# $CO_2$ – By the Numbers

Snow's Library Adult Education Program

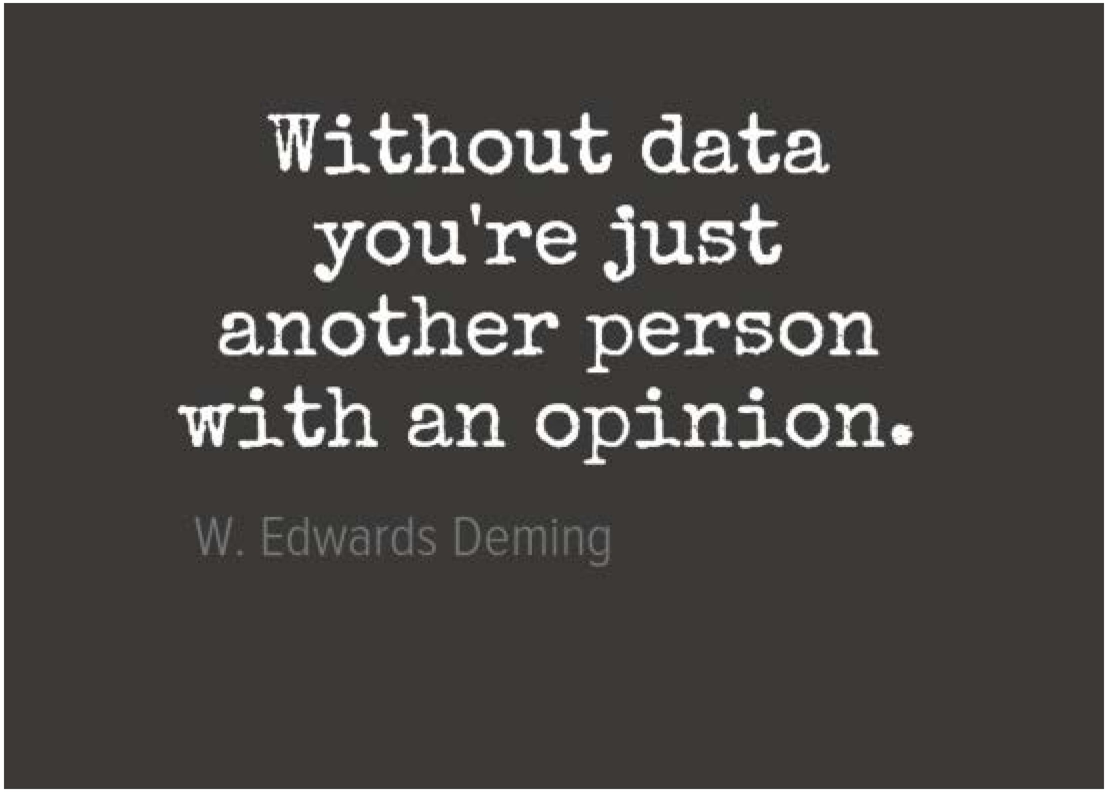
Part 1

November 2, 2016

Pete Baldwin

pete_baldwin@base-e.net

617-306-7419




Today, we debate philosophical positions…..

….supported by anecdotes.

# Energy Policy = Choice of Fuel(s)

# 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) | 19.4 | 17.6 | 8.0 | 4.8 | 3.8 | 3.7 |
| Installed Generating Capacity GW | 1,505 | 1,063 | 255 | 293 | 177 | 242 |
| % of World at 5,291 GW | 28% | 20% | 5% | 6% | 3% | 5% |
| Electric Production TWh | 5,650 | 4,048 | 1,052 | 966 | 585 | 1,064 |
| Electric Consumption TWh | 5,523 | 3,832 | 865 | 921 | 540 | 1,065 |
| Aggregate Load Factor | 42.9% | 43.5% | 47.1% | 37.6% | 37.7% | 50.2% |
| Natural Gas Production - BCM | 121.5 | 782.2 | 31.7 | 4.7 | 10.1 | 578.7 |
| Natural Gas Consumption - BCM | 180.4 | 759.4 | 50.6 | 134.3 | 77.5 | 409.2 |
| Refined Petroleum Products Production - mmbbl/d | 9.9 | 19.1 | 4.4 | 3.3 | 2.2 | 6.1 |
| Refined Petroleum Products Consumption - mmbbl/d | 10.5 | 19.0 | 3.7 | 4.3 | 2.4 | 2.8 |
| Coal Production - Million Tonnes Oil Equivalent | 1827.0 | 455.2 | 283.9 | 0.7 | 42.9 | 184.5 |
| Coal Consumption - Million Tonnes Oil Equivalent | 1920.4 | 396.3 | 407.2 | 119.4 | 78.3 | 88.7 |

**Source: CIA World Factbook**

World Total Installed Electrical Generating Capacity 5,291 GW

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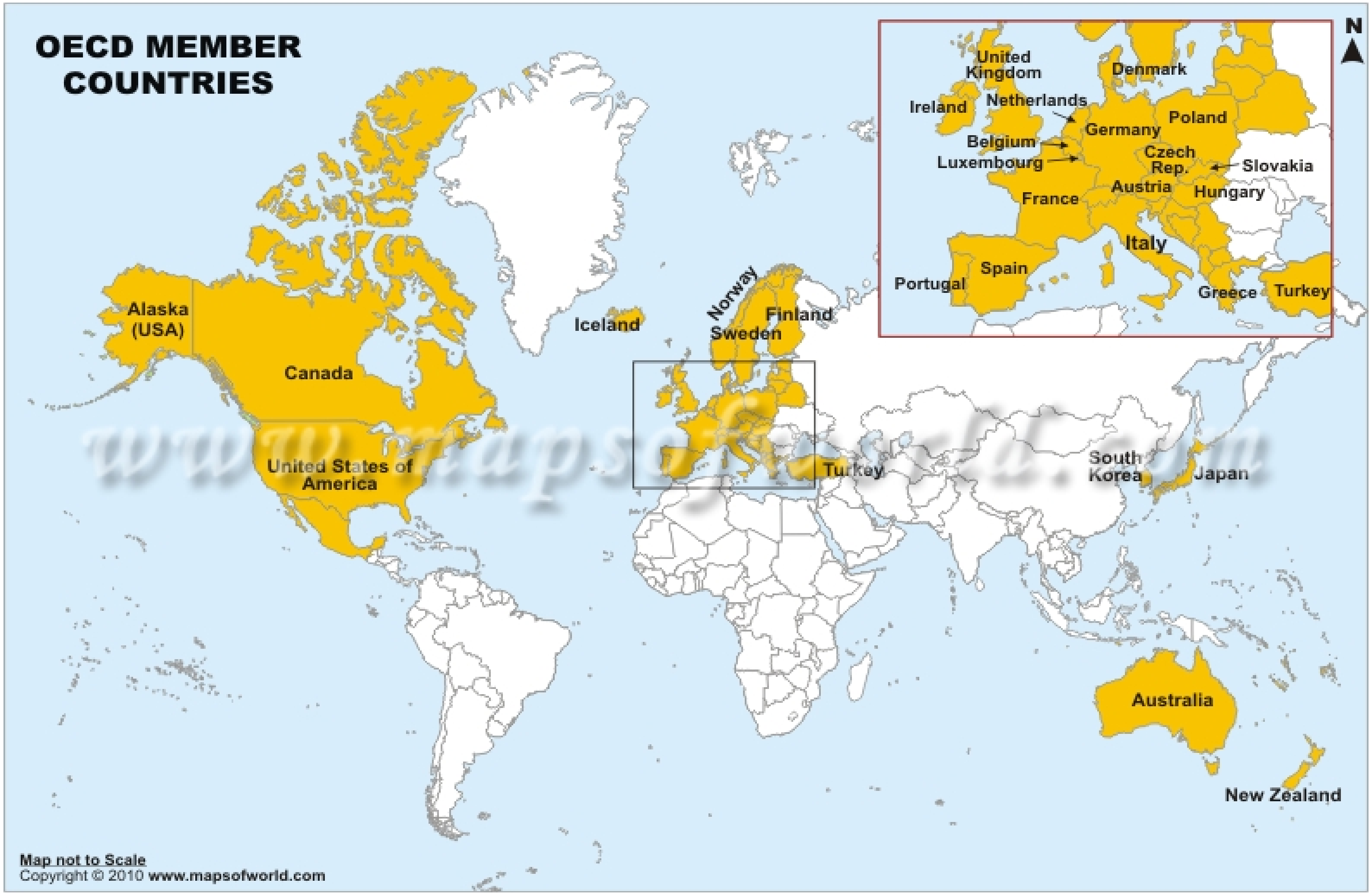
Ps…….Total Value of Outstanding Student Loans - $1.3 trillion
U.S. health care cost 2014 - $3.0 trillion

# OECD Member Countries -2010

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# World Energy Consumption Mtoe

13,147.3 Mtoe = 521.3Quads

| Million tonnes oil equivalent | Oil | Natural Gas | Coal | Nuclear Energy | Hydro electric | Renew - ables | Total | Percent of 2015 Total |
|---|---|---|---|---|---|---|---|---|
| US | 851.6 | 713.6 | 396.3 | 189.9 | 57.4 | 71.7 | **2280.6** | 17.3% |
| Canada | 100.3 | 92.2 | 19.8 | 23.6 | 86.7 | 7.3 | **329.9** | 2.5% |
| Mexico | 84.3 | 74.9 | 12.8 | 2.6 | 6.8 | 3.5 | **185.0** | 1.4% |
| **Total North America** | **1036.3** | **880.7** | **429.0** | **216.1** | **150.9** | **82.6** | **2795.5** | 21.3% |
| Brazil | 137.3 | 36.8 | 17.4 | 3.3 | 81.7 | 16.3 | **292.8** | 2.2% |
| **Total S. & Cent. America** | **322.7** | **157.3** | **37.1** | **5.0** | **152.9** | **24.2** | **699.3** | 5.3% |
| | | | | | | | | 0.0% |
| France | 76.1 | 35.1 | 8.7 | 99.0 | 12.2 | 7.9 | **239.0** | 1.8% |
| Germany | 110.2 | 67.2 | 78.3 | 20.7 | 4.4 | 40.0 | **320.6** | 2.4% |
| Italy | 59.3 | 55.3 | 12.4 | - | 9.9 | 14.7 | **151.7** | 1.2% |
| Russian Federation | 143.0 | 352.3 | 88.7 | 44.2 | 38.5 | 0.1 | **666.8** | 5.1% |
| Spain | 60.5 | 24.8 | 14.4 | 12.9 | 6.3 | 15.4 | **134.4** | 1.0% |
| Turkey | 38.8 | 39.2 | 34.4 | - | 15.1 | 3.8 | **131.3** | 1.0% |
| Ukraine | 8.4 | 25.9 | 29.2 | 19.8 | 1.4 | 0.3 | **85.1** | 0.6% |
| United Kingdom | 71.6 | 61.4 | 23.4 | 15.9 | 1.4 | 17.4 | **191.2** | 1.5% |
| **Total Europe & Eurasia** | **862.2** | **903.1** | **467.9** | **264.0** | **194.4** | **142.8** | **2834.4** | 21.6% |
| Iran | 88.9 | 172.1 | 1.2 | 0.8 | 4.1 | 0.1 | **267.2** | 2.0% |
| Saudi Arabia | 168.1 | 95.8 | 0.1 | - | - | ^ | **264.0** | 2.0% |
| Other Middle East | 83.3 | 45.4 | 0.8 | - | 1.8 | 0.1 | **131.4** | 1.0% |
| **Total Middle East** | **425.7** | **441.2** | **10.5** | **0.8** | **5.9** | **0.5** | **884.7** | 6.7% |
| South Africa | 31.1 | 4.5 | 85.0 | 2.4 | 0.2 | 1.0 | **124.2** | 0.9% |
| Other Africa | 93.5 | 39.2 | 11.0 | - | 23.8 | 2.4 | **169.9** | 1.3% |
| **Total Africa** | **183.0** | **121.9** | **96.9** | **2.4** | **27.0** | **3.8** | **435.0** | 3.3% |
| Australia | 46.2 | 30.9 | 46.6 | - | 3.1 | 4.5 | **131.4** | 1.0% |
| China | 559.7 | 177.6 | 1920.4 | 38.6 | 254.9 | 62.7 | **3014.0** | 22.9% |
| India | 195.5 | 45.5 | 407.2 | 8.6 | 28.1 | 15.5 | **700.5** | 5.3% |
| Indonesia | 73.5 | 35.8 | 80.3 | - | 3.6 | 2.4 | **195.6** | 1.5% |
| Japan | 189.6 | 102.1 | 119.4 | 1.0 | 21.9 | 14.5 | **448.5** | 3.4% |
| South Korea | 113.7 | 39.2 | 84.5 | 37.3 | 0.7 | 1.6 | **276.9** | 2.1% |
| **Total Asia Pacific** | **1501.4** | **631.0** | **2798.5** | **94.9** | **361.9** | **110.9** | **5498.5** | 41.8% |
| **Total World** | **4331.3** | **3135.2** | **3839.9** | **583.1** | **892.9** | **364.9** | **13147.3** | 100.0% |
| | 32.9% | 23.8% | 29.2% | 4.4% | 6.8% | 2.8% | 100.0% | |

**U.S.**
**– 3.0% Renewables**
**– 2.5% Hydro**

**Renewables**
**– Germany 12.5%**
**– Spain 11.5%**

**Nuclear**
**– France 41.4%**

**Asia Pacific Represents 72.9% of Coal Consumption**

**53.0% Gas & Coal** ⟷ **2.8% Renewables**

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# World Total Primary Energy Consumption - Quads

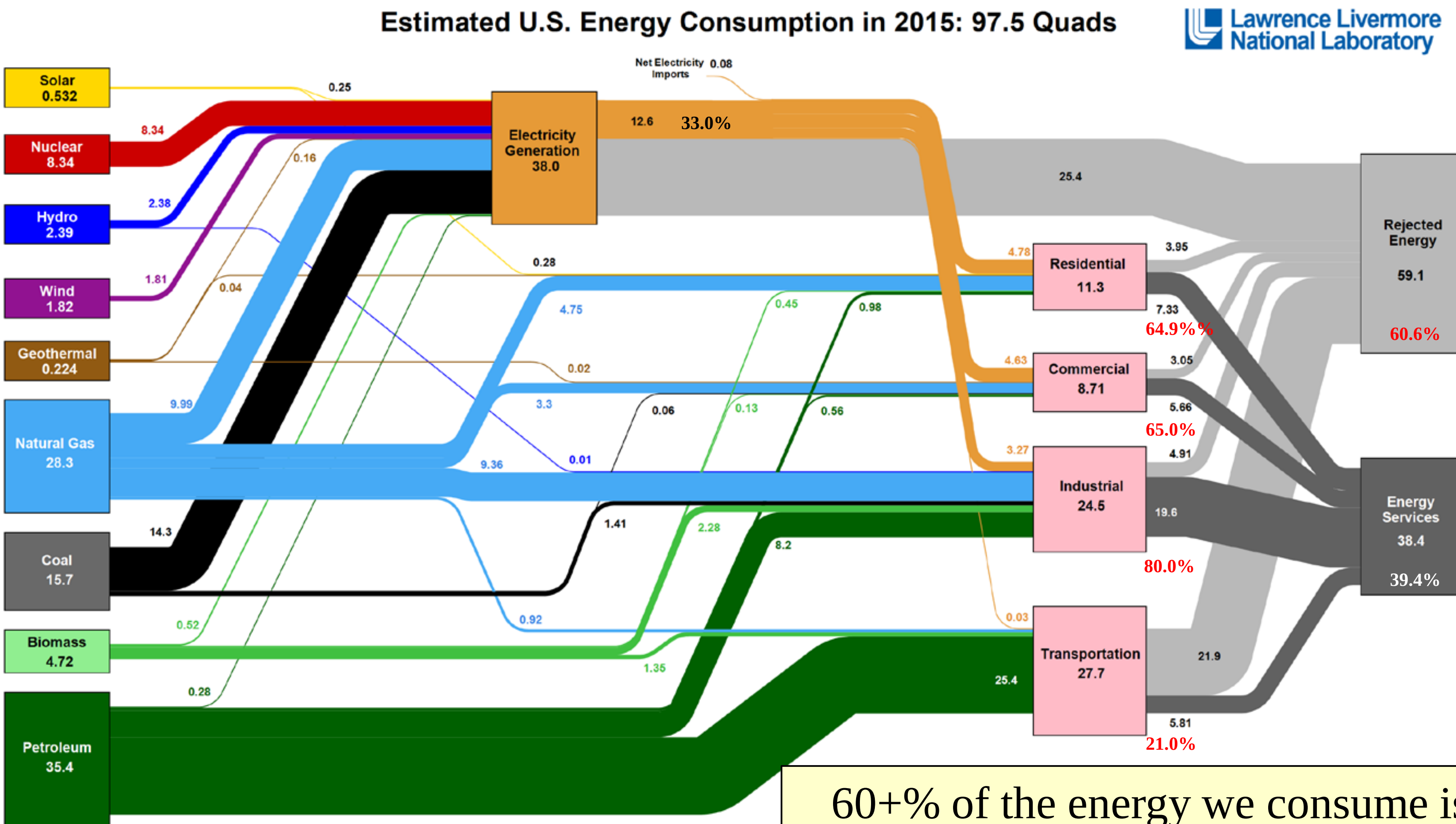
| World total primary energy consumption by region, Reference case (Quadrillion Btu) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Region/Country | 2008 | 2011 | 2015 | 2020 | 2025 | 2030 | 2035 | Growth Rate (2008-2035) |
| OECD | | | | | | | | |
| **OECD Americas** | **122.9** | **121.3** | **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%** |

**USA ~ 100 Quads**

**Note ~3% Growth Rate**

**Overall 1.6% Growth Rate**

# U.S. Energy Flow – 97.5 Quads




60+% of the energy we consume is rejected as waste heat

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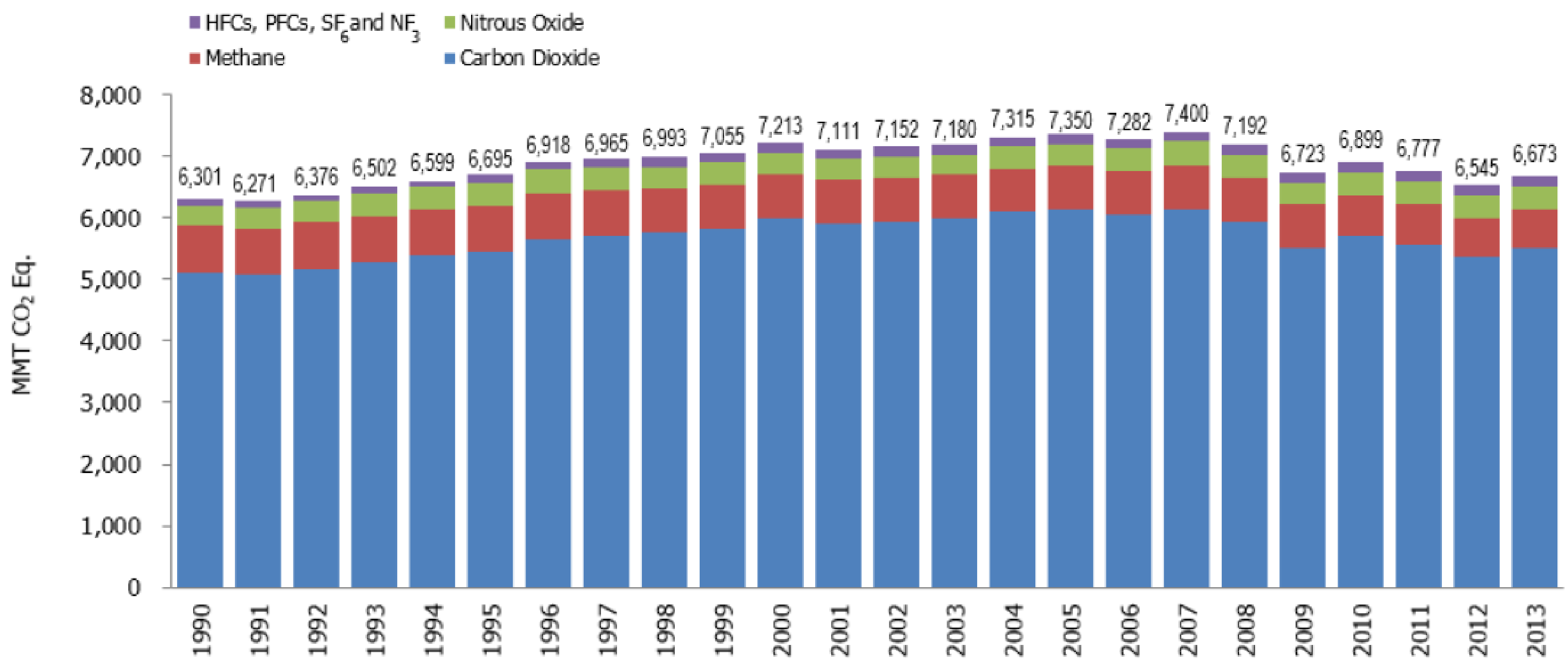
# Where Does $CO_2$ Come From?

