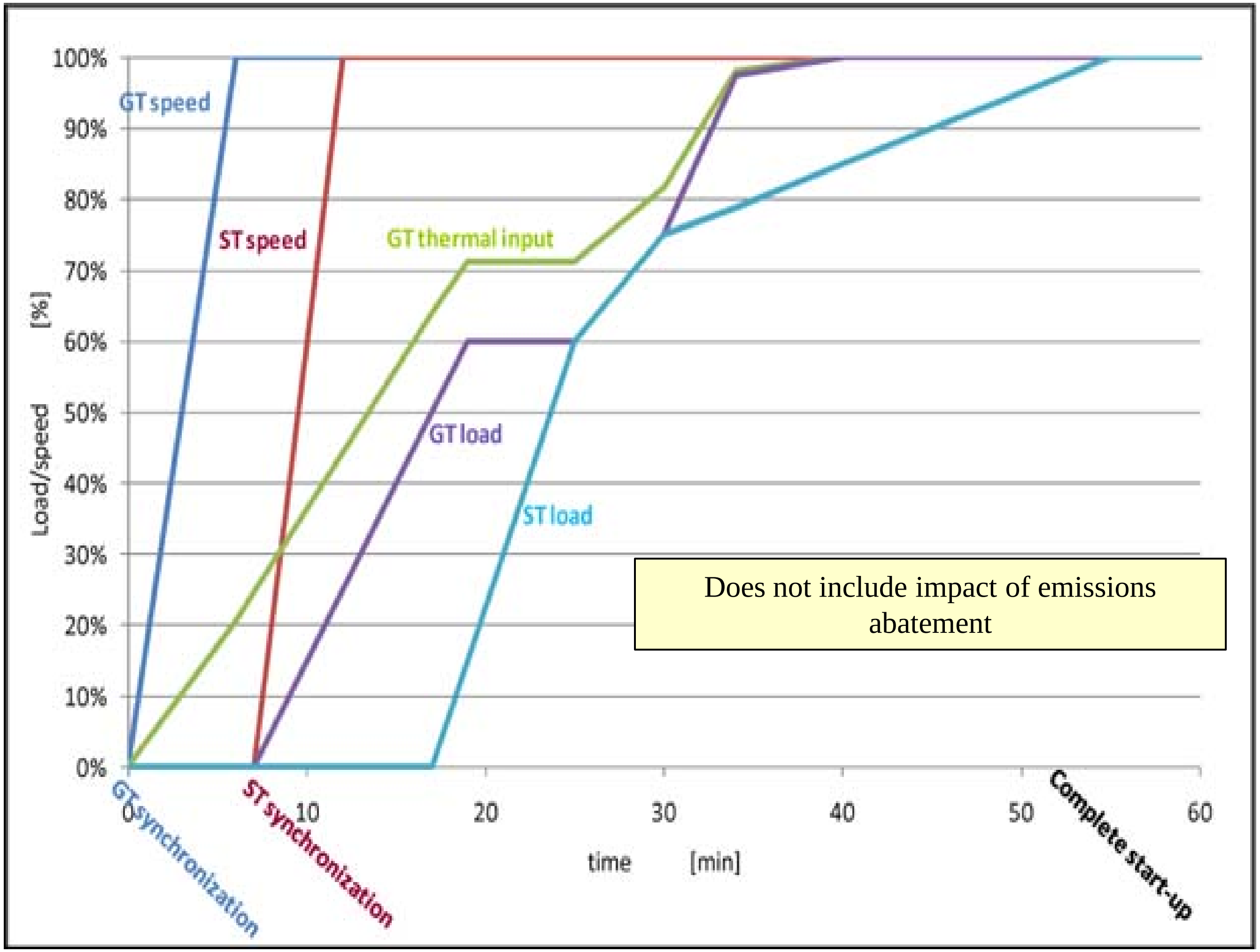
Natural Gas Combined Cycle - NGCC



Simples Cycle Gas Turbine Section
40% LHV Efficiency
1100 lb-CO_2/MWh

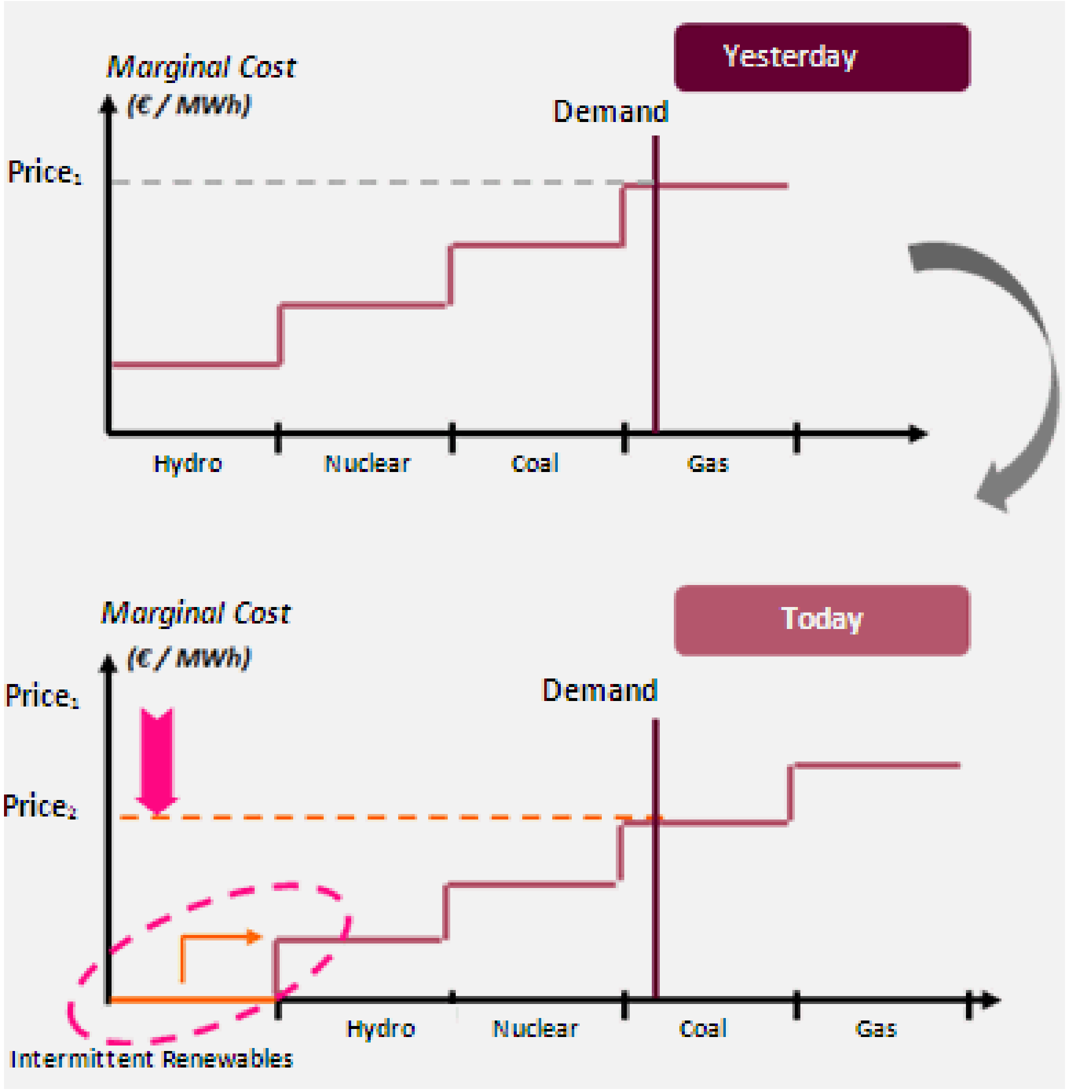
Combined Cycle "Adder"
60% LHV Efficiency
800 lb-CO2/MWh

Gas Turbine Start Sequence

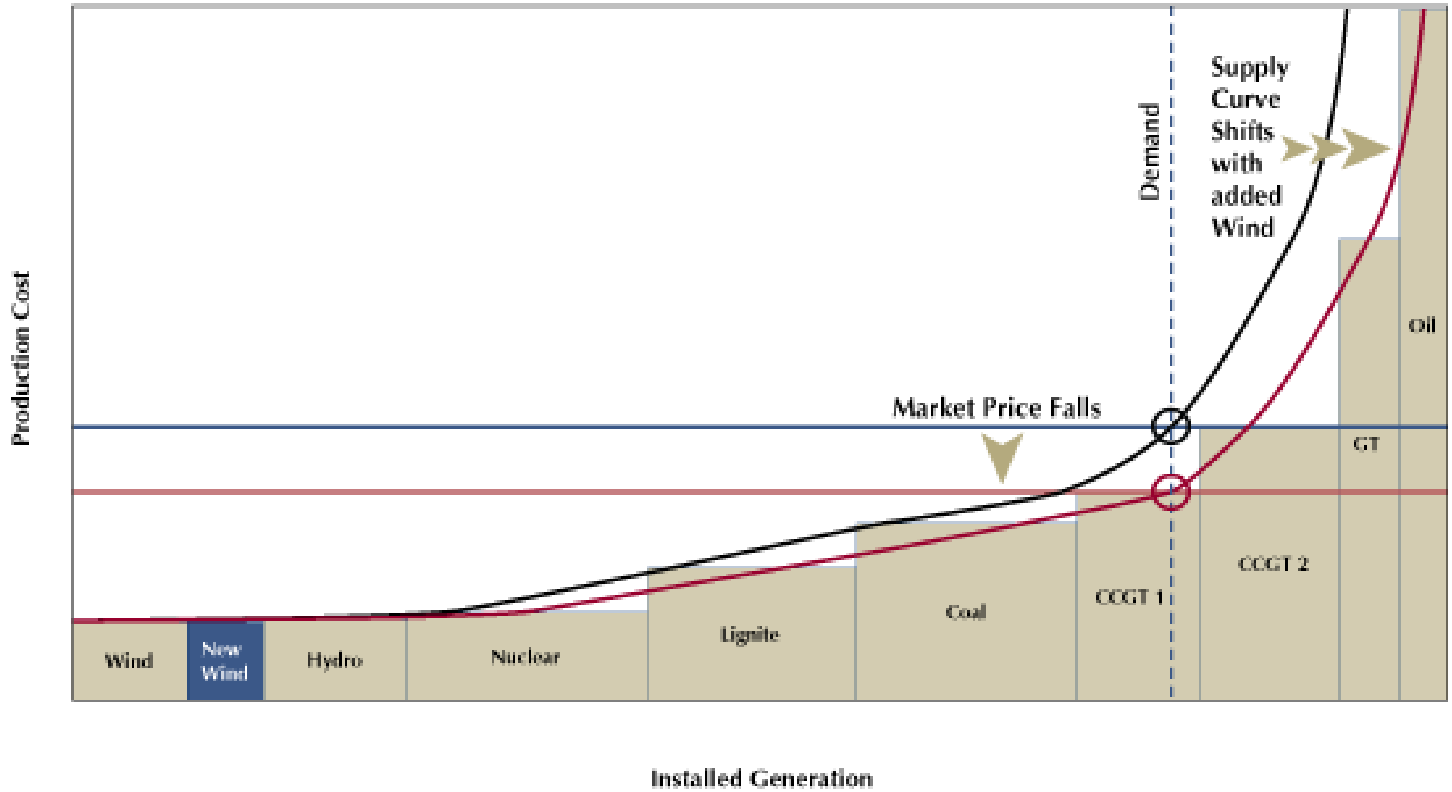


Does not include impact of emissions abatement

Impact of Intermittent Renewables on Merit Order



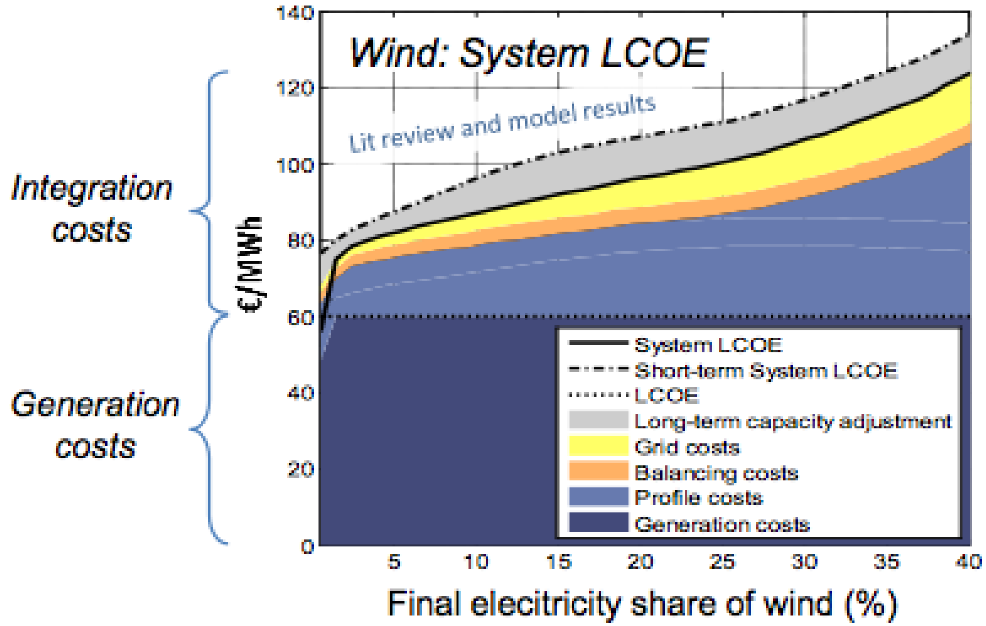
Shift in Supply Cost Curve with Renewables



Wind Integration Costs

– Integration includes:
  – Fluctuating output profile costs
  – Output uncertainties balancing costs
  – Grid costs

At higher penetration, integration costs for wind exceed generation costs.



Source: System LCOE: What are the costs of variable renewables?
Falko Ueckerdt, Lion Hirth, Gunnar Luderer, Ottmar Edenhofer
Paris, June 20, 2013 32th International Energy Workshop

As presented by John Thompson Clean Air Task Force CCS – Pittsburgh 2104

The German Experience

- The German government established a feed-in tariff (FIT) incentive system, which guarantees long-term fixed tariffs per unit of renewable power produced
  - Germany underestimated the ultimate cost of the FIT, which to date is $412 billion, including guaranteed and grated rates that have not yet been paid
  - By 2022, the estimated cost of the FIT program will reach $884 billion and the country will pay $31.1 billion in 2014 alone.
- Though the FIT program has succeeded in bringing a large amount of renewables onto the grid in a short amount of time consumers have suffered as a result
  - Electricity prices in Germany have doubled from $.18/kWh in 2000 to $.38/kWh in 2013.
  - Wholesale prices have dropped from about $121-128/MWh to $50/MWh in 2013
- The rapid decrease in baseload power and increase in intermittent sources is causing more issues for the grid and expense for the government
  - *Grid interventions have increased significantly as operators have to intervene and switch off or start plants that are not programmed to run following market-based dispatching. It is higher amounts of renewables with low full load hours relative to the total portfolio of power production that creates greater variability and strains on the grid.*
- "This has created a large amount of load and margin destruction for utilities that built and financed [fossil] plants," which in turn caused many plants to shutter or require additional subsidies to stay online
- As more renewables are introduced Germany must
  - Invest in energy storage technologies
  - Invest in expanding grid infrastructure to reach onshore and offshore wind projects
- These projects are estimated to cost around $52 billion over the next 10 years.

Source: Finadvice July 2014

Demand Response

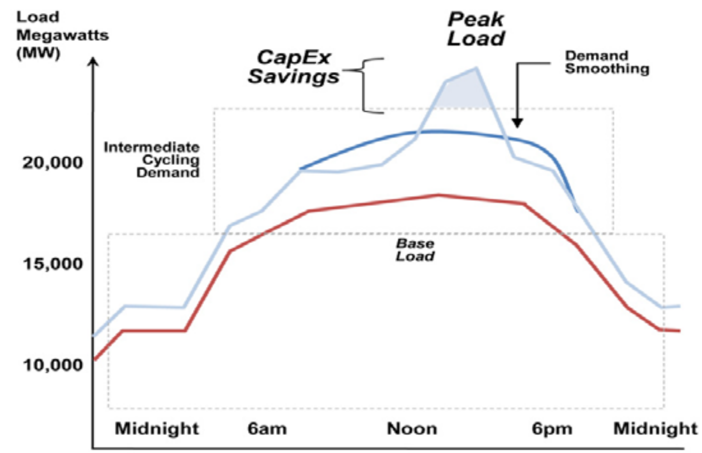
– DR as changes (usually reductions) in electricity **usage by end-use customers from their normal** consumption patterns.

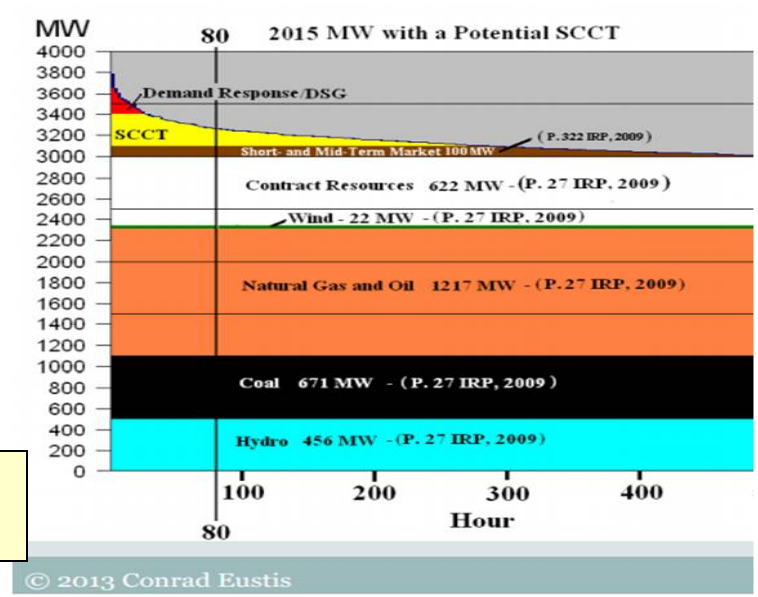
– They are in response to **changes in the price of electricity or to direct incentives**, typically at times of high wholesale market prices or when system reliability is jeopardized.

– An important distinction for DR is that it must be **dispatchable by a utility or system operator**, or be initiated by a customer in response to a non-fixed price signal.

– Thus, static time-of-use rates and scheduled thermal energy storage are not typically considered to be DR;

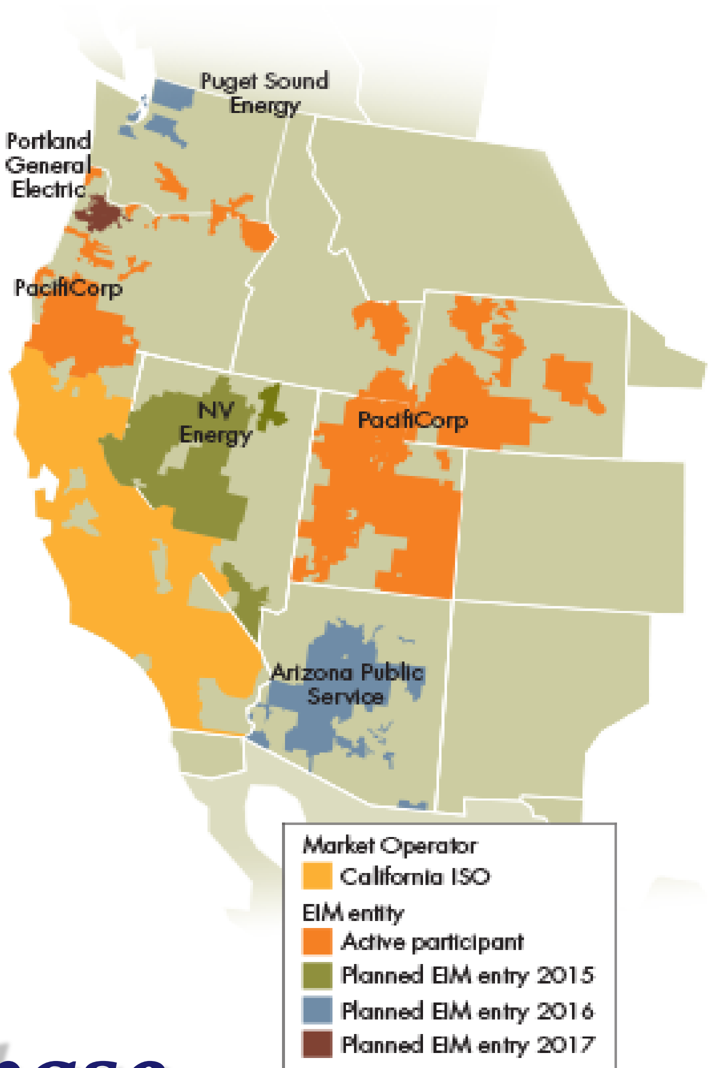
– Critical peak pricing-where the highest price tier is only in effect periodically as called by the utility or operator-is characterized as DR.





Demand Response is an important component of "Smart Grid"

Energy Imbalance Market - EIM



– ISO advanced market systems automatically balance supply and demand for electricity every 15-minutes, dispatching the least-cost resources every 5-minutes.

– Voluntary energy imbalance market service became available in November 2014 as a way to share reserves and integrate renewable resources across a larger geographic region--reliably and efficiently.

– Benefits of EIM

  – Efficiency Automated dispatch to balance load and generation is more efficient than manual dispatch

  – A wider portfolio of resources to maintain system balance could reduce the costs of energy and capacity

  – Improved situational awareness and real-time visibility of transmission constraints, and dispatches resources to reduce and avoid congestion issues. Captures the benefits of geographical diversity of load and resources

base e

Net Metering

- Net Metering is a service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period.
- Net metering policies can vary significantly by country and by state or province
- Net metering can be implemented solely as an accounting procedure, and requires no special metering, or even any prior arrangement or notification
- **Unlike a feed-in-tariff (FIT), which requires two meters, net metering uses a single, bi-directional meter and can measure current flowing in two directions.**

–With one meter (net metering), the user/generator receives retail price for any electricity generated

–With two meters (FIT), the user/generator receives wholesale price for any electricity generated

Time of Day Rates Encourage Customer DR

Summer

	On-Peak	Mid-Peak	Off-Peak	Total
Annual Operating Hours	650	975	2015	3640
Electric Demand Charge - $/kW/month	16.50	2.45	3.30	5.43
Electric Rate - $/kWh	0.1445	0.0680	0.0430	0.0678
Demand Charge - $/kWh	0.1269	0.0126	0.0082	0.0306
Average Electric Rate - $/kWh	0.2714	0.0806	0.0512	0.0984

Months of Operation-Summer: 5

Winter

	On-Peak	Mid-Peak	Off-Peak	Total
Annual Operating Hours	0	1972	3124	5096
Electric Demand Charge - $/kW/month	0.00	0.00	3.30	2.02
Electric Rate - $/kWh	0.0000	0.0800	0.0460	0.0592
Demand Charge - $/kWh	0.0000	0.0000	0.0074	0.0045
Average Electric Rate - $/kWh	0.0000	0.0800	0.0534	0.0637

