The Greenhouse Effect and Global Warming

April 3, 2017
The Greenhouse Effect (Ch. 9)

- For an actual greenhouse, glass panels allow solar energy inside and suppress *thermal convection* that would cool the room.

- In the planetary greenhouse effect, certain atmospheric gases such as CO$_2$, CH$_4$, NO$_x$ absorb *infrared light* (*thermal radiation*) emitted by the Earth, warming the atmosphere by preventing its escape into space.
The Greenhouse Effect

- Some energy is reflected back out to space
- Earth’s surface is heated by the sun and radiates the heat back out towards space
- Solar energy from the sun passes through the atmosphere
- Greenhouse gases in the atmosphere trap some of the heat
Earth’s energy balance

Earth’s temperature depends on the balance between energy coming in from the sun and energy that is radiated back to space. (Figure 9.1)
Current contribution of CO₂ and other gases to expected warming

- CO₂ (85%)
- CH₄ (8%)
- N₂O (5%)
- CFC (2%)
Distribution of U.S. CO$_2$ emissions (5.8 × 10$^9$ t/y)

- Transportation (34%)
- Homes (21%)
- Commercial (19%)
- Industry (26%)
### Table 9.1  GREENHOUSE GASES

<table>
<thead>
<tr>
<th>Gas</th>
<th>Sources</th>
<th>U.S. Emissions (MT/yr)</th>
<th>GWP*</th>
<th>Atmospheric Lifetime (years)</th>
<th>2010 Concentration (ppM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Fossil fuels, deforestation</td>
<td>5500</td>
<td>1</td>
<td>100</td>
<td>392</td>
</tr>
<tr>
<td></td>
<td>GWP × conc. = 392</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>Rice fields, cattle, landfills</td>
<td>600</td>
<td>21</td>
<td>12</td>
<td>1.8</td>
</tr>
<tr>
<td>Nitrogen Oxides</td>
<td>Fertilizers, deforestation</td>
<td>16</td>
<td>310</td>
<td>120</td>
<td>0.31</td>
</tr>
<tr>
<td>CFCs</td>
<td>Aerosol sprays, refrigerants</td>
<td>1</td>
<td>1300–12,000</td>
<td>70–100</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>
Your largest contribution to global warming in a year probably comes from

A. your use of freon propellants
B. your consumption of electricity (77%)
C. driving your car
D. your consumption of beef

A. 0%
B. 12%
C. 77%
D. 12%
Changes in Atmospheric Concentration
CO$_2$, CH$_4$, and N$_2$O – A Thousand Year History

Changes in Atmospheric Concentration
CO₂, CH₄, and N₂O – A Ten Thousand Year History

Correlation with temperature

(a) Radiative forcing (W m⁻²)

(b) Reconstructed (grey) and simulated (red) NH temperature
Recent CO$_2$ analysis

See figure caption on the next slide.

Citation: *Physics Today* **69**, 11, 48 (2016); [http://dx.doi.org/10.1063/PT.3.3365](http://dx.doi.org/10.1063/PT.3.3365)
Figure 1. The relentless climb of atmospheric carbon dioxide.
(a) Since the late 1950s, atmospheric CO$_2$ concentrations have been measured at the Mauna Loa Observatory in Hawaii and the South Pole Observatory in Antarctica. The prominent annual cycles in the Mauna Loa record reflect the seasonal uptake and release of CO$_2$ by plants and soils in the Northern Hemisphere. The difference in CO$_2$ between Mauna Loa and the South Pole has grown larger as fossil-fuel emissions have increased because emissions are concentrated in the Northern Hemisphere.
(b) The annual growth rate of CO$_2$ at Mauna Loa and the CO$_2$ growth rate expected from fossil-fuel emissions are plotted with the deviation in global temperature $\Delta T$ relative to the 1950–80 average. Except during strong El Niño conditions in 1972–73 and 1997–98, the observed CO$_2$ growth rate is lower than expected from fossil-fuel emissions because of CO$_2$ uptake by the ocean and by plants and soils on land (see box 1). When temperatures are warm, as commonly found during El Niño periods (gray shading), CO$_2$ increases more rapidly. Strong volcanic eruptions (dashed vertical lines) generally result in cooler temperatures and slower rates of change in CO$_2$.

(Atmospheric CO$_2$ concentration data courtesy of Scripps Institution of Oceanography, global temperature data courtesy of NASA, and fossil-fuel emissions data courtesy of Oak Ridge National Laboratory. Emissions estimates for 2014–15 from ref. 16.)

Citation: Physics Today 69, 11, 48 (2016); full article
Effects of Global Warming
(partial list)

- **Extreme weather**
  - High temperatures, modified agriculture
  - Enhanced rainfall some places, drought in others, stronger storms?

- **Rising sea levels**
  - Melting glaciers
  - Thermal expansion of the water

- **Warmer oceans**
  - Effect on sea creatures, coral, plants?
  - Less dissolved CO₂… **positive feedback**

(pp. 287-288)
The situation is complicated...

- Warmer climate means more plant growth, carbon sequestration.
- Deforestation makes the tropics more reflective, tends to cool the Earth.
- More water vapor means more clouds, net cooling effect. Particulate air pollution (smog) has a similar effect.