# $CO_2$ 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**

# $CO_2$ Emission from Electric Power

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

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

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

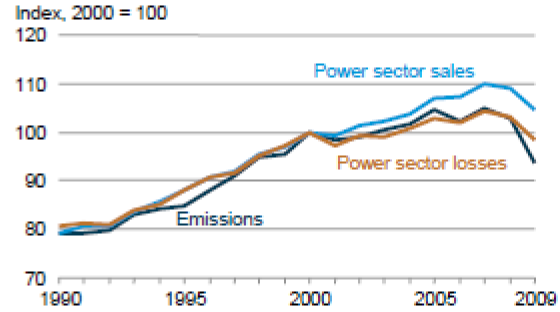



**Table 12. U.S. carbon dioxide emissions from electric power sector energy consumption, 1990-2009 (million metric tons carbon dioxide)**

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

**38.5% from Fossil Fuel PowerGen**

**2,302.9 (2.3Gt) total in 2005**

**2005 @ 2416 Mt (2.416 Gt) is benchmark for CPP(until EPA changes it again)**

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# EPA Clean Power Plan - 2015

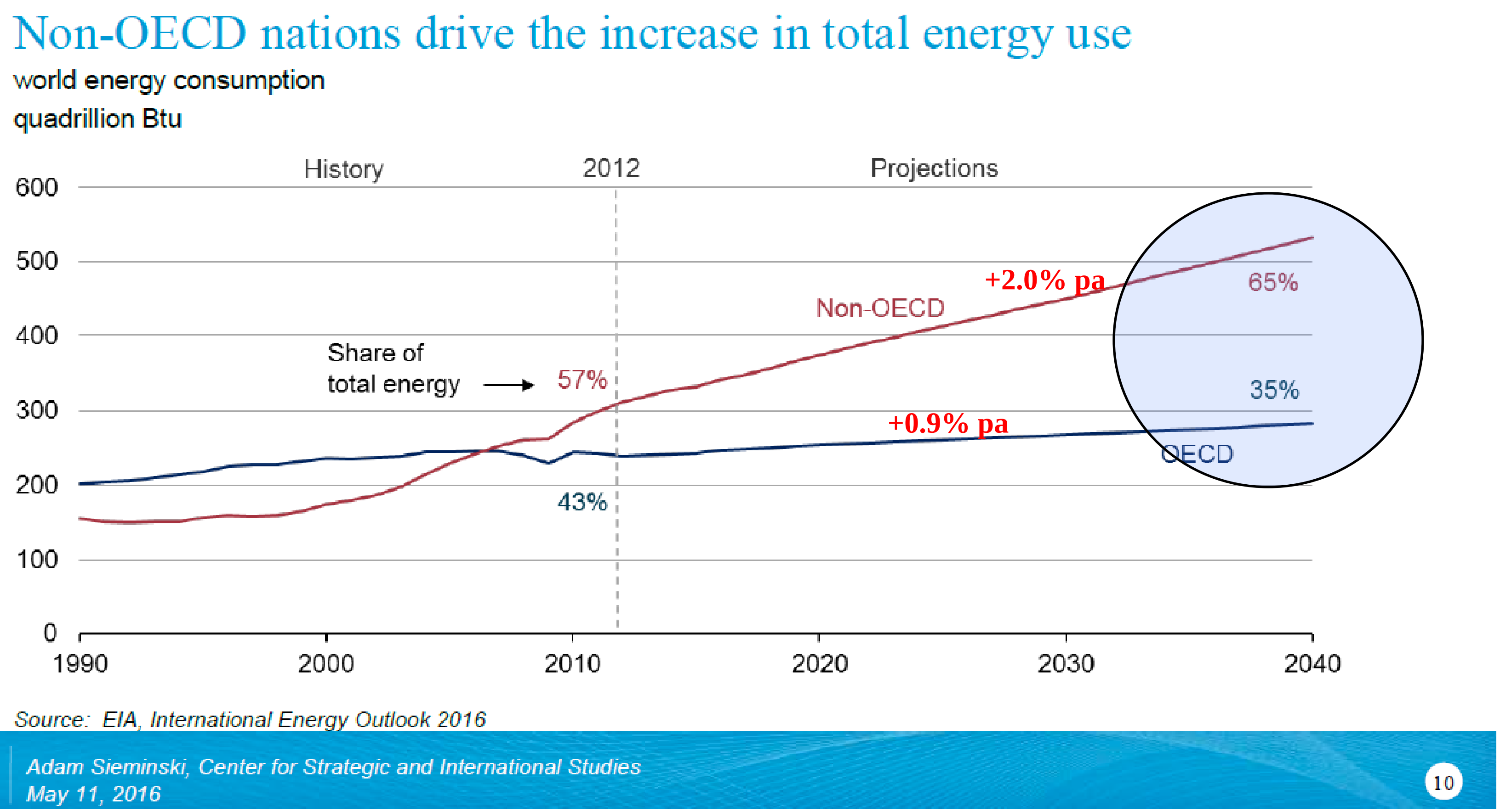
| 2030 | | Economic Growth: Ref Case | Economic Growth: High EG |
|---|---|---|---|
| O&G Resource: Ref Case | 2005 Ref | 2416 | |
| | AEO2015 | 2177 | 2262 |
| | CPP | 1596 | 1727 |
| | CPPEXT | 1553 | |
| | Obama 2015? | 1643 | |
| O&G Resource: High OGR | AEO2015 | 2089 | 2171 |
| | CPP | 1606 | 1738 |

| 2040 | | Economic Growth: Ref Case | Economic Growth: High EG |
|---|---|---|---|
| O&G Resource: Ref Case | 2005 Ref | 2416 | |
| | AEO2015 | 2195 | 2266 |
| | CPP | 1691 | 1827 |
| | CPPEXT | 1329 | |
| O&G Resource: High OGR | AEO2015 | 2179 | 2249 |
| | CPP | 1701 | 1838 |

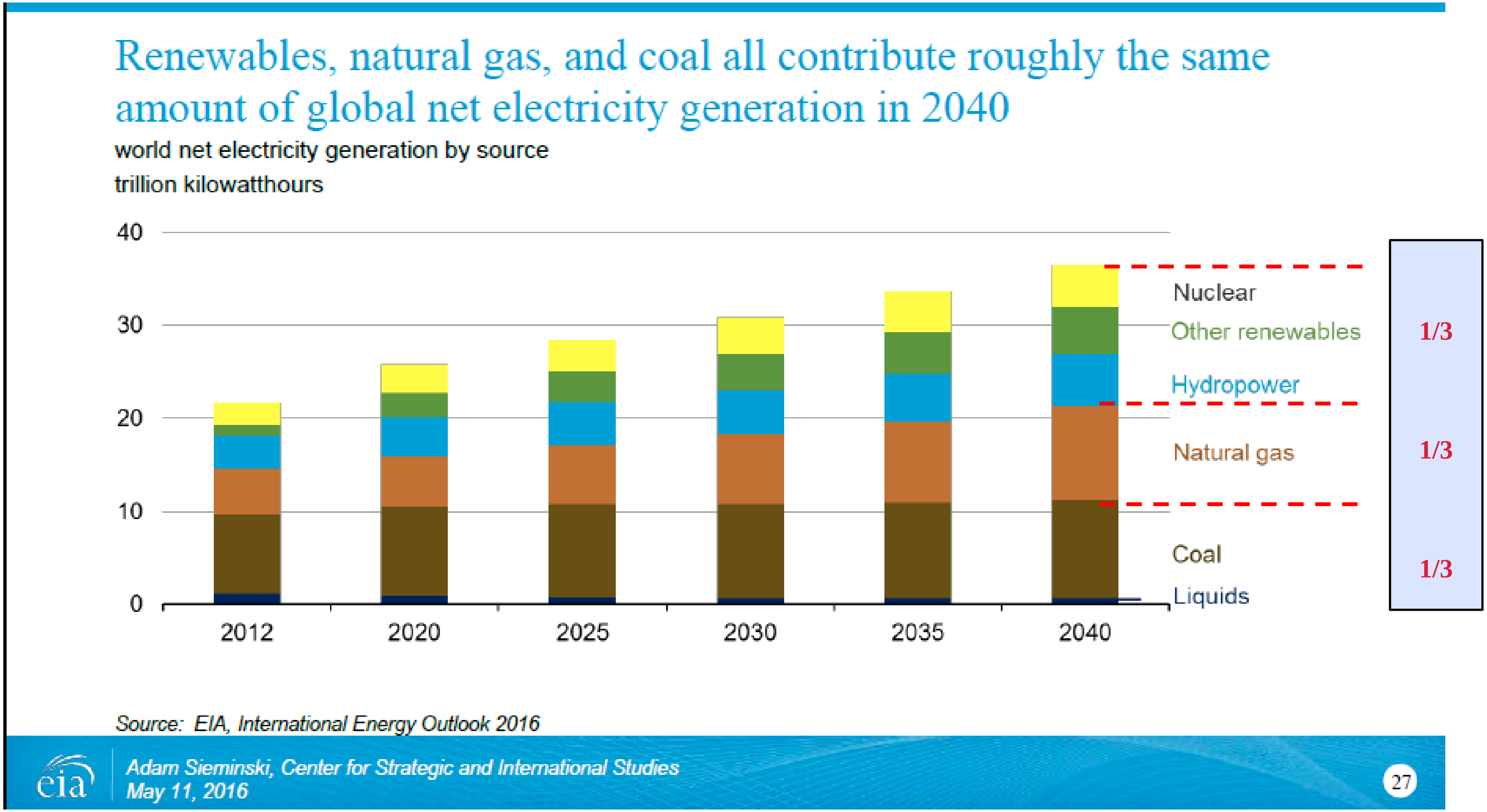
**"32% reduction in 2005 power plant $CO_2$ emissions by 2030"**

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

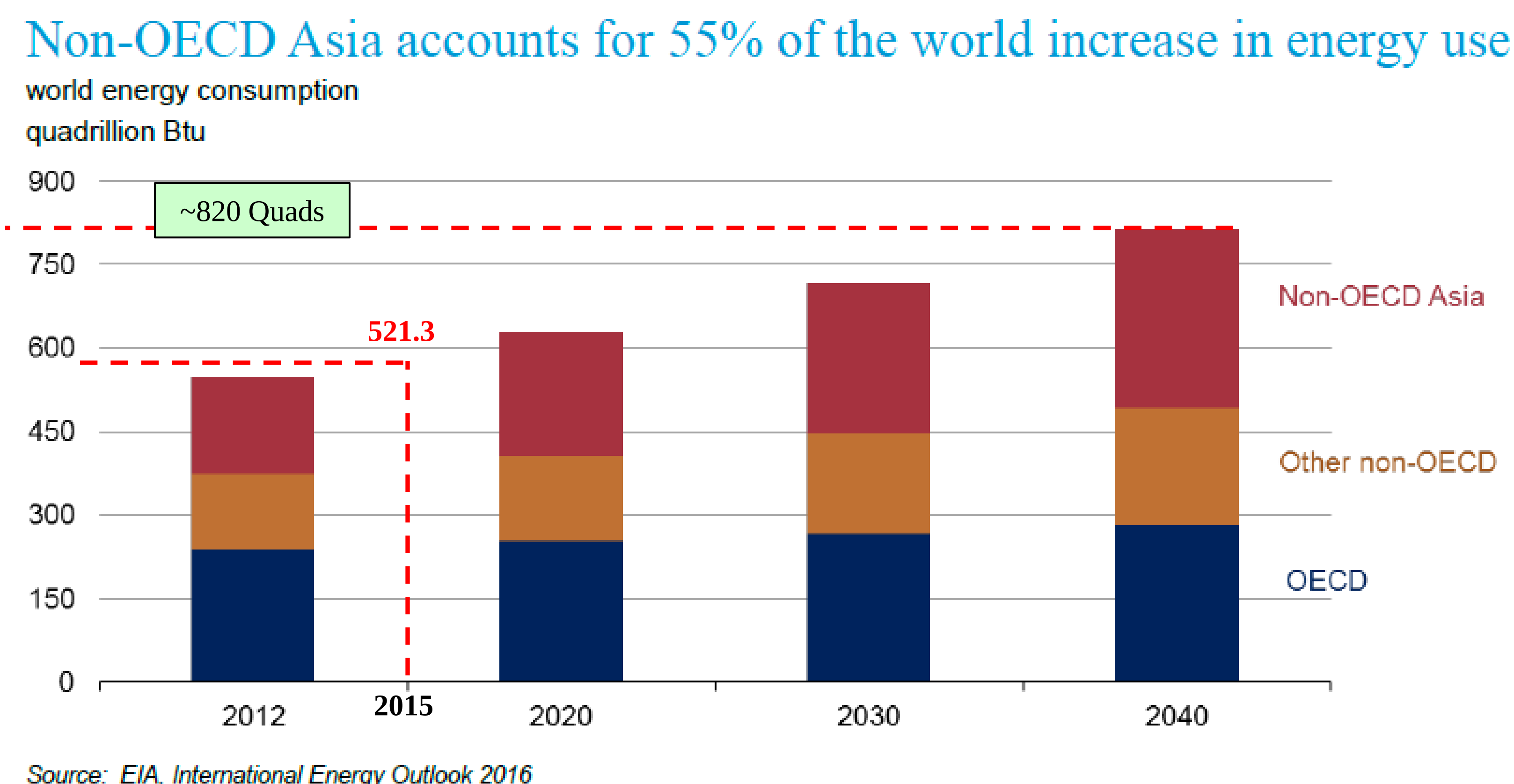
# World Energy Consumption - Quads



# Fuel Mix 2040



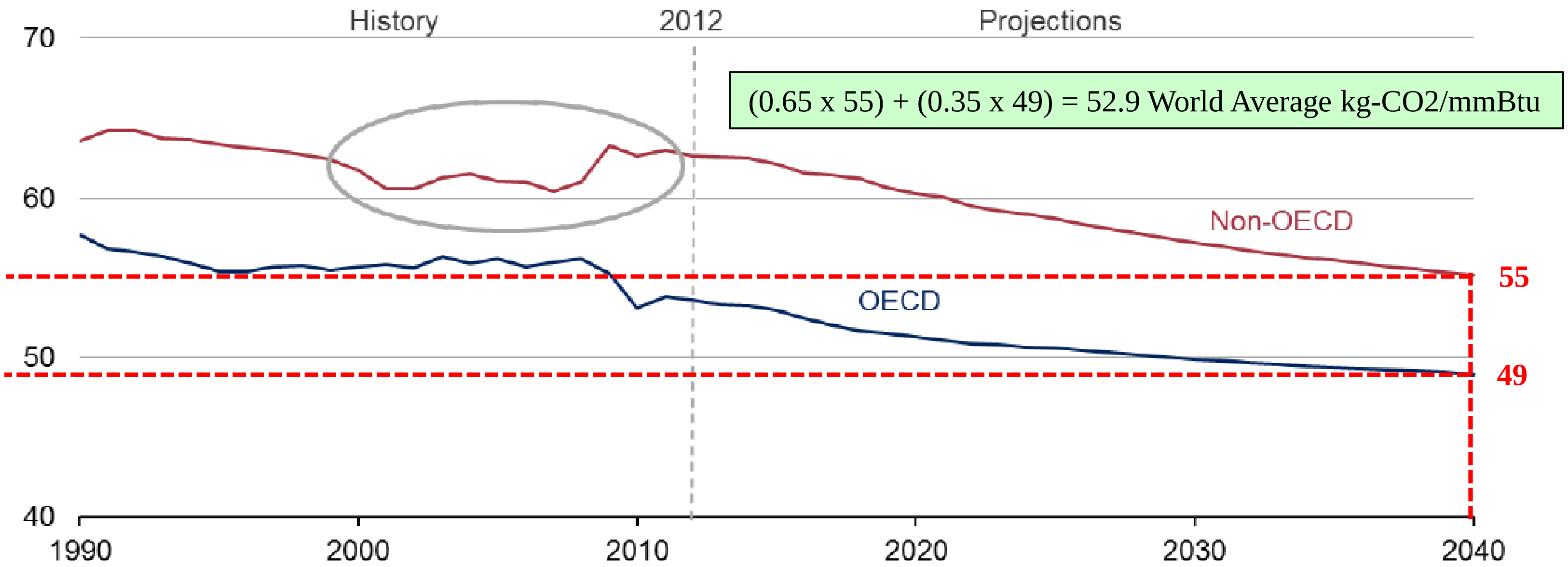
# Non-OECD Asia Accounts for 55% of Increase



# Projected CO2e Decline to 52.9 kg/mmBtu in 2040

## Projected carbon intensity of energy use (CO2/E) declines through 2040 in both OECD and non-OECD; non-OECD CO2/E rose over 2000–12

carbon intensity of energy consumption, 1990-2040
kilograms CO2 per million Btu

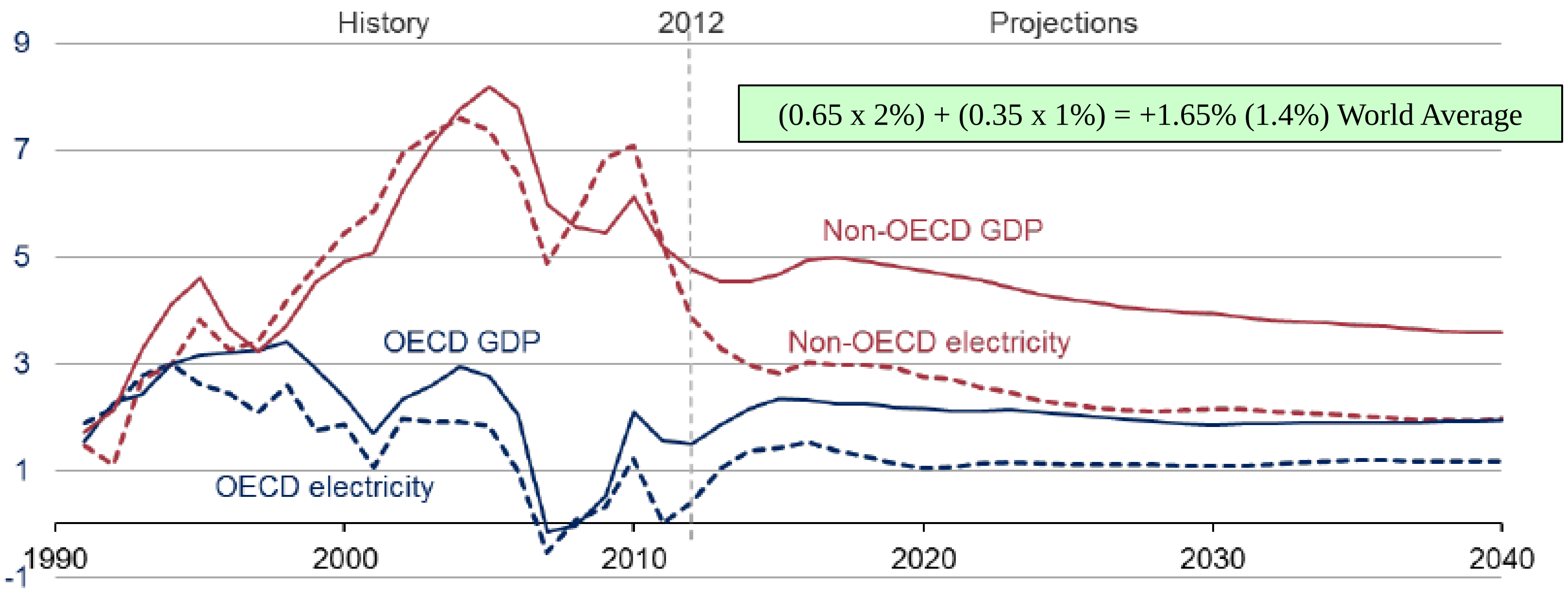



*Source: EIA, International Energy Outlook 2016*

# Electric Power Generation Growth Rate

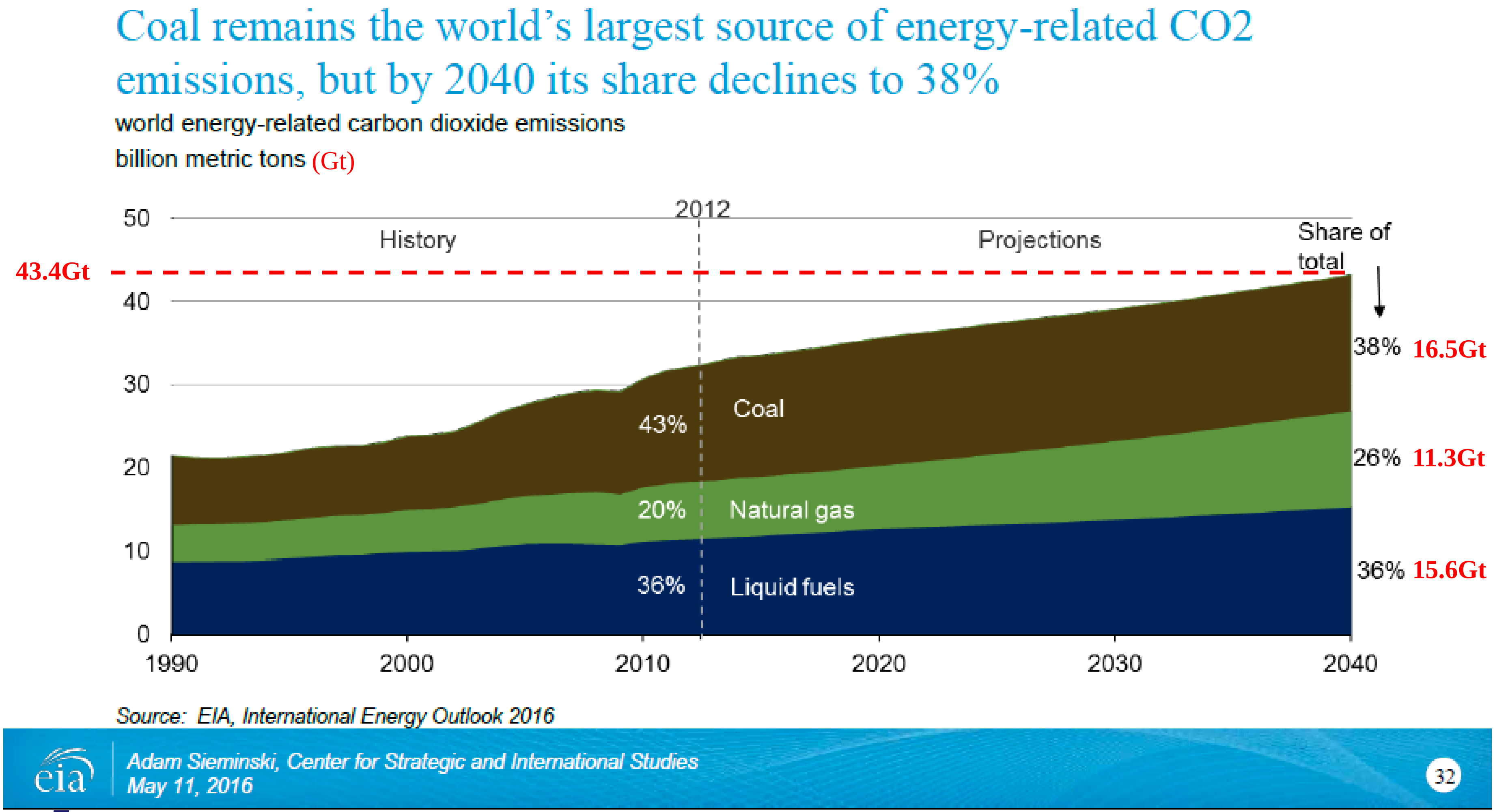
## GDP drives electricity demand growth, but the electricity growth rate compared to the GDP growth rate becomes smaller over time

world GDP and net electricity generation
percent growth (rolling average of 3-year periods)




*Source: EIA, International Energy Outlook 2016*

# Energy Related CO2 Emissions

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# Key Findings IEO2016 Reference Case

- World energy consumption increases from 549 quadrillion Btu in 2012 to 629 quadrillion Btu in 2020 and then to 815 quadrillion Btu in 2040, a 48% increase (1.4%/year). Non-OECD Asia (including China and India) account for more than half of the increase.