Months of Operation-Winter: 7

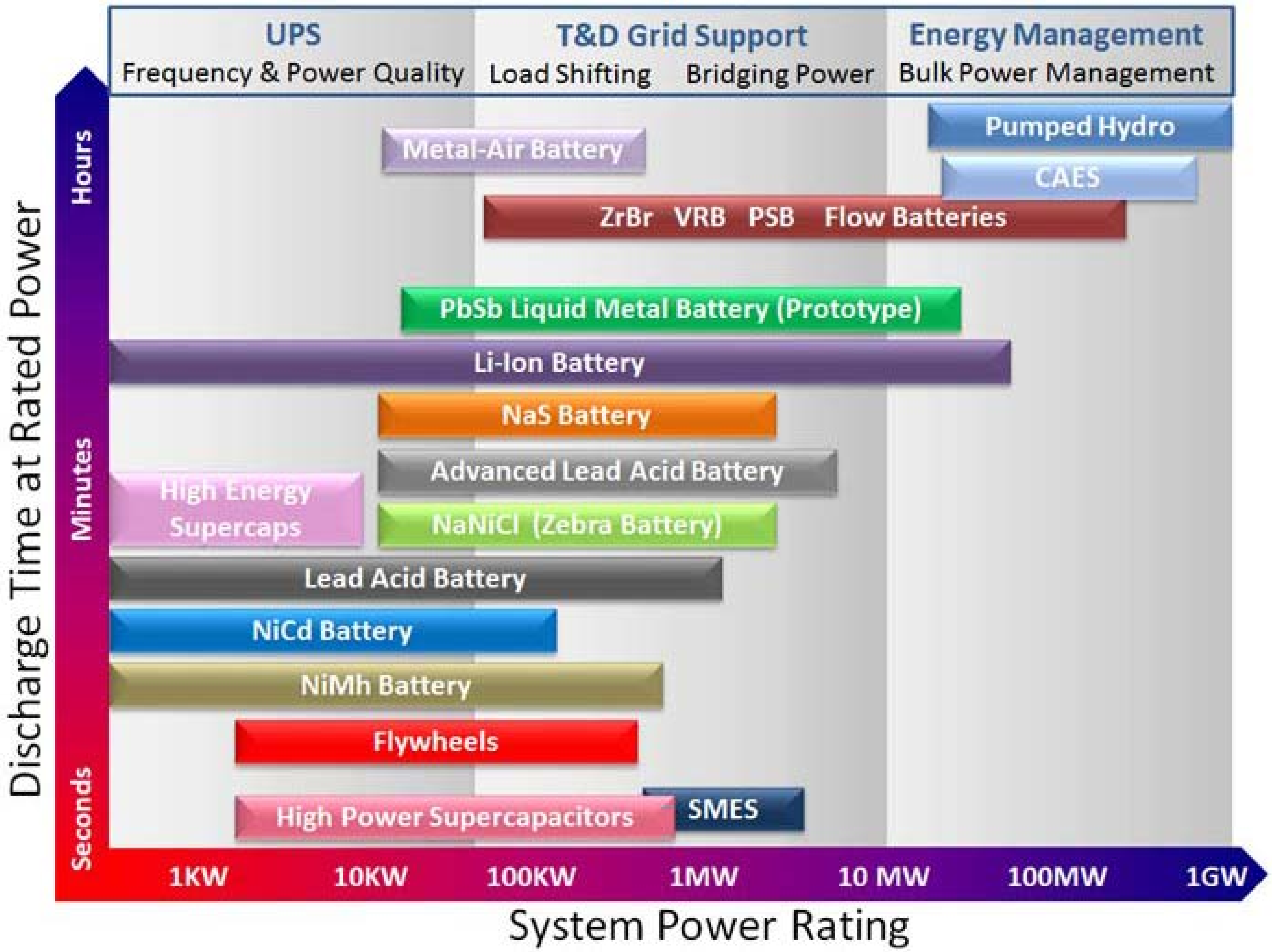
Total

	On-Peak	Mid-Peak	Off-Peak	Total
Annual Operating Hours	650	2947	5139	8736
Electric Demand Charge - $/kW/month	16.50	0.81	3.30	3.44
Electric Rate - $/kWh	0.1445	0.0760	0.0448	0.0628
Demand Charge - $/kWh	0.1269	0.0042	0.0077	0.0154
Average Electric Rate - $/kWh	0.2714	0.0802	0.0525	0.0781

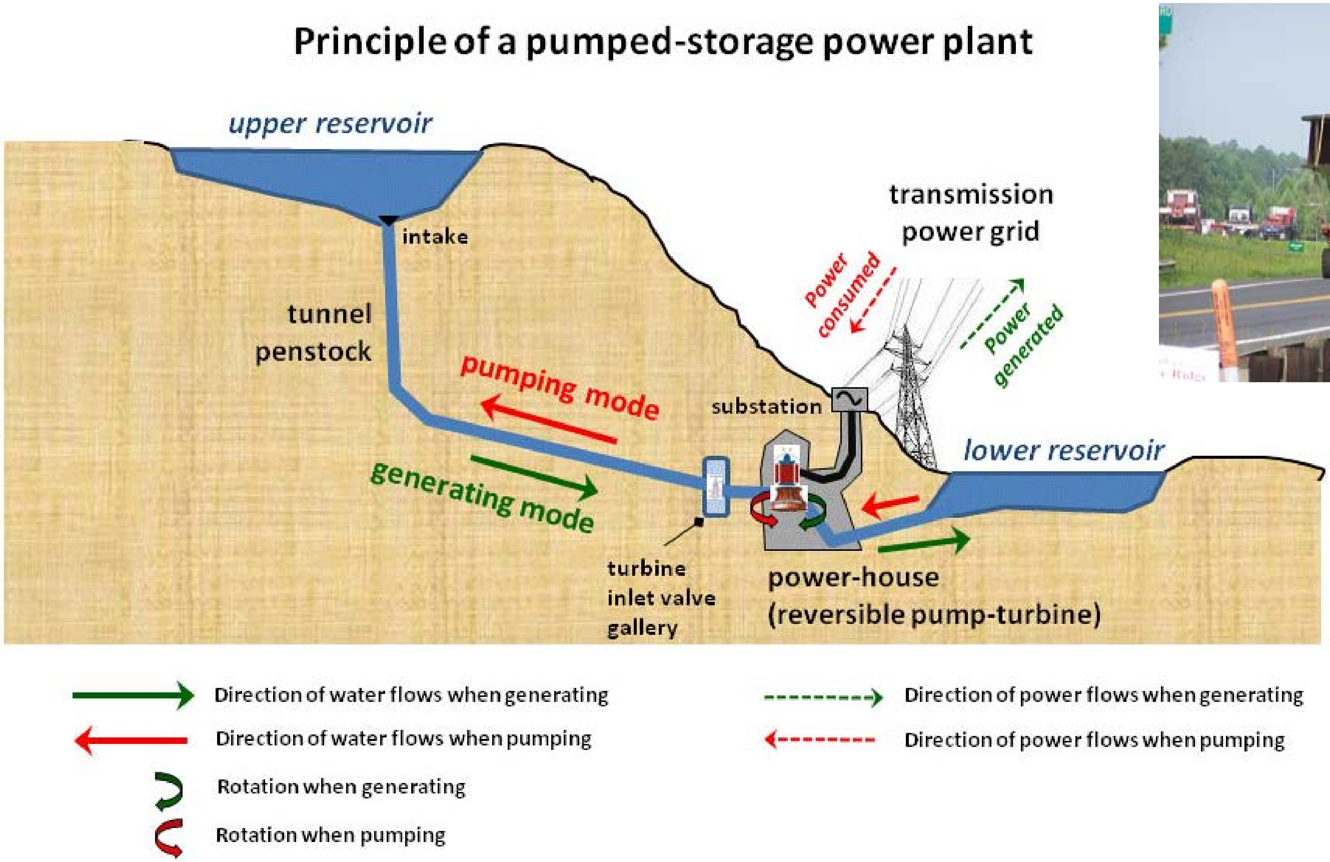
Months of Operation-Total: 12

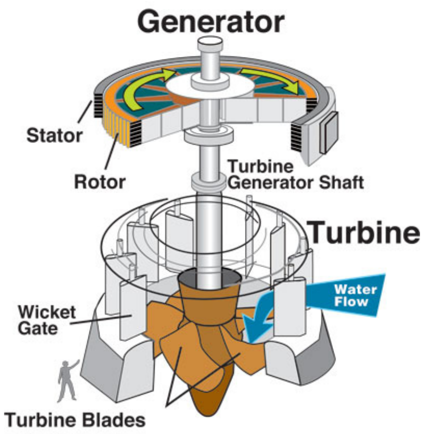
Resource Dispatch Under User Control

Energy Storage Technologies

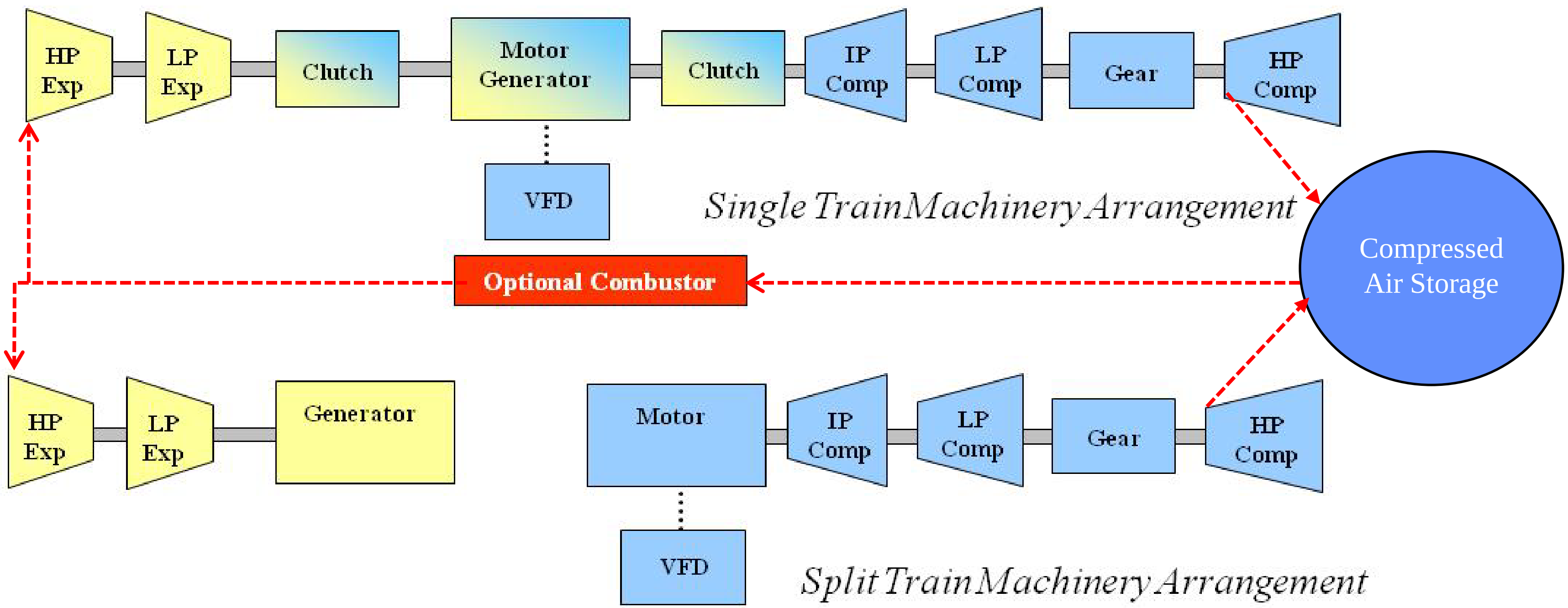


Pumped Hydro Storage





Compressed Air Energy Storage (CAES)



Split the two components of a gas turbine

1. Compressor
2. Turbine (Expander)

So they can operate at different time(s) of day

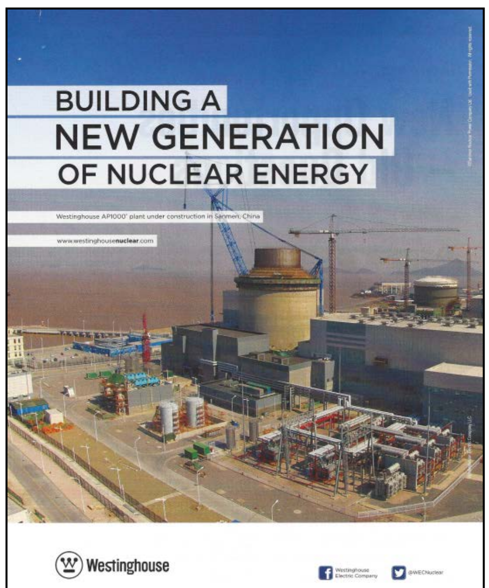
Turbine may be "fired" or "un-fired"

Source: Dresser-Rand

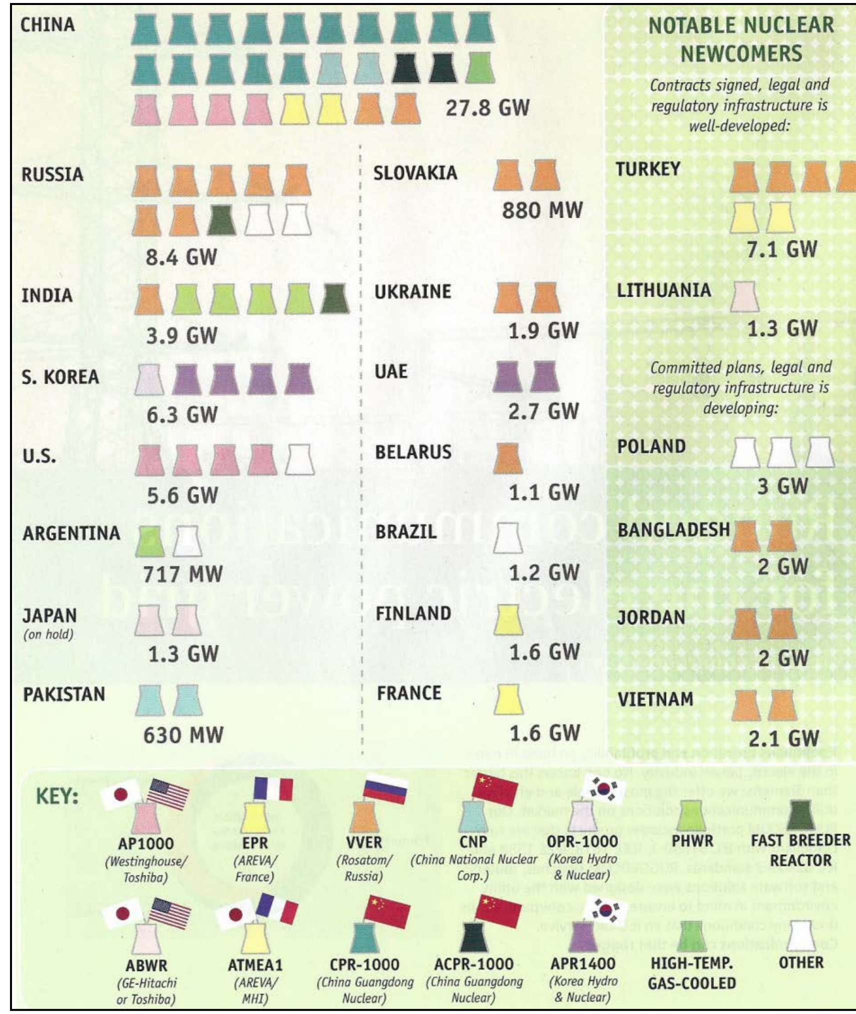
Fuel Switching

“The Big Picture: Next-Gen Nuclear”

- Compliments of Power magazine April 2014
- 72 mostly advanced nuclear reactions under construction
- A total of 68GW (12% of installed base)
- China represents 40% of the total
- France will cap nuclear capacity at the current 63.2GW, forcing closures w/capacity additions
  - Currently at 75% share of generation
  - Goal is 50% by 2025



Westinghouse AP1000® plant under construction in Sanmen, China



Installed Generating Capacity (2012) = 5,550 GW

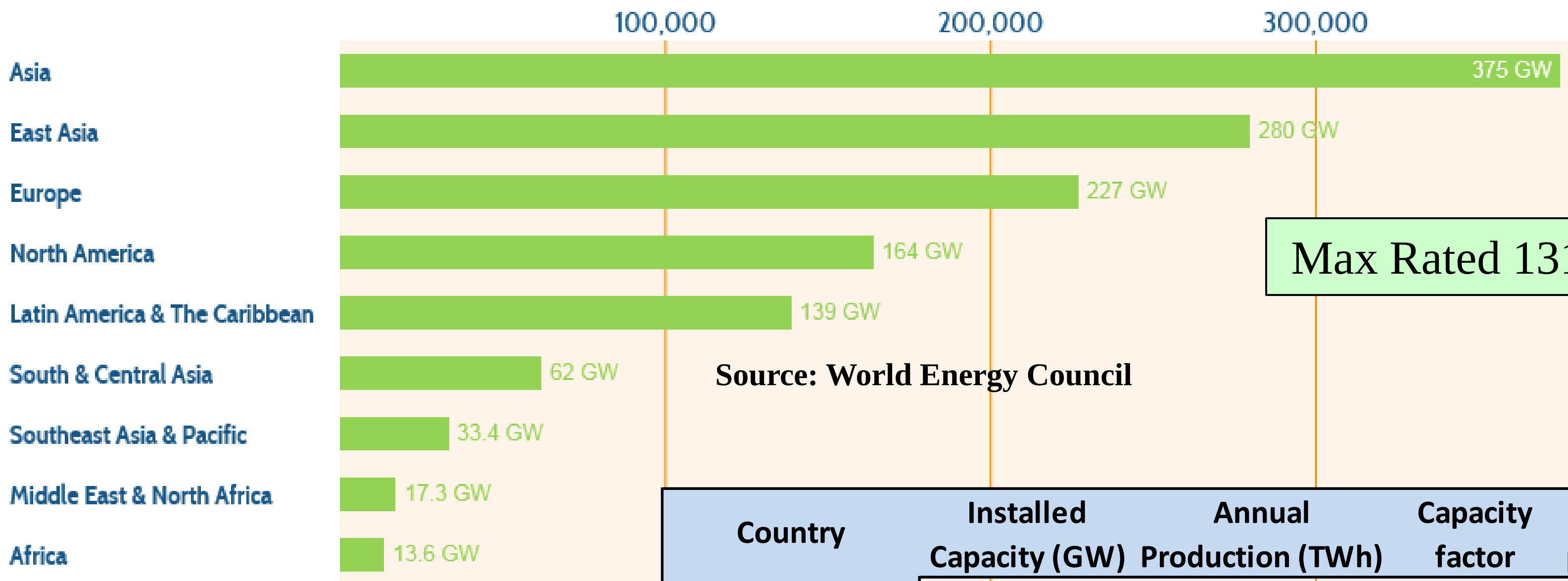
French “Royal Bill” Initiatives

- **Cut GHG emissions by:**
  - By 40% between 1990 (412 Mt) and 2030 (247 Mt)
  - By 50% in 2050 (206 Mt)
- **Nuclear**
  - Cap nuclear capacity at the current 63.2GW,
  - Forcing closures w/any capacity additions
    - Currently at 75% share of generation
    - Goal is 50% by 2025
- **Cut fossil fuels in energy mix by 30% vs. 2012**
- **Increase renewables to 32% of energy mix by ??**
  - Renewables 2013 = 5.9
  - Hydro 2013 = 15.8
  - Total 2013 247.2 Mtoe

(5.9 + 15.8)/ 247.2 = 8.8% ⇒ 32.0%

- **Increase the Carbon Tax on fossil fuels**
  - €65/Mt in 2020 (a 4x increase)
  - €100/Mt in 2030

World Hydroelectric Capacity – 936 GW



Max Rated 1311

Source: World Energy Council

Country	Installed Capacity (GW)	Annual Production (TWh)	Capacity factor	% of total production
China	196.8	652.1	0.37	22.3
Canada	89.0	369.5	0.59	61.1
Brazil	69.1	363.8	0.56	85.6
United States	79.5	250.6	0.42	5.7
Russia	45.0	167.0	0.42	17.6
Norway	27.5	140.5	0.49	98.3
India	33.6	115.6	0.43	15.8
Venezuela	14.6	86.0	0.67	69.2
Japan	27.2	69.2	0.37	7.2
Sweden	16.2	65.5	0.46	44.3
Total	598.5	2279.7	0.435	

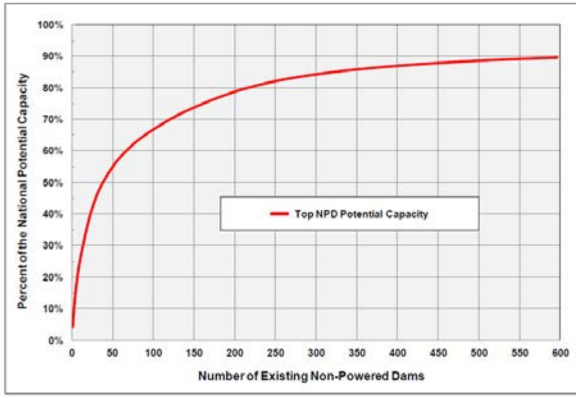
China Three Gorges – 18GW

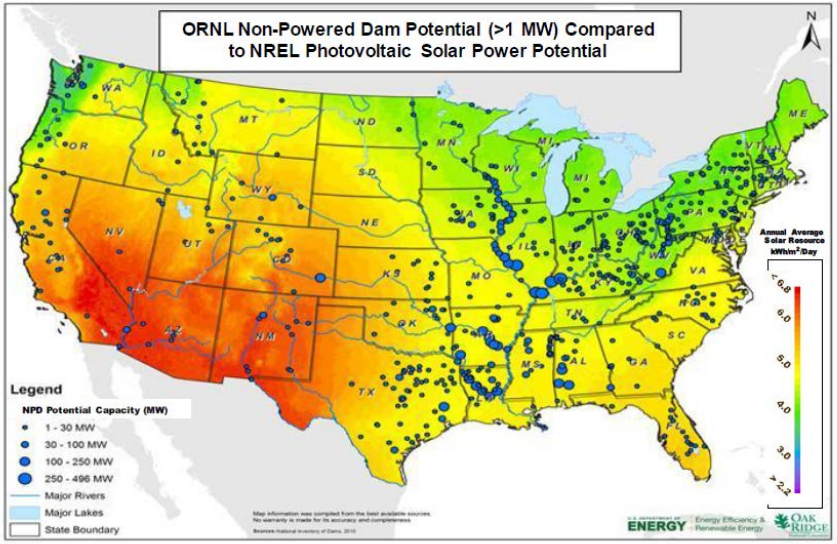
World Total Hydro 3884.6 TWh = 16.5%

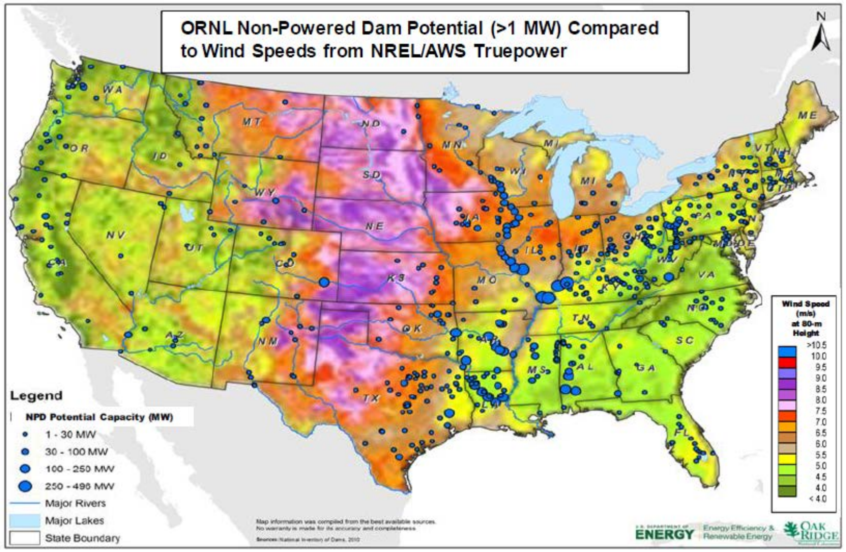
2014 World Electricity Production = 23,537 TWh

12GW Complimentary Non-Power Dams (NPD)

Hydrologic Regions (HUC02)	Potential Capacity (MW)	Potential Generation (TWh/yr)	Hydrologic Regions (HUC02)	Potential Capacity (MW)	Potential Generation (MWh/yr)
1 New England	243	1.110	10 Missouri	258	0.865
2 Mid-Atlantic	479	1.997	11 Arkansas-White-Red	1898	5.960
3 South Atlantic-Gulf	1618	3.778	12 Texas-Gulf	608	1.308
4 Great Lakes	156	0.903	13 Rio Grande	98	0.241
5 Ohio	3236	13.603	14 Upper Colorado	53	0.145
6 Tennessee	53	0.197	15 Lower Colorado	124	0.370
7 Upper Mississippi	2027	9.943	16 Great Basin	29	0.080
8 Lower Mississippi	743	2.802	17 Pacific Northwest	225	0.871
9 Souris-Red-Rainy	58	0.239	18 California	156	0.586







Cumulative Geothermal Installed Capacity – 12.6GW

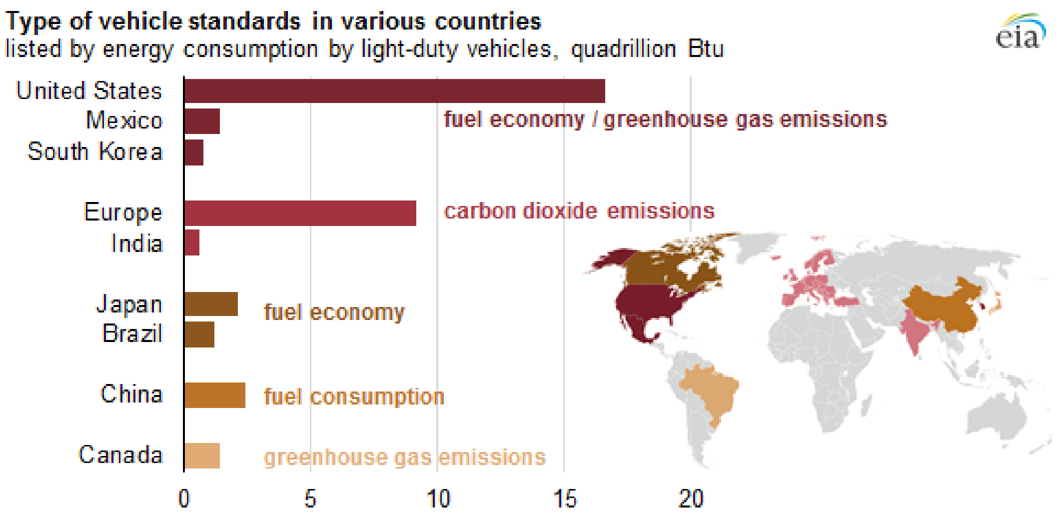
Cumulative installed geothermal power capacity*

