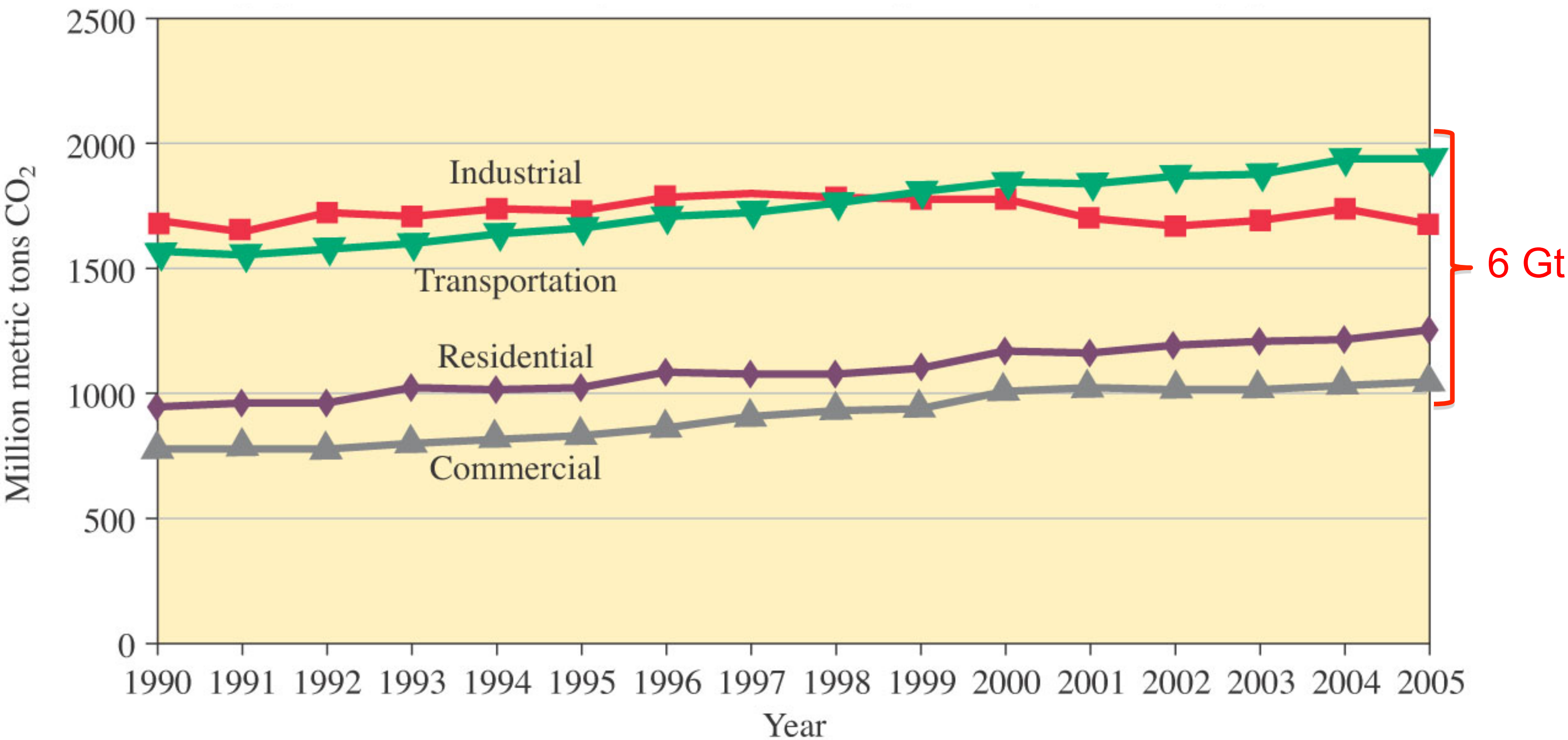