- The industrial sector continues to account for the largest share of delivered energy consumption; the world industrial sector still consumes over half of global delivered energy in 2040.

- Renewable energy is the world's fastest-growing energy source, increasing by 2.6%/year; nuclear energy grows by 2.3%/year, from 4% of the global total in 2012 to 6% in 2040.

- Fossil fuels continue to supply more than three-fourths of world energy use in 2040.

- Among the fossil fuels, natural gas grows the fastest. Coal use plateaus in the mid-term as China shifts from energy-intensive industries to services and worldwide policies to limit coal use intensify. By 2030, natural gas surpasses coal as the world's second largest energy source.

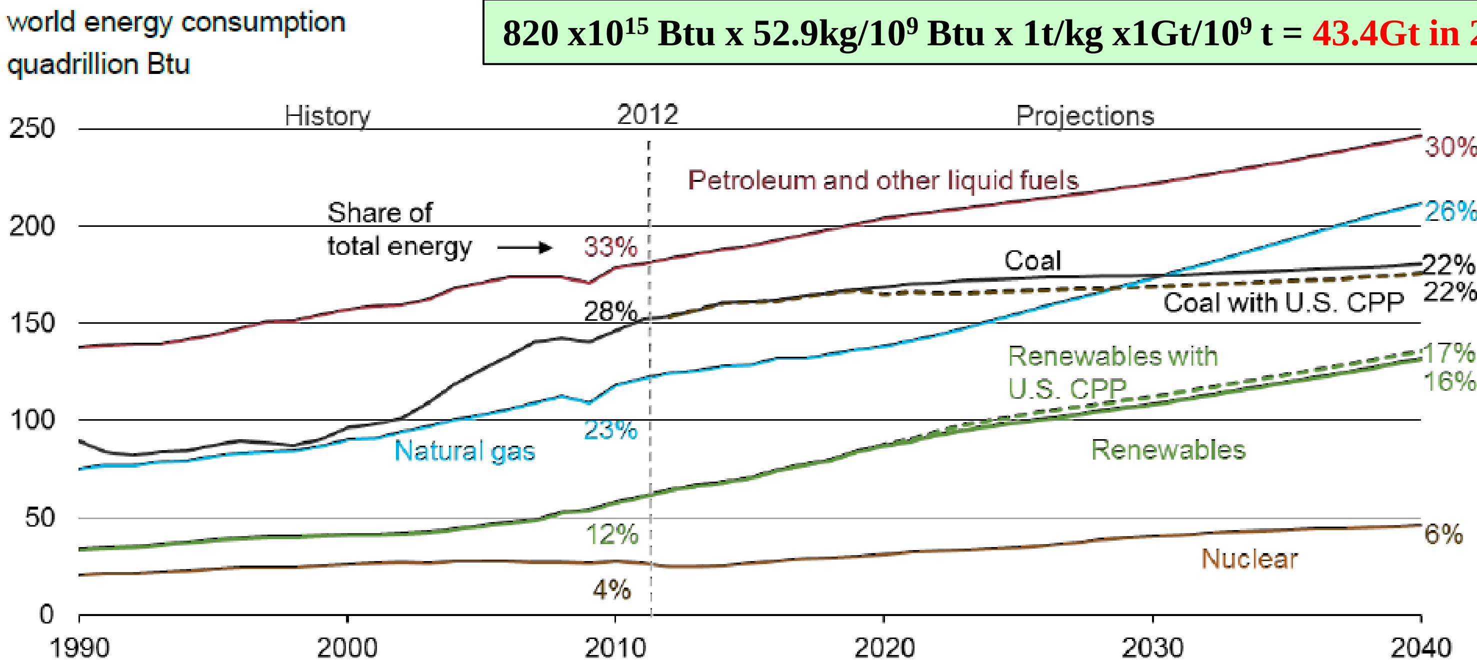
- In 2012, coal provided 40% of the world's total net electricity generation. By 2040, coal, natural gas, and renewable energy sources provide roughly equal shares (28-29%) of world generation.

- With current policies and regulations, worldwide energy-related carbon dioxide emissions rise from about 32 billion metric tons in 2012 to 36 billion metric tons in 2020 and then to 43 billion metric tons in 2040, a 34% increase.

# 820 Quads = 43.4Gt CO2e in 2040

## Renewables grow fastest, coal use plateaus, natural gas surpasses coal by 2030, and oil maintains its leading share

**820 x$10^{15}$ Btu x 52.9kg/$10^9$ Btu x 1t/kg x1Gt/$10^9$ t = 43.4Gt in 2040**



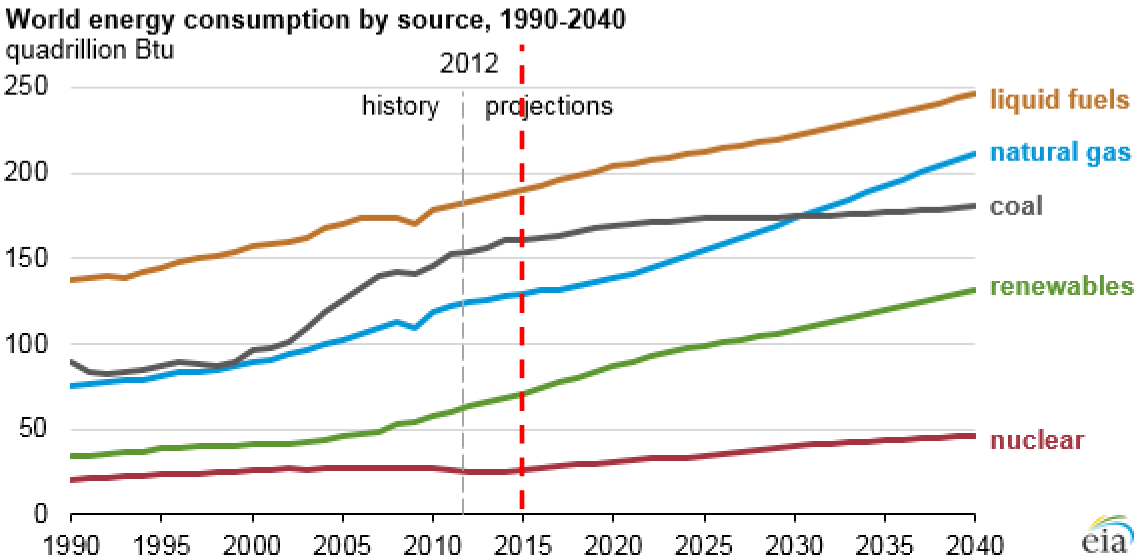

| |
|---|
| 248 |
| 212 |
| 180 |
| 135 |
| <u>45</u> |
| **820 Quads** |

*Source: EIA, International Energy Outlook 2016 and EIA, Analysis of the Impacts of the Clean Power Plan (May 2015)*



2015 = 521.3 Quads

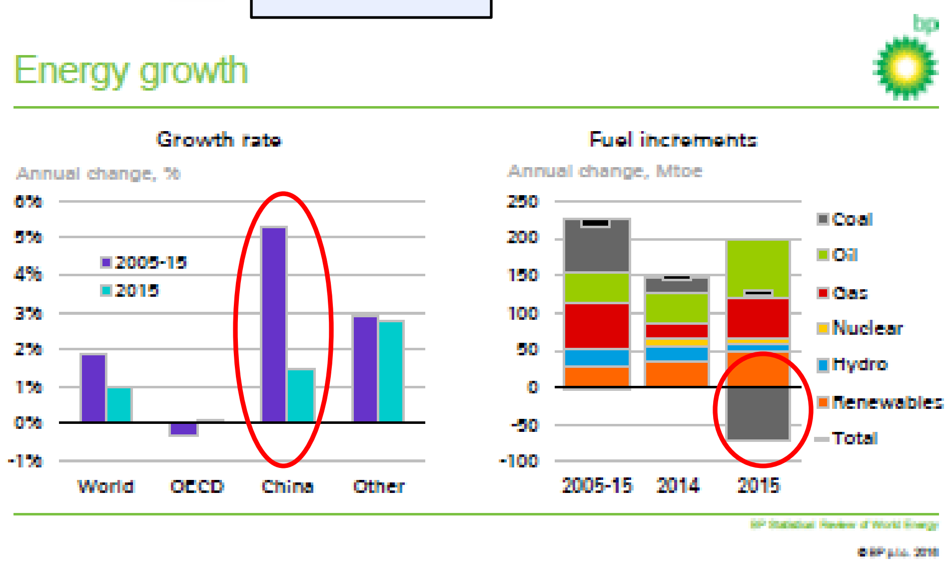
# World Energy Consumption IEA IEO2016




| 2015 | 2040 | 2040/2015 |
|---|---|---|
| 171.7 | 248.0 | +44.4% |
| 124.3 | 212.0 | +70.5% |
| 152.3 | 180.0 | +18.2% |
| 49.9 | 135.0 | +270.5% |
| 23.1 | 45.0 | +94.8% |
| 521.3 | 820.0 | +57.3% |

Source: EIA International Energy Outlook 2016

Much of the analysis conducted for the IEO2016 was done before the release of the U.S. Environmental Protection Agency's final Clean Power Plan (CPP). For this reason, the IEO2016 Reference case does not include the potential effects of the CPP regulations in the United States, analysis that shows the potential for significant reductions in U.S. coal consumption and increases in U.S. renewable consumption compared with the Reference case projection.




Energy in 2015: A Year of Plenty
Spencer Dale – BP June 8, 2016
BP Statistical Review of World Energy 2015

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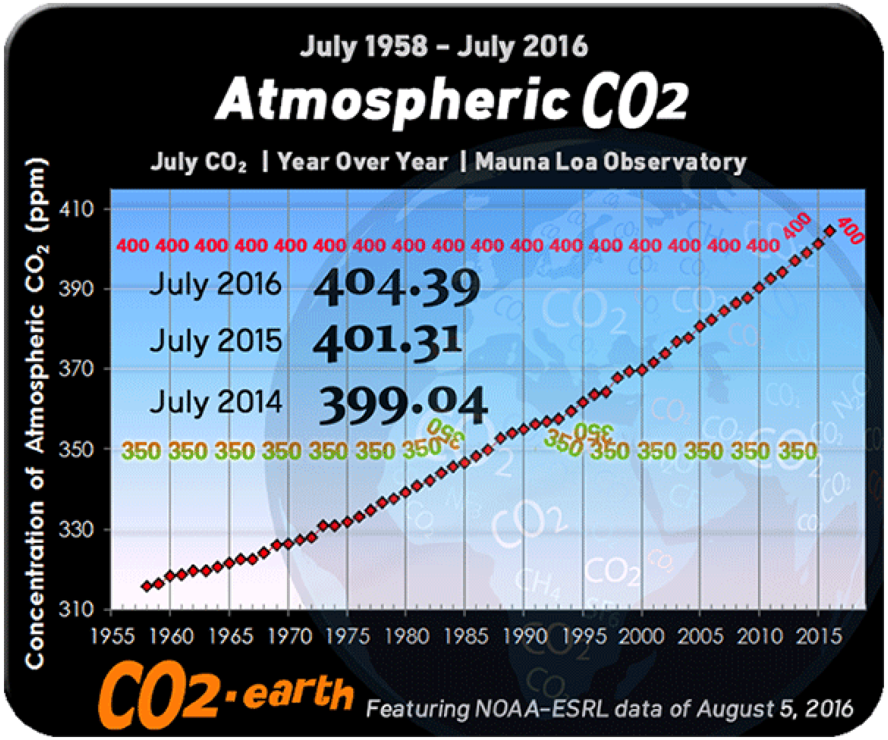
# What's Our Target?

# 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)**

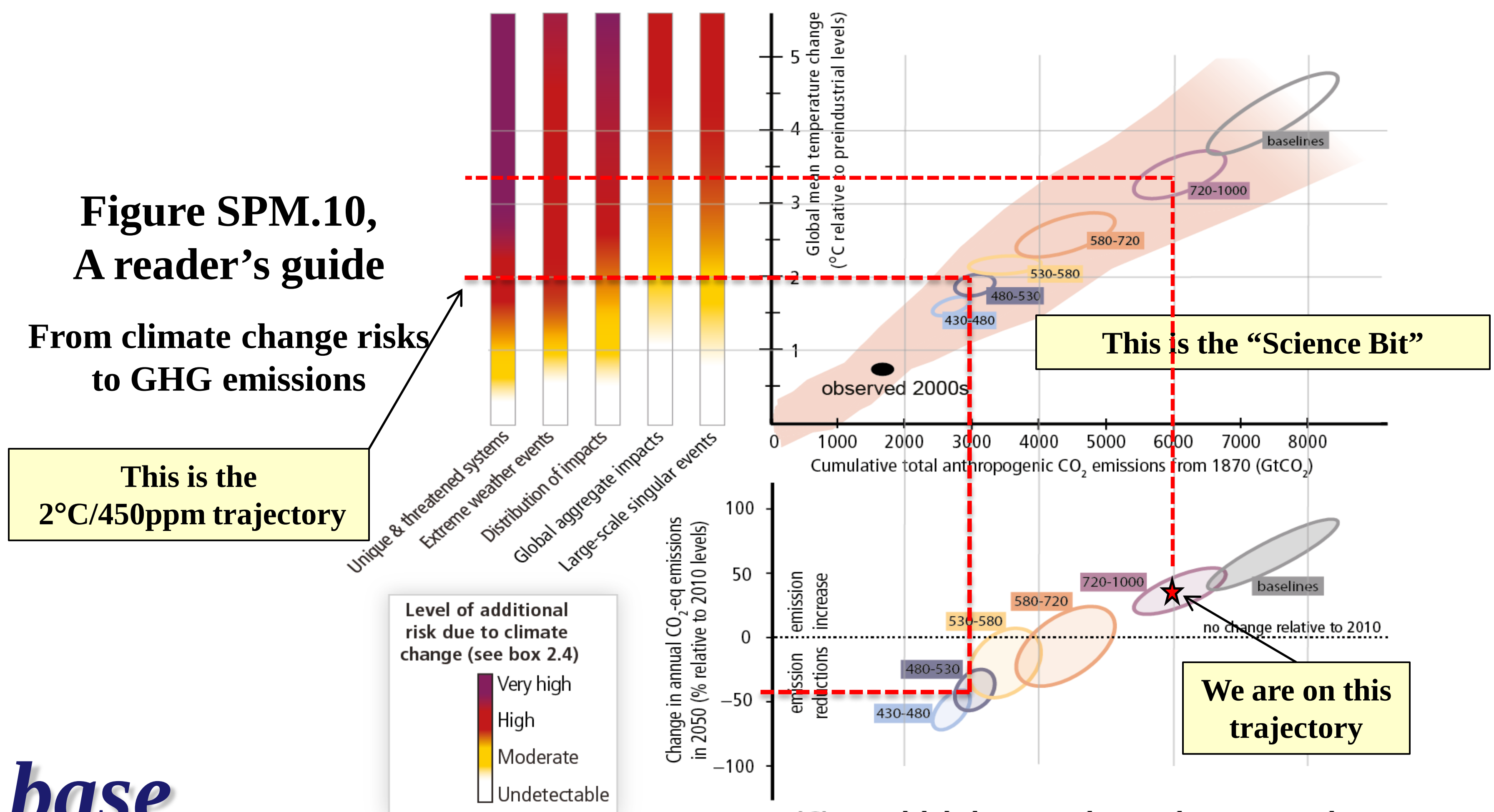
**Value July 2016 at Mauna Loa was 404.30ppm(v)**

# This is the “Science Bit”

(A) Risks from climate change... (B) ...depend on cumulative $CO_2$ emissions...

**Figure SPM.10, A reader’s guide**

**From climate change risks to GHG emissions**

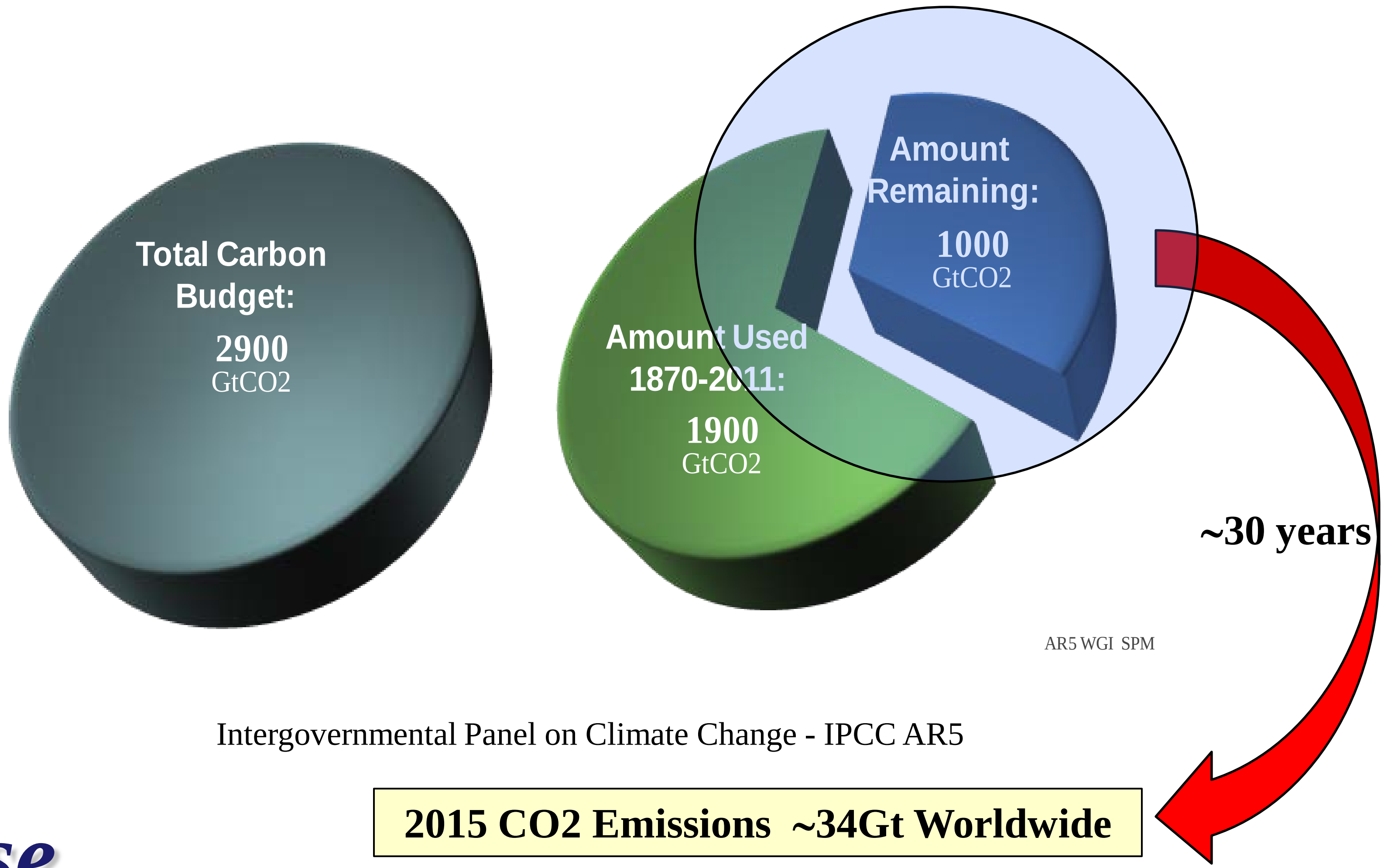



(C) …which in turn depend on annual emissions over the next decades

base e

*“Practical Strategies fo*

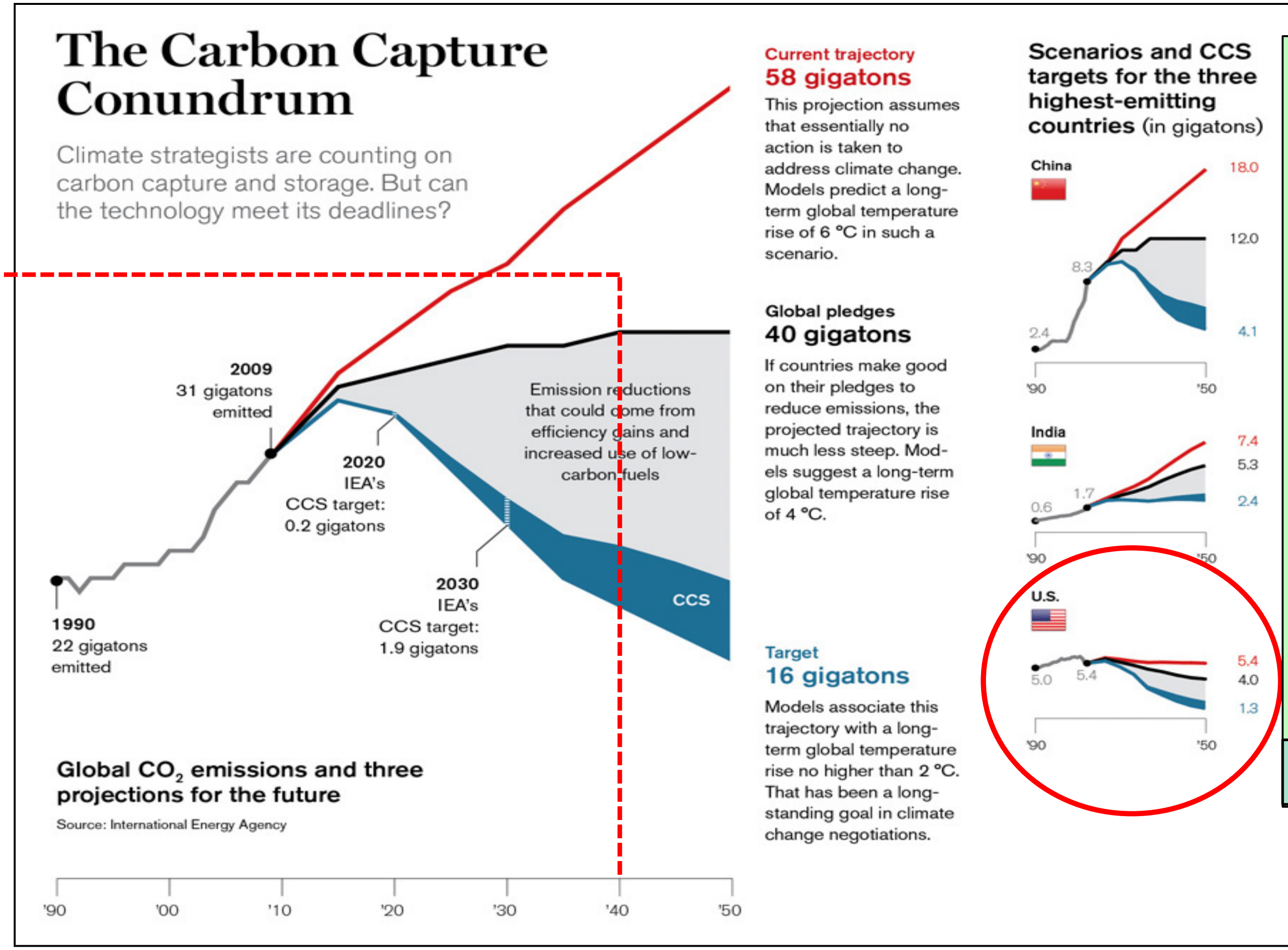
# The $CO_2$ Budget – 65% Already Used




Intergovernmental Panel on Climate Change - IPCC AR5

**2015 CO2 Emissions ~34Gt Worldwide**

# The Carbon Conundrum




MIT Technology Review – Mike Orcott

U.S. target to sustain 2°C/450ppmv is 1.3Gt …..