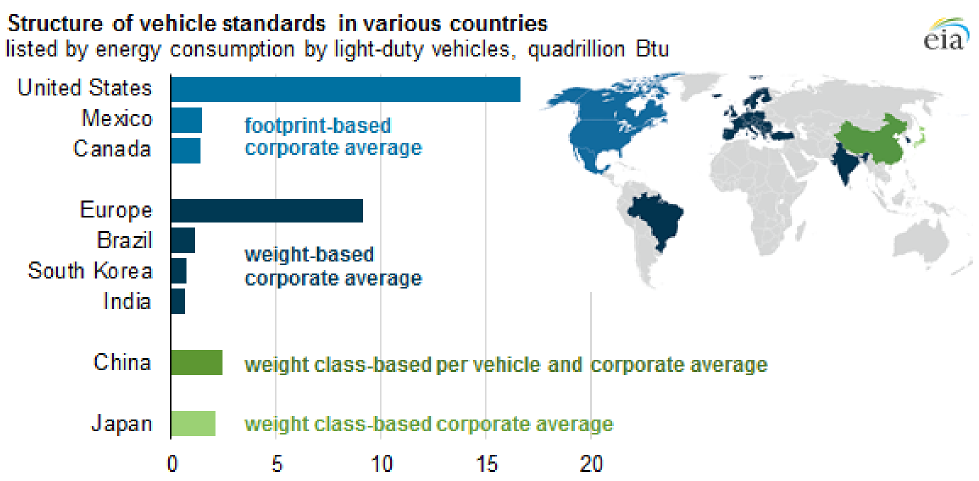
Megawatts	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	**2014**	Change 2014 over 2013	2014 share of total
China	28	28	28	28	24	24	24	24	24	27	**27**	0.0%	0.2%
Costa Rica	163	163	163	163	163	166	166	208	208	208	**208**	0.0%	1.7%
El Salvador	151	151	195	195	204	204	204	204	204	204	**204**	0.0%	1.6%
Iceland	202	202	312	485	576	576	575	665	665	665	**665**	0.0%	5.3%
Indonesia	807	850	850	980	1052	1189	1193	1209	1339	1339	**1401**	4.6%	11.1%
Italy	791	791	811	811	811	843	883	883	875	876	**916**	4.6%	7.3%
Japan	535	534	534	532	532	500	502	502	502	503	**539**	7.2%	4.3%
Kenya	167	167	167	170	174	174	209	212	217	253	**590**	133.7%	4.7%
Mexico	960	960	960	960	965	965	965	887	812	834	**834**	0.0%	6.6%
New Zealand	370	425	425	443	585	625	723	723	723	971	**971**	0.0%	7.7%
Philippines	1932	1978	1978	1958	1958	1953	1966	1783	1848	1868	**1917**	2.6%	15.2%
Russia (Kamchatka)	79	79	79	82	82	82	82	82	82	82	**82**	0.0%	0.7%
Turkey	20	20	28	28	35	82	94	114	114	226	**368**	62.6%	2.9%
US	2866	2893	2940	3037	3163	3289	3308	3318	3450	3524	**3525**	0.0%	28.0%
Total World	**9225**	**9396**	**9655**	**10121**	**10575**	**10928**	**11152**	**11071**	**11397**	**11917**	**12594**	**5.7%**	**100.0%**

Sources: International Geothermal Association, ThinkGeoEnergy, and national sources

Vehicle Fuel Economy (and GHG Emissions Standards)

- Footprint-based corporate average
  - Sets GHG emission and fuel economy targets and GHG emission targets based on the footprint of the vehicle, which is its wheelbase multiplied by average track width
  - Overall target of the manufacturer is determined by averaging the target for each footprint the manufacturer produces
- Weight-based corporate average
  - Similar to the footprint-based standard except they are based on vehicle weight
- Weight-class based per vehicle and corporate average
  - More stringent than the weight-based corporate average standard alone.
  - Light-duty vehicle manufacturers must meet a fuel consumption standard at each weight class level
  - Must meet an overall corporate average fuel consumption standard
- Weight-class based corporate average
  - Each light-duty vehicle in a weight class must meet the standard for the weight class rather than an overall manufacture standard





Renewable Fuels Standards

- **The Renewable Fuel Standard (RFS)** is a USA federal program that requires transportation fuel sold in the U.S. to contain a minimum volume of renewable fuels.
- The RFS originated with the **Energy Policy Act of 2005**
- Expanded and extended by the **Energy Independence and Security Act of 2007 (EISA).**
- Requires renewable fuel to be blended into transportation fuel in increasing amounts each year, escalating to **36 billion gallons by 2022**.
- Each renewable fuel category in the RFS program must emit lower levels of greenhouse gases relative to the petroleum fuel it replaces.

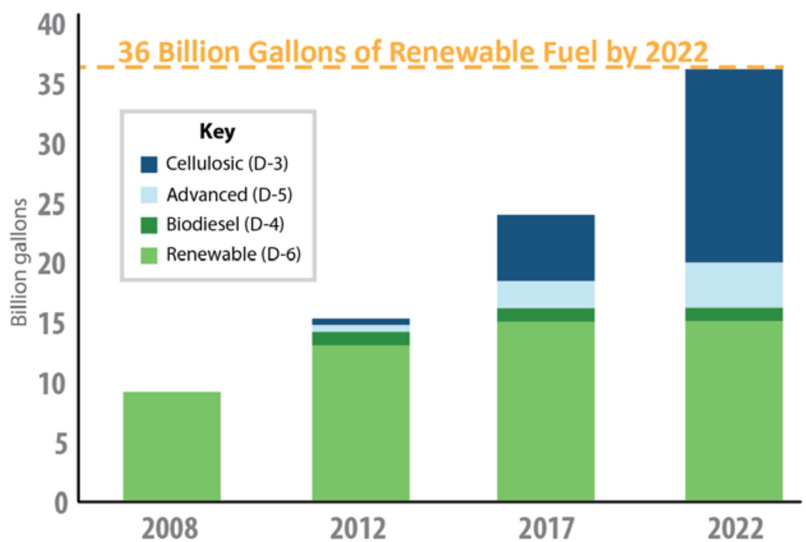
This is an ethanol subsidy….

Energy balance [1]

Country	Type	Energy balance
United States	Corn ethanol	1.3
Brazil	Sugarcane ethanol	8.0
Germany	Biodiesel	2.5
United States	Cellulosic ethanol	†2–36

† depending on production method Wikipedia

Congressional Volume Target for Renewable Fuel



Well-to-Wheels Comparison Electric vs. Gasoline

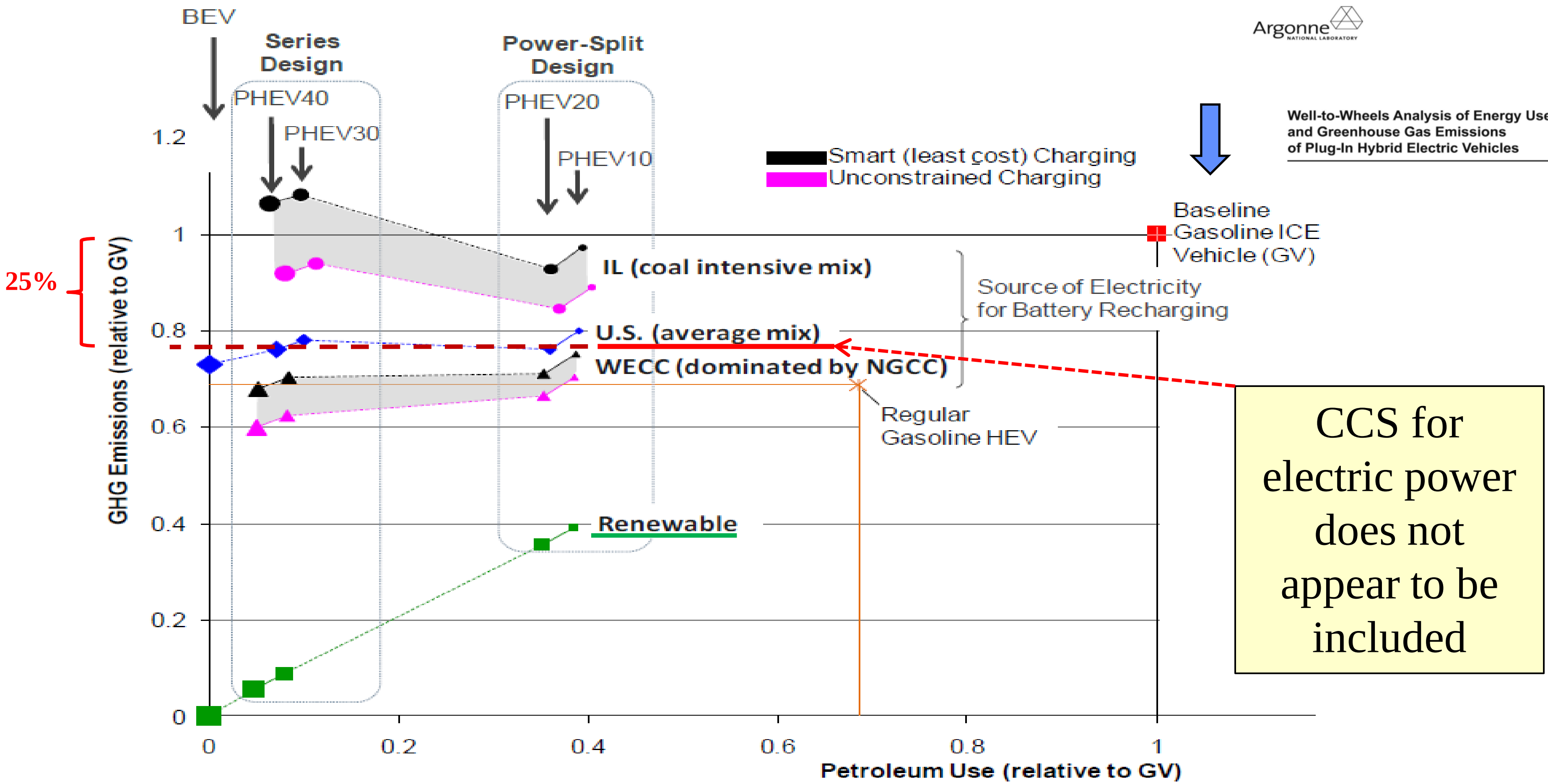


FIGURE ES.1 WTW Petroleum Use and GHG Emissions for CD Operation of Gasoline PHEVs and BEVs Compared with Baseline Gasoline ICEVs and Regular Gasoline HEVs

EPA CO_2 Regulations

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 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

Fuel Carbon Factors – lb-CO_2/mmBtu

Rank	State of Origin	CO2 Factors lbs per 10^6 Btu	Average
Anthracite	Pennsylvania	227.38	
Bituminous	Alabama	205.46	
Bituminous	Arizona	209.68	
Bituminous	Arkansas	211.60	
Bituminous	Colorado	206.21	
Bituminous	Illinois	203.51	
Bituminous	Indiana	203.64	
Bituminous	Iowa	201.57	
Bituminous	Kansas	202.79	
Bituminous	Kentucky: East	204.80	
Bituminous	Kentucky: West	203.23	
Bituminous	Maryland	210.16	
Bituminous	Missouri	201.31	
Bituminous	Montana	209.62	
Bituminous	New Mexico	205.71	
Bituminous	Ohio	202.84	
Bituminous	Oklahoma	205.93	
Bituminous	Pennsylvania	205.72	
Bituminous	Tennessee	204.79	
Bituminous	Utah	204.08	
Bituminous	Virginia	206.23	
Bituminous	Washington	203.62	
Bituminous	West Virginia	207.10	
Bituminous	Wyoming	206.48	
Bituminous	Texas	204.39	205.44

Rank	State of Origin	CO2 Factors lbs per 10^6 Btu	Average
Subbituminous	Alaska	214.00	
Subbituminous	Colorado	212.72	
Subbituminous	Iowa	200.79	
Subbituminous	Missouri	201.31	
Subbituminous	Montana	213.42	
Subbituminous	New Mexico	208.84	
Subbituminous	Utah	207.09	
Subbituminous	Washington	208.69	
Subbituminous	Wyoming	212.71	208.84
Lignite	Arkansas	213.54	
Lignite	California	216.31	
Lignite	Louisiana	213.54	
Lignite	Montana	220.59	
Lignite	North Dakota	218.76	
Lignite	South Dakota	216.97	
Lignite	Texas	213.54	
Lignite	Washington	211.68	
Lignite	Wyoming	215.59	215.61
Natural Gas		116.38	116.38

Source: Energy Information Administration, Quarterly Coal Report, Jan.-Mar. 1994, DOE-EIA-0121(94/Q1) (Washington, D.C, August 1994), pp. 1-8.)

This is where "Natural Gas is ½ of Coal" comes from

EPA NSPS Output Ratings 2014 – 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	9452	6313	6848	9276	8721	8412	7580
- Efficiency - HHV%	36.1%	54.0%	49.8%	36.8%	39.1%	40.6%	45.0%
- Efficiency - LHV%	40.1%	60.0%	55.3%	40.8%	43.4%	45.0%	50.0%
- Thermal Input - mmBtu	850	850	850	850	850	850	850
- Rating - MW@850 mmBtu/hr	89.93	134.64	124.12	91.63	97.47	101.05	112.14
Emissions - lb-CO2/MWh							
- Unabated	1100.0	734.7	797.0	1886.0	1773.2	1710.3	1541.2
- Applicable Threshold	1100	1000	1000	1000	1000	1000	1000
CCS % required to meet threshold	0.0%	0.0%	0.0%	47.0%	43.6%	41.5%	35.1%

NSPS = New Source Performance Standards

$$lb-CO_2/MWh = \frac{lb-CO_2/Btu/kWh}{1000}$$

$$lb-CO_2/MWh = \frac{116.4 \times 6848}{1000} = 797$$

$$HHV\ efficiency = \frac{3412\,Btu/kWh}{Heat\ Rate} = \frac{3412}{6848} = 49.8\%$$

Natural Gas HHV	21,501
Natural Gas LHV	23,860

DOE baseline Carbon Factors

“The War on Coal”- EPA NSPS 2014

	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

SCPC vs. NGCC
First Cost $/kW is ~5x
LCOE is 2.3x
Efficiency is ~1/2
w/Natural Gas at $6.13

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Power Generation Shift 2015-2016

- The USA is the world's largest producer of nuclear power, accounting for more than 30% of worldwide nuclear generation of electricity.
- There are now 99 units operable (98.7 GWe) and five under construction.
- Following a 30-year period in which few new reactors were built, it is expected that six new units may come on line by 2020
- However, lower gas prices since 2009 have put the economic viability of some existing reactors and proposed projects in doubt.

TYPE OF PLANT (2015-2016)	ADDITIONS (MW)	RETIREMENTS (MW)	NET (MW)
BATTERIES	10.50	—	10.50
CONVENTIONAL HYDROELECTRIC	637.00	323.00	314.00
CONVENTIONAL STEAM COAL	380.00	16,961.50	(16,581.50)
GEOTHERMAL	3.70	—	3.70
LANDFILL GAS	56.40	22.40	34.00
MUNICIPAL SOLID WASTE	96.00	—	96.00
NATURAL GAS FIRED COMBINED CYCLE	14,584.00	139.00	14,445.00
NATURAL GAS FIRED COMBUSTION TURBINE	2,225.20	1,709.00	516.20
NUCLEAR	1,269.90	—	1,269.90
OFFSHORE WIND TURBINE	30.00	—	30.00
ONSHORE WIND TURBINE	17,103.10	25.30	17,077.80
OTHER NATURAL GAS	1,058.20	874.20	184.00
OTHER WASTE BIOMASS	61.60	1.20	60.40
PETROLEUM LIQUIDS	56.70	1,086.80	(1,030.10)
SOLAR PHOTOVOLTAIC	8,472.60	—	8,472.60
SOLAR THERMAL WITH ENERGY STORAGE	131.00	—	131.00
SOLAR THERMAL WITHOUT ENERGY STORAGE	773.40	—	773.40
WOOD/WOOD WASTE BIOMASS	223.70	33.50	190.20
ALL OTHER	146.00	—	146.00
NET TOTAL 2015	18,965.00	14,938.20	4,026.80
NET TOTAL 2016	28,354.00	6,237.70	22,116.30
NET TOTAL 2015-2016	**47,319.00**	**21,175.90**	**26,143.10**

These are nameplate ratings…
………..be mindful of load factor.

EPA Clean Power Plan - 2015

2030			Economic Growth	
O&G Resource			Ref Case	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			Economic Growth	
O&G Resource			Ref Case	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!

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High Efficiency, Low Emissions Coal (HELE)

Figure 10: Reducing CO_2 emissions from pulverised coal-fired power generation

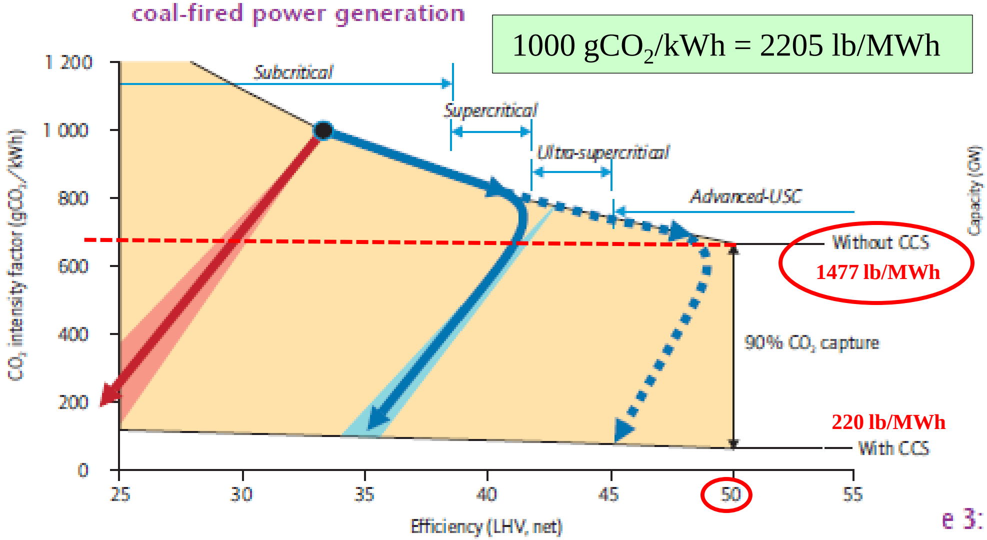
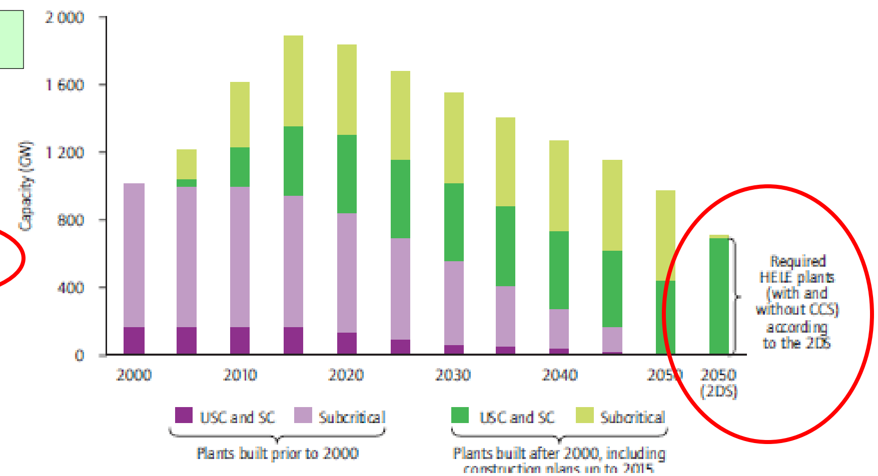


Figure 8: Projected capacity of coal-fired power generation to 2050



e 3: Performance of HELE coal-fired power technologies

Fuel type	Plant type	Emissions: CO_2 (g/kWh)	Emissions: NO_x (mg/Nm³)	Emissions: SO_2 (mg/Nm³)	Emissions: PM (mg/Nm³)	Max. unit capacity (MWe)	Capacity factor (%)	CCS energy penalty (%-points)
Coal	PC (USC)	740	<50 to 100 (by SCR)	<20 to 100 (by FGD)	<10	1 100[3]	80	7 to 10 (post-combustion and oxy-fuel)
	CFBC	880 to 900	<200	<50 to 100 (in situ)	<50	460	80	
	PC (A-USC)[1]	670 (700°C)	<50 to 100 (by SCR)	<20 to 100 (by FGD)	<10	<1 000 (possible)	-	
	IGCC[1,2]	670 to 740	<30	<20	<1	335	70	7
	IGFC[1]	500 to 550	<30	<20	<1	<500	-	

- U.S. consumption of coal totaled 18 quadrillion Btu in 2013, a 4-percent increase from 2012
- Electric power sector consumption accounted for 91 percent of total consumption in 2013
- The price of coal averaged $2.52 per million Btu in the United States in 2013, a 3-percent decrease from 2012
- Prices ranged from $1.44 per million Btu in Nebraska to $4.90 per million Btu in Alaska.

Source: IEA Technology Roadmap
High Efficiency Low Emissions Coal-fired Power Generation

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???

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“The (New) War on Coal”- EPA NSPS 2015

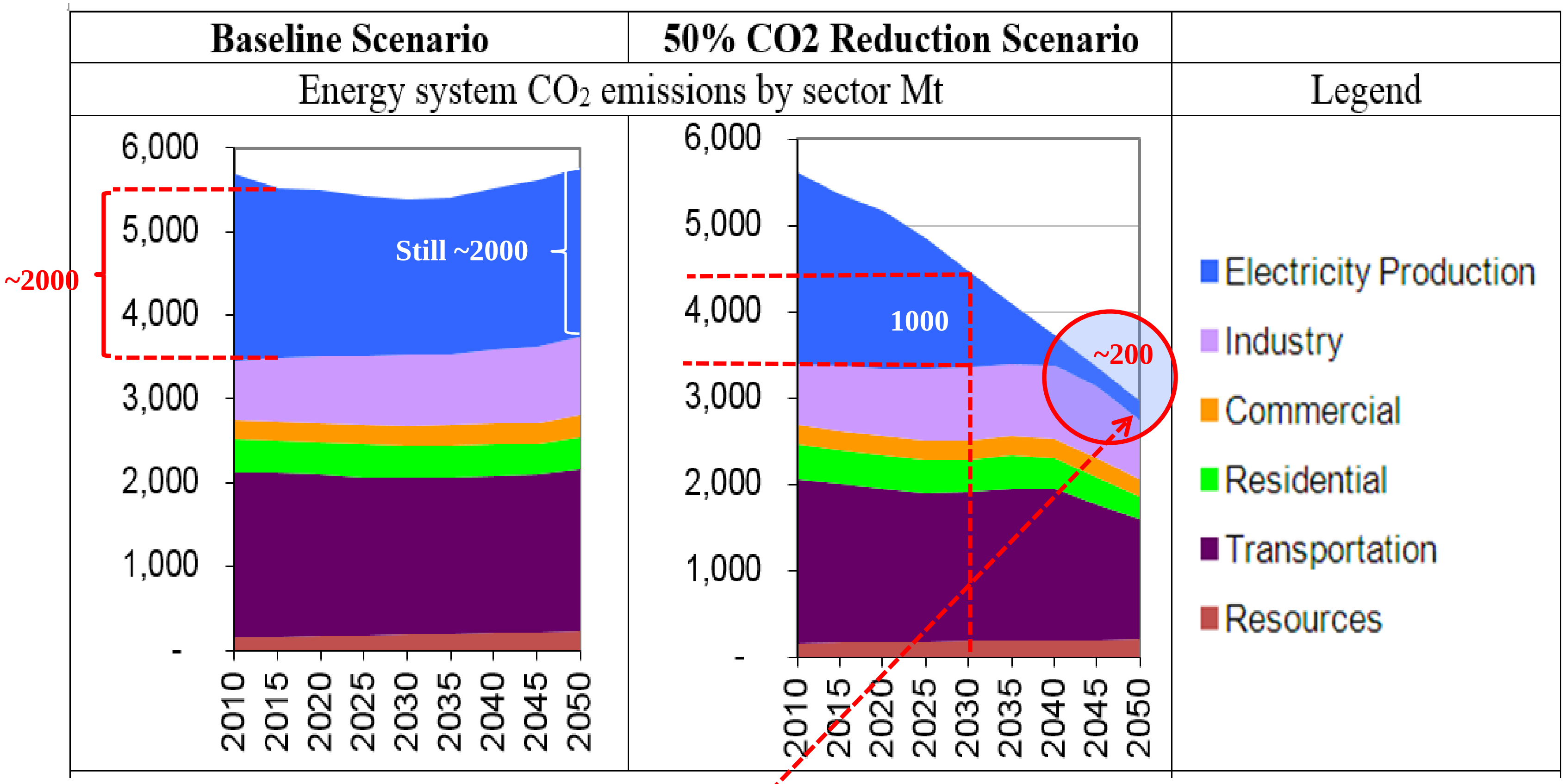
	Supercritical PC		NGCC	
Case	11	12	13	14
CO2 Capture	No	Yes	No	Yes
Gross Power Output - kWe	580,400	662,800	564,700	511,000
Auxilliary Power Requirements - kWe	30,410	112,830	9,620	37,430
Report Net Power Output - kWe	549,990	549,970	555,080	473,570
Net Plant HHV Efficiency - %	39.30%	28.40%	50.20%	42.80%
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%
$70.00 per tonne	$229,892	$31,726	$105,511	$10,524
CO2 Cost vs. NGCC Case 13	$124,381	($73,785)	–	($94,987)
tonnes-CO2/year	3,284	453	1,507	150

SCPC vs. NGCC
First Cost $/kW is ~3x
LCOE is 1.35x
Efficiency is ~3/4
w/Natural Gas at $6.13

CCS is totally eliminated as a viable option

Is That Good Enough?

