Carbon Emissions Primer

Symposium on Greenhouse Gas and the Regional Power System

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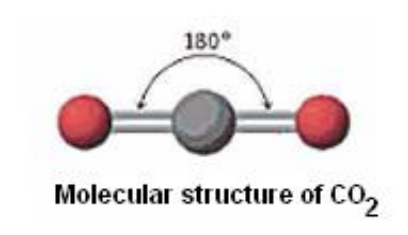
CO_2 Chemistry

1 molecule of CO_2 = 1 atom carbon
+ 2 atoms oxygen



Molecular structure of CO_2

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CO_2 Chemistry

- 1 mole of carbon = 6.02×10^{23} carbon atoms
- Atomic mass of CO_2
  - Carbon = 12 grams/mole
  - Oxygen = 16 grams/mole

➢ 1 mole of CO_2 weighs 44 grams
(i.e., 12+ (2*16))

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CO_2 Chemistry

- Carbon weight as percent of CO_2 weight
  - ➢ 12/44 = 27.27%
- 1 Metric ton (tonne) = 2,204.6 lbs
- Carbon content per tonne of CO_2
  - ➢ 27.27%*2,204.6 = 601.2 lbs carbon/tonne CO_2

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CO_2 Volume

- 1 lb CO_2 = 8.1 cubic feet (~2'x2'x2')
- 1 tonne CO_2 = 17,860 cubic feet (~26.2'x26.2'x26.2')

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CO_2 Content by Fuel Type
(lbs of CO_2 per Million Btu of Fuel)

Coal (subbituminous)	212.7
Natural gas	117.1

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Fuel Conversion Efficiencies
(MMBtu of Fuel per Megawatt-hour of Power)

- Coal-fired generation
  - Conventional (existing PNW fleet) 10.70
- Natural gas-fired generation
  - Combined-cycle combustion turbine 6.93
  - Single-cycle combustion turbine 9.37
  - Large reciprocating engine 8.85

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Emissions by Generation Type
(lbs of CO_2 per Megawatt-hour of Power)

- Coal-fired generation
  - ➢ Existing PNW fleet 2,276
    (i.e., 212.7 lbs CO_2/MMBtu * 10.70 MMBtu/MWh)

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Emissions by Generation Type
(lbs of CO_2 per Megawatt-hour of Power)

- Natural gas-fired generation
  - Combined-cycle combustion turbine 812
    (i.e., 117.1 lbs CO_2/MMBtu * 6.93 MMBtu/MWh)
  - Single-cycle combustion turbine 1,097
  - Large reciprocating engine 1,036

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CO_2 Costs by Generation Type
(Dollars per Megawatt-hour)

	CO2 Tax or Price	
	$10/ tonne	$40/ tonne
Coal-fired generation		
• Conventional (existing PNW fleet) (e.g., (2,276/2,204.6)*10 = 10.33)	$10.33	$41.30
Natural gas-fired generation		
• Combined-cycle combustion turbine	$3.68	$14.73
• Single-cycle combustion turbine	$4.98	$19.91
• Large reciprocating engine	$4.70	$18.81

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Regulatory Approaches to Reduce CO_2 Emissions

- Mandates (e.g., emissions performance standards, renewable portfolio standards)
  - Simple, somewhat inflexible
  - Do not price emissions directly
- Carbon taxes
  - Use market forces to achieve compliance (less)
  - Costs are known, effects are uncertain
- Cap and trade programs
  - Use market forces to achieve compliance (more)
  - Effects are known, costs are uncertain

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U.S. CO_2 Emissions All Sectors, by Fuel Type

Annual 2012
Millions of Metric Tons

Fuel Type	
Coal	1,657
Natural Gas	1,367
Gasoline	1,110
Distillate+Jet Fuel	785
Other	371
Total	5,292

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U.S. CO_2 Emissions
All Fuels, by Sector

Annual 2012
Millions of Metric Tons

Sector	Total	Electricity	Non-Electricity
Residential	1,058	760	298
Commercial	938	732	206
Industrial	1,480	543	937
Transportation	1,816	4	1,812
Total	5,292	2,039	3,253