…..a reduction of 4.7 Gt from 2005 value of 6.0Gt (5.996)

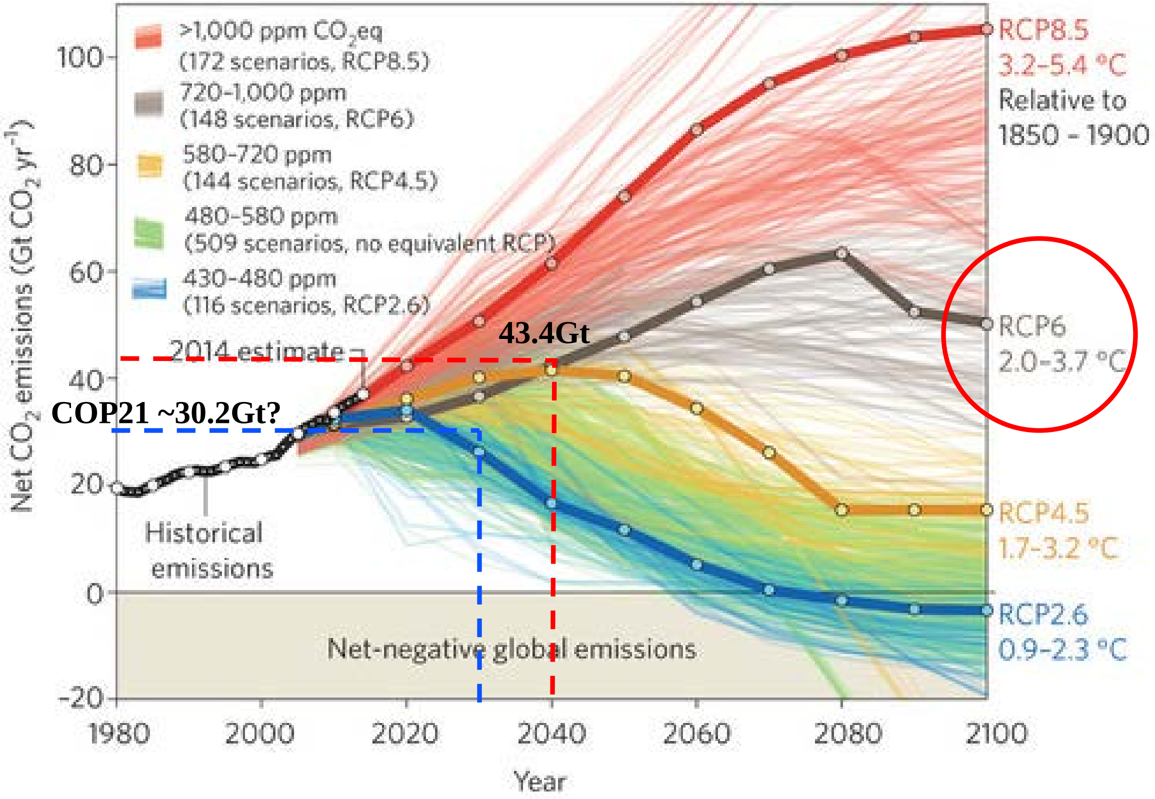
38.5% of 4.7 Gt requires a "fair share" reduction of 1.8-2.0 Gt from fossil fuel PowerGen

To a level of 0.5Gt

# “Busted”

The world appears to be on the >RCP6 720-1000 ppm path

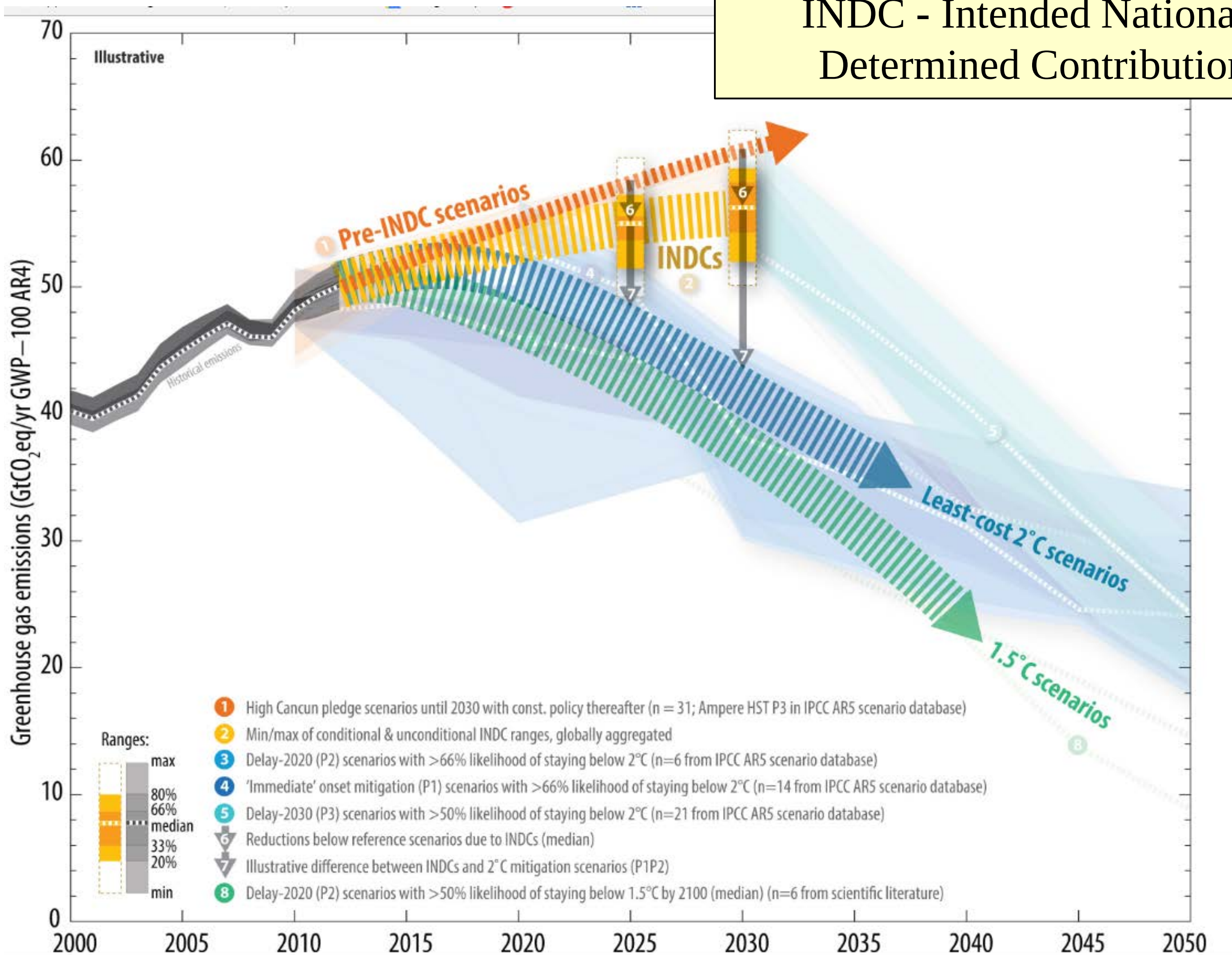
At least the CIA forecast appears to be a candid assessment☺



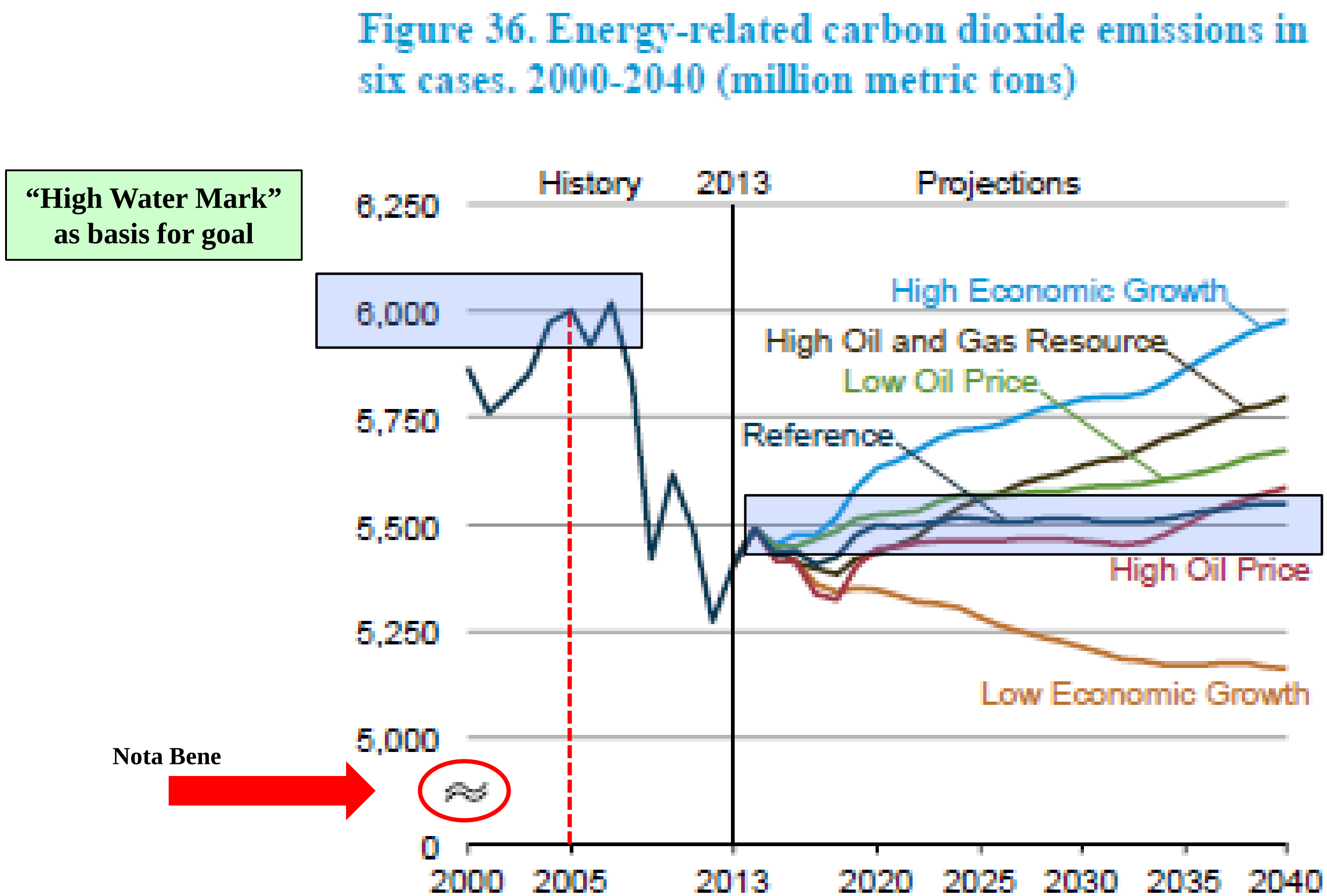

Source: IPCC AR5

# COP21 & Supporting INDC's

INDC - Intended Nationally Determined Contributions



# EIA Energy Related $CO_2$ Forecast




Reference Case is: "Business as Usual"

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

# Worldwide $CO_2$ Emissions (Million metric tonnes)

CO2 Emissions (Million metric tonnes)

| | 2010 | 2011 | 2012 | 2013 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | Share 2015 | Share 2040 | Growth (2012-2040) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **OECD** | | | | | | | | | | | | | |
| **OECD Americas** | 6502 | 6558 | 6343 | 6467 | 6478 | 6569 | 6620 | 6675 | 6769 | 6887 | 19.3% | 15.9% | 0.30% |
| United States | 5458 | 5483 | 5272 | 5404 | 5428 | 5499 | 5511 | 5514 | 5521 | 5549 | 16.2% | 12.8% | 0.20% |
| Canada | 547 | 562 | 563 | 561 | 557 | 557 | 577 | 587 | 621 | 647 | 1.7% | 1.5% | 0.50% |
| Mexico/Chile | 498 | 513 | 508 | 501 | 492 | 513 | 533 | 573 | 628 | 690 | 1.5% | 1.6% | 1.10% |
| **OECD Europe** | 4247 | 4193 | 4124 | 3997 | 4054 | 4096 | 4170 | 4252 | 4317 | 4415 | 12.1% | 10.2% | 0.20% |
| **OECD Asia** | 2190 | 2270 | 2322 | 2317 | 2335 | 2361 | 2388 | 2407 | 2460 | 2513 | 7.0% | 5.8% | 0.30% |
| Japan | 1169 | 1185 | 1247 | 1245 | 1215 | 1176 | 1175 | 1159 | 1144 | 1111 | 3.6% | 2.6% | -0.40% |
| South Korea | 577 | 642 | 639 | 641 | 685 | 734 | 742 | 761 | 803 | 850 | 2.0% | 2.0% | 1.00% |
| Australia/New Zealand | 444 | 442 | 436 | 431 | 435 | 451 | 470 | 487 | 513 | 552 | 1.3% | 1.3% | 0.80% |
| **Total OECD** | **12939** | **13021** | **12790** | **12781** | **12867** | **13026** | **13178** | **13334** | **13547** | **13815** | 38.4% | 32.0% | 0.30% |
| **Non-OECD** | | | | | | | | | | | | | |
| **Non-OECD Europe and Eurasia** | 2717 | 2845 | 2938 | 2922 | 2832 | 2914 | 3038 | 3128 | 3198 | 3170 | 8.4% | 7.3% | 0.30% |
| Russia | 1665 | 1695 | 1795 | 1818 | 1762 | 1814 | 1862 | 1897 | 1924 | 1864 | 5.3% | 4.3% | 0.10% |
| Other | 1051 | 1150 | 1143 | 1105 | 1070 | 1100 | 1176 | 1231 | 1275 | 1306 | 3.2% | 3.0% | 0.50% |
| **Non-OECD Asia** | 11005 | 11785 | 12195 | 12615 | 13201 | 14456 | 15505 | 16386 | 17482 | 18682 | 39.4% | 43.2% | 1.50% |
| China | 7383 | 8119 | 8378 | 8760 | 9125 | 9861 | 10371 | 10636 | 10878 | 11051 | 27.2% | 25.6% | 1.00% |
| India | 1624 | 1663 | 1778 | 1804 | 1932 | 2143 | 2394 | 2693 | 3161 | 3732 | 5.8% | 8.6% | 2.70% |
| Other | 1998 | 2003 | 2038 | 2051 | 2144 | 2452 | 2740 | 3057 | 3443 | 3898 | 6.4% | 9.0% | 2.30% |
| **Middle East** | 1732 | 1828 | 1894 | 1949 | 2090 | 2399 | 2608 | 2887 | 3171 | 3446 | 6.2% | 8.0% | 2.20% |
| Africa | 1133 | 1120 | 1184 | 1187 | 1267 | 1438 | 1594 | 1760 | 1973 | 2239 | 3.8% | 5.2% | 2.30% |
| Central and South America | 1215 | 1242 | 1271 | 1279 | 1282 | 1398 | 1509 | 1608 | 1725 | 1865 | 3.8% | 4.3% | 1.40% |
| Brazil | 459 | 475 | 501 | 498 | 503 | 549 | 599 | 650 | 704 | 764 | 1.5% | 1.8% | 1.50% |
| Other | 755 | 767 | 769 | 782 | 779 | 849 | 910 | 958 | 1021 | 1101 | 2.3% | 2.5% | 1.30% |
| **Total Non-OECD** | **17801** | **18818** | **19481** | **19952** | **20671** | **22605** | **24254** | **25769** | **27549** | **29402** | 61.6% | 68.0% | 1.50% |
| **Total World** | **30741** | **31839** | **32271** | **32733** | **33538** | **35631** | **37432** | **39103** | **41096** | **43217** | 100.0% | 100.0% | **1.00%** |
| | | | | | 33.5 Gt | | | | | 43.2 Gt | | | |

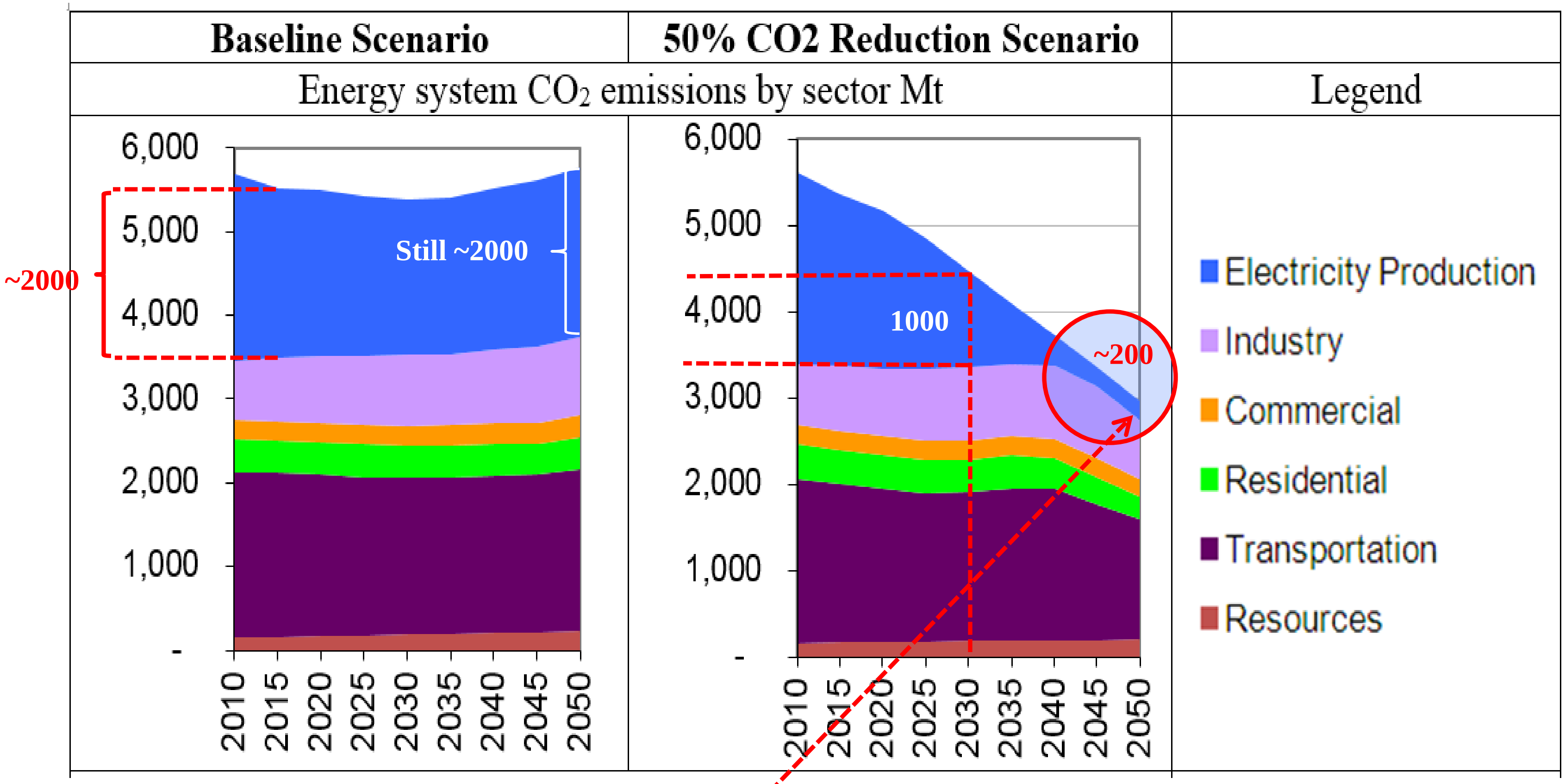
*"Practical Strategies for Emerging Energy Technologies"*