A Credible 50% CO2 Reduction Scenario by 2050



Source: DOE SCO2 Conference 2014, as presented by EPA

2°/450 ppm number is 1300, not 3000
Electricity Production is 500 Mt
200 Mt if everyone does not pulls their fair share

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Is that Good Enough?

The World	33,457 Mt (33.457 Gt)
The USA	6,000
PowerGen	2,416
EPA/CPP	1,600-1,800
6°C	~ 2,100
4°C	~ 1,560
2°C/450 ppm - 16Gt	~ 200-500

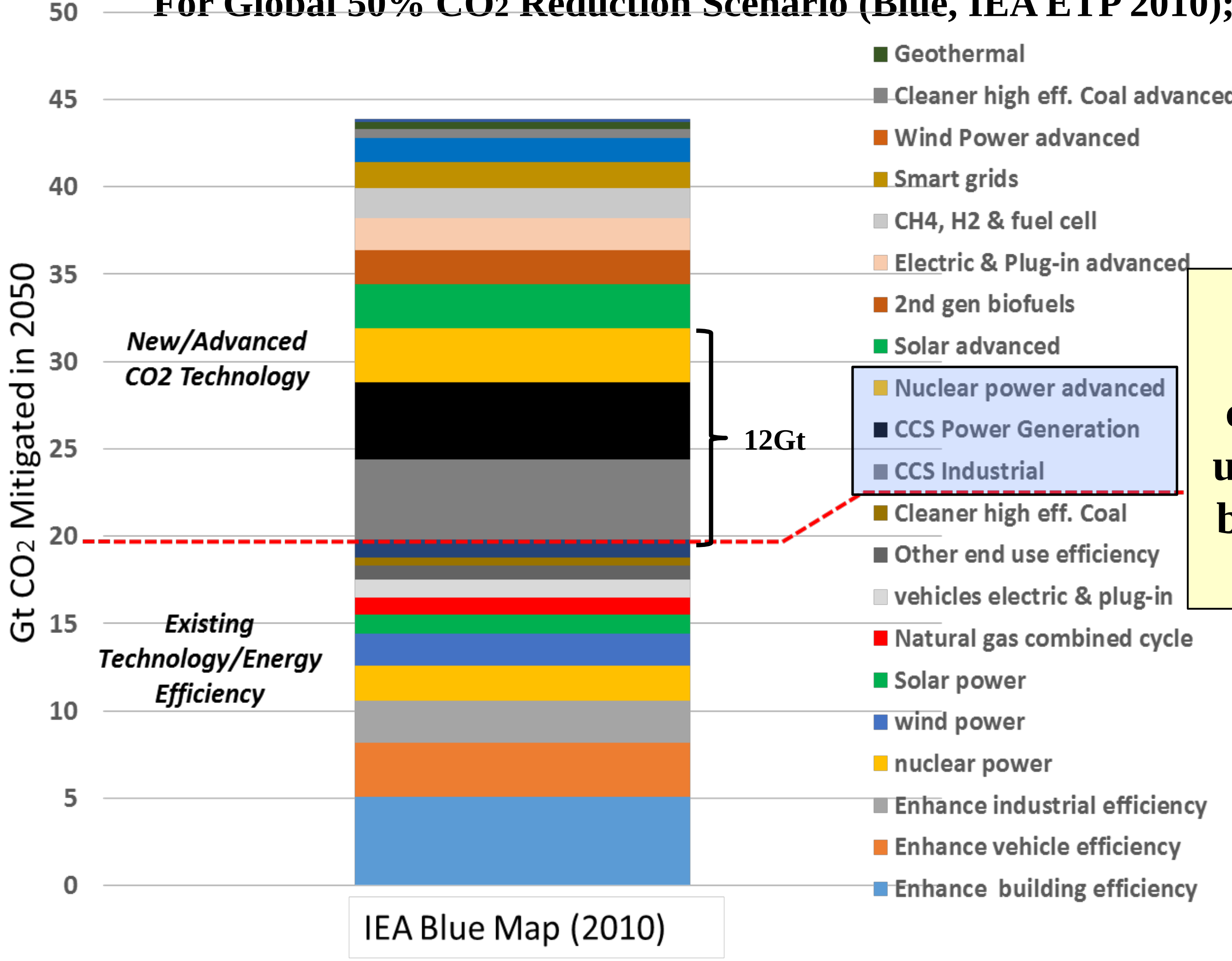
EPA CPP Track

No….

…and that does not even consider that the non-PowerGen contributors will have a much larger challenge to match PowerGen

New & Advanced Technologies Needed

For Global 50% CO_2 Reduction Scenario (Blue, IEA ETP 2010);



These are being completely undermined by CPP and NSPS

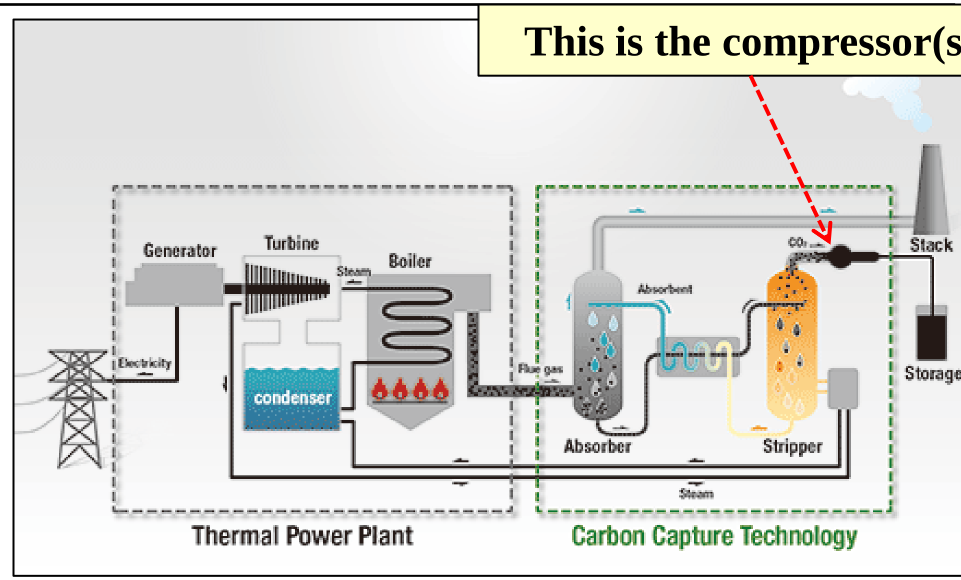
Source: DOE SCO2 Conference 2014, as presented by EPA

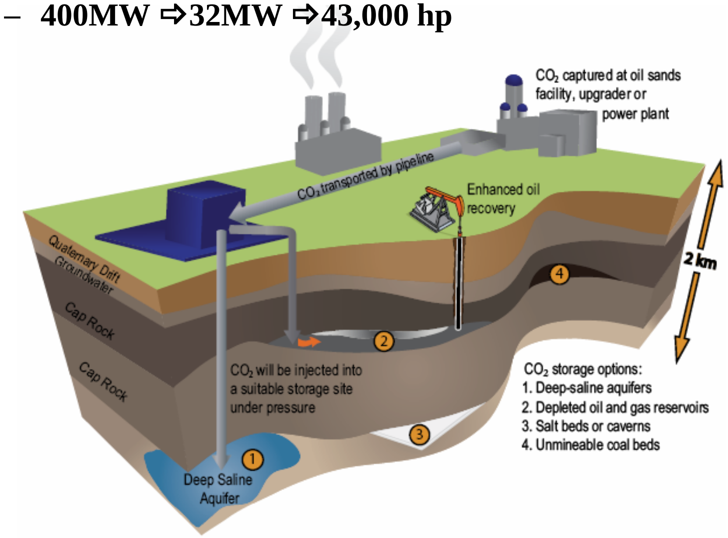
What is Carbon Capture & Storage (CCS)?

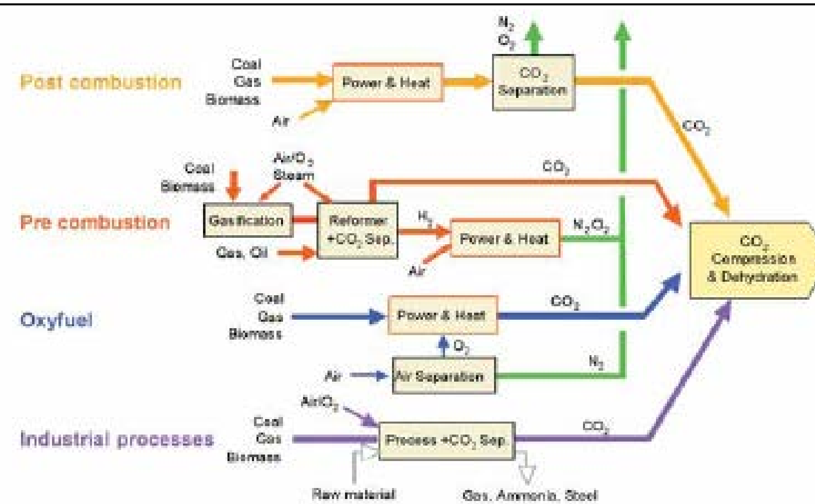
Fossil Fuel Power Plant – CC&S

- All fossil fuel power plants produce some level of CO2
- CO2 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

This is the compressor(s)







Compression Costs are 36% of Total Cost/Mt of CO2

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This is what 6000 hp Compressor Really Looks Like

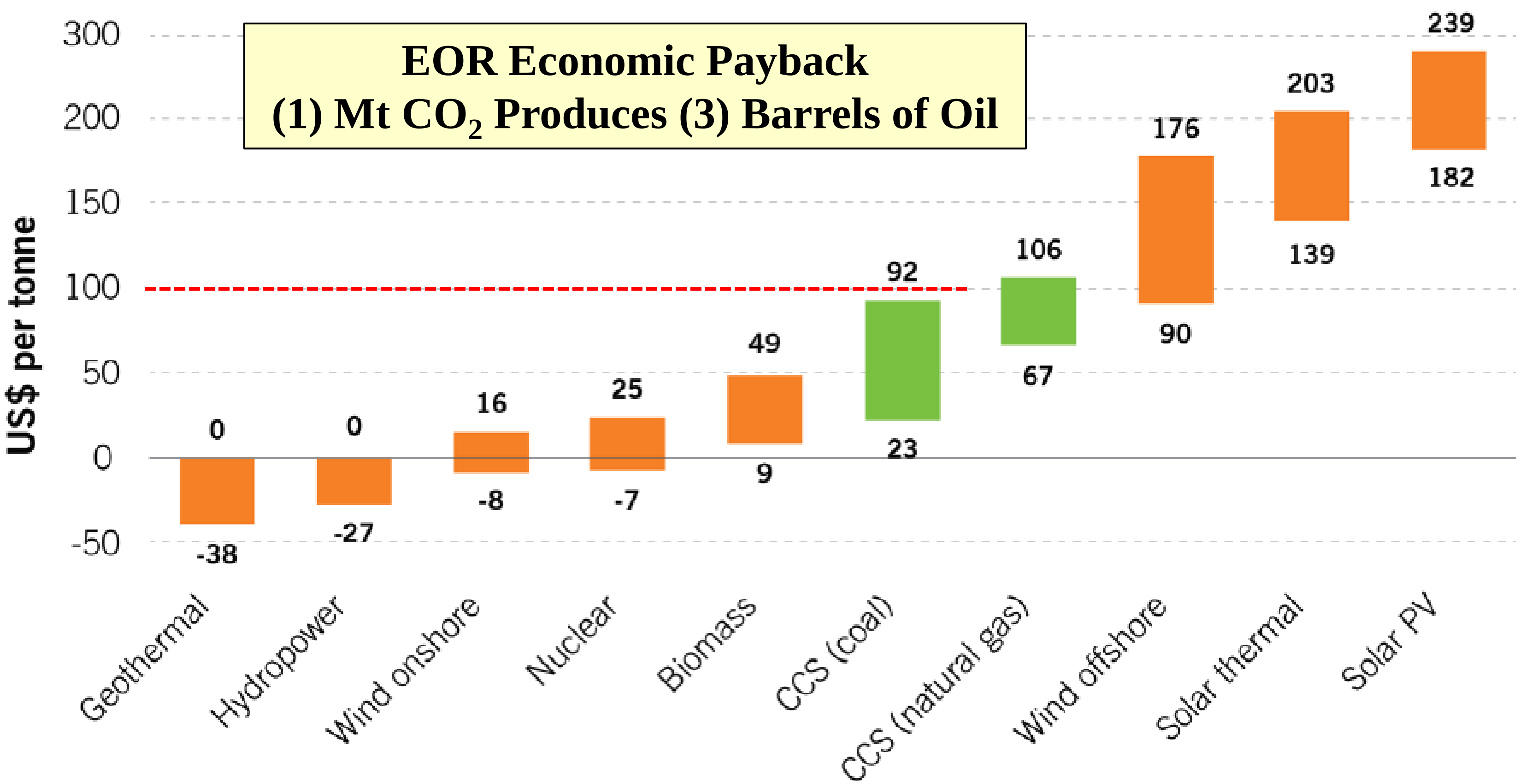
Pr 200:1
1.70 Pr per stage
10-stage
6000 hp
$8.0 million
$1350/hp

Costs of CO_2 Avoided

Costs of CO_2 avoided

Source: Global CCS Institute Victor Der July 2013

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



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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

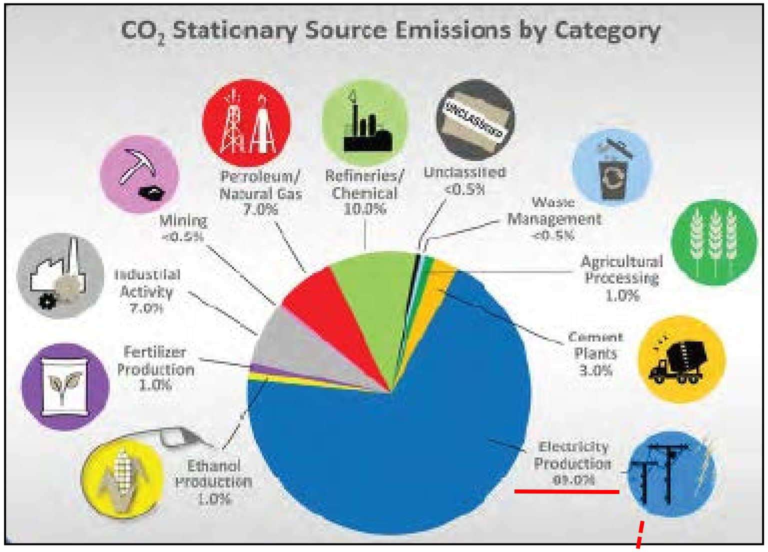
RCSP or Geographic Region	CO_2 Stationary Sources		CO_2 Storage Resource Estimates (billion metric tons of CO_2)								
			Saline Formations			Oil and Gas Reservoirs			Unmineable Coal Areas		
	CO_2 Emissions (million metric tons per year)	Number of Sources	Low	Med***	High	Low	Med***	High	Low	Med***	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 (Slide 12)

– 2011 = 5601 (37.6%)

– 2015 = 5680 (37.3%)

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

Putting a Value on CO_2 – Two Popular Choices

"Cap & Trade"

- Is really two distinct components
- "Trade" is easy with existing market mechanisms already in place
- "Cap" is political, given to influence
- Do we really want politicians in the middle of this?
- Do they want to be in the middle of this?
- This is what destroyed the EU CO_2 Market when too many credits were given away

"Carbon Tax" – two concepts

- "Tax/Fee & Dividend
  - Administered thru political process
  - "Revenue Neutral" because the money is returned to the public (minus an admin fee, of course)
  - Actual impact on behavior is questionable – demand is generally inelastic
- Simple Energy Tax

Most parties agree the most important action is to put a value on CO_2

Third Choice – Waste Disposal Fee

"Waste Disposal Fee"

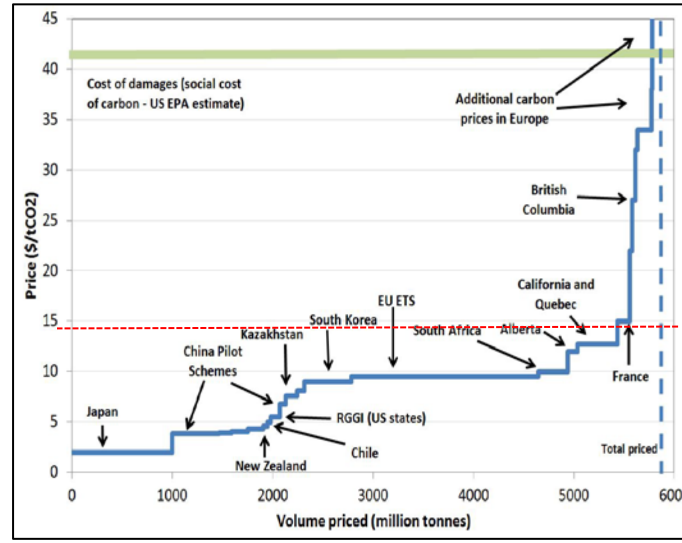
- Limited political oversight required
- Fee based on usage
- Actually use the money to fix the problem
- We don't have sufficient disposal options & we are not developing any at this time

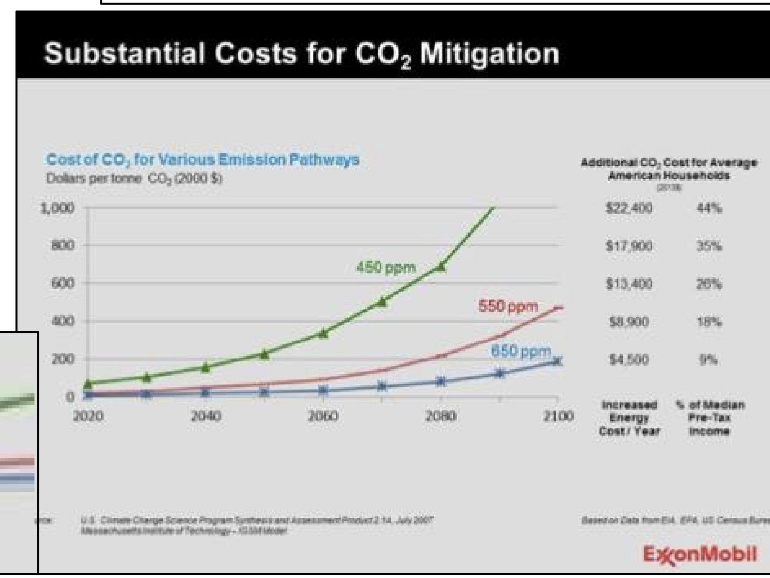
CO_2 Pricing

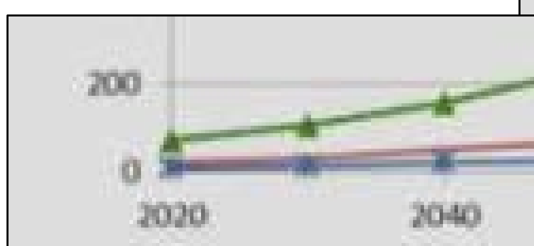
Source: On Climate Change Policy

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 thus 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.







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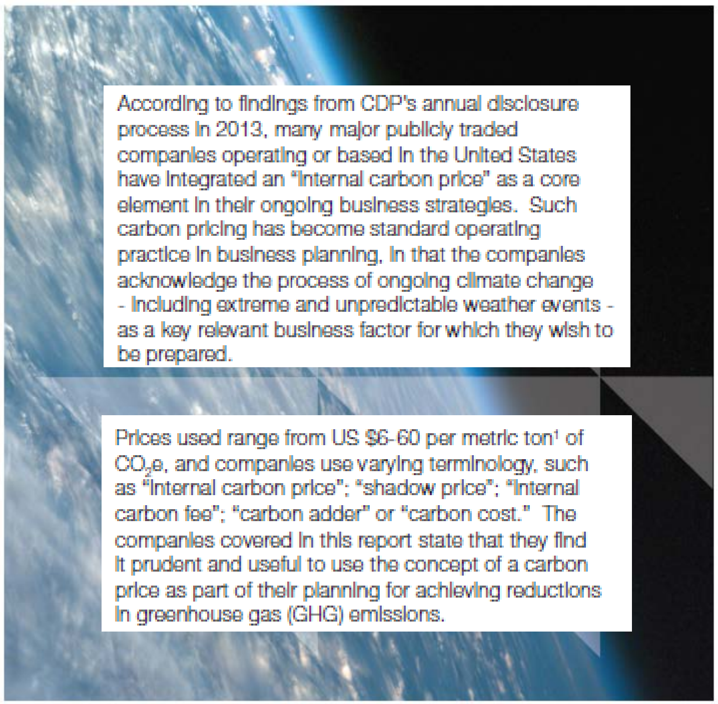
Corporate "Shadow" Pricing

CDP
DRIVING SUSTAINABLE ECONOMIES

Use of internal carbon price by companies as incentive and strategic planning tool

A review of findings from CDP 2013 disclosure

December 2013



According to findings from CDP's annual disclosure process in 2013, many major publicly traded companies operating or based in the United States have integrated an "internal carbon price" as a core element in their ongoing business strategies. Such carbon pricing has become standard operating practice in business planning, in that the companies acknowledge the process of ongoing climate change - including extreme and unpredictable weather events - as a key relevant business factor for which they wish to be prepared.

Prices used range from US $6-60 per metric ton[1] of CO_2e, and companies use varying terminology, such as "internal carbon price"; "shadow price"; "internal carbon fee"; "carbon adder" or "carbon cost." The companies covered in this report state that they find it prudent and useful to use the concept of a carbon price as part of their planning for achieving reductions in greenhouse gas (GHG) emissions.

A white paper from CDP North America

Figure 1: 29 Companies disclose using an internal price on carbon*

Consumer Discretionary	
	Delphi Automotive Plc
	Walt Disney Company, $10-20 **
Consumer Staples	
	ConAgra Foods, Inc.
	Wal-Mart Stores, Inc.
Energy	
	Apache Corporation
	BP, $40
	Chevron Corporation
	ConocoPhillips, $8 – 46
	Devon Energy Corporation, $15
	Exxon Mobil Corporation, $60
	Hess Corporation
	Royal Dutch Shell, $40
	Total, $34
Financials	
	Wells Fargo & Company
Industrials	
	Cummins Inc.
	Delta Air Lines
	General Electric Company
Information Technology	
	Google Inc., $14
	Jabil Circuit, Inc.
	Microsoft Corporation, $6-7 **
Materials	
	E.I. du Pont de Nemours and Company
Utilities	
	Ameren Corporation, $30
	American Electric Power Company, Inc.
	CMS Energy Corporation
	Duke Energy Corporation
	Entergy Corporation
	Integrys Energy Group
	PG&E Corporation
	Xcel Energy Inc., $20

Exxon Mobil $60/Mt

Oil Company Chiefs Back Climate Change Pact

The chief executives of 10 large oil and gas companies have agreed to collaborate on cutting emissions of greenhouse gases, calling for an international agreement on climate change at the "COP21" summit next December in Paris.

In a "joint collaborative declaration," members of the Oil & Gas Climate Initiative said they have lowered GHG emissions from operations by a collective 20% over the past 10 years and continue to invest in natural gas, carbon capture and storage (CCS), renewable energy, and research.

At the Paris meeting, held under auspices of the United National Environmental Program, world leaders will seek agreement on steps to lower emissions thought to be enough to keep globally averaged temperature from rising more than 2°C. above preindustrial levels.

The declaration noted a dual challenge to governments of allowing energy supply to grow as needed and of lowering GHG emissions.

"It is our hope that COP21 will help to overcome these challenges and put us on a progressive pathway for addressing climate change," it said.

