04-Emissions

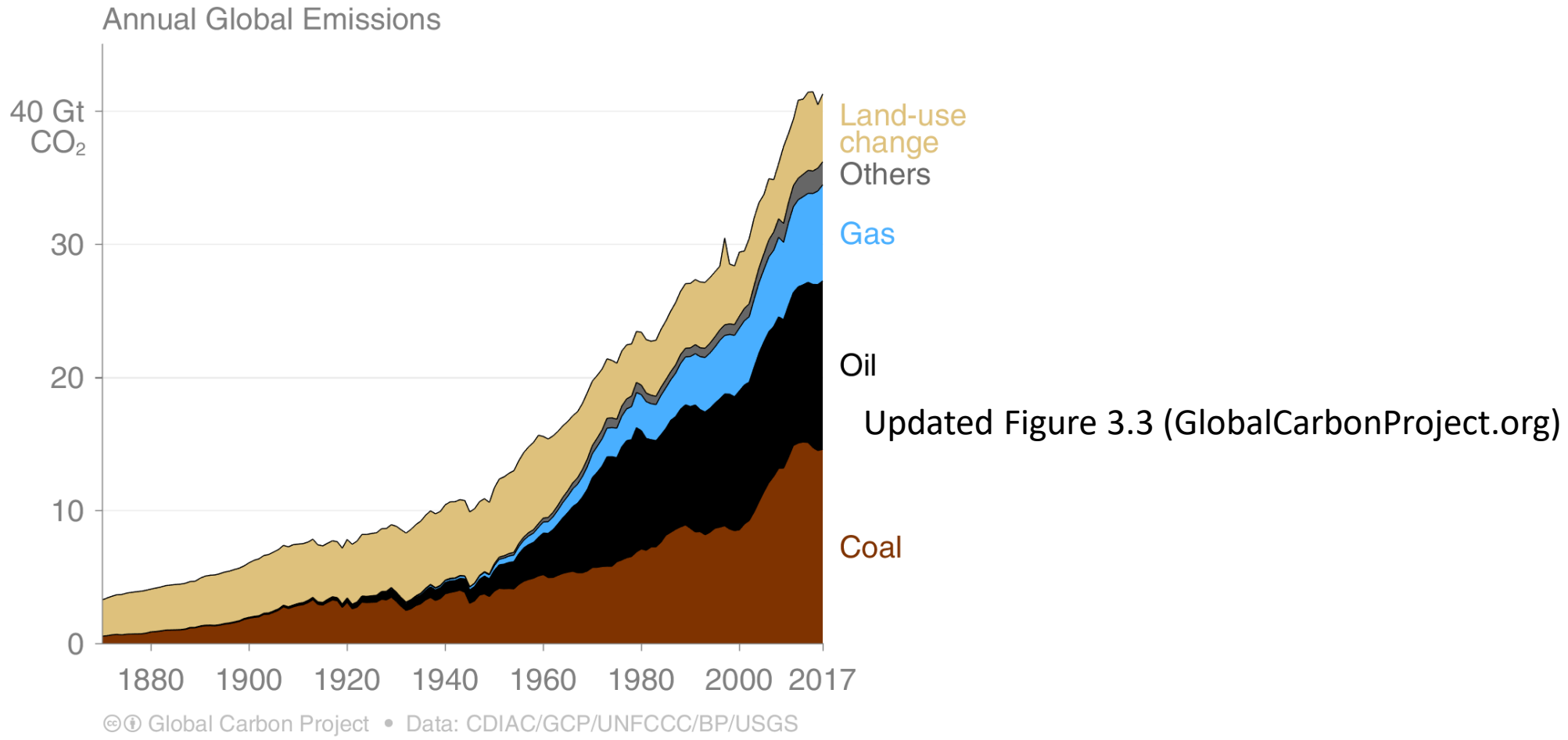
ECEGR 4530

Renewable Energy Systems

Overview

- CO_2 Emissions
- Emissions Calculations

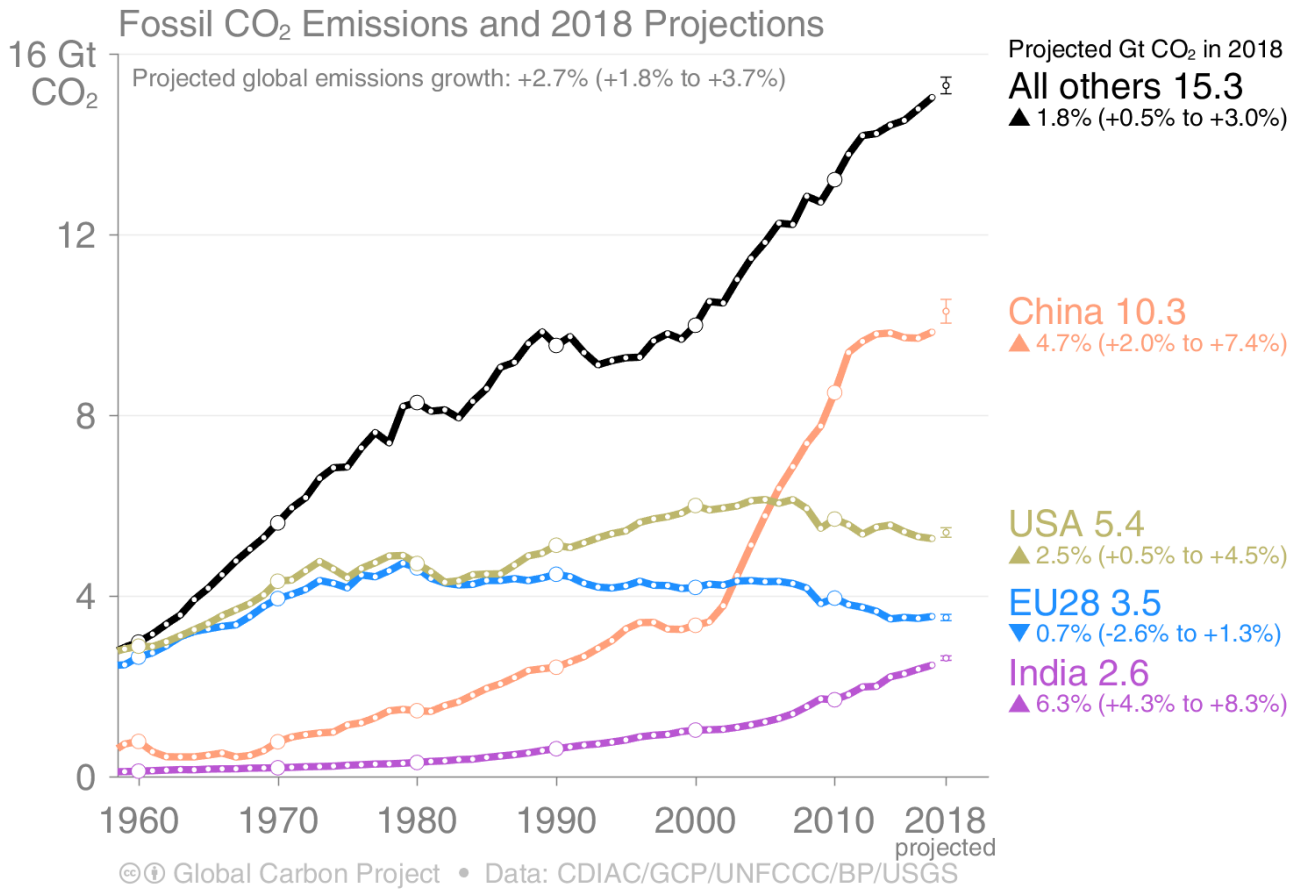
Vast Majority of Carbon Dioxide Emissions come from Fossil Fuels



Updated Figure 3.3 (GlobalCarbonProject.org)

SEATTLEU

Who is using fossil fuel?



Also see interactive site here: https://www.theguardian.com/environment/ng-interactive/2014/dec/01/carbon-emissions-past-present-and-future-interactive

Most Slides Adapted from Dr. Lauer

Two key ways in which greenhouse gases differ from each other

1. **Reactive Efficiency**
   - The Global Warming Potential (GWP) is a measure of the radiative effect of each unit of gas over a specified period of time (usually 100 years, sometimes 20 years), expressed relative to the radiative effect of carbon dioxide (CO_2).