Source: US DOE EIA May 2013 Monthly Energy Review

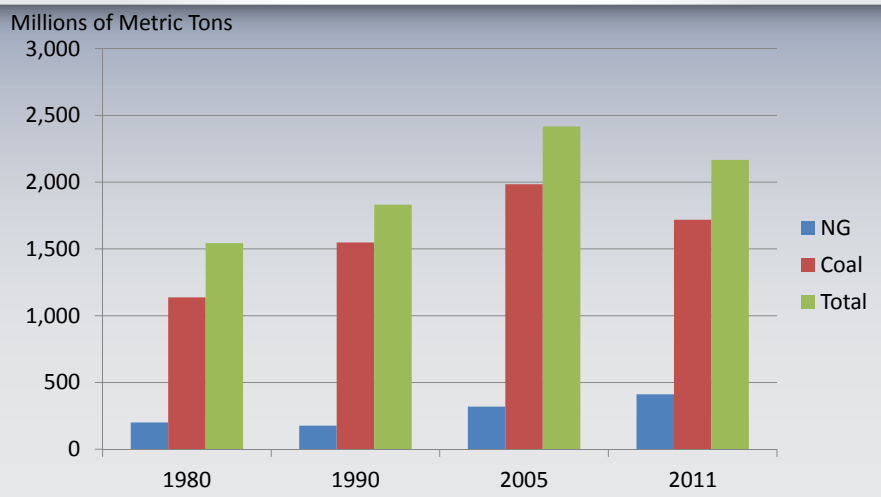
U.S. CO_2 Emissions
Electric Power Sector

Annual 2012
Millions of Metric Tons

Fuel Type	
Coal	1,514
Natural Gas	494
Other	31
Total	2,039

Source: EIA May 2013 Monthly Energy Review

U.S. CO_2 Emissions
Electric Power Sector



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Forces Driving the Reduction in CO_2 Emissions by the Electric Sector

- Power plant dispatch costs have shifted – natural gas is now competitive with coal
  - Lower natural gas prices
  - Higher coal prices (coal growing as export commodity)
- Coal plant retirements
  - State emissions performance standards
  - More stringent regulation of non-CO2 emissions
  - Aging coal fleet, needs for refurbishment

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The U.S. Coal Fleet Is Aging

- 75% of nameplate capacity > 30 years old
- 50% of nameplate capacity > 37 years old
- 40% of nameplate capacity > 40 years old

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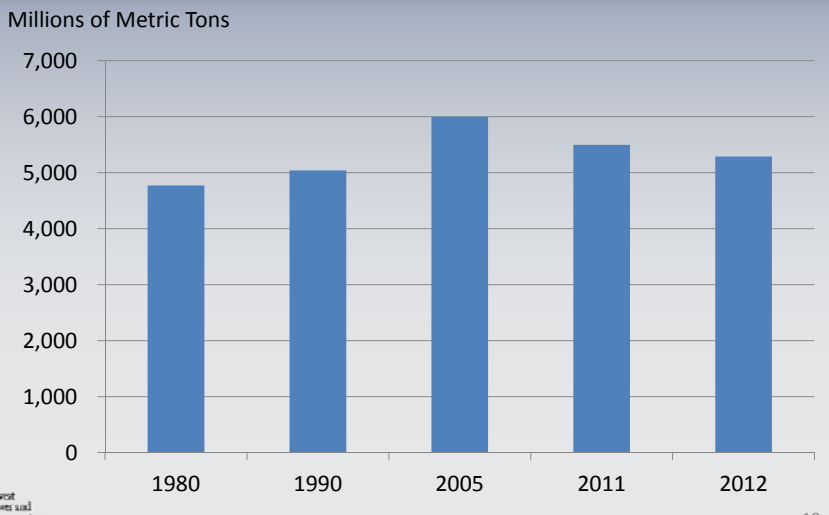
U.S. CO_2 Emissions – All Sectors



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Forces Driving the Overall Reduction in CO_2 Emissions by the U.S.

- Energy intensity of economy is decreasing
  - Product mix
  - Energy efficiency
- Recession?
  - GDP in 2011 was 5.6% higher than 2005

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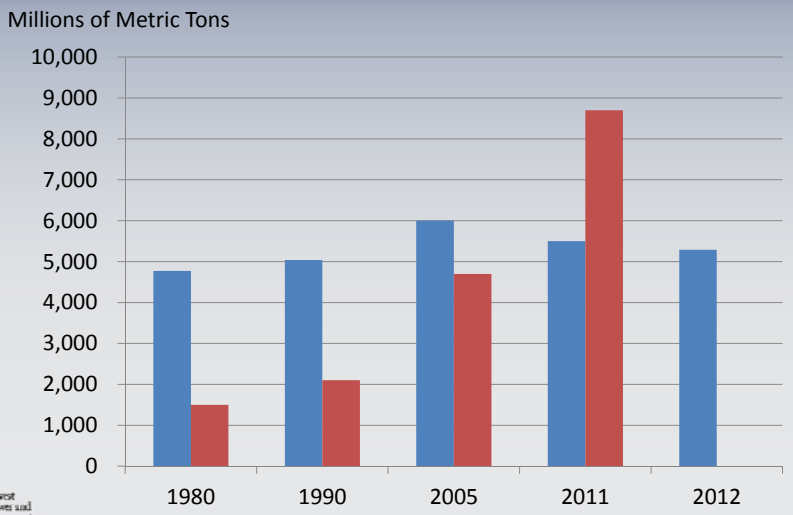
U.S. and China CO_2 Emissions



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