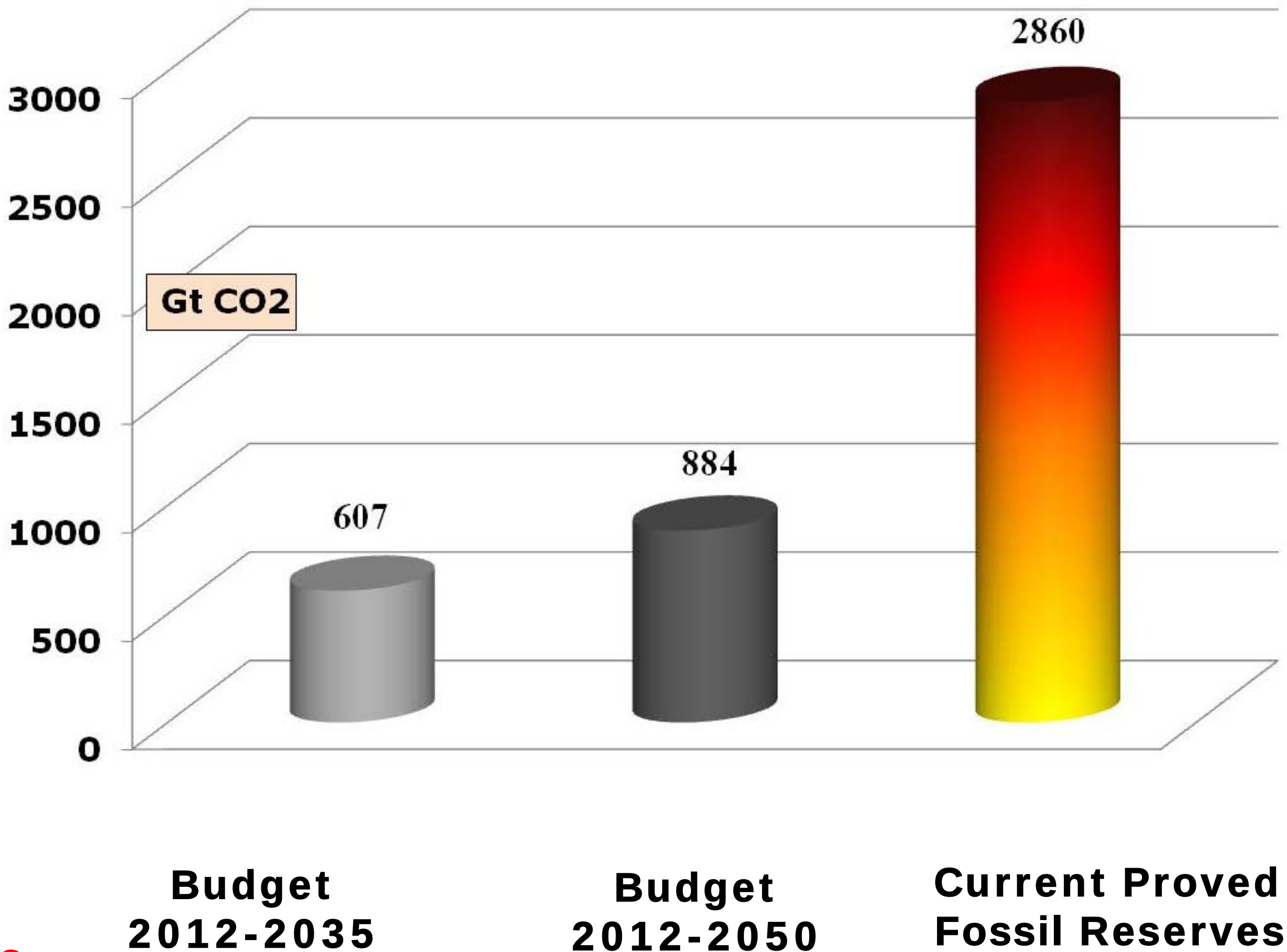
Signatories represent **BG Group, BP, Eni, Pemex, Reliance Industries Ltd., Repsol, Shell, Saudi Aramco, Statoil, and Total.**

They committed to collaborate, "with the aim of going beyond the sum of our individual efforts," in these areas.

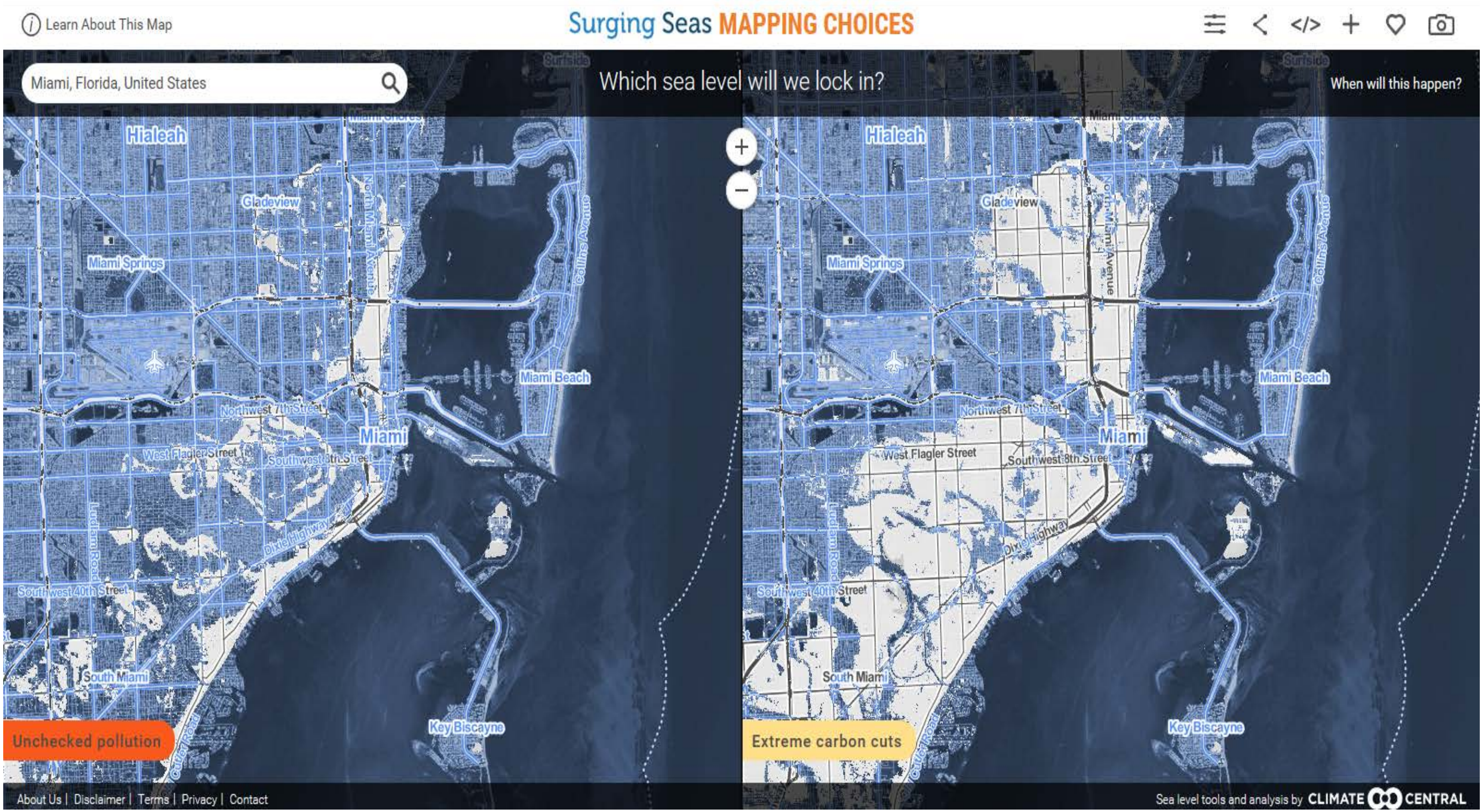
O&G Journal 10/16/2015

Stranded fossil Assets

Source: IEA, WEO 2012 ©OECD/IEA 2012



How About Putting a Value on Miami?



Miami 2050

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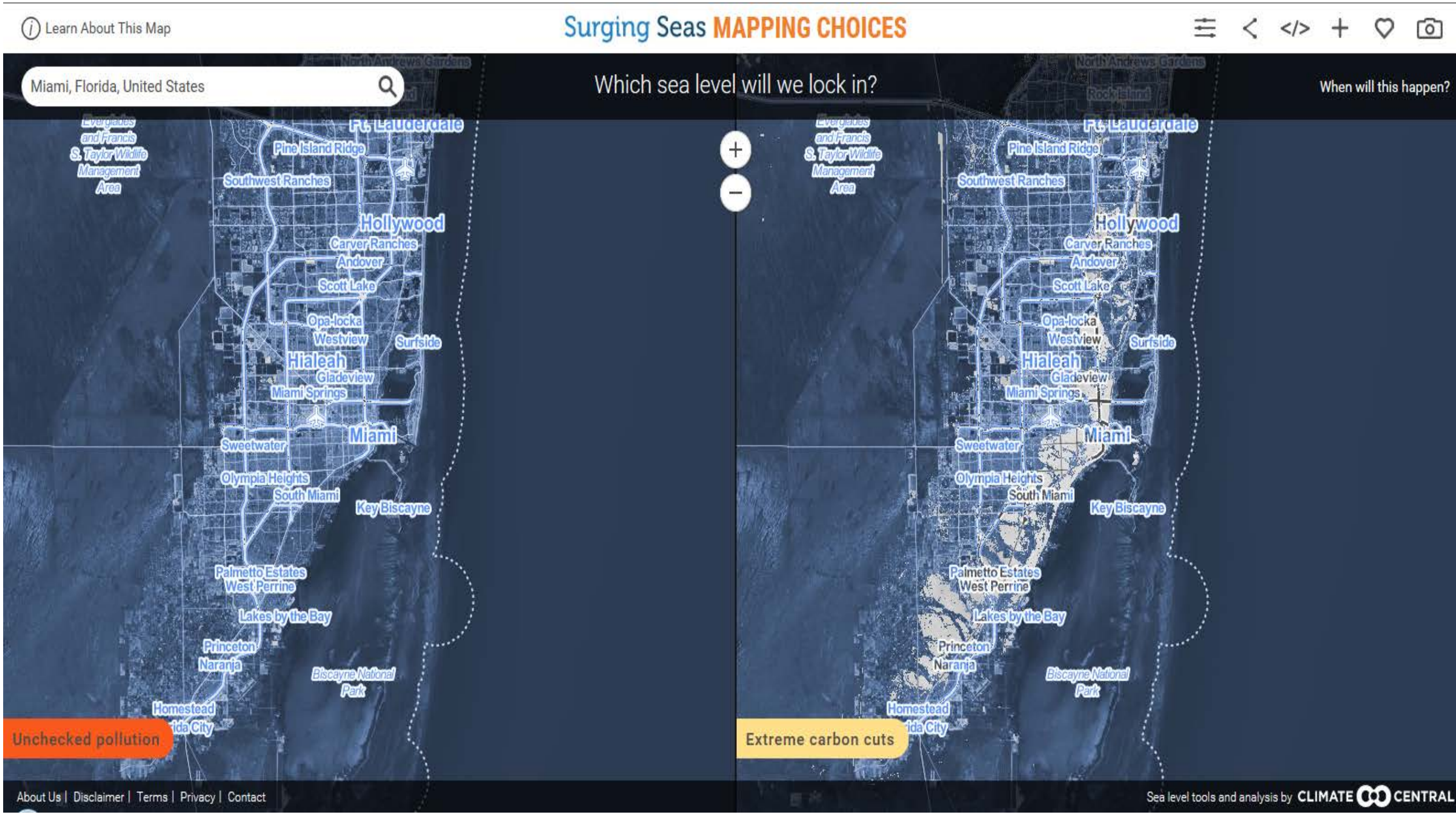
How About Putting a Value on Miami?



Miami 2100

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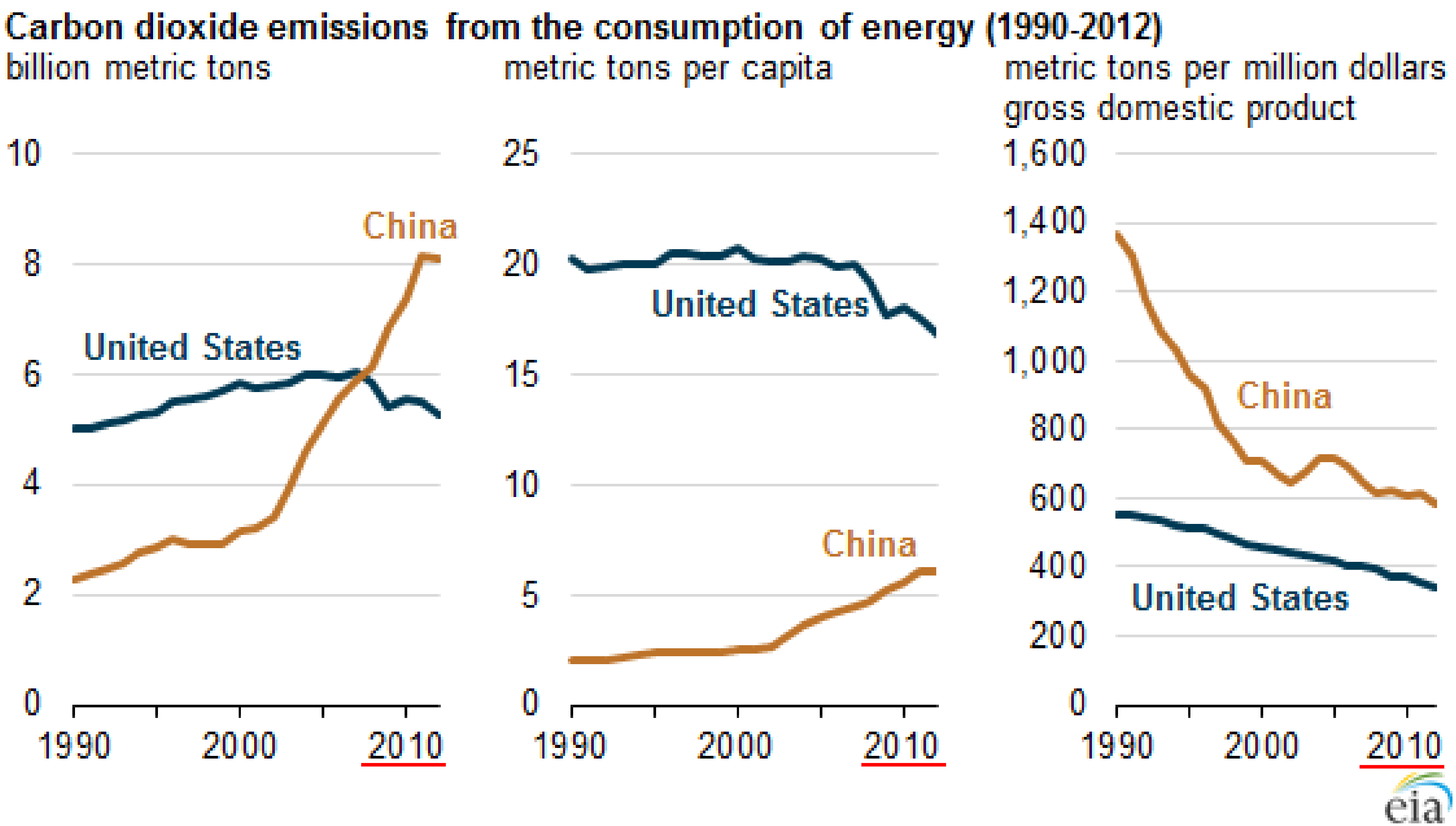
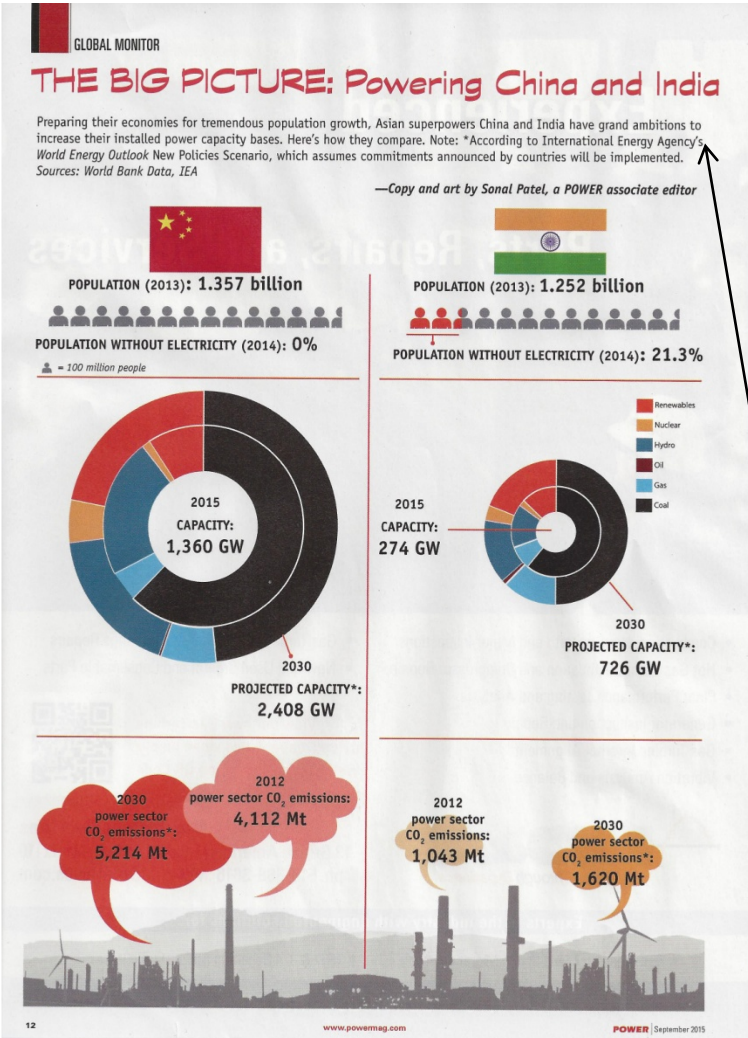
Targets and Measurements (goal setting)

- Developed Economies want hard targets on tonnes of CO_2 emitted
- Developing Economies want tonnes-CO_2/GDP to allow their economies to continue to grow
  - Some have suggested reparations are in order to compensate developing countries for the damage caused by the developed economies
- China, the USA, and now India are the only countries in that can make a difference in this discussion and in reaching any of the goals.
  - The other countries will follow in line once these “big three” reach agreement.
  - That said, such an agreement may take a while.
- The are very few scenarios to reaching 450 ppm/2°C that do not include both nuclear and CCS
- Placing a value on CO_2 can eliminate the “need” for goals and maybe political involvement!!!

Paris Targets



China & India



China Power Sector

- 2012
  - 4,112 Mt vs. 8,381 Mt total – 49.1%
- 2030
  - 5,214 Mt vs. 12,262 Mt – 42.5%

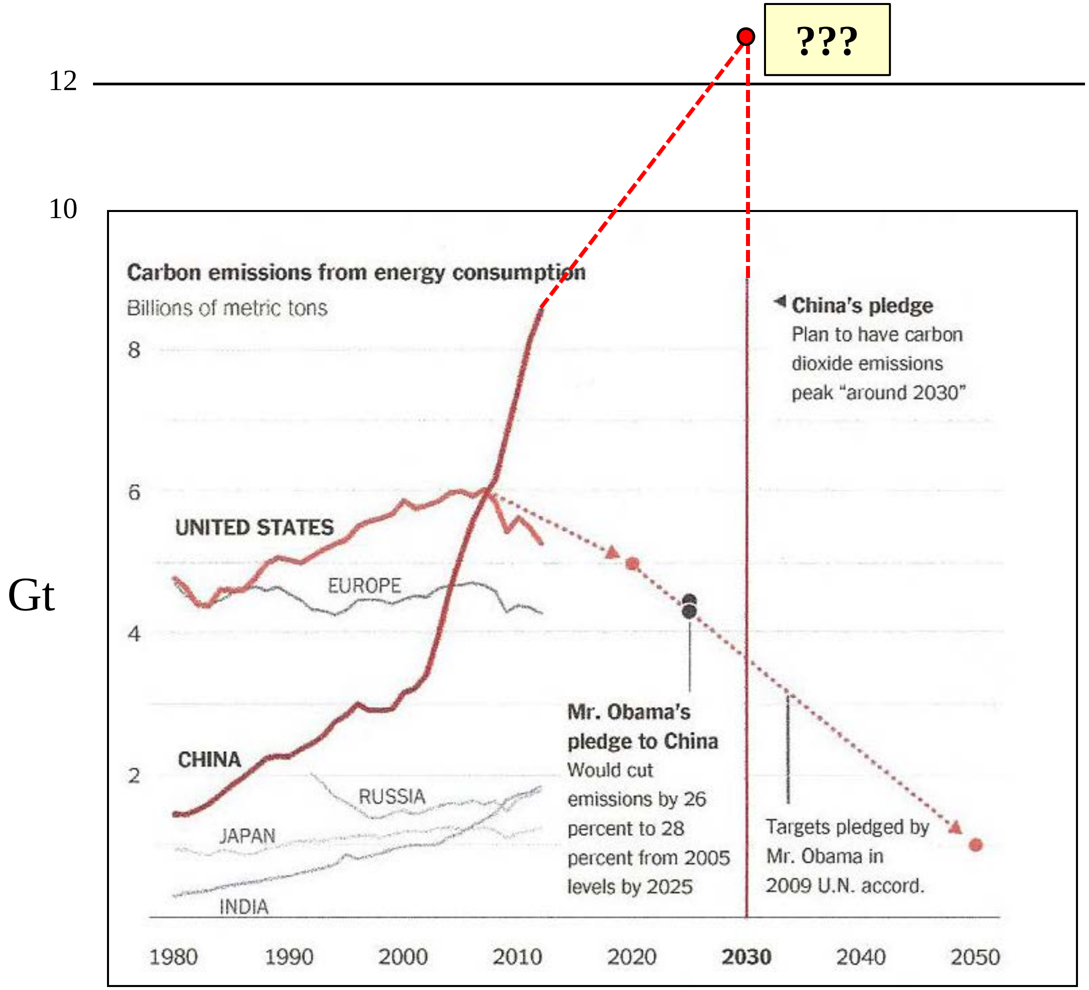
India Power Sector

- 2012
  - 1,043 Mt vs. 1,633 Mt total – 63.9%
- 2030
  - 1,620 Mt vs. 2,728 Mt – 59.4%

Note: "According to IEA World Energy Outlook, New Policies Scenario, which assumes commitments announced by countries will be implemented."

Source: EIA via Power Magazine September 2015

The China-U.S. – 2014 CO2 Emissions Agreement - Gt



New York Times

China agreed to peak CO2 emission by 2030

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Pete's Pet Peaves

This is water vapor

Cost or Price

This is a smoke stack

It's Climate Change….
….not Global Warming

1 Short Ton = 2000 lbs
1 metric tonne = 2205 lbs

These are cooling towers

What Should We Do Now?

- Put a Value on CO_2
  - My favorite - "CO_2 Waste Disposal Fee"
  - Get the 'politico's out of the process
- Drive CCS for all Power Plants at 300 lb-CO_2/MWh
  - Forces capture for all types of Power Plants
  - Incents NGCC to design "Capture Ready
  - Uses the lower cost of natural gas to offset the added cost of CCS
  - Actually get on the "learning curve" and the trajectory to 2°C/450PPM
  - Supports all clean motor vehicle applications
- Accelerate CCS selection & pre-permitting process for "solutions"
  - Capture processes
  - Pipelines
  - Storage sites
- Eliminate distorting Renewable Portfolio Standards & Production Tax Credits

Policy Parity

Put a price on CO_2 and a value on Miami!