   - Carbon dioxide (CO_2) is the reference gas that has always has GWP = 1.
2. **Lifetime**
   - Measures how long the gas stays in the atmosphere before natural processes (e.g. chemical reaction) remove it.

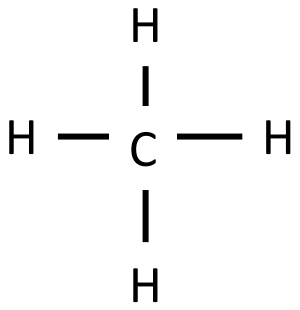
Greenhouse Gas	Chemical Formula	100-yr GWP	Lifetime
Carbon Dioxide	CO_2	1	100+
Methane	CH_4	25	12
Nitrous Oxide	N_2O	298	114
Chlorofluorocarbons	CCl_2F_2	10,900	100

Greenhouse Gases

- Different GHG contribute differently to the greenhouse effect
- Global Warming Potential (GWP)
  - ratio of warming caused by a 1kg GHG to 1kg CO_2
- GWP of some GHG:
  - Carbon dioxide (CO_2): 1
  - Methane: 21
  - N_2O: 310

CO_2 Emissions

- How much CO_2 is released by burning a kg of Methane? Oil? Coal?
- First consider methane (CH_4)
  - 4 hydrogen
  - 1 carbon