These are examples of negative feedback (pp. 287-288)
Sea Level Rise of 17 Feet (5.2 m)
Western Antarctic Ice Sheet Melts

http://www.pbs.org/wgbh/warming/waterworld
Sea level rise simulations

www.climatecentral.org 11/08/2015

SHANGHAI

After 4°C of warming

After 2°C of warming
It is *postulated* that fresh meltwater could interrupt the north Atlantic ocean circulation (see p. 285 of the textbook)

The evidence is not very strong, see above link for Wikipedia discussion

Sensationalized by *The Day After Tomorrow* movie (2004)
Besides rising ocean levels, what effect might the melting of the polar ice caps have on the average global temperature?

A. Cooling due to increased reflection of sunlight
B. Cooling due to decreased R-value of melted ice
C. Warming due to decreased reflection of sunlight
D. Warming due to increased thermal emission by ocean

The correct answer is C.
There are four main categories of air pollutants:

- Carbon (CO$_2$, CO, hydrocarbons)
- Sulfur (SO$_2$)
- Nitrogen ($NO_x$)
- Particulates (aerosols)
Carbon-based air pollutants

- CO₂ is toxic in high concentrations, but it is helpful for plants so it’s not classified as a pollutant.
- CO (carbon monoxide) is highly toxic and emitted by incomplete combustion of fossil fuels. In dense traffic CO levels can be sufficiently high to cause health problems.
- Hydrocarbons (also known as Volatile Organic Compounds) participate in a variety of chemical reactions that form ozone and photochemical smog.
The carbon cycle

- Without human influence, the flow of carbon between the air, plants, and oceans would be roughly balanced
- Fossil fuel combustion adds about 9 billion tons (as of 2014) of carbon (primarily as $\text{CO}_2$) into the atmosphere
- Oceans contain 55 times as much carbon as the atmosphere, and 20 times as much as land plants
The Carbon Cycle

Figure 9.9 (p.287) of the textbook, numbers (in billions of tons) seem old.
Figure 2 (p. 352). Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2005–2014.
Another way to visualize the carbon cycle, with more recent data

Figure 3 (p. 370). Combined components of the global carbon budget illustrated in Fig. 2 (in document linked above) as a function of time, for emissions from fossil fuels and industry (grey) and emissions from land-use change (brown), as well as their partitioning among the atmosphere (light blue), land (green), and oceans (dark blue). All time series are in GtC yr$^{-1}$. See the text for more details of each component and their uncertainties.
Figure 5 (p. 372). CO$_2$ emissions from fossil fuels and industry for (a) the globe, (b) global emissions by fuel type, (c) territorial (full line) and consumption (dashed line) emissions for the countries listed in the Annex B of the Kyoto Protocol versus non-Annex B countries, (d) territorial CO$_2$ emissions for the top three country emitters and for the European Union, and (e) per capita emissions for the top three country emitters and the EU and the world.
Yet another way to visualize the carbon budget

Citation: Physics Today 69, 11, 48 (2016); full article
Each row of the diagram represents a carbon reservoir, with the amount of carbon in each reservoir in 1870 shown in the middle column in petagrams (1 Pg = 10^{15} g). The boxes and arrows to the left and right depict the carbon budget in petagrams for the period 1870–2014.
Suppose your car barely passes the 3.0 gram/mile limit for CO emission. If you drive 15,000 mi/y, about how much CO has your car emitted in a year?

A. 1,500 kg
B. 450 kg
C. 150 kg
D. 45 kg
Suppose your car barely passes the 3.4 gram/mile limit for CO emission. If you drive 15,000 mi/y, about how much CO has your car emitted in a year?

A. 1,500 kg  
B. 450 kg  
C. 150 kg  
D. 45 kg

\[
\frac{15,000 \text{ mi}}{\text{year}} \times \frac{0.0030 \text{ kg}}{\text{mi}} = 45 \text{ kg/y}
\]
How much air does the car poison?

EPA air quality standard for CO: 9.0 ppM (p. 259)

\[
\frac{m_{\text{CO}}}{M_{\text{air}}} = 9.0 \times 10^{-6}
\]

\[
M_{\text{air}} = \frac{45 \text{ kg}}{9.0 \times 10^{-6}} = 5.0 \times 10^6 \text{ kg}
\]

\[
V_{\text{air}} = \frac{M_{\text{air}}}{1.29 \text{ kg/m}^3} = 3.88 \times 10^6 \text{ m}^3
\]
How much air does the car poison?

If the atmospheric density were constant, its depth

\[ h = \frac{P}{\rho g} = \frac{101325 \text{ Pa}}{(1.29 \text{ kg/m}^3)(9.8 \text{ m/s}^2)} = 8015 \text{ m} \]

So the poisoned air would cover an area of

\[ A_{\text{air}} = \frac{V_{\text{air}}}{h} = \frac{3.88 \times 10^6 \text{ m}^3}{8015 \text{ m}} = 484 \text{ m}^2 = 72 \text{ ft} \times 72 \text{ ft} \]
How much air would all the cars in Wisconsin poison?

If there were $3.0 \times 10^6$ vehicles in Wisconsin, $NA_{air} = (3.0 \times 10^6)(484 \text{ m}^2) = 1,450 \text{ km}^2$

That's the area that's poisoned annually. If all the air remained in Wisconsin, the air would be completely poisoned after

$$t = \frac{140,673 \text{ km}^2}{1,450 \text{ km}^2/\text{yr}} = 97 \text{ years}$$