Winchester Unitarian Society

478 Main St, Winchester, MA 01890

(781) 729-0949

http://winchesteruu.org/

Pete Baldwin

(617)-306-7419

www.base-e.net

Appendix

AEO2014 Cost & Performance New Generating Tech

Technology	Online Year[1]	Size (MW)	Lead time (years)	Base Overnight Cost in 2013 (2012 $/kW)	Project Contingency Factor[2]	Technological Optimism Factor[3]	Total Overnight Cost in 2013 (2012 $/kW)	Variable O&M (2012 $/MWh)	Fixed O&M (2012$/kW-yr.)	Heatrate[6] in 2013 (Btu/kWh)	nth-of-a-kind Heatrate (Btu/kWh)
Scrubbed Coal New	2017	1300	4	2,734	1.07	1.00	2,925	4.47	31.18	8,800	8,740
Integrated Coal-Gasification Comb Cycle (IGCC)	2017	1200	4	3,525	1.07	1.00	3,771	7.22	51.39	8,700	7,450
IGCC with carbon sequestration	2017	520	4	5,958	1.07	1.03	6,567	8.45	72.84	10,700	8,307
Conv Gas/Oil Comb Cycle	2016	620	3	871	1.05	1.00	915	3.60	13.17	7,050	6,800
Adv Gas/Oil Comb Cycle (CC)	2016	400	3	945	1.08	1.00	1,021	3.27	15.37	6,430	6,333
Adv CC with carbon sequestration	2017	340	3	1,856	1.08	1.04	2,084	6.78	31.79	7,525	7,493
Conv Comb Turbine[8]	2015	85	2	924	1.05	1.00	971	15.45	7.34	10,817	10,450
Adv Comb Turbine	2015	210	2	641	1.05	1.00	673	10.37	7.04	9,750	8,550
Fuel Cells	2016	10	3	6,099	1.05	1.10	7,044	42.99	0.00	9,500	6,960
Adv Nuclear	2019	2234	6	4,763	1.10	1.05	5,501	2.14	93.28	10,464	10,464
Distributed Generation - Base	2016	2	3	1,414	1.05	1.00	1,485	7.76	17.45	9,027	8,900
Distributed Generation - Peak	2015	1	2	1,698	1.05	1.00	1,783	7.76	17.45	10,029	9,880
Biomass	2017	50	4	3,590	1.07	1.02	3,919	5.26	105.64	13,500	13,500
Geothermal[7,9]	2016	50	4	2,375	1.05	1.00	2,494	0.00	112.92	9,716	9,716
Municipal Solid Waste	2014	50	3	7,751	1.07	1.00	8,294	8.75	392.81	18,000	18,000
Conventional Hydropower[9]	2017	500	4	2,213	1.10	1.00	2,435	2.65	14.83	9,716	9,716
Wind	2014	100	3	2,061	1.07	1.00	2,205	0.00	39.55	9,716	9,716
Wind Offshore	2017	400	4	4,503	1.10	1.25	6,192	0.00	74.00	9,716	9,716
Solar Thermal[7]	2016	100	3	4,715	1.07	1.00	5,045	0.00	67.26	9,716	9,716
Photovoltaic[7,10]	2015	150	2	3,394	1.05	1.00	3,564	0.00	24.69	9,716	9,716

AEO 2014 Early Release

Gross vs. Net Power

	Integrated Gasification Combined Cycle						Pulverized Coal Boiler				NGCC	
	GEE		CoP		Shell		PC Subcritical		PC Supercritical		Advanced F Class	
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 9	Case 10	Case 11	Case 12	Case 13	Case 14
CO_2 Capture	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Gross Power Output (kW_e)	770,350	744,960	742,510	693,840	748,020	693,555	583,315	679,923	580,260	663,445	570,200	520,090
Auxiliary Power Requirement (kW_e)	130,100	189,285	119,140	175,600	112,170	176,420	32,870	130,310	30,110	117,450	9,840	38,200
Net Power Output (kW_e)	640,250	555,675	623,370	518,240	635,850	517,135	550,445	549,613	550,150	545,995	560,360	481,890
Coal Flowrate (lb/hr)	489,634	500,379	463,889	477,855	452,620	473,176	437,699	646,589	411,282	586,627	N/A	N/A
Natural Gas Flowrate (lb/hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	165,182	165,182
HHV Thermal Input (kW_{th})	1,674,044	1,710,780	1,586,023	1,633,771	1,547,493	1,617,772	1,496,479	2,210,668	1,406,161	2,005,660	1,103,363	1,103,363
Net Plant HHV Efficiency (%)	38.2%	32.5%	39.3%	31.7%	41.1%	32.0%	36.8%	24.9%	39.1%	27.2%	50.8%	43.7%
Net Plant HHV Heat Rate (Btu/kW-hr)	8,922	10,505	8,681	10,757	8,304	10,674	9,276	13,724	8,721	12,534	6,719	7,813
Raw Water Usage, gpm	4,003	4,579	3,757	4,135	3,792	4,563	6,212	12,187	5,441	10,444	2,511	3,901
Total Plant Cost ($ x 1,000)	1,160,919	1,328,209	1,080,166	1,259,883	1,256,810	1,379,524	852,612	1,591,277	866,391	1,567,073	310,710	564,628
Total Plant Cost ($/kW)	1,813	2,390	1,733	2,431	1,977	2,668	1,549	2,895	1,575	2,870	554	1,172
LCOE (mills/kWh)[1]	78.0	102.9	75.3	105.7	80.5	110.4	64.0	118.8	63.3	114.8	68.4	97.4
CO_2 Emissions (lb/hr)	1,123,781	114,476	1,078,144	131,328	1,054,221	103,041	1,038,110	152,975	975,370	138,681	446,339	44,634
CO_2 Emissions (tons/year) @ CF[1]	3,937,728	401,124	3,777,815	460,175	3,693,990	361,056	3,864,884	569,524	3,631,301	516,310	1,661,720	166,172
CO_2 Emissions (tonnes/year) @ CF[1]	3,572,267	363,896	3,427,196	417,466	3,351,151	327,546	3,506,185	516,667	3,294,280	468,392	1,507,496	150,750
CO_2 Emissions (lb/MMBtu)	197	19.6	199	23.6	200	18.7	203	20.3	203	20.3	119	11.9
CO_2 Emissions (lb/MWh)[2]	1,459	154	1,452	189	1,409	149	1,780	225	1,681	209	783	85.8
CO_2 Emissions (lb/MWh)[3]	1,755	206	1,730	253	1,658	199	1,886	278	1,773	254	797	93

[1] Capacity factor is 80% for IGCC cases and 85% for PC and NGCC cases

[2] Value is based on gross output

[3] Value is based on net output

Note magnitude of Auxiliary Power

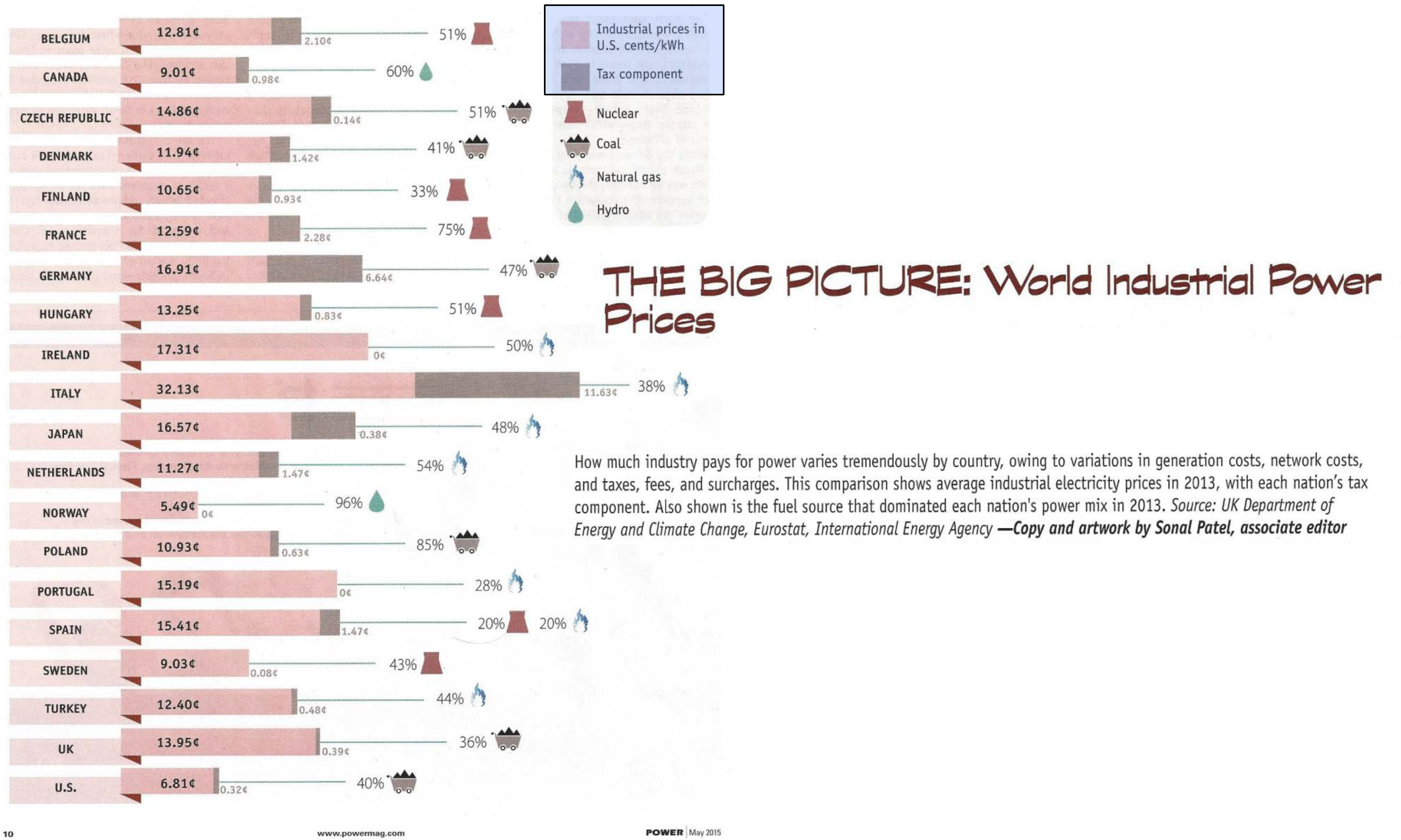
Cost and Performance Baseline for Fossil Energy Plants

DOE/NETL-2007/1281

base e

"Practical Strategies for Emerging Energy Technologies"

The Big Picture: World Industrial Power Prices



“Practical Strategies for Emerging Energy Technologies”

British Columbia Carbon Tax “Success”

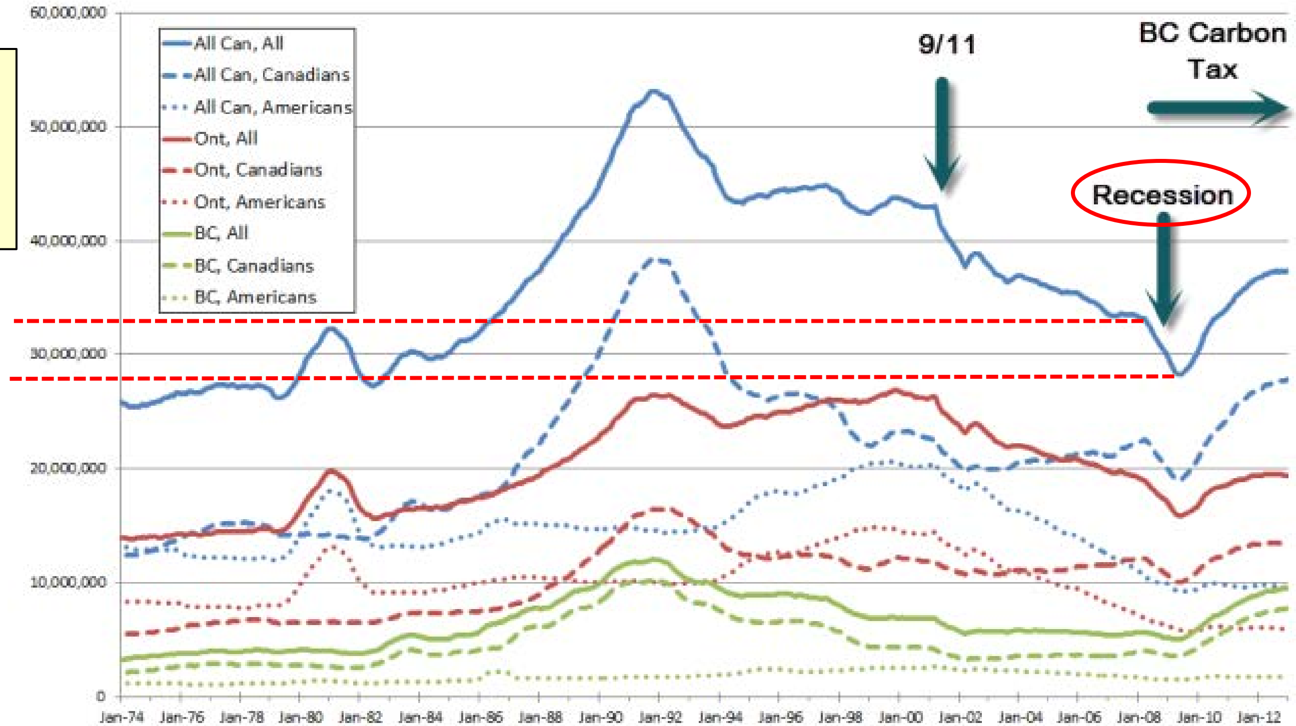
- “Successful implementation”
  - 16% drop in consumption after introduction in 2008
- Initially \$C10/tonne, increasing to current \$C30/tonne
  - \$C30/tonne = 7 cents/liter = 26.5 cents/gallon
- Use of ½ Carbon Tax funds for Regional Transit expansion denied
- A 2nd Carbon Tax is being discussed to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

33,000,000
Δ-15%
28,000,000



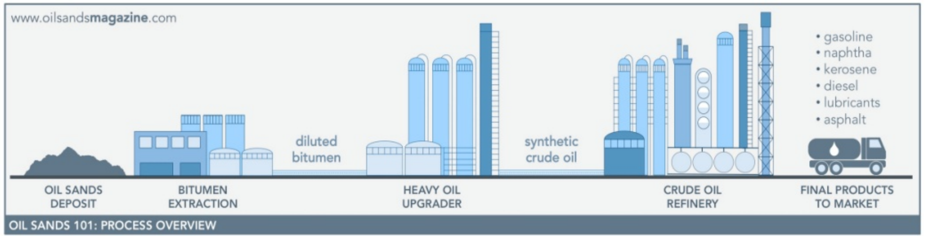
19.64 lb-CO_2/gal
750 gal
14,730 lb-CO_2
6.68 tonnes
\$200 @ \$30/tonne

base$_e$

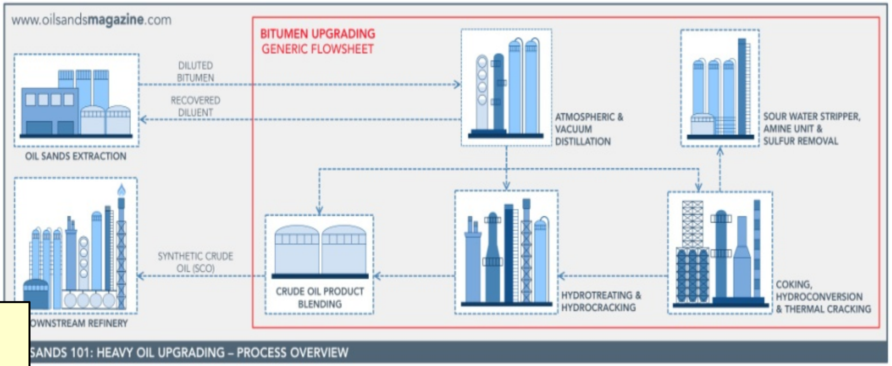
“Practical Strategies for Emerging Energy Technologies”

Oil Sands (aka, Tar Sands, XL Pipeline)

- **Petroleum products are produced from the oil sands through 3 basic steps:**
  - Extraction of the bitumen from the oil sands, where the solids and water are removed
  - Upgrading of the heavy bitumen to a lighter, intermediate crude oil product
  - Refining of the crude oil into final products such as fuels, lubricants and diluents.



- **There are currently 6 operating upgraders in Canada:**
  - 3 located north of Fort McMurray, AB (Suncor, Syncrude and CNRL)
  - 1 located south of Fort McMurray, AB (CNOOC/Nexen)
  - 1 located NE of Edmonton, AB (Shell), and
  - 1 located in Lloydminster, SK (Husky).

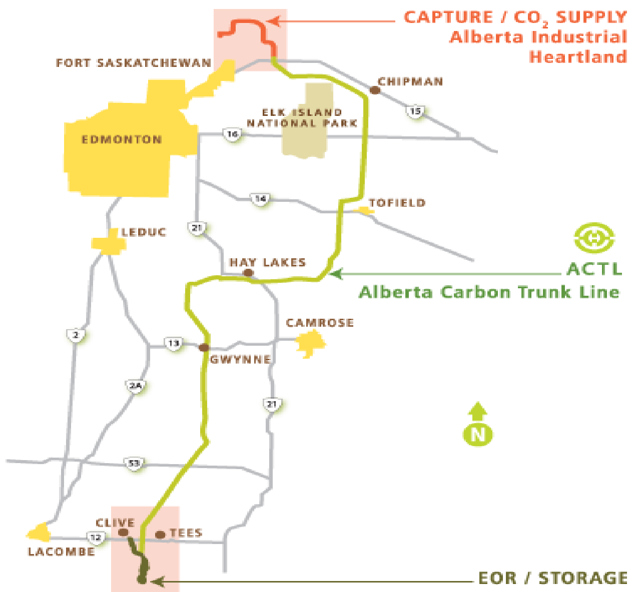


There is no acknowledgment of the upgrade process or of CO_2 Capture in any of the rhetoric "south of the border"

"Practical Strategies for Emerging Energy Technologies"

Enhance Energy - Alberta Trunk Line

- At full capacity the **ACTL** route will provide access to reservoirs capable of producing an additional one billion barrels of high quality light crude oil.
- These reservoirs will safely and securely store **14.6 million tonnes** of CO_2 per year as the oil is produced.



- **Enhance** is still pursuing the construction and operation of the Alberta Carbon Trunkline targeting to be onstream with first CO_2 injection at the end of 2016.
- **North West Refining** is significantly under construction.
  - Committed over $5Billion to the project (total cost $8.5 B), a
  - Scheduled to be in commercial operation in September 2017.
  - Using – Lurgi Rectisol – was selected as pure CO_2 is a byproduct of the process.
  - Other refineries use Steam Methane Reforming (SMR) which results in impure CO_2 as a byproduct, which would require additional processing to allow for use in CO_2 EOR or Carbon Capture and Utilization (CCUS).
- **Shell Quest** project is operational as of June 2015.
  - Presently they are injecting their CO_2 into an aquifer approximately 100 kms Northeast of Edmonton.
- **Weyburn CO2**
  - DGC (Dakota Gasification Company) in Beulah North Dakota.
  - Weyburn is also receiving CO_2 from the SaskPower Boundary Dam project

NREL Levels of Renewable Energy Potential

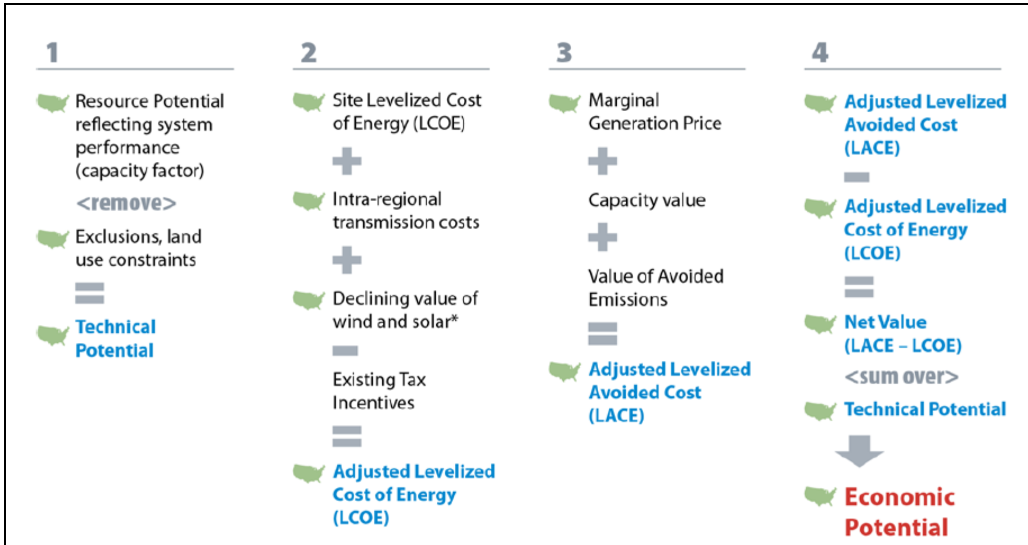
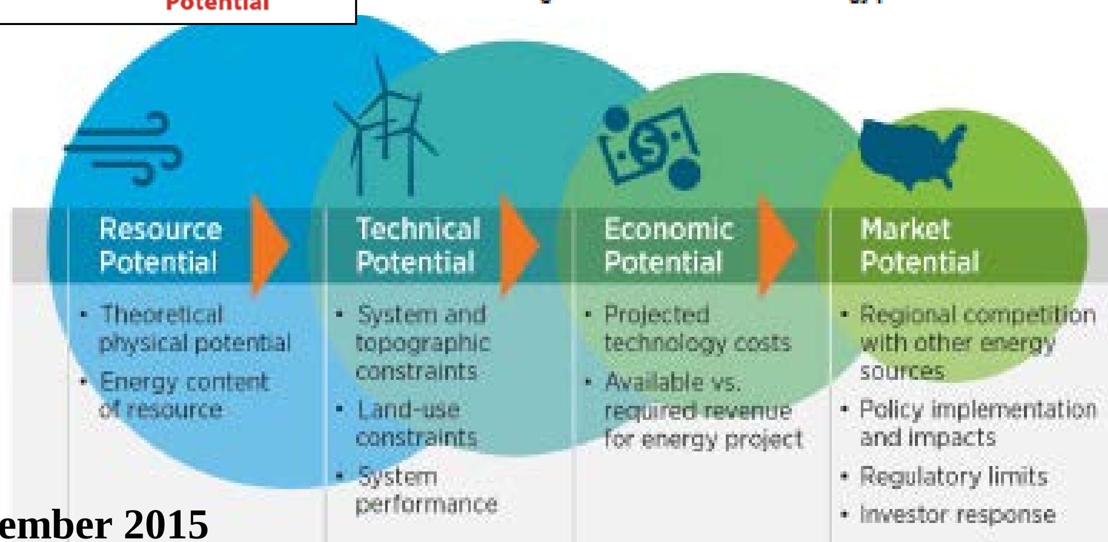


Figure 1. Levels of renewable energy potential



NREL November 2015

Economic Potential – U.S. Renewables

Table ES-1. Aggregated Estimated U.S. Economic Potential for Primary Cases

		Economic Potential - Annual Generation (TWh)						
Primary Case	Specific Cases	Wind	UPV	DPV[5]	Hydro-power	Geo-thermal	Bio-power	Sum of Assessed
Reference Data	2013 Generation[1]	168	11	10	269	17	60	534
	Technical Potential[2]	22,195	297,475	1,560	278	234	445	322,187
Primary Case 1 - LACE Only[3]	Primary Case with Full Capacity Value	319	6,468	194	50	109	0	7,140
	Primary Case with No Capacity Value	135	2,789	194	38	29	0	3,184
Primary Case 2 - LACE including Value of Avoided External Costs[3]	Primary Case with Full Capacity Value	7,870	33,523	287	76	153	0	41,909
	Primary Case with No Capacity Value	4,590	7,713	287	64	131	0	12,785
Primary Case 3 - LACE including Value of Avoided External Costs and Declining Value of Variable Generation[4]	Primary Case with Full Capacity Value*	869	606	287	76	153	0	1,991
	Primary Case with No Capacity Value*	548	430	287	64	131	0	1,460

Generated in 2012 – 4048 (36%)

Notes

1 As reported in 2013 Renewable Energy Data Book (2014); including Alaska and Hawaii. Total generaton from all sources in 2013 was ~ 4100 Twh.

2 As updated in this report; excluding Alaska and Hawaii. Estimates may differ from prior assessments including Lopez et al. (2012) due to differences in the classification of resources (e.g., in some cases hydropower upgrades are not considered as new technical potential), advancements in technology (e.g., the availability of higher productivity wind turbines), or other factors.

3 Does not include Alaska and Hawaii; in addition to existing generation.

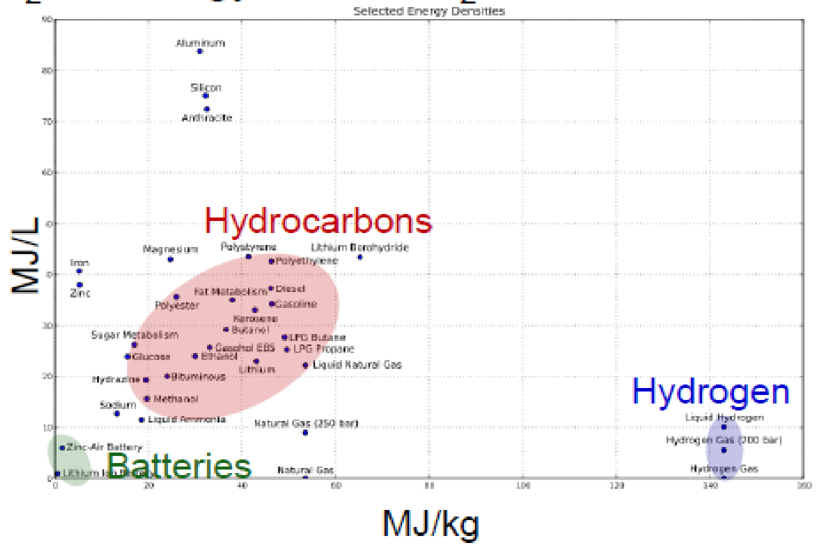
4 Does not include Alaska and Hawaii; in addition to existing generation. Declining value applied to Wind and UPV only. An asterisk symbol (*) to the right of a case name indicates that wind generation potential exceeds 40% of 2013 total generation in some regions and may be overstated as the declining value method applied does not reduce the value of wind further as its potential share of generation exceeds 40%.

5 Not all cases run for DPV, hydropower, geothermal, and biopower; gray-shaded cells indicate that another case is used as a substitute.