EIA AEO2016 Reference Case September 2016

# Reference Case EIA AEO2016 Forecast

| CO2 (Gt) | 2010 | 2011 | 2015 | 2020 | 2025 | 2030 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **OECD** | | | | | | | | | | | | |
| **OECD Americas** | 6.5 | 6.6 | 6.5 | 6.6 | 6.6 | 6.7 | 6.8 | 6.8 | 6.8 | 6.9 | 6.9 | 6.9 |
| United States | 5.5 | 5.5 | 5.4 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 |
| Canada | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Mexico/Chile | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 |
| **OECD Europe** | 4.2 | 4.2 | 4.1 | 4.1 | 4.2 | 4.3 | 4.3 | 4.3 | 4.4 | 4.4 | 4.4 | 4.4 |
| **OECD Asia** | 6.5 | 2.3 | 2.3 | 2.4 | 2.4 | 2.4 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Japan | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| South Korea | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Australia/New Zealand | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 |
| **Total OECD** | 12.9 | 13.0 | 12.9 | 13.0 | 13.2 | 13.3 | 13.5 | 13.6 | 13.7 | 13.7 | 13.8 | 13.8 |
| | | | | | | | | | | | | |
| **Non-OECD** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Non-OECD Europe and Eurasia** | 2.7 | 2.8 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Russia | 1.7 | 1.7 | 1.8 | 1.8 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| Other | 1.1 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| **Non-OECD Asia** | 11.0 | 11.8 | 13.2 | 14.5 | 15.5 | 16.4 | 17.5 | 17.7 | 17.9 | 18.2 | 18.4 | 18.7 |
| China | 7.4 | 8.1 | 9.1 | 9.9 | 10.4 | 10.6 | 10.9 | 10.9 | 11.0 | 11.0 | 11.0 | 11.1 |
| India | 1.6 | 1.7 | 1.9 | 2.1 | 2.4 | 2.7 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 |
| Other | 2.0 | 2.0 | 2.1 | 2.5 | 2.7 | 3.1 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 |
| **Middle East** | 1.7 | 1.8 | 2.1 | 2.4 | 2.6 | 2.9 | 3.2 | 3.2 | 3.3 | 3.3 | 3.4 | 3.4 |
| Africa | 1.1 | 1.1 | 1.3 | 1.4 | 1.6 | 1.8 | 2.0 | 2.0 | 2.1 | 2.1 | 2.2 | 2.2 |
| Central and South America | 1.2 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.8 | 1.8 | 1.8 | 1.9 |
| Brazil | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 |
| Other | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 |
| **Total Non-OECD** | 17.8 | 18.8 | 20.7 | 22.6 | 24.3 | 25.8 | 27.5 | 27.9 | 28.3 | 28.7 | 29.0 | 29.4 |
| **Total World** | **30.7** | **31.8** | **33.5** | **35.6** | **37.4** | **39.1** | **41.1** | **41.5** | **41.9** | **42.4** | **42.8** | **43.2** |
| | | **1,900.0** | **2,030.2** | **2,202.0** | **2,383.7** | **2,574.2** | **2,773.5** | **2,814.6** | **2,856.1** | **2,898.1** | **2,940.4** | **2,983.2** |

# 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**

base$_e$ ®

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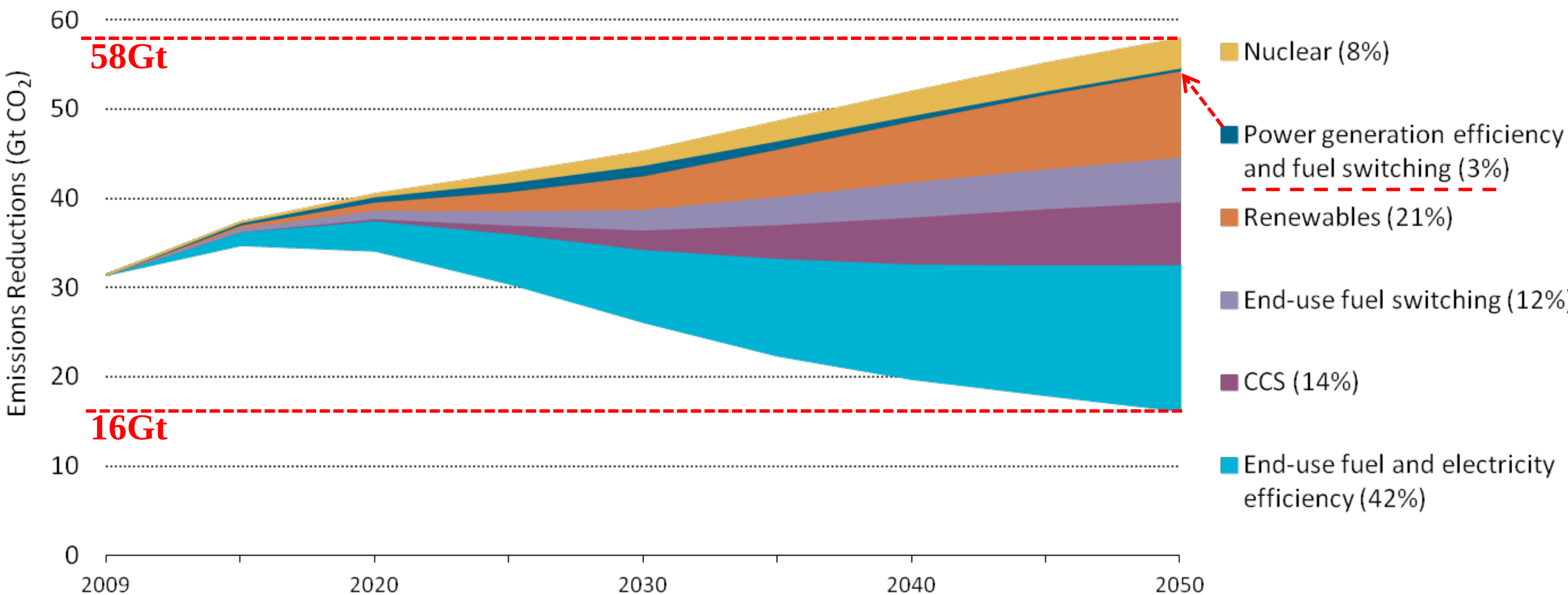
# IEA Vision May 2013




**Nuclear and CCS technologies currently on "life support"**

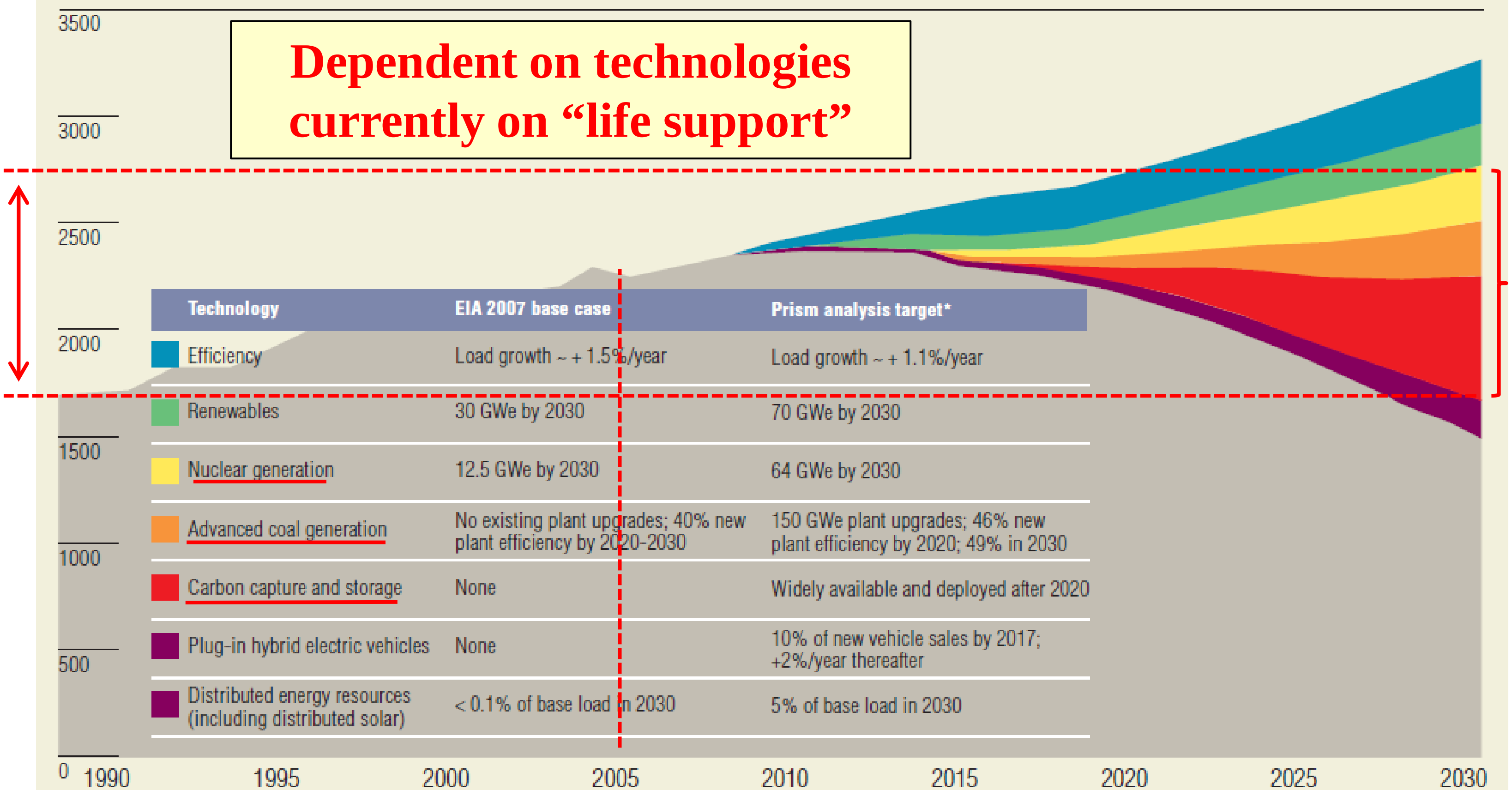

**12th Annual CCUS Conference**
**Pittsburgh, 15 May 2013**

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

# Electric Power Research Institute PRISM Analysis

**TABLE 1**

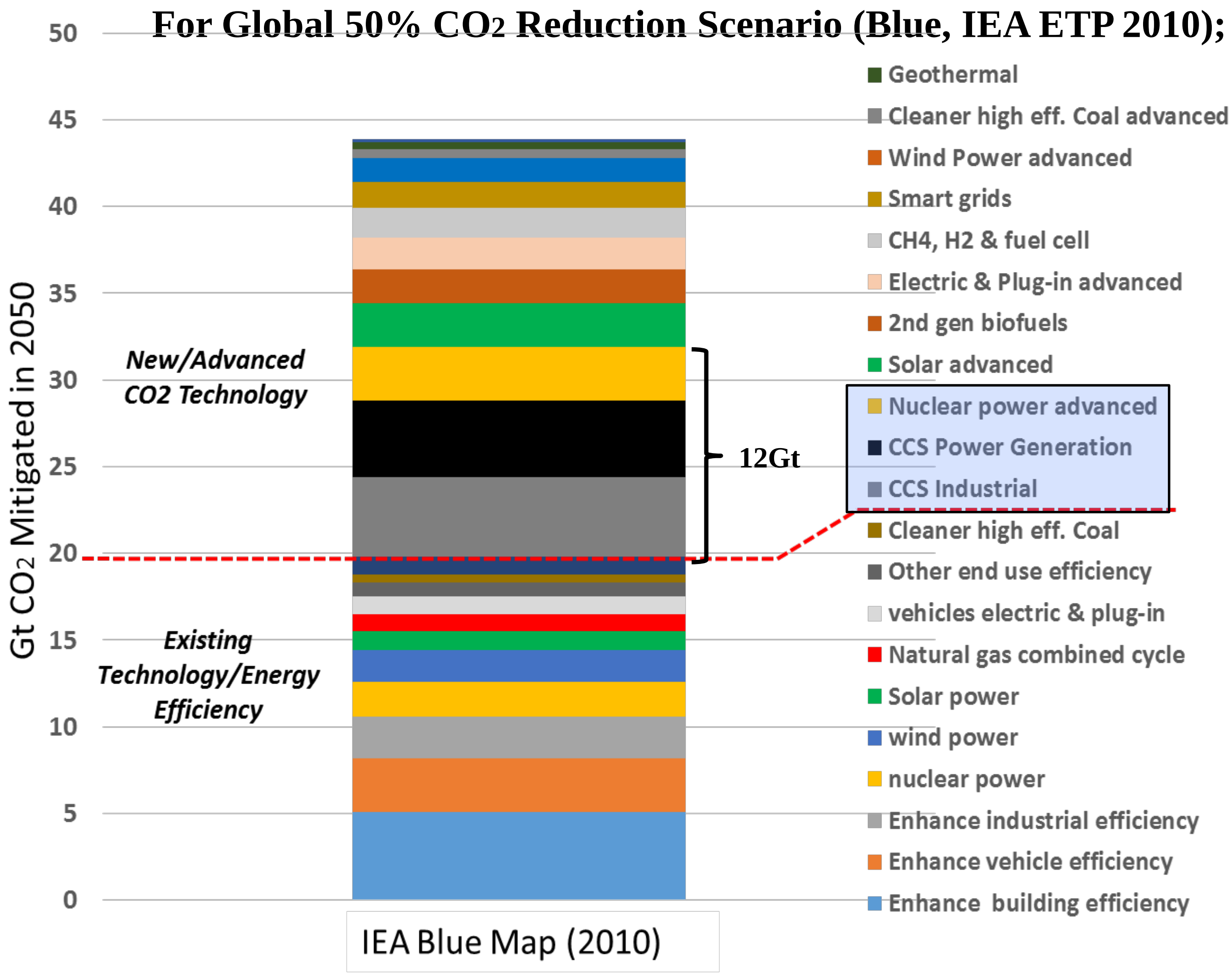
**U.S. ELECTRIC SECTOR**




| 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 |

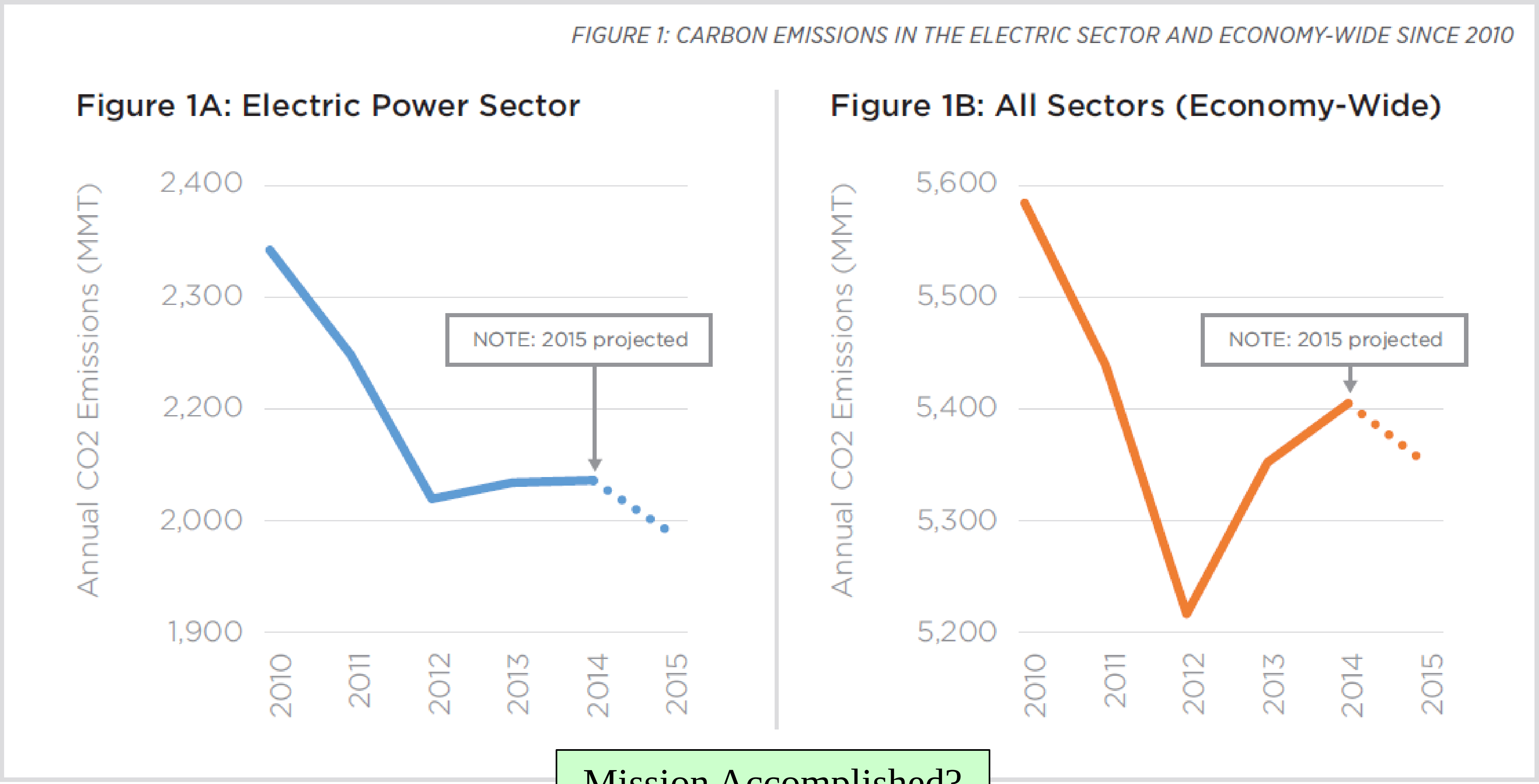
* Prism analysis targets do not reflect economic or potential regulatory and siting constraints.

# New & Advanced Technologies Needed




Source: DOE SCO2 Conference 2014, as presented by EPA

# Sierra Club Fact Sheet – November 3, 2015

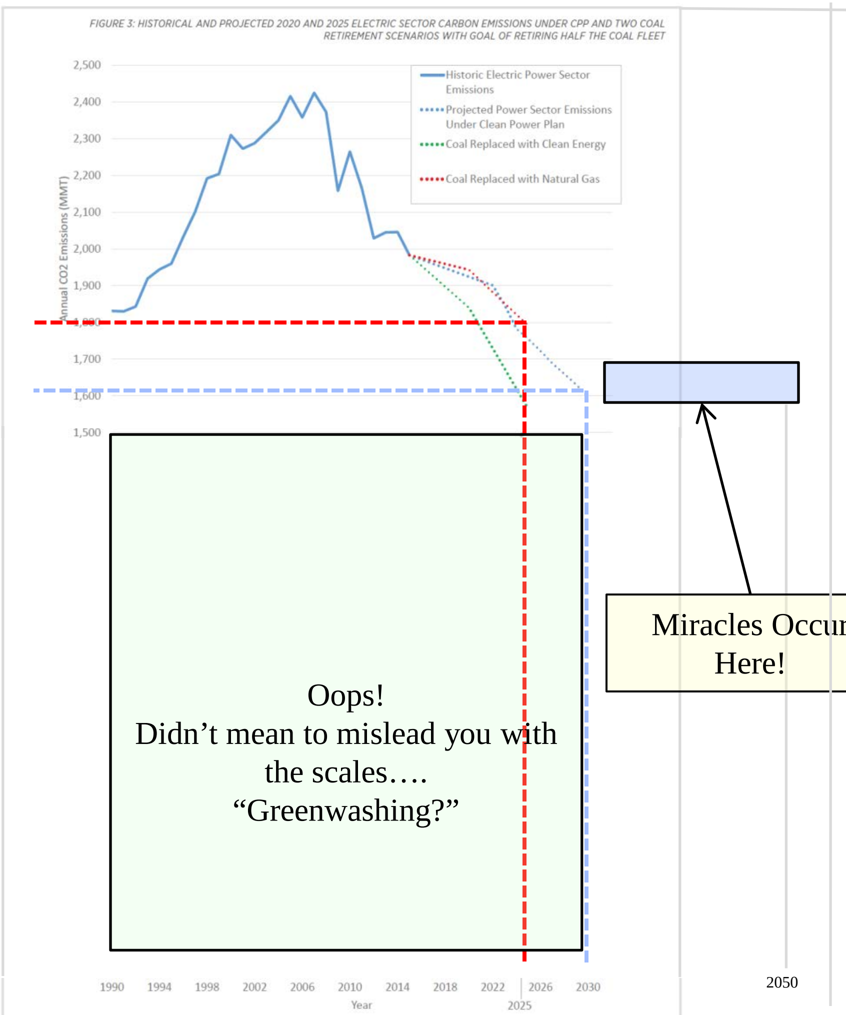



Mission Accomplished?

base$_e$

*"Practical Strategies for Emerging Energy Technologies"*

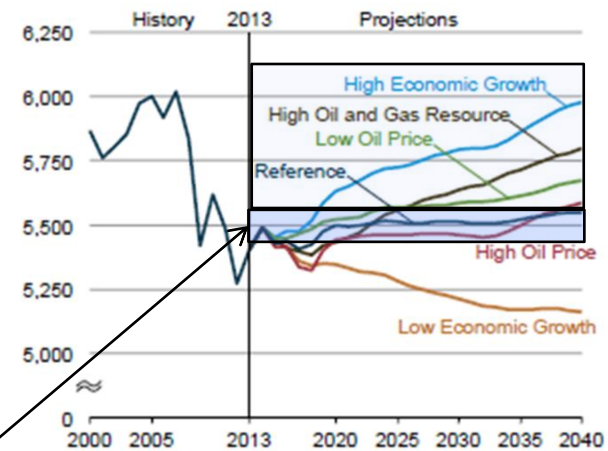
# Sierra Club Fact Sheet – November 3, 2015  (Re-scaled)




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

Miracles Occur Here!