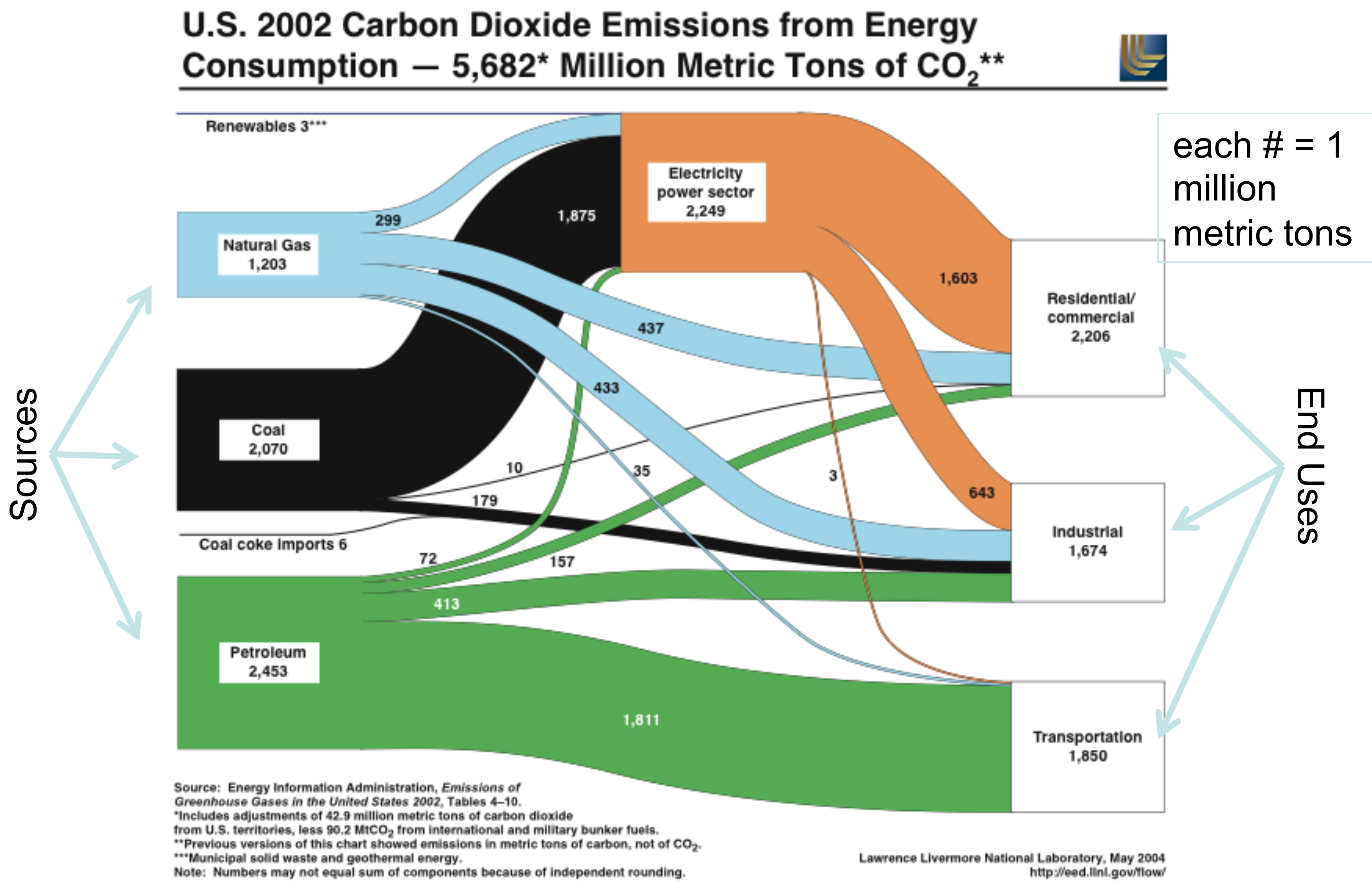
US Emissions of CO_2