NREL November 2015

Conversion of CO_2 to Fuels

- Converting CO_2 to fuels is just a means of energy storage
  - Creating fuel: CO_2 + A + energy → Fuel + O_2
  - Consuming fuel: Fuel + O_2 → energy + A + CO_2
- Uses primary energy source to convert CO_2 into a hydrocarbon
- Liquid fuels can be useful
  - High energy density
  - But emit CO_2 when burned



- Round Trip Efficiency 6 – 18%

CO_2 vs. Top 50 Chemical Produced

		US Production, Estimated 2009			Global Production, Estimated 2009		
		Mt/yr	Gmol/yr	GWe at 90% capture	Mt/yr	Gmol/yr	GWe at 90% capture
1	Sulfuric Acid	38.7	394	2.1	199.9	1879	10.0
2	Nitrogen	32.5	1159	6.2	139.6	4595	24.5
3	Ethylene	25.0	781	4.2	112.6	3243	17.3
4	Oxygen	23.3	829	4.4	100.0	3287	17.5
5	Lime	19.4	347	1.8	283.0	4653	24.8
6	Polyethylene(HDPE, LDPE, LLDPE, etc.)	17.0	530	2.8	60.0	1729	9.2
7	Propylene	15.3	354	1.9	53.0	1134	6.0
8	Ammonla, Synthetic Anhydrous	13.9	818	4.4	153.9	8332	44.3
9	Chlorine	12.0	169	0.9	61.2	795	4.2
10	Phosphoric Acid	11.4	116	0.6	22.0	207	1.1
...	...	...	...	...	...	...	...
45	Acetic Acid	2.3	38	0.2	8.0	123	0.7
46	Propylene Oxide	2.1	37	0.2	6.3	100	0.5
47	Phenolic Resins	2.1	21	0.1	6.8	63	0.3
48	Calcium Carbonate (Precipitated)	2.0	20	0.1	13.0	120	0.6
49	Butadiene (1.3)	2.0	36	0.2	10.3	175	0.9
50	Nylon Resins & Fibers	1.9	8	0.0	2.3	8	0.0
	TOTAL	419	8,681	46	2,412	48,385	257
	2009 Coal-fired Net Generation, GWe-yr			200			>1000+
	Coal-fired Capacity, GWe			314			>1000+
	CO_2 from Electricity	2,400	54,545		~9600	218,182	
	CO_2 from All Sources	6,000	136,364		~31200	750,000	

$A + CO_2 \rightarrow ACO_2$

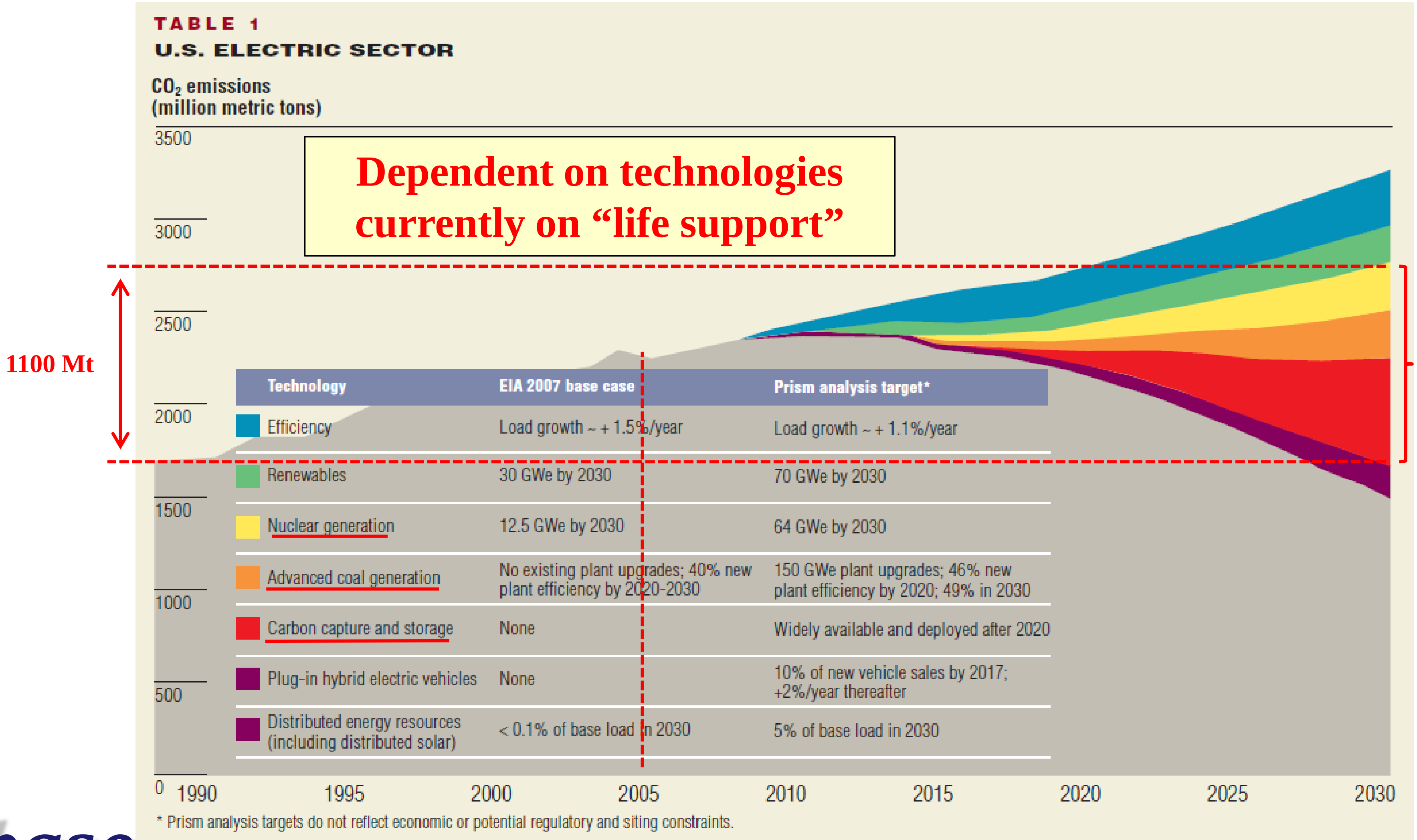
Limited supplies of A & limited sales of ACO_2

Need to regenerate A or make A without producing CO_2

Bhown and Freeman, Environ. Sci. Tech., **45**, 8624, 2011

ELECTRIC POWER RESEARCH INSTITUTE

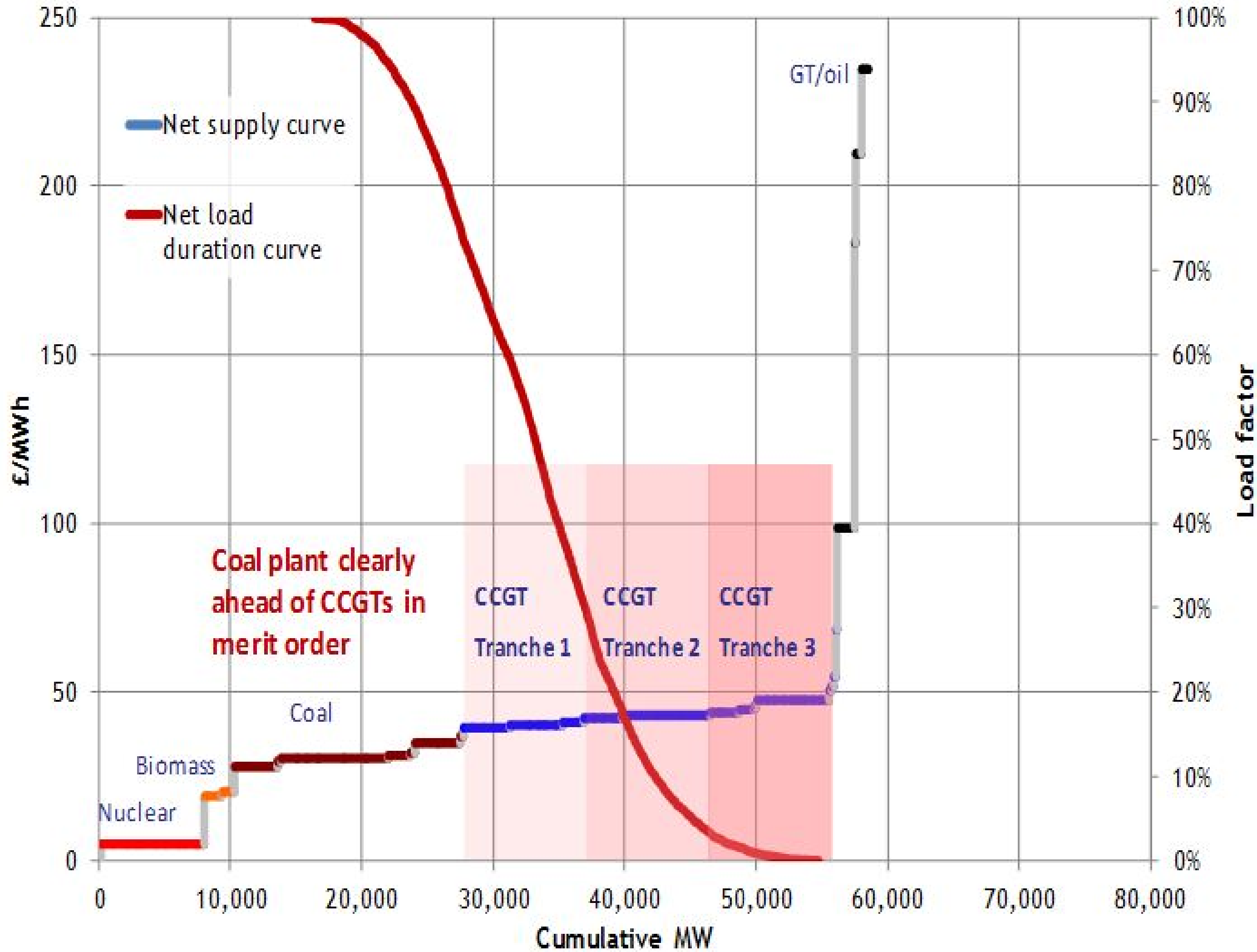
Electric Power Research Institute PRISM Analysis



Technology	EIA 2007 base case	Prism analysis target*
Efficiency	Load growth ~ + 1.5%/year	Load growth ~ + 1.1%/year
Renewables	30 GWe by 2030	70 GWe by 2030
Nuclear generation	12.5 GWe by 2030	64 GWe by 2030
Advanced coal generation	No existing plant upgrades; 40% new plant efficiency by 2020-2030	150 GWe plant upgrades; 46% new plant efficiency by 2020; 49% in 2030
Carbon capture and storage	None	Widely available and deployed after 2020
Plug-in hybrid electric vehicles	None	10% of new vehicle sales by 2017; +2%/year thereafter
Distributed energy resources (including distributed solar)	< 0.1% of base load in 2030	5% of base load in 2030

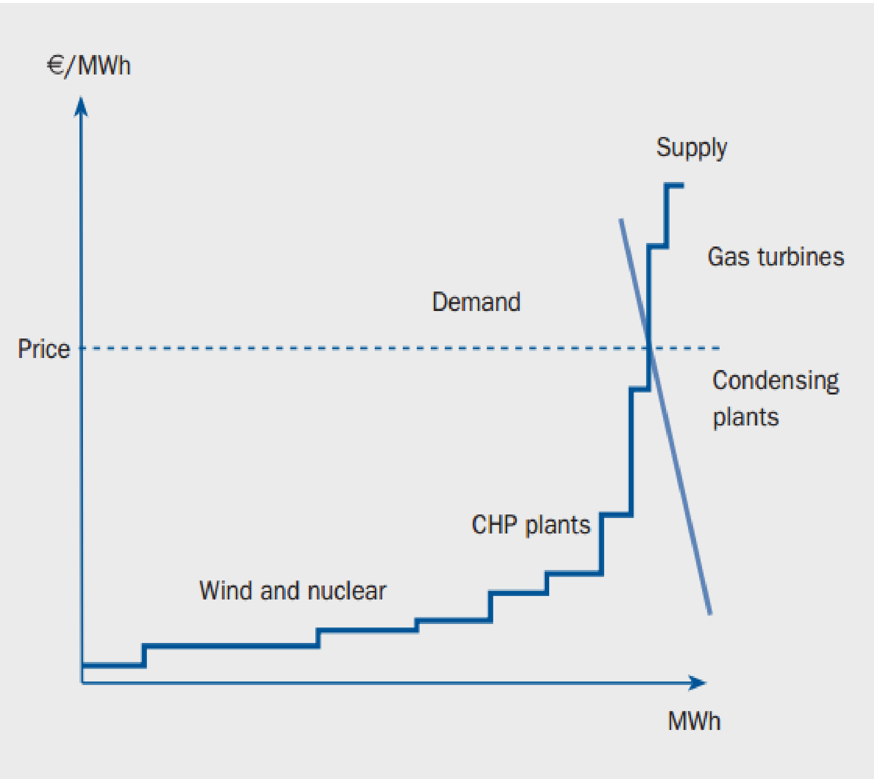
* Prism analysis targets do not reflect economic or potential regulatory and siting constraints.

Traditional Generation Merit Order



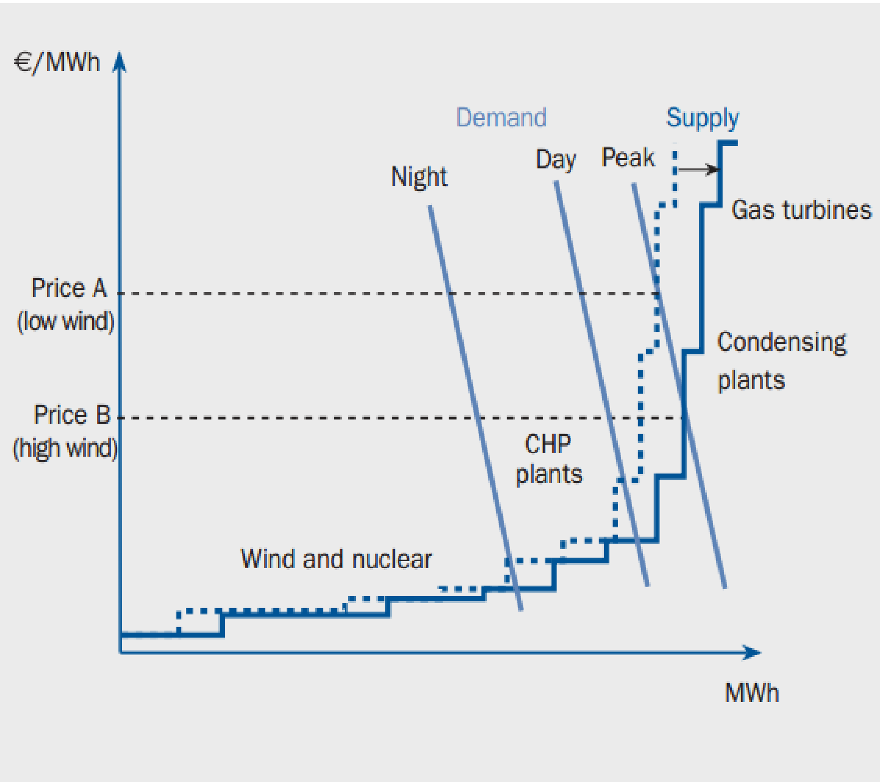
Shift in Supply Cost Curve with Renewables

FIGURE 0.10: **Supply and Demand Curve for the NordPool Power Exchange**



Source: Risø DTU

FIGURE 0.11: **How wind power influences the power spot price at different times of day**



Source: Risø DTU

base e

"Practical Strategies for Emerging Energy Technologies"

EPA Final Rule for Existing Plants "Clean Power Plan"

- In its final rule for existing fossil fuel-fired plants, EPA establishes mandatory CO2 emissions "goals" for each state's electricity sector, including "interim" goals beginning in 2022 (separated into three steps in 2022-2024, 2025-2027, and 2028-2029), and a "final" goal in 2030.
- The mandatory goals are expressed in terms of statewide rate-based and mass-based CO2 emissions goals. The goals are calculated based on 2012 emissions data, and EPA has prepared "State Specific Fact Sheets" and a Table estimating the percentage reductions from 2012 CO2 emissions.
- For existing fossil fuel-fired electric generating units, EPA has determined that three "building blocks" reflect the BSER, including:
  - 1) Heat rate improvements at existing coal units;
  - 2) Shifting from coal-fired generation to generation from existing NGCC units; and
  - 3) Shifting from coal-fired generation to generation from renewables, primarily wind and solar.
- EPA calculates state goals based on this BSER, and has developed separate emissions performance rates for coal and natural gas plants, including:
  - An interim emissions rate for existing coal units of 1,534 lbs CO2 per Net MWh, and a final rate of 1,305 lbs CO2 per Net MWh
  - An interim emissions rate for existing natural gas units of 832 lbs CO2 per Net MWh and the final rate is 771 lbs CO2 per Net MWh.
  - Under the rule, states would be required to submit detailed plans to meet their mandatory CO2 goals.
- EPA states: "One cost-effective way that states can meet their goals is emissions trading, through which affected power plants may meet their emission standards via emission rate credits (for a rate-based standard) or allowances (for a mass-based standard)."

High Efficiency, Low Emissions Coal (HELE)

Figure 10: Reducing CO_2 emissions from pulverised coal-fired power generation

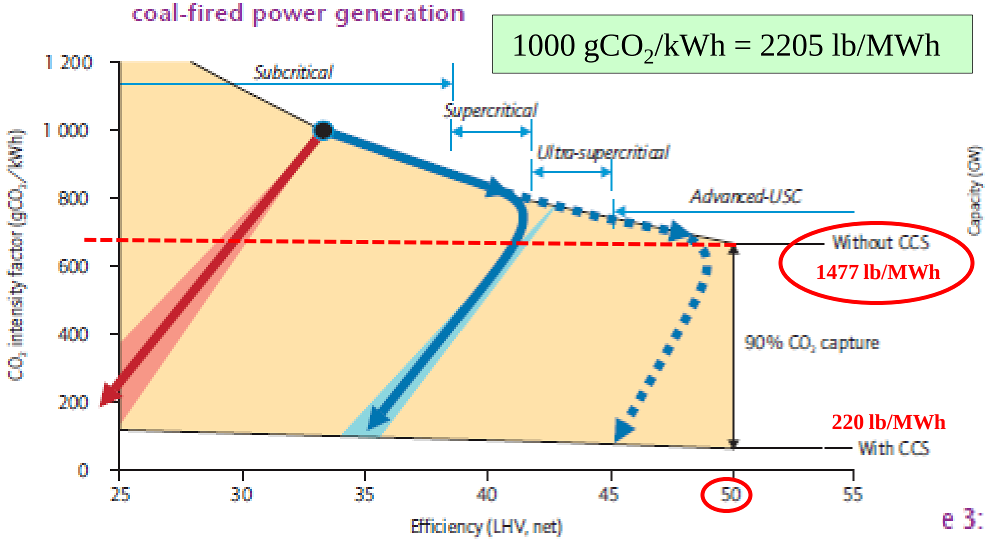
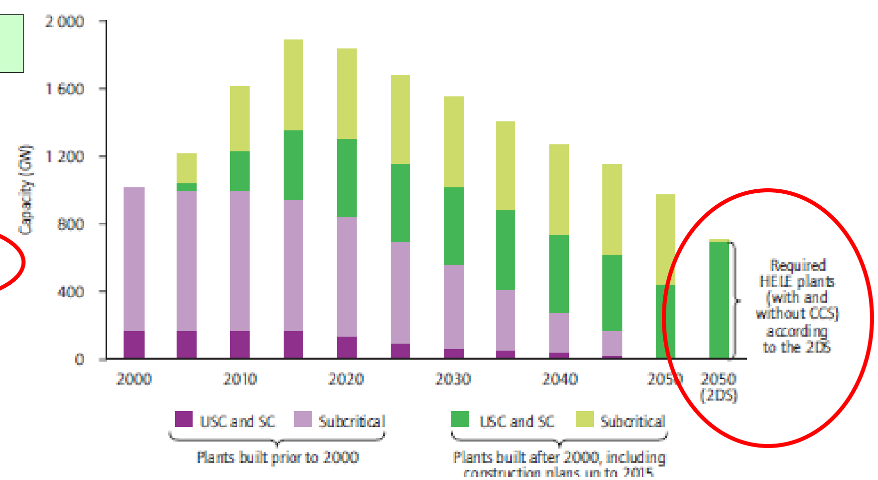


Figure 8: Projected capacity of coal-fired power generation to 2050



- U.S. consumption of coal totaled 18 quadrillion Btu in 2013, a 4-percent increase from 2012
- Electric power sector consumption accounted for 91 percent of total consumption in 2013
- The price of coal averaged \$2.52 per million Btu in the United States in 2013, a 3-percent decrease from 2012
- Prices ranged from \$1.44 per million Btu in Nebraska to \$4.90 per million Btu in Alaska.

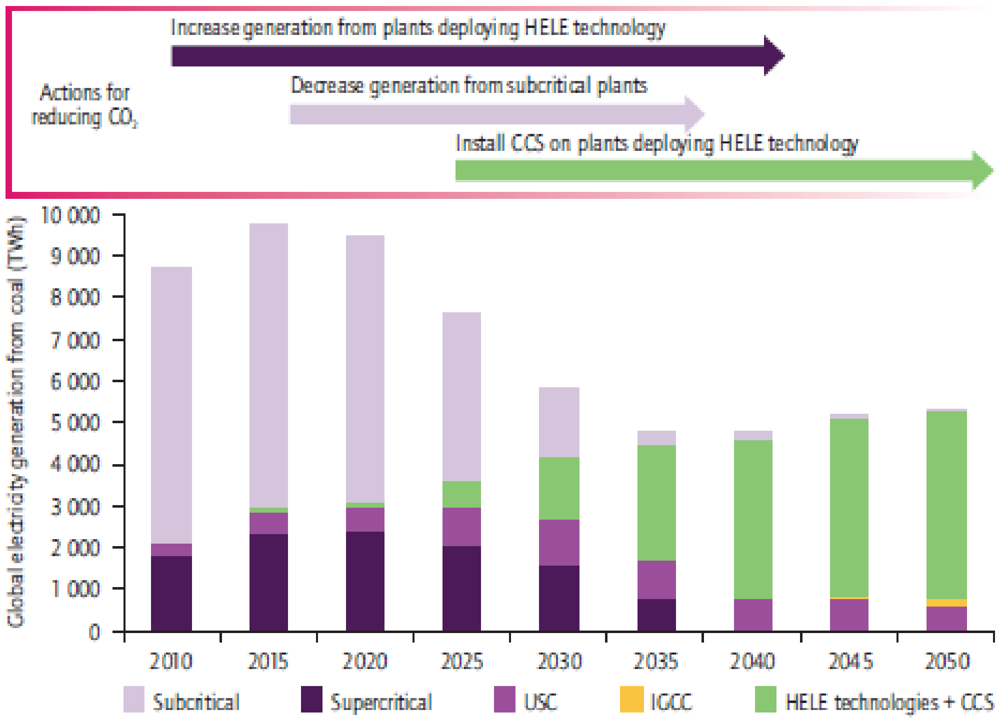
e 3: Performance of HELE coal-fired power technologies

Fuel type	Plant type	Emissions				Max. unit capacity (MWe)	Capacity factor (%)	CCS energy penalty (%-points)
		CO_2 (g/kWh)	NO_x	SO_2 (mg/Nm³)	PM			
Coal	PC (USC)	740	<50 to 100 (by SCR)	<20 to 100 (by FGD)	<10	1 100[3]	80	7 to 10 (post-combustion and oxy-fuel)
	CFBC	880 to 900	<200	<50 to 100 (in situ)	<50	460	80	
	PC (A-USC)[1]	670 (700°C)	<50 to 100 (by SCR)	<20 to 100 (by FGD)	<10	<1 000 (possible)	-	
	IGCC[1,2]	670 to 740	<30	<20	<1	335	70	7
	IGFC[1]	500 to 550	<30	<20	<1	<500	-	

Source: IEA Technology Roadmap
High Efficiency Low Emissions Coal-fired Power Generation

Coal-fired PowerGen Options - 2DS

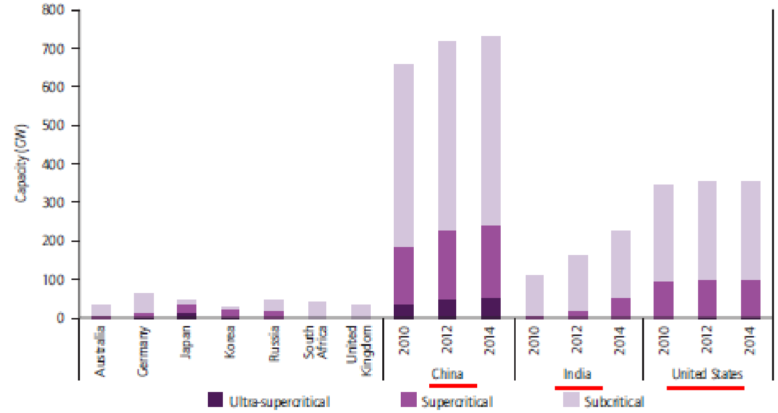
Figure 7: Electricity generation from different coal-fired power technologies in the 2DS



Note: Carbon capture is integrated with HELE coal-fired units to minimise coal consumption and CO_2 abatement cost.