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

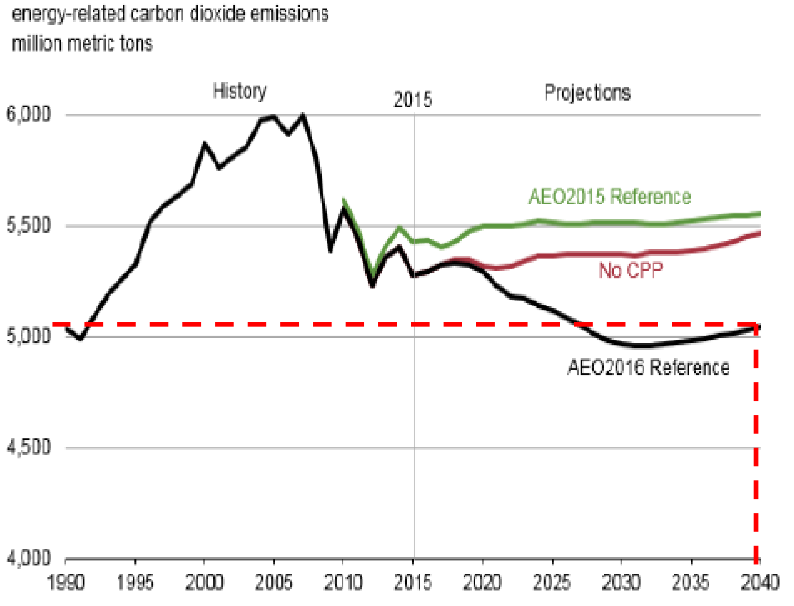



OBTW - The Sierra Club has admitted to accepting $27 million contribution from the natural gas industry, presumably to fund their "Beyond Coal" initiative, but only after the facts became known.

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

# AEO2016 Early Release – Two Cases May 17, 2016

## CO2 emissions are lower in AEO2016 Reference case than AEO2015 Reference Case, even without the Clean Power Plan (CPP)




*Source: EIA, Annual Energy Outlook 2016*

- Key drivers for the lower energy-related CO2 emissions in AEO2016 include:
  - Lower natural gas prices that support higher electricity generation from natural gas with or without the CPP
  - Lower technology costs for wind and solar, combined with extended tax credits and the CPP, and
  - Reduced coal generation as a result of the CPP, which emit the most CO2 per kilowatthour.

# The New Reference Case Includes Full Effect of CPP

## Key takeaways from the two cases: Electricity

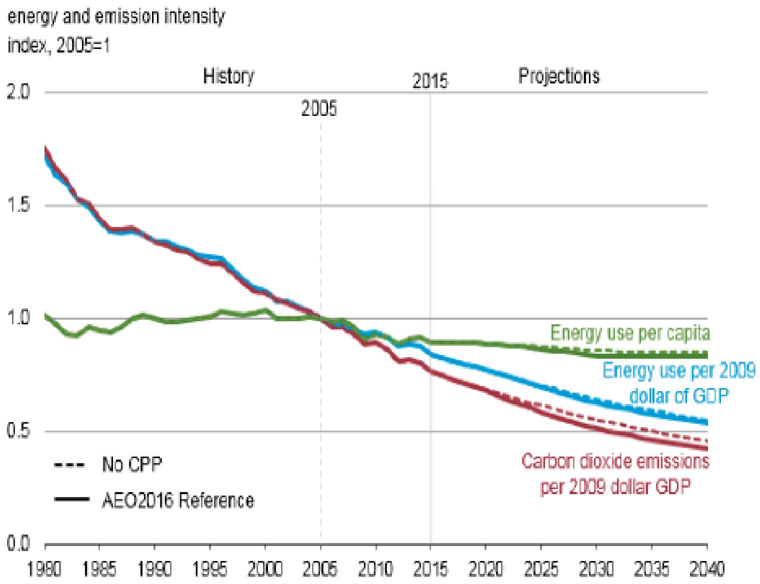
- Implementation of the Clean Power Plan (CPP) using a mass-based approach reduces annual electricity-related carbon dioxide (CO2) emissions to between 1,550 and 1,560 million metric tons (MMT) in the 2030-40 period, substantially below their 2005 and 2015 levels of 2,416 MMT and 1,891 MMT, respectively. Coal's share of total electricity generation, which was 50% in 2005 and 33% in 2015, falls to 21% in 2030 and to 18% in 2040.
- Even without the CPP, electricity-related CO2 emissions remain well below their 2005 level at 1,942 MMT in 2030 and 1,959 MMT in 2040; this outcome reflects both low load growth and generation mix changes driven by the extension of key renewable tax credits, reduced solar photovoltaic (PV) capital costs, and low natural gas prices.

Full CPP Δ to reference plan only 400 MMt

- With the mass-based approach, the strong growth in wind and solar generation spurred by tax credits leads to a short-term decline in natural gas-fired generation between 2015 and 2021. However, natural gas generation then grows significantly under a mass-based CPP implementation, increasing by more than 67% from 2021 through 2040, when it is by far the largest generation source.

# Sorry But, CPP is Business as Usual!

CO2 emissions per dollar of gross domestic product (GDP) decline faster than energy use per dollar of GDP with a shift towards low- and no-carbon fuels




Source: EIA, Annual Energy Outlook 2016 Reference case

- The economy's energy intensity, carbon intensity, and per-capita energy use are projected to decline steadily. In the Reference case, energy use per dollar of GDP declines at an average annual rate of 1.8% over 2015-40, while energy use per capita declines at an average annual rate of 0.3%. With renewables and natural gas providing larger shares of total energy use, CO2 per dollar of GDP declines faster than energy intensity.
- The structure and efficiency of the U.S. economy changes in ways that lower total energy use and energy use per dollar of GDP. The nonindustrial and services sector share of the economy remains near 77% throughout the projection, but there is a shift towards non-energy-intensive industries within manufacturing that is slightly smaller in the absence of the CPP.
- Energy-use-per-capita declines, driven by gains in appliance efficiency, a shift in population from cooler to warmer regions, and an increase in vehicle efficiency standards, combined with modest growth in travel per licensed driver.



You know there is a problem when the discussion shifts to CO2 per GDP

# EIA May 17, 2016 Early Release Mmt/$Million GDP

**Data table for: GDP long-term forecast, Total, Million US dollars, 2009 – 2060**

| | 2005 | 2009 | 2010 | 2015 |
|---|---|---|---|---|
| China | | 8,264,462 | 9,127,849 | 13,325,589 |
| India | | 3,259,867 | 3,622,119 | 4,751,391 |
| United States | | 13,263,170 | 13,595,648 | 15,423,341 |
| World | 47,104,046 | 54,942,708 | 57,674,148 | 68,077,321 |
| | | | | |
| Million tonnes CO2 | 28533 | 30,158.0 | 31,544.1 | 33,508.4 |
| Cummulative | | | | 2,032,971 |
| | | | | |
| MMt/GDP | 0.000606 | 0.000549 | 0.000547 | 0.000492 |
| | | | 0.9029 | 0.8999 |
| | | | | |
| US Percent of World GDP | | 24.1% | 23.6% | 22.7% |

Source: OECD Economic Outlook: Statistics and Projections

- The key factor is the calculated MMt of CO2 per million dollars of GDP, 0.000492 in 2015.
- There was a 10% reduction in this value for both the 2005-2010 and the 2010-2015 periods, based on the data and can be interpreted as an improvement in overall efficiency of use.
- I included the 1900GtCO2 in the 2C/450 ppm already consumed between 1870-2011 as the 2012 staring value.

# EIA May 17, 2016 Early Release Mmt/$Million GDP

**Data table for: GDP long-term forecast, Total, Million US dollars, 2009 – 2060**

| | 2020 | 2025 | 2030 | 2035 | 2040 | 2041 | 2045 | 2050 | 2055 | 2060 |
|---|---|---|---|---|---|---|---|---|---|---|
| China | 17,709,685 | 21,987,556 | 26,307,248 | 31,117,405 | 36,477,854 | | 41,497,785 | 45,730,397 | 49,722,574 | 53,827,698 |
| India | 6,337,715 | 8,437,521 | 11,162,212 | 14,504,379 | 18,401,049 | | 22,832,998 | 27,817,822 | 33,324,548 | 39,211,023 |
| United States | 17,743,025 | 20,025,623 | 22,482,236 | 24,988,766 | 27,461,839 | | 29,898,935 | 32,341,599 | 34,792,848 | 37,206,576 |
| World | 81,452,490 | 95,570,319 | 111,074,203 | 128,015,627 | 145,962,170 | 149,409,817 | 164,034,207 | 182,273,171 | 201,423,865 | 221,232,567 |
| Million tonnes CO2 | 36,082.6 | 38,103.0 | 39,855.8 | 41,341.3 | 42,423.3 | 42,519.8 | 42,908.2 | 42,911.3 | 42,677.8 | 42,187.4 |
| Cummulative | 2,069,054 | 2,255,484 | 2,451,226 | 2,654,940 | 2,864,881 | 2,907,401 | 3,078,450 | 3,293,001 | 3,506,856 | 3,718,772 |
| MMt/GDP | 0.000443 | 0.0003987 | 0.0003588 | 0.0003229 | 0.0002906 | 0.0002846 | 0.0002616 | 0.0002354 | 0.0002119 | 0.0001907 |
| | 0.9000 | 0.9000 | 0.9000 | 0.9000 | 0.9000 | | 0.9000 | 0.9000 | 0.9000 | 0.9000 |
| US Percent of World GDP | 21.8% | 21.0% | 20.2% | 19.5% | 18.8% | | 18.2% | 17.7% | 17.3% | 16.8% |

Source: OECD Economic Outlook: Statistics and Projections

- The OECD GDP Forecast is shown without modification.
- The same efficiency of use improvements are assumed throughout the forecast period to 2060
- The calculated yearly increment is based on this GDP Forecast data and underlying efficiency of use assumptions.
- This efficiency of use assumptions are not likely to apply uniformly around the world, but that assumption is embedded in the calculation.
- We bust the 2900Gt budget in 2041 and reach 3719Gt by 2060.
- This is equivalent to 550-600 ppm and perhaps 4°C temperature rise.

**If 0.90 becomes 0.95:**

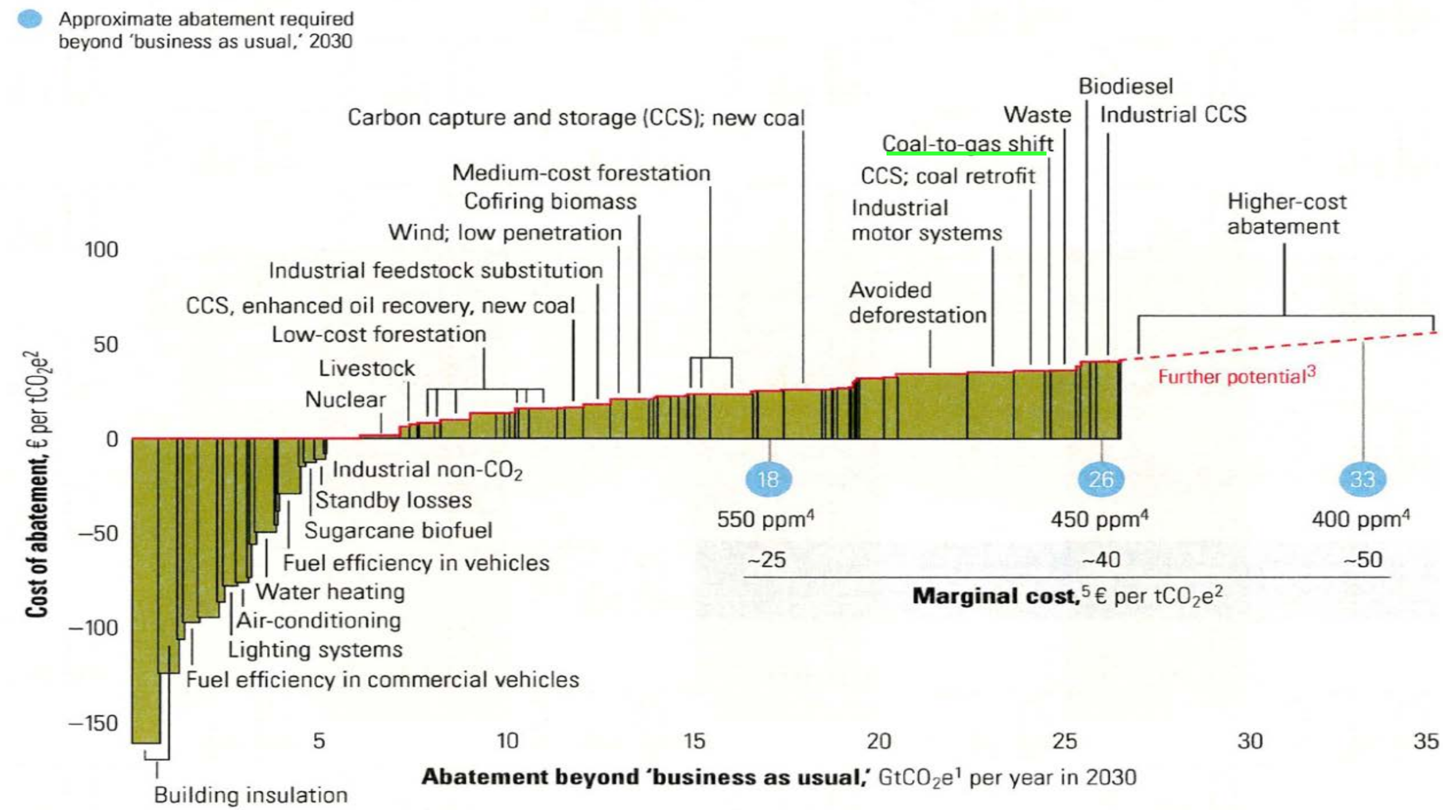
- **We bust the 2900Gt budget in 2038**
- **Total ytd 2060 is 4272Gt**
- **Annual release 55Gt 2040; 69Gt 2060**

# What Can We Do?

- **Stop Producing or Produce Less $CO_2$**
  - Fuel Switching
    - Renewables
    - Biofuels
    - Nuclear
    - Hydro
    - Waste to Energy
  - End Use Efficiency
    - Combined Heat & Power
    - CAFÉ Standards
    - Demand Response
    - Building Efficiency
    - Storage
    - Smart Grid
- **Put the CO2 back**
  - Carbon Capture & Storage
- **Adapt to its effects (live with it)**
  - Build seawalls
    - Dikes/Locks
  - Harden vulnerable assets
    - Relocate/Raise Critical Infrastructure
    - Create Barriers
    - High Capacity Pumping Systems
- **Use the CO2**
  - As a Fuel
  - Chemical Feedstock
  - Biomass Nutrient
  - Carbon(ate) - Based Product
  - Enhanced Oil Recovery (EOR)

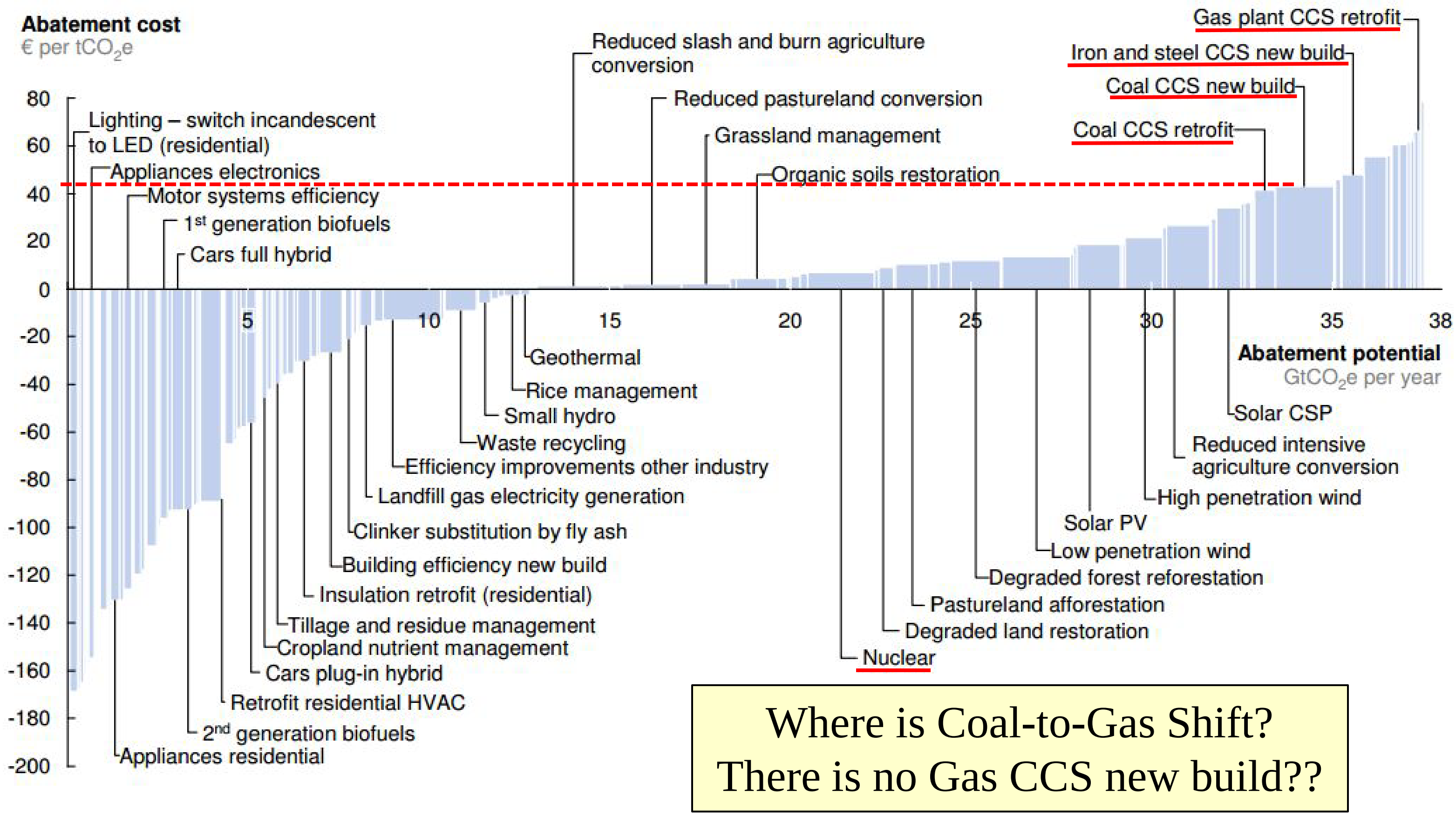
# McKinsey $CO_2$ Cost Curve V1.0

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.