CO_2 Emissions

- Atomic weights
  - Hydrogen: 1
  - Carbon: 12
- Total weight per Methane molecule:
  - 12 + 1 + 1 + 1 + 1 = 16
- Carbon makes up 12/16 or 75% of the mass of methane
- 1kg of methane contains 0.75 kg of carbon

CO_2 Emissions

- Combustion reaction for methane:
  - $CH_4 + 2O_2 => CO_2 + 2H_2O$
    - water vapor is a by-product
- Atomic weight of Oxygen is 16
- The carbon in CO_2 makes up 27.3% of its weight (12/(2 x 16 + 12))
- To put it another way: for every 1kg of carbon combusted, 3.67 kg of CO_2 is released
  - 1/0.27 = 367%

CO_2 Emissions

- If 1 kg of methane is combusted, how much CO_2 is released?
  - 1 kg of methane x 0.75(kg carbon/kg methane) = 0.75kg of carbon
  - 0.75 x 3.67 = 2.7 kg of CO_2
  - Note: more mass of CO_2 is released than there was of mass of methane

Emissions from Coal

- Coal contains
  - Carbon
  - Hydrogen
  - Sulfur
  - Nitrogen
  - others

Emissions from Coal

- Ratio of carbon mass to the molecular mass varies depending on type of coal

- A reasonable assumption range is 60-90%
  - Lignite on the lower end
  - Anthracite on the higher end

Emissions from Oil

- Emissions depend on the type of oil
- Consider $C_{16}H_{34}$
  - Ratio of carbon: (16 x 12)/(16 x 12 + 34) = 85%
- How much CO_2 is released when 1 kg of $C_{16}H_{34}$ is combusted?

Emissions from Oil

- How much CO_2 is released when 1 kg of $C_{16}H_{34}$ is combusted?
  - 1kg of $C_{16}H_{34}$ contains 0.85 kg of carbon
  - 0.85 kg of carbon produces 3.11kg of CO_2 (0.85 x 3.67)

Emissions Calculations

- Usually we are interested in metrics such as kg of CO_2 emissions per kWh of energy or per gallon
- How many kg of CO_2 are released from one gallon of diesel fuel?
  - Assume 3 kg of diesel fuel per gallon

Emissions Calculations

- A back-of-the-envelope calculation:
  - Assume 3 kg of diesel fuel per gallon
  - 3 x 0.85 x 3.67 = 9.36 kg of CO_2 /gallon
  - EPA value: 10.1 kg of CO_2 /gallon

Emissions Calculations

- Specific energy densities (approximate values shown)
  - Methane: 56 MJ/kg
  - Natural Gas: 53 MJ/kg
  - Coal: 15-30 MJ/kg
  - Diesel: 45 MJ/kg

Emissions Calculations

- Energy conversion efficiencies (approximate values shown)
  - Natural gas (Brayton cycle): ~25-35%
  - Coal (Rankine cycle): ~30-45%
  - Diesel (Diesel cycle): ~30-45%
- $E_{out} = \eta E_{in}$

Emissions Calculations

- What is the mass of the CO_2 released in order to generate 1kWh of electrical energy using:
  - Natural gas (Brayton cycle, $\eta = 30\%$)
  - Coal (Rankine cycle, $\eta = 40\%$)

Emissions Calculations

- First compute how many kg of fuel are used:
  - 1kWh = 3.6MJ
  - Accounting for efficiency
    - E_{in} = 3.6/0.3 = 12 MJ
  - Using the specific energy density
    - $m_{nat\ gas}$ = 12/53 = 0.23 kg

Emissions Calculations

- Compute the mass of carbon:
  - $m_C = 0.23 \times 0.75 = 0.17$ kg
- Next compute how many kg of CO_2 are produced:
  - $m_{Co2} = 0.17 \times 3.67 = \underline{0.62 \text{ kg}}$

Emissions Calculations

- Compute for coal assuming:
  - Anthracite: 90% carbon, 32 MJ/kg
  - Rankine efficiency: 40%

Emissions Calculations

- E_{in} = 3.6/0.4 = 9 MJ
- m_{coal} = 9/32 = 0.28 kg
- m_c = 0.28 x 0.9 = 0.25 kg
- m_{CO2} = 0.25 x 3.67 = <u>0.92 kg</u>

Emissions Calculations

- In this example:
  - Natural gas: 0.62 kg/kWh
  - Coal: 0.92 kg/kWh
- Actual values closer to
  - Natural gas: 0.50 kg/kWh
  - Coal: 1.00 kg/kWh

Questions

- How much money are you willing to pay to prevent all CO_2 from power plants from being emitted into the atmosphere?
- What happens if we do not reduce mankind's greenhouse gas emissions?
- Should the U.S. reduce its greenhouse gas emissions if China does not?