Source: IEA Technology Roadmap
High Efficiency Low Emissions Coal-fired Power Generation

Figure 4: Capacity of supercritical and ultra-supercritical plant in major countries



Note: Refers to capacity in 2010 unless specified otherwise. Definitions of subcritical, supercritical (SC) and ultra-supercritical (USC) technology are described in Box 3.
Source: Platts, 2011.

Table 1: CO_2 intensity factors and fuel consumption values

	CO_2 intensity factor (Efficiency [LHV, net])	Coal consumption[1]
A-USC (700°C[2]) IGCC (1 500°C[3])	670-740 g CO_2/kWh (45-50%)	290-320 g/kWh
Ultra-supercritical	740-800 g CO CO_2/kWh (up to 45%)	320-340 g/kWh
Supercritical	800-880 g CO CO_2/kWh (up to 45%)	340-380 g/kWh
Subcritical	≥880 g CO CO_2/kWh (up to 45%)	≥380 g/kWh

[1] For coal with heating value 25 MJ/kg; [2] Steam temperature; [3] Turbine inlet temperature.

Note: The CO_2 intensity factor is the amount of carbon dioxide emitted per unit of electricity generated from a plant. For example, a CO_2 intensity factor of 800g CO_2/kWh means that the coal-fired unit emits 800g of CO_2 for each kWh of electricity generated.

Source: VBG, 2011.

1000 gCO2/kWh = 2204 lb/MWh

base$_e$

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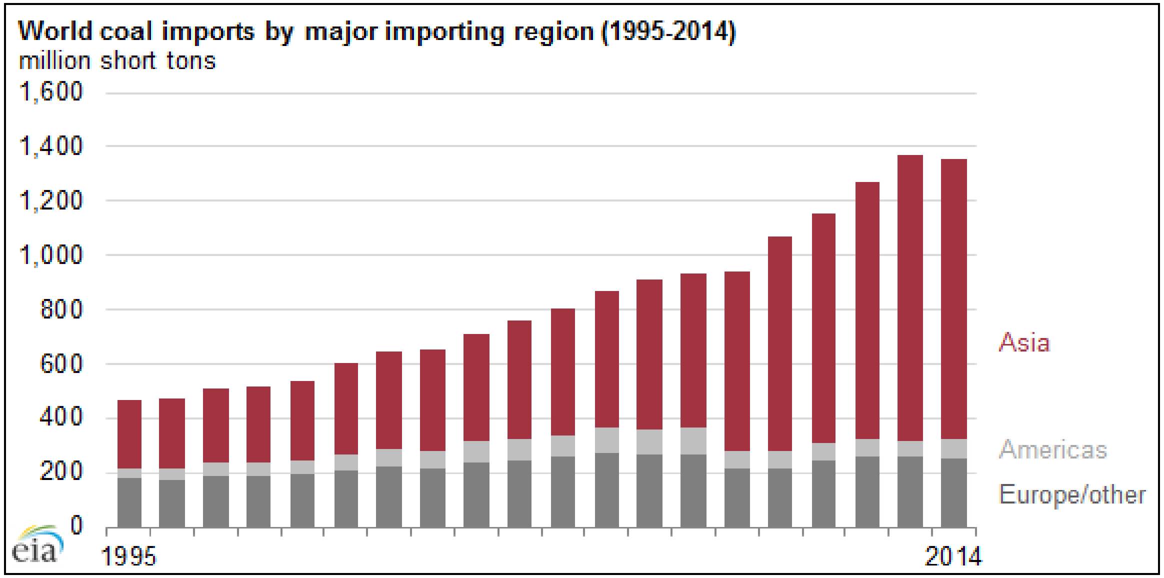
EPA Output Ratings 2015 – lb-CO_2/MWh

Fuel	Subbituminous Coal				Lignite			
Carbon Factor - lb-CO2/mmBtu	208.8	208.8	208.8	208.8	215.6	215.6	215.6	215.6
Power Plant								
- Type	PC	SCPC	USCPC	USCPC	PC	SCPC	USCPC	USCPC
- Heat Rate (HHV) - Btu/kWh	8795	8268	7975	7187	8795	8268	7975	7187
- Efficiency - HHV%	38.8%	41.3%	42.8%	47.5%	38.8%	41.3%	42.8%	47.5%
- Efficiency - LHV%	43.1%	45.8%	47.5%	52.7%	43.1%	45.8%	47.5%	52.7%
- Thermal Input - mmBtu	850	850	850	850	850	850	850	850
- Rating - MW@850 mmBtu/hr	96.65	102.80	106.58	118.28	96.65	102.80	106.58	118.28
Emissions - lb-CO2/MWh								
- Unabated	1836.7	1726.8	1665.6	1500.9	1896.2	1782.7	1719.6	1549.5
- Applicable Threshold								
- Interim	1534	1534	1534	1534	1534	1534	1534	1534
- Final	1305	1305	1305	1305	1305	1305	1305	1305
CCS % required to meet final threshold	28.95%	24.43%	21.65%	13.05%	31.18%	26.80%	24.11%	15.78%

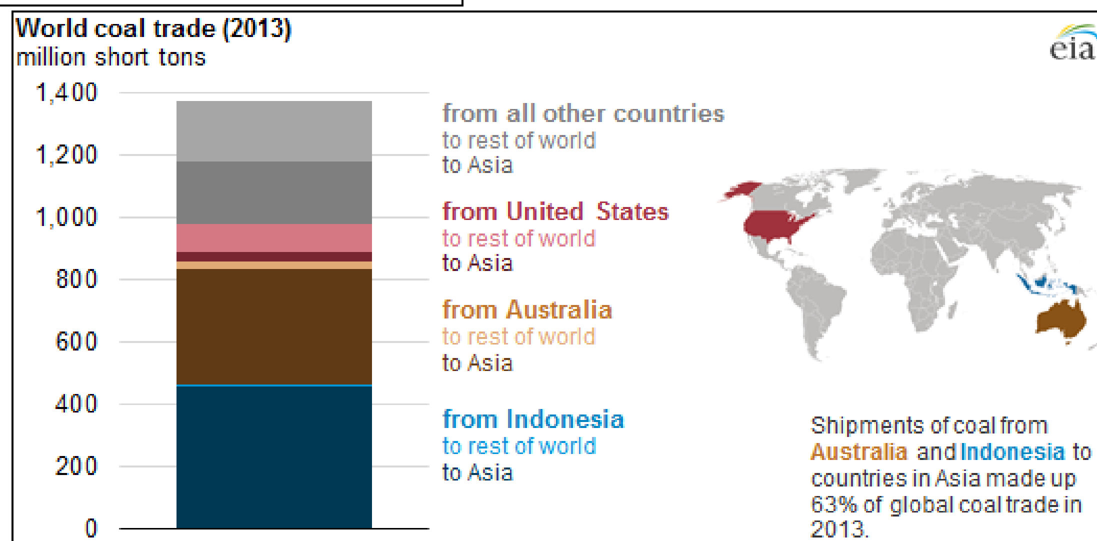
EPA NSPS Output Ratings 2014 – lb-CO_2/MWh

Fuel	Subbituminous Coal				Lignite			
Carbon Factor - lb-CO2/mmBtu	208.8	208.8	208.8	208.8	215.6	215.6	215.6	215.6
Power Plant								
- Type	PC	SCPC	USCPC	USCPC	PC	SCPC	USCPC	USCPC
- Heat Rate (HHV) - Btu/kWh	9276	8721	8412	7580	9276	8721	8412	7580
- Efficiency - HHV%	36.8%	39.1%	40.6%	45.0%	36.8%	39.1%	40.6%	45.0%
- Efficiency - LHV%	40.8%	43.4%	45.0%	50.0%	40.8%	43.4%	45.0%	50.0%
- Thermal Input - mmBtu	850	850	850	850	850	850	850	850
- Rating - MW@850 mmBtu/hr	91.63	97.47	101.05	112.14	91.63	97.47	101.05	112.14
Emissions - lb-CO2/MWh								
- Unabated	1937.2	1821.3	1756.7	1583.0	2000.0	1880.3	1813.7	1634.3
- Applicable Threshold	1000	1000	1000	1000	1000	1000	1000	1000
CCS % required to meet threshold	48.4%	45.1%	43.1%	36.8%	50.0%	46.8%	44.9%	38.8%

India & China Drive Recent Changes in Coal Trade

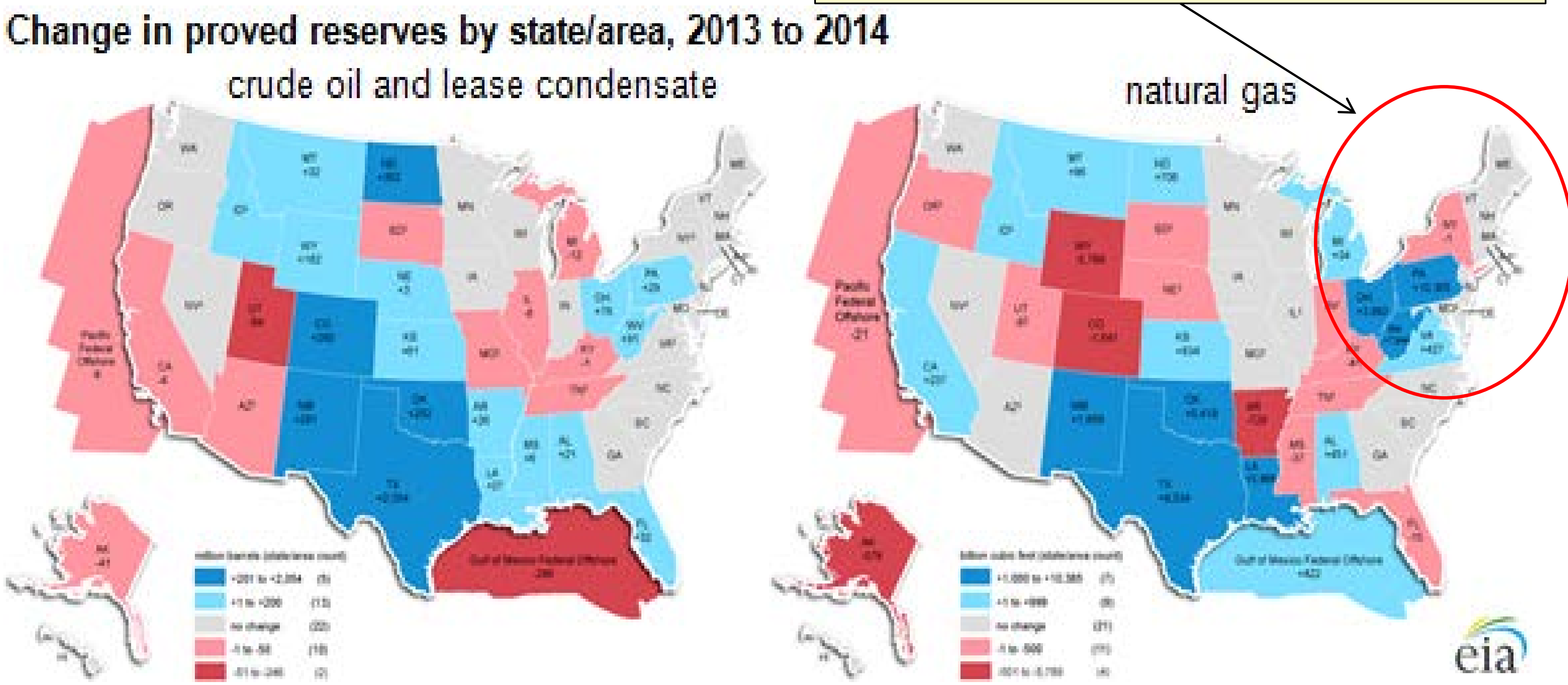


- China and India accounted for 98% of the increase in world coal trade from 2008 to 2013
- Nearly all of the 47% growth in total world coal trade between 2008 and 2013 was driven by rising coal import demands by countries in Asia, specifically China and India.

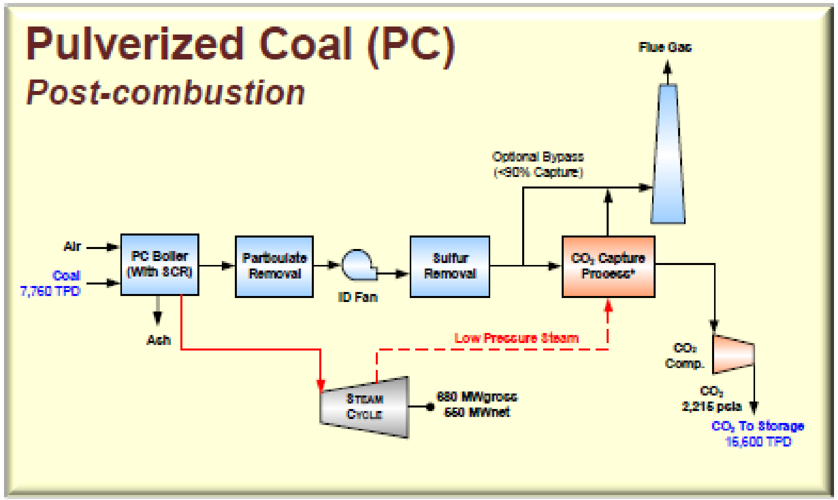


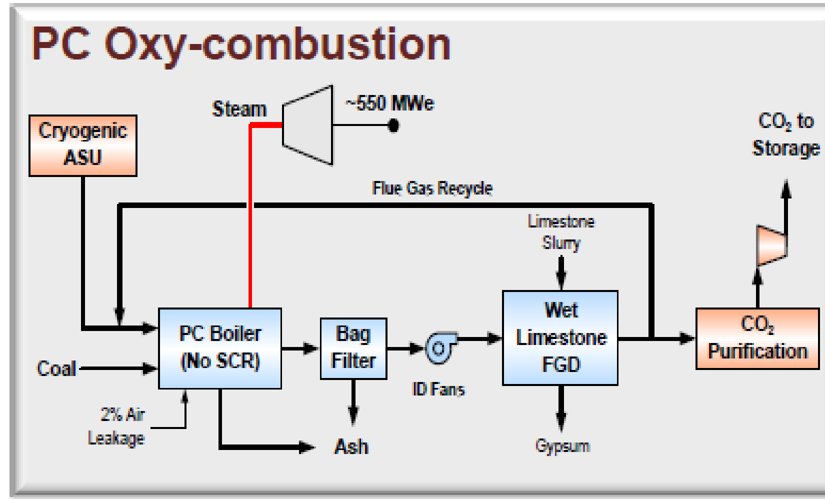
Proven Reserves – U.S.

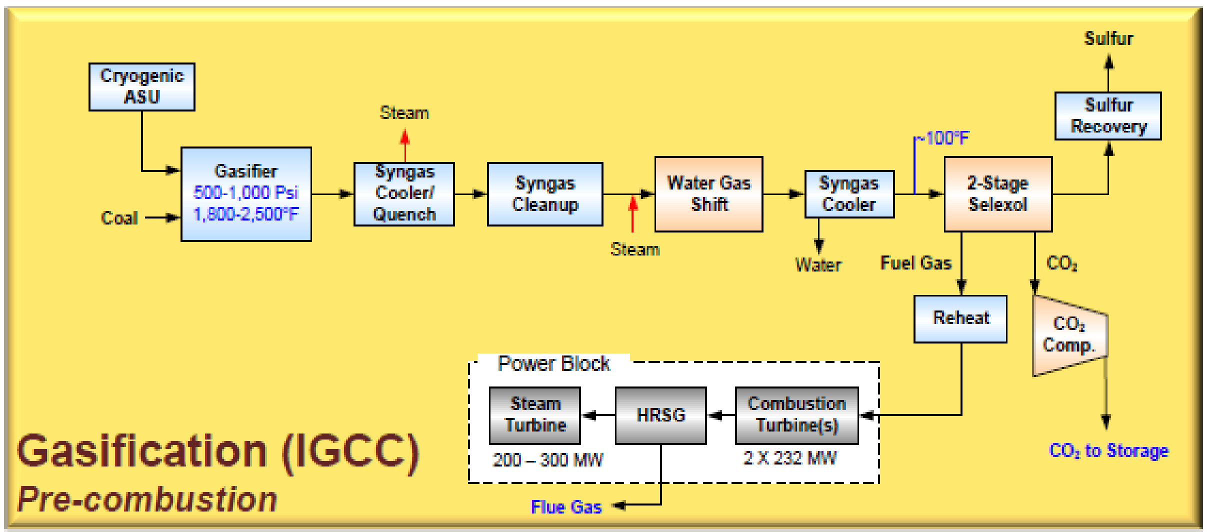
Current New England Pipeline Issue



CO_2 Power Plant/Capture Options





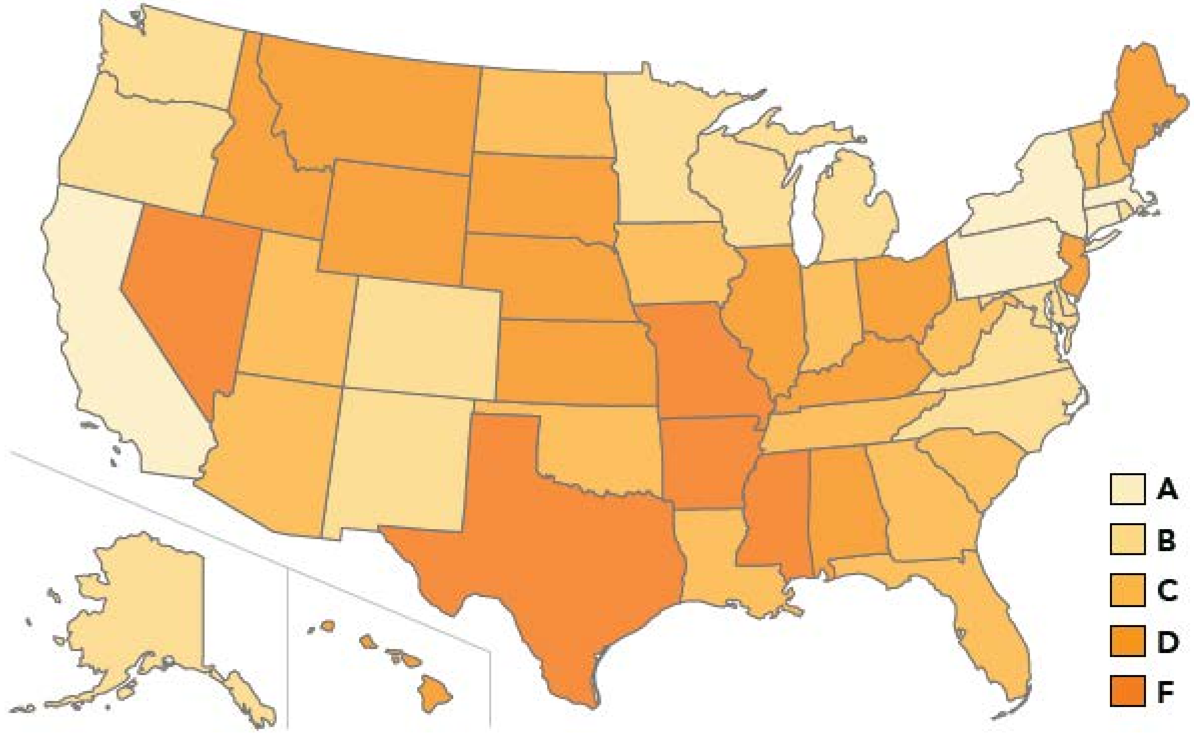


Source: Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity; NETL, May 2007.

State Preparedness

Areas of Interest:

- Extreme heat
- Summer draught
- Wildfires
- Inland flooding
- Coastal flooding



BEST GRADE	
California	A
New York	A
Massachusetts	A
Pennsylvania	A
Connecticut	A-
Delaware	B+
North Carolina	B+
Maryland	B+
Washington	B+
Virginia	B

WORST GRADE	
Arkansas	F
Texas	F
Nevada	F
Mississippi	F
Missouri	F
Alabama	D-
Ohio	D-
Montana	D-
South Dakota	D-
Kentucky	D

Anyone Surprised?

U.S. GHG Gas Emissions & Sinks – CO_2

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**5,123.7**	**6,134.0**	**5,500.6**	**5,704.5**	**5,568.9**	**5,358.3**	**5,505.2**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Electricity Generation	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Transportation	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Industrial	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Residential	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Commercial	217.4	223.5	223.5	220.2	221.0	197.1	220.7
U.S. Territories	27.9	49.9	43.5	46.2	39.8	38.6	32.0
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Iron and Steel Production & Metallurgical Coke Production	99.8	66.7	43.0	55.7	60.0	54.3	52.3
Natural Gas Systems	37.6	30.0	32.2	32.3	35.6	34.8	37.8
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.6	28.1	23.7	27.4	26.4	26.5	26.5
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Petroleum Systems	4.4	4.9	4.7	4.2	4.5	5.1	6.0
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7

EPA GHG Inventory 1990-2013 Table ES-2 (page 1)

U.S. GHG Gas Emissions & Sinks – CO_2

Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Aluminum Production	6.8	4.1	3.0	2.7	3.3	3.4	3.3
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.1	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(775.8)*	*(911.9)*	*(870.9)*	*(871.6)*	*(881.0)*	*(880.4)*	*(881.7)*
Wood Biomass and Ethanol Consumption[b]	*219.4*	*229.8*	*250.5*	*265.1*	*268.1*	*267.7*	*283.3*
International Bunker Fuels[c]	*103.5*	*113.1*	*106.4*	*117.0*	*111.7*	*105.8*	*99.8*

EPA GHG Inventory 1990-2013 Table ES-2 (page 2)

U.S. GHG Gas Emissions & Sinks – CH4 Methane

CH_4	**745.5**	**707.8**	**709.5**	**667.2**	**660.9**	**647.6**	**636.3**
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5
Natural Gas Systems	179.1	176.3	168.0	159.6	159.3	154.4	157.4
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6
Manure Management	37.2	56.3	59.7	60.9	61.4	63.7	61.4
Petroleum Systems	31.5	23.5	21.5	21.3	22.0	23.3	25.2
Wastewater Treatment	15.7	15.9	15.6	15.5	15.3	15.2	15.0
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3
Stationary Combustion	8.5	7.4	7.4	7.1	7.1	6.6	8.0
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Forest Fires	2.5	8.3	5.8	4.7	14.6	15.7	5.8
Mobile Combustion	5.6	3.0	2.3	2.3	2.3	2.2	2.1
Composting	0.4	1.9	1.9	1.8	1.9	1.9	2.0
Iron and Steel Production & Metallurgical Coke Production	1.1	0.9	0.4	0.6	0.7	0.7	0.7
Field Burning of Agricultural Residues	0.3	0.2	0.3	0.3	0.3	0.3	0.3
Petrochemical Production	0.2	0.1	+	0.1	+	0.1	0.1
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*

EPA GHG Inventory 1990-2013 Table ES-2 (page 3)

U.S. GHG Gas Emissions & Sinks – N_2O

N_2O	**329.9**	**355.9**	**356.1**	**360.1**	**371.9**	**365.6**	**355.2**
Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7
Stationary Combustion	11.9	20.2	20.4	22.2	21.3	21.4	22.9
Mobile Combustion	41.2	38.1	24.6	23.7	22.5	20.2	18.4
Manure Management	13.8	16.4	17.0	17.1	17.3	17.3	17.3
Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7
Wastewater Treatment	3.4	4.3	4.6	4.7	4.8	4.9	4.9
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0
Forest Fires	1.7	5.5	3.8	3.1	9.6	10.3	3.8
Settlement Soils	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Composting	0.3	1.7	1.7	1.6	1.7	1.7	1.8
Forest Soils	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Semiconductor Manufacture	+	0.1	0.1	0.1	0.2	0.2	0.2
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.9*	*1.0*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*

EPA GHG Inventory 1990-2013 Table ES-2 (page 4)

U.S. GHG Gas Emissions & Sinks – HFC’s+

HFCs	**46.6**	**131.4**	**142.9**	**152.6**	**157.4**	**159.2**	**163.0**
Substitution of Ozone Depleting Substances[d]	0.3	111.1	136.0	144.4	148.4	153.5	158.6
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1
Semiconductor Manufacture	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Magnesium Production and Processing	0.0	0.0	+	+	+	+	0.1
PFCs	**24.3**	**6.6**	**3.9**	**4.4**	**6.9**	**6.0**	**5.8**
Aluminum Production	21.5	3.4	1.9	1.9	3.5	2.9	3.0
Semiconductor Manufacture	2.8	3.2	2.0	2.6	3.4	3.0	2.9
SF_6	**31.1**	**14.0**	**9.3**	**9.5**	**10.0**	**7.7**	**6.9**
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.6	1.4
Semiconductor Manufacture	0.5	0.7	0.3	0.4	0.4	0.4	0.4
NF_3	+	**0.5**	**0.4**	**0.5**	**0.7**	**0.6**	**0.6**
Semiconductor Manufacture	+	0.5	0.4	0.5	0.7	0.6	0.6
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**
Net Emissions (Sources and Sinks)	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

EPA GHG Inventory 1990-2013 Table ES-2 (page 5)