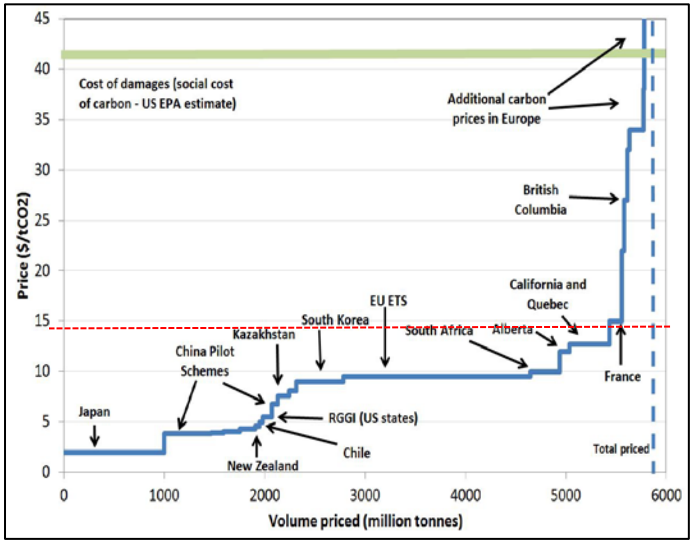
Source: Global GHG Abatement Cost Curve v2.1

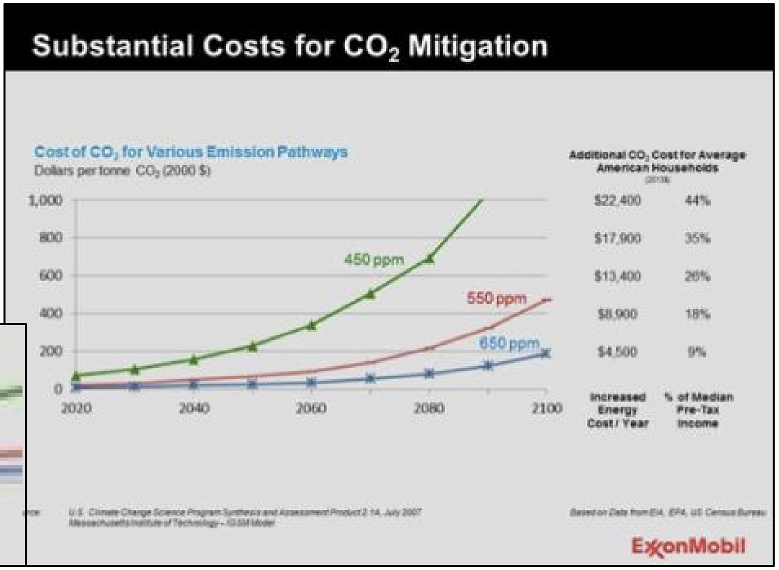
# $CO_2$ Pricing

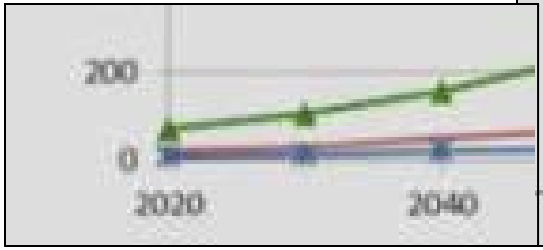
Source: On Climate Change Policy

## 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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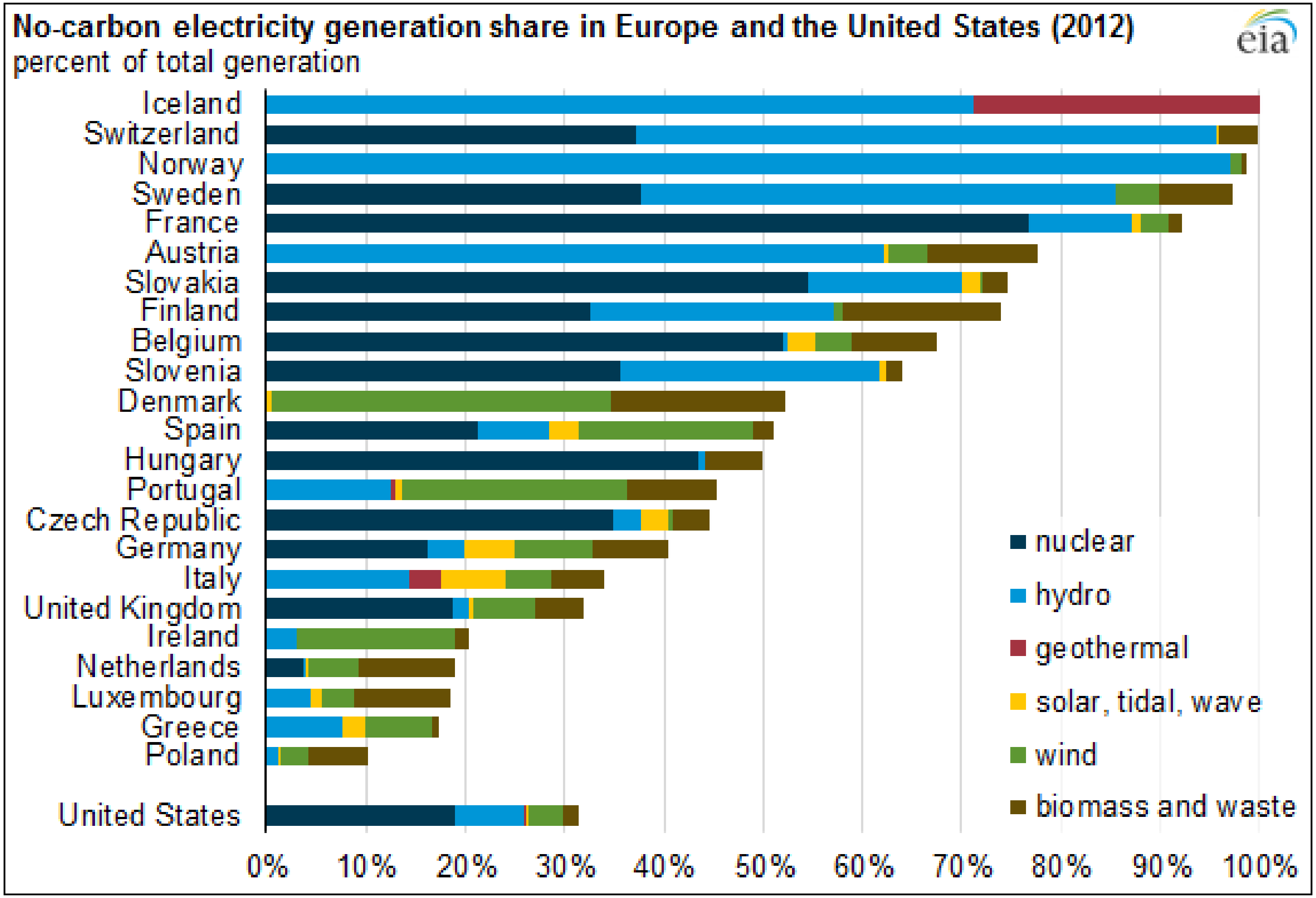
# Electric Power Generation

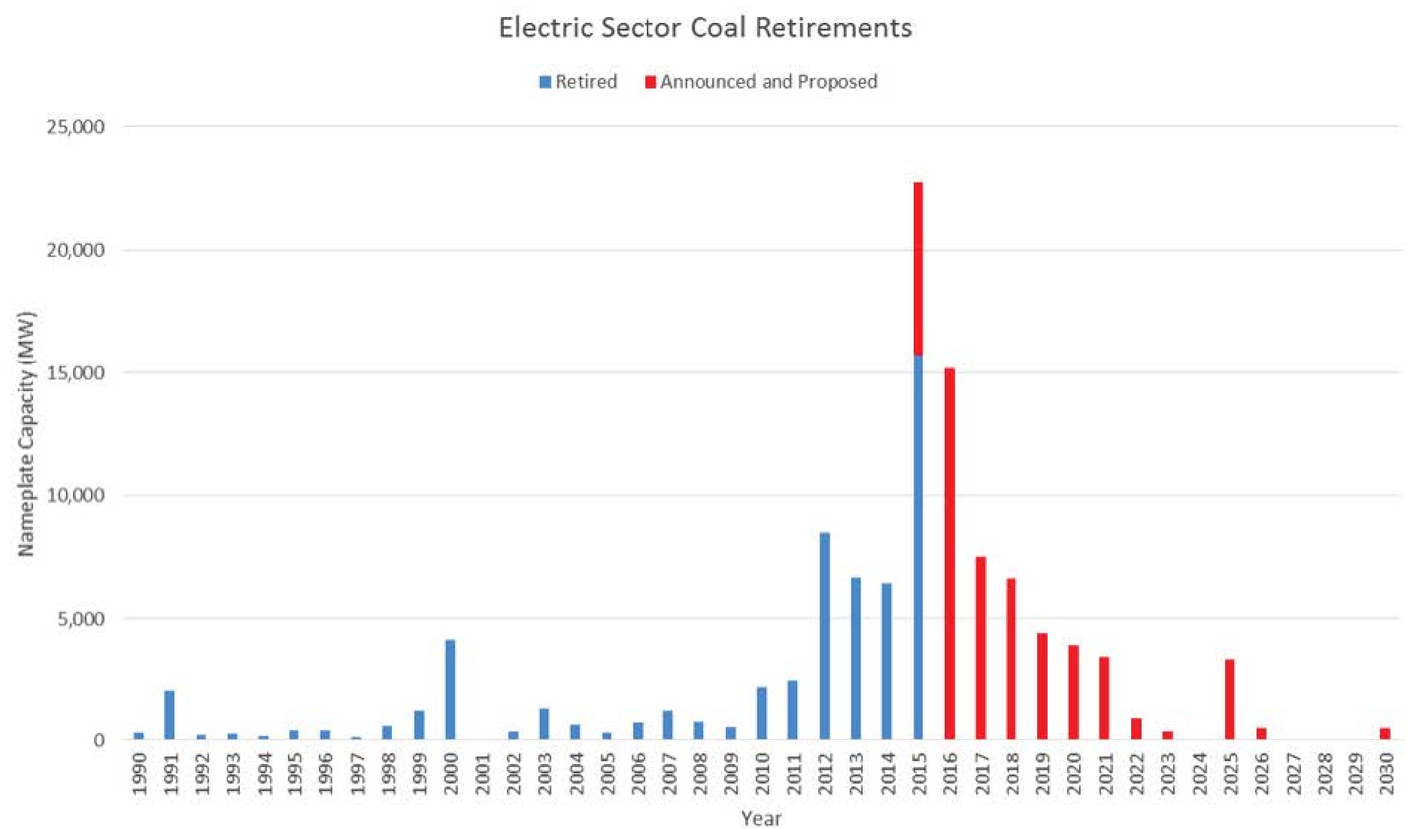
# No Carbon Sources



# Fuel Switching

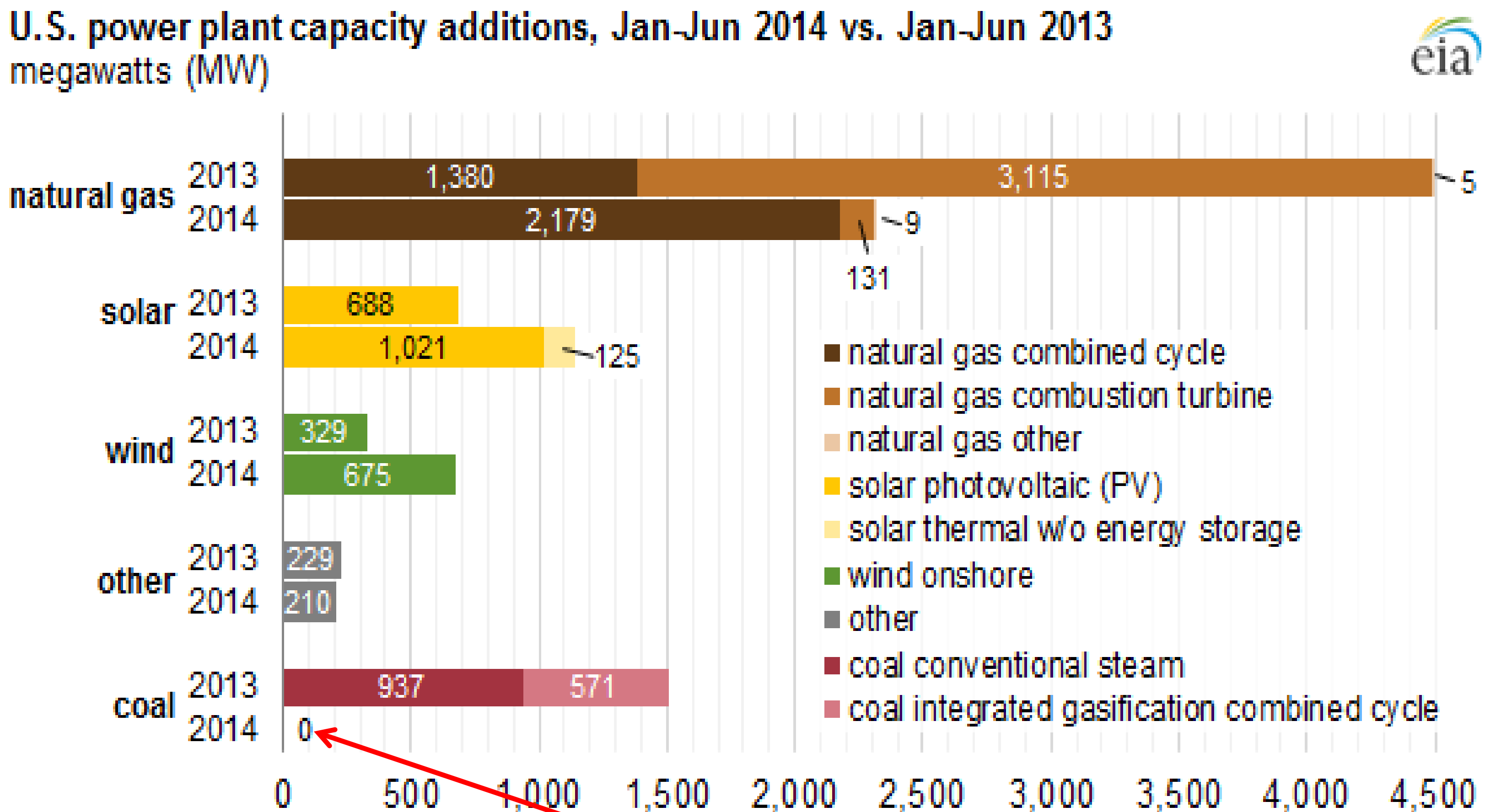
# U.S. Coal Plant Retirements

FIGURE 2: COAL RETIREMENTS ACTUAL, ANNOUNCED AND PROPOSED SINCE 1990




THIS CHART SHOWS THE MEGAWATTS OF COAL CAPACITY RETIRED TO DATE PLUS PROJECTED RETIREMENT DATES FOR UNITS ANNOUNCED OR PROPOSED RETIREMENTS INCLUDED IN A UTILITY'S RESOURCE PLANS. SOURCES: SIERRA CLUB, EIA.

# U.S. Power Plant Addition 2013-2014 (6 mos.)




It's working exactly as planned!
And, btw, killing CCS and
Nuclear in the process

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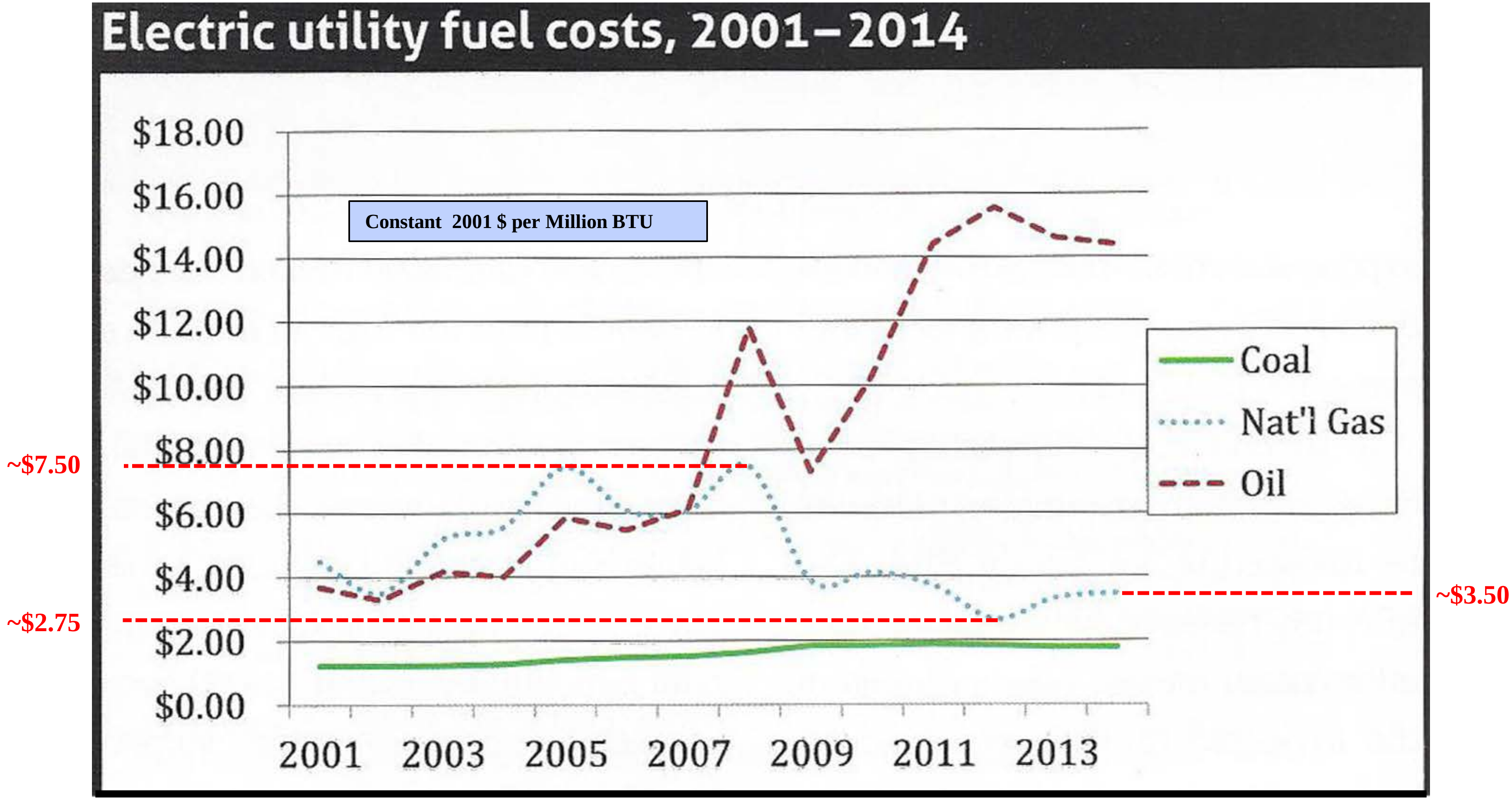
# U.S. Power Generation Shift 2015-2016

- The USA is the world's largest producer of nuclear power
  - More than 30% of worldwide nuclear generation of electricity.
  - 99 units operable (98.7 GWe)
  - 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
- Lower gas prices (and the ability to permit a natural gas-fueled plant without abatement) since 2009 have put the economic viability of some existing reactors and proposed new 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.

# U.S. Electric Utility Fuel Cost – 2001 to 2014




Source: ACCCE, Trisko (2014)

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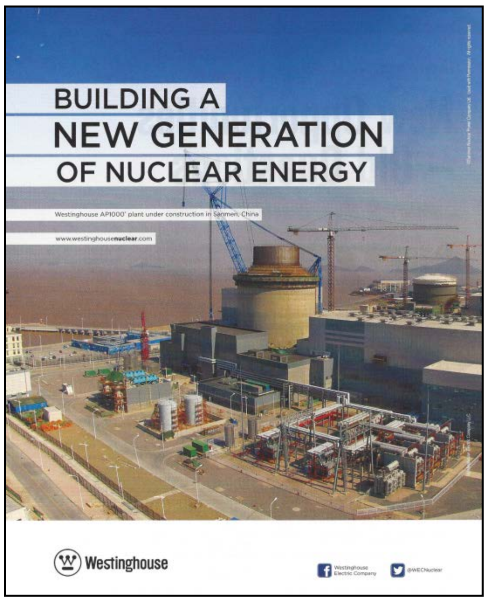
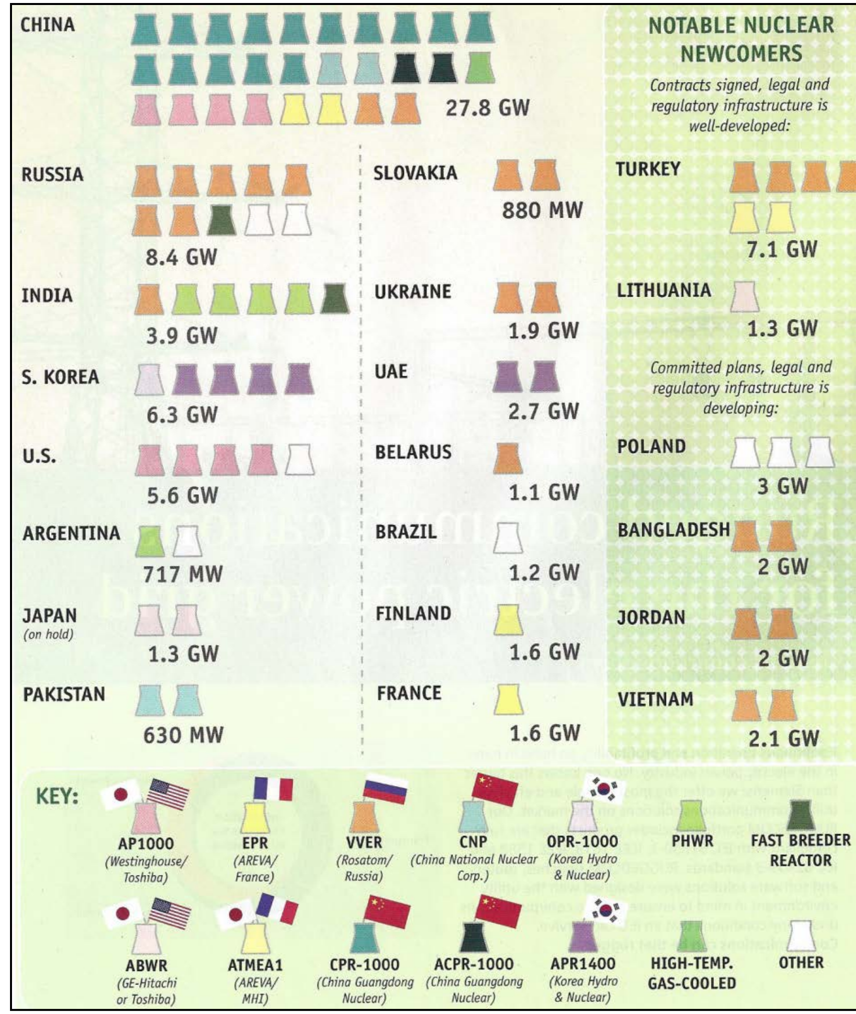
# "The Big Picture: Next-Gen Nuclear"

- 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

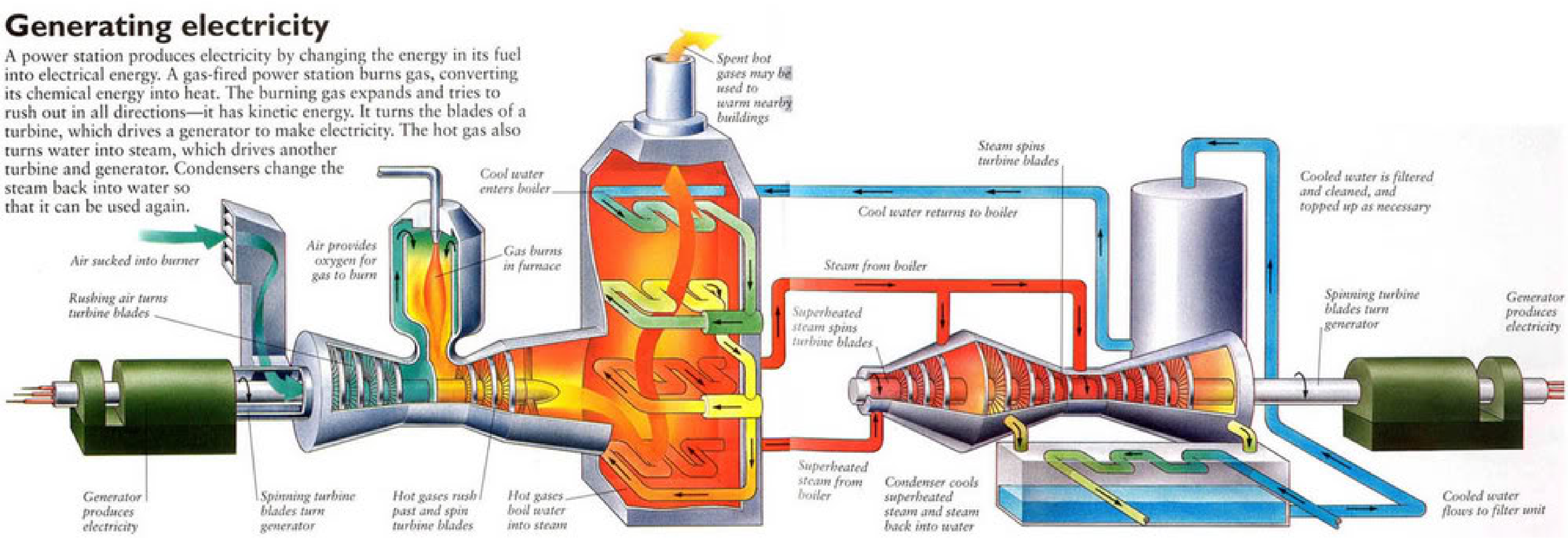



Westinghouse AP1000® plant under construction in Sanmen, China




Installed Generating Capacity (2012) = 5,550 GW

# 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

# High Efficiency, Low Emissions Coal (HELE)

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

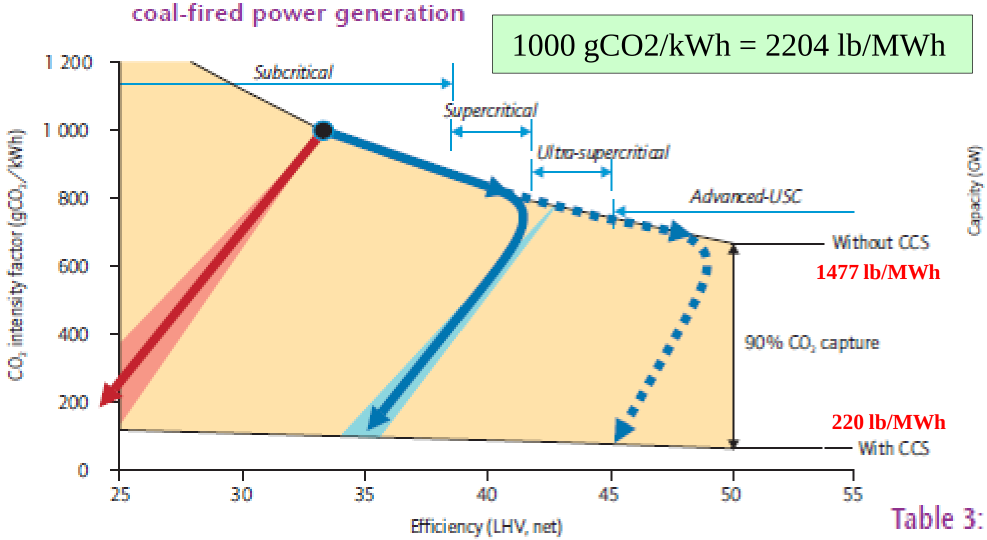



Figure 8: Projected capacity of coal-fired power generation to 2050

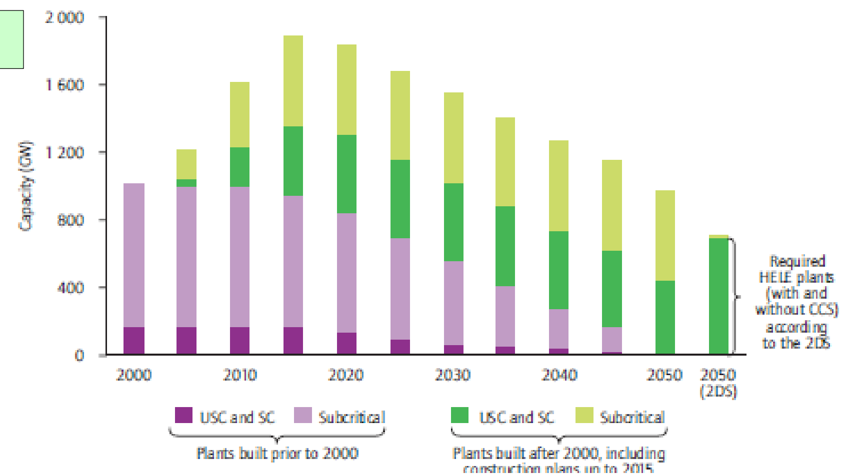



Table 3: Performance of HELE coal-fired power technologies

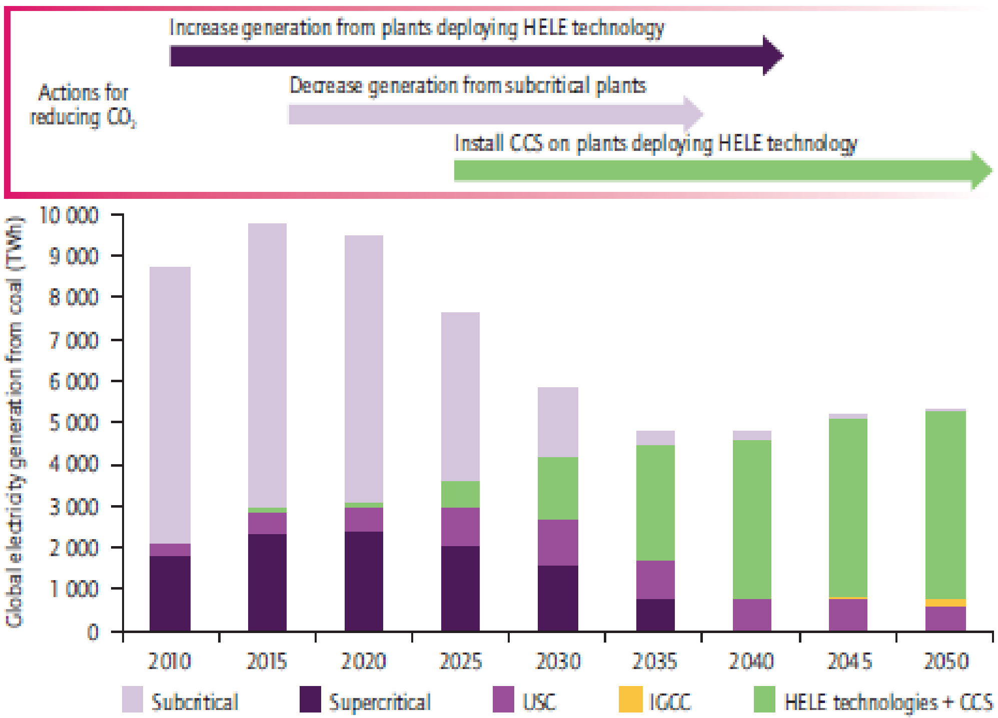
| Fuel type | Plant type | Emissions: $CO_2$ (g/kWh) | Emissions: $NO_x$ | Emissions: $SO_2$ (mg/Nm³) | PM | Max. unit capacity (MWe) | Capacity factor (%) | CCS energy penalty (%-points) |
|---|---|---|---|---|---|---|---|---|
| Coal | PC (USC) | 740 | <50 to 100 (by SCR) | <20 to 100 (by FGD) | <10 | 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

# Coal-fired PowerGen Options - 2DS

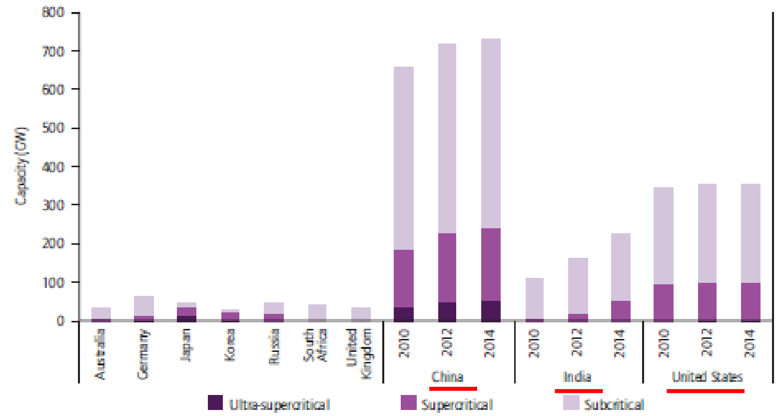
Figure 7: Electricity generation from different coal-fired power technologies in the 2DS




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

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# Coal-to-Gas Shift – nature.com

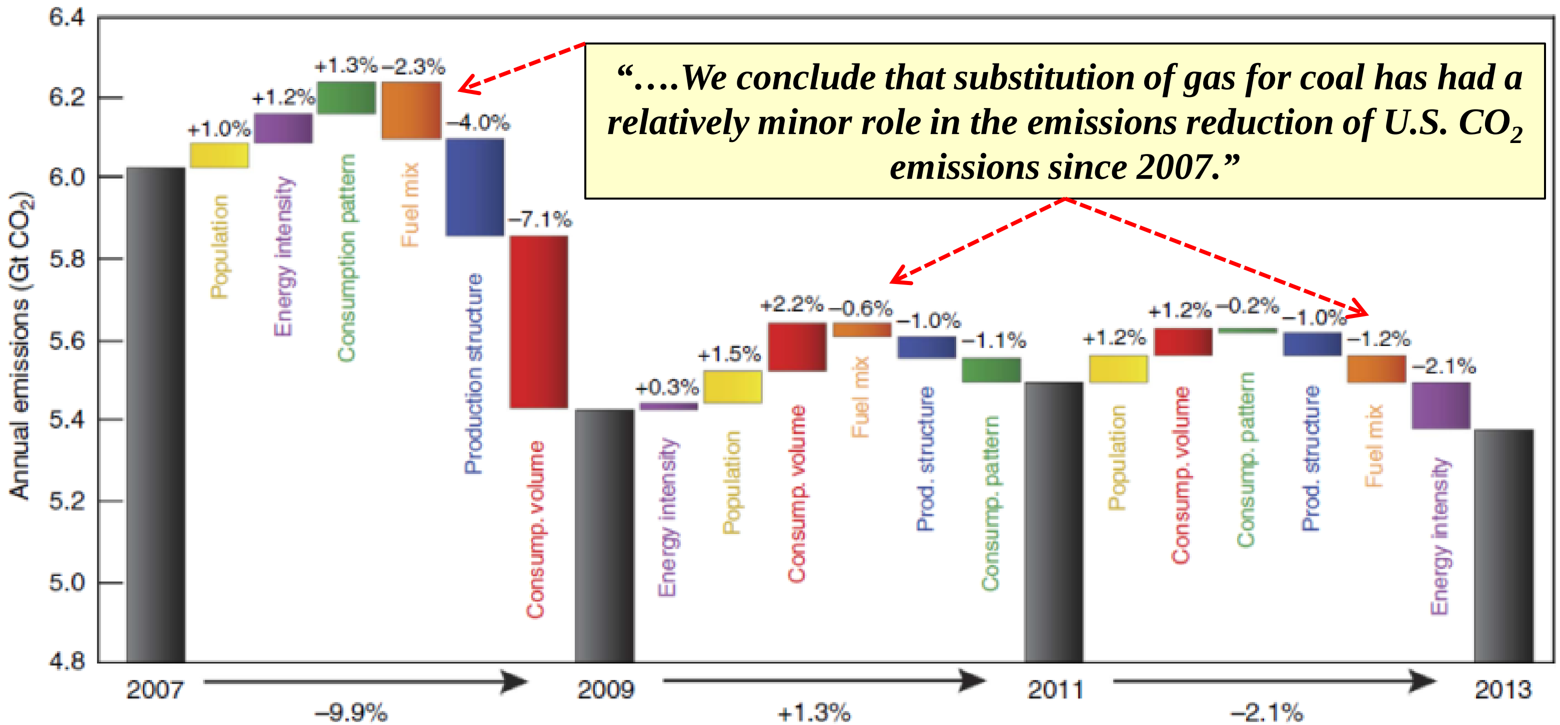



**Figure 3 | Contributions of different factors to the decline in US $CO_2$ emissions 2007-2009 and 2009-2011 and 2011-2013.** Between 2007 and 2009, decreases in the volume of goods and services consumed during the economic recession (red) was the primary contributor to the nearly 10% drop in emissions.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

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

# Gas Bridge to Renewables Already Built

– For the U.S. to reach its climate goals, the deadline for constructing the last gas-fired power plant is coming up shortly — if not already past

– Gas has a significant near-term role in reducing dependence on coal-fired power and helping the transition to intermittent renewable sources. But, to reduce greenhouse gas emissions to a target of 80% below 1990 levels by 2050, the nation must ultimately eliminate almost all use of fossil fuels, including natural gas

– "A power plant on the drawing boards today could still be operational in 2050 and well beyond. With each passing year, the likely life span of new natural gas power plants moves further beyond 2050 ".

– The U.S. EPA's Clean Power Plan might do more harm than good because substituting gas-fired power for coal capacity is one of the options for complying with the rules requirements. Rather, lawmakers should consider setting a final date beyond which no new natural gas power plants can be approved, Weissman advised.

– Almost 237 GW of gas-fired generation capacity was added between 2000 and 2010, making up 81% of all the generation capacity added in that decade. This momentum could increasingly complicate efforts to cut back on gas use.

– "As more people and institutions invest in natural gas, political pressure to sustain its use grows. It will become more and more difficult to achieve long-range greenhouse gas reduction goals". "Natural gas cannot play a long-term role in creating our desired carbon-constrained future, as its benefits are not enough to support our carbon reduction goals"

**Steve Weissman – Senior Policy Advisor, Center for Sustainable Energy/Source: Sarah Smith SNL Thursday, March 31, 2016**

# Well-to-Wheels Comparison Electric vs. Gasoline

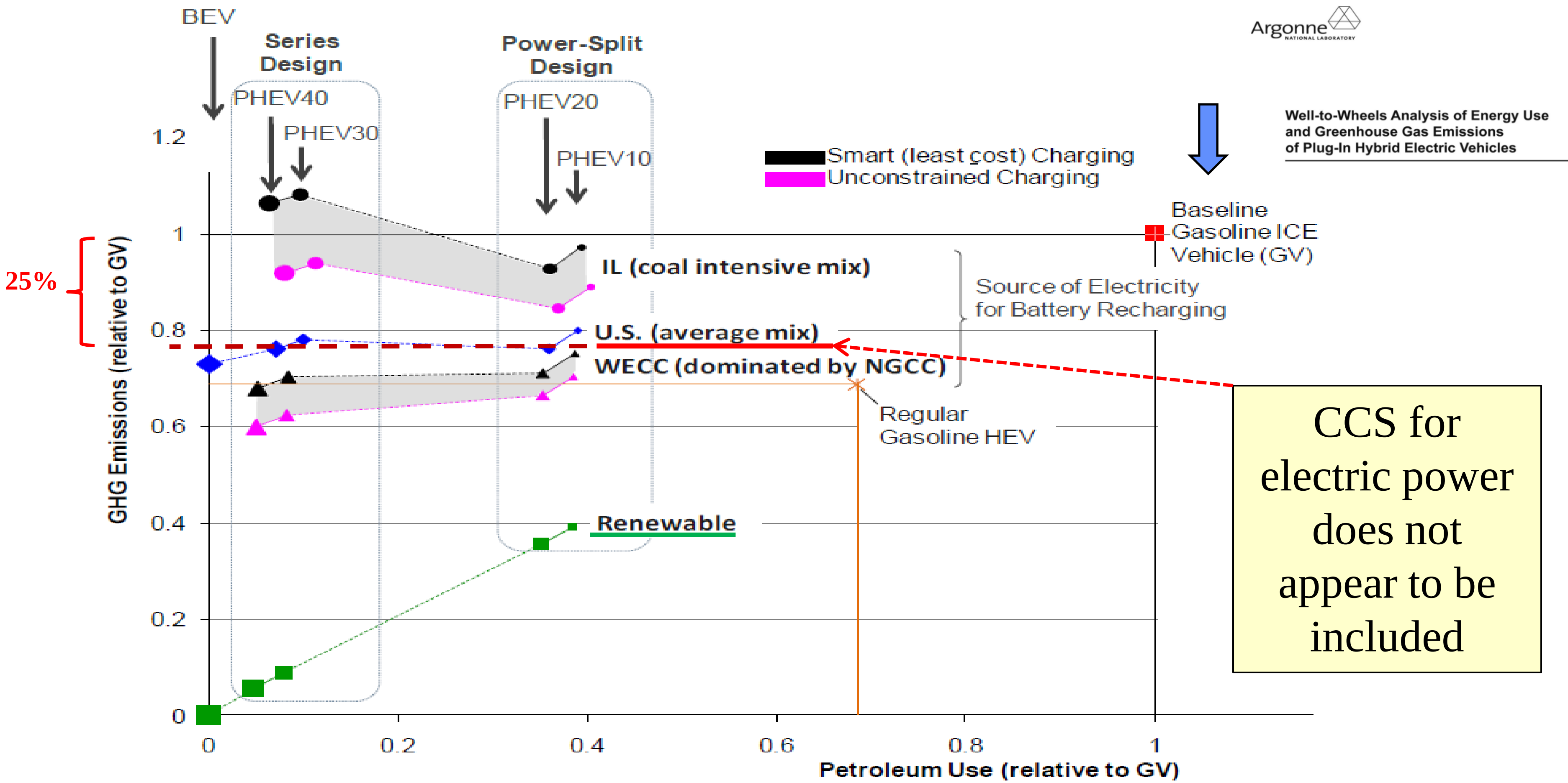
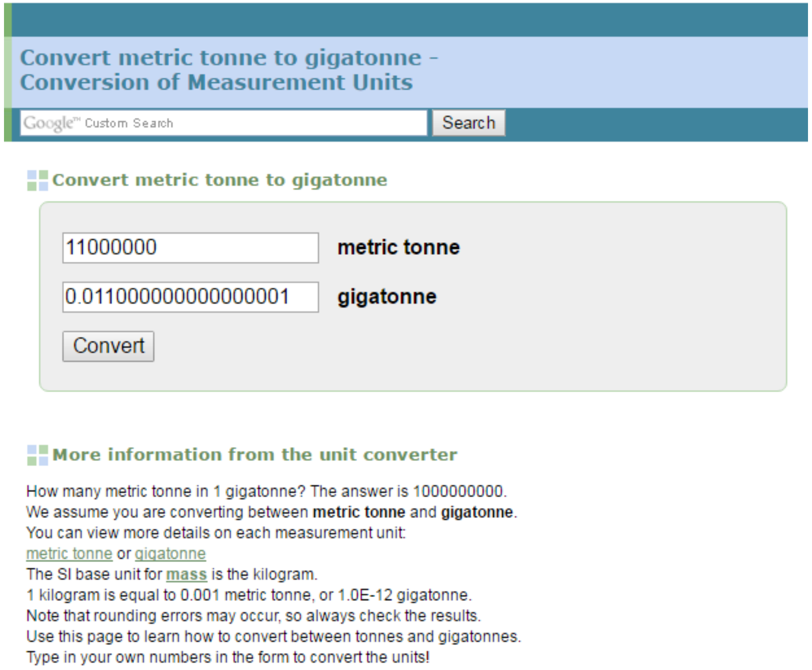



**FIGURE ES.1 WTW Petroleum Use and GHG Emissions for CD Operation of Gasoline PHEVs and BEVs Compared with Baseline Gasoline ICEVs and Regular Gasoline HEVs**

# Methane Leaks & Regulation

- On May 12, 2016, the U.S. Environmental Protection Agency (EPA) announced a Strategy to:
  - Reduce Methane Emissions to cut methane emissions from the large and complex oil and natural gas industry
  - achieve its goal of cutting methane emissions from the oil and gas sector by 40 to 45 percent from 2012 levels by 2025.
- Methane has a global warming potential more than 25 times greater than that of carbon dioxide
- Methane is the second most prevalent greenhouse gas emitted by human activities in the United States,
- 1/3 come from oil production and the production, processing, transmission and storage of natural gas.
- **Reducing methane emissions is an essential part of an overall strategy to address climate change**.
- The final NSPS is expected to:
  - Reduce 510,000 short tons of methane in 2025, the equivalent of reducing 11 million metric tons of carbon dioxide.
  - 11,000,000 metric tonnes = 0.011 Gt = 0.28% of U.S. emissions of 4Gt




***"Essential Part"….Really?***

***How about CO2 from Natural Gas Power Plants at 11.4Gt in 2040?***

# 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 advertises/uses LLV
  - Natural Gas
    - LHV = 23,860 Btu/lb
    - HHV = 21,501 Btu/lb
  - The effect is a 10% difference in claimed efficiency
- Net Output vs. Gross Output

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

# 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

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

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

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

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

DOE baseline Carbon Factors

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# 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% |

# "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**

# 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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# 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 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% |

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# "The (New) War on Coal"- EPA NSPS 2015

| | Supercritical PC | | NGCC | |
|---|---|---|---|---|
| Case | 11 | 12 | 13 | 14 |
| $CO_2$ 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 |
| $CO_2$ 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 |
| $CO_2$ Cost vs. NGCC Case 13 | $124,381 | ($73,785) | – | ($94,987) |
| tonnes-$CO_2$/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**

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# Power Engineering

## Updated Estimates of Power Plant Capital and Operating Costs

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

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

"It's still 5X"

# 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 CO2 sources will face much greater challenges to achieve targets than PowerGen**

# 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

Make CCS & Nuclear "OK, i.e., Green"

Policy Parity

Put a price on $CO_2$ and a value on Miami!

# 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

# Nominal Power Plant Comparisons

| | 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

# 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)