If CO_2 is participating in the *enhanced* greenhouse effect, it would be good to know how much is being made with respect to how much C is in the world…

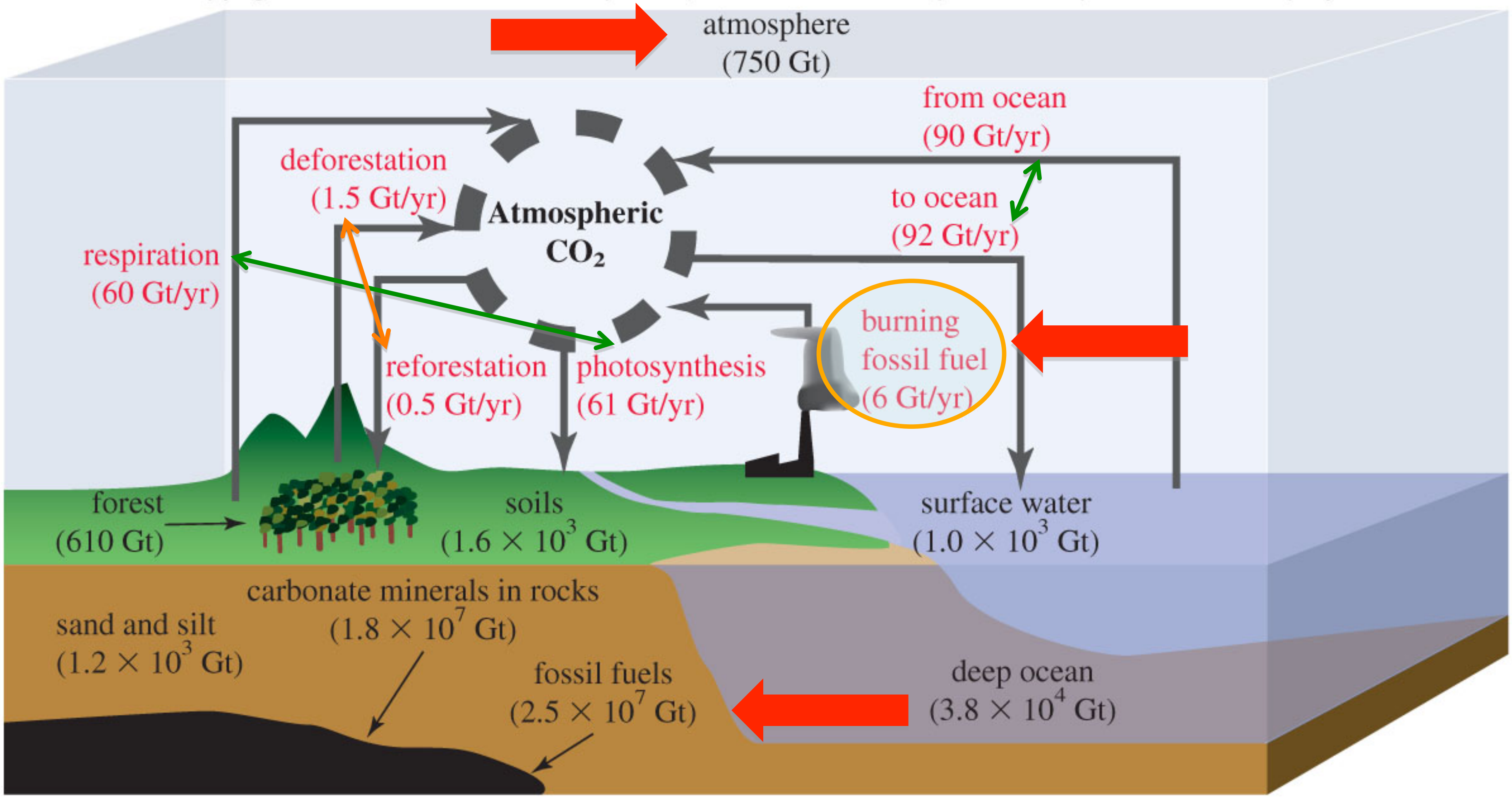


Gt=gigatonne (a billion (10^9) metric tons, 2200 billion pounds ($2.2x10^{12}$)

A Different Look at US CO_2 Emissions (2002)



Carbon (C) Cycle



De-reforestation 1 Gt/year
Burning fossil fuels 6 Gt/year
Total: 7 Gt/year

Net to ocean 2 Gt/year
Respiration-Photosynthesis 1 Gt/year
Total: 3 Gt/year

~3-4 Gt C/year addition to atmosphere

Gt=gigatonne (a billion metric tons (10^9), 2200 billion pounds (2.2×10^{12})

How much CO_2 do you emit when you drive to Denver?

$$60 \text{ miles} \times \frac{1 \text{ gal}}{20 \text{ miles}} \times \frac{6 \text{ lbs}}{1 \text{ gal}} \times \frac{1 \text{ kg}}{2.2 \text{ lbs}} \times \frac{1000 \text{ g}}{1 \text{ kg}}$$

= 8,200 g gasoline used, but we want to know how much CO_2 was produced while driving that distance…

Molar mass of gasoline? (assume C_8H_{18})

8x12.0 g = 96.0 g
18x1.0 g = 18.0 g
= 114.0 g/mol C_8H_{18}

Converting from C_8H_{18} to CO_2?

$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$

2 moles C_8H_{18} = 16 moles CO_2

Molar mass of CO_2?

1x12.0 g = 12.0 g
2x16.0 g = 32.0 g
= 44.0 g/mol CO_2

Building Solution here: $8{,}200 \text{ g gasoline} \times \frac{1 \text{ mol } C_8H_{18}}{114 \text{ g}} \times \frac{16 \text{ mol } CO_2}{2 \text{ mol } C_8H_{18}} \times \frac{44 \text{ g } CO_2}{1 \text{ mol } CO_2}$ = 25,000 g CO_2

How much CO_2 is emitted by a coal train worth of coal?

Coal train:

120 cars

120 tons/car=14,400 tons

1 ton = 1016 kg $\Rightarrow 1.46 \times 10^7$ kg Coal

grams → moles → moles → grams

Molar mass of coal? (assume $C_{135}H_{96}O_9NS$)

135x12.0 g = 1620.0 g
96x1.0 g = 96.0 g
9x16.0 g = 144.0 g
1x14.0 g = 14.0 g
1x32.0 g = 32.0 g
= 1906.0 g/mol $C_{135}H_{96}O_9NS$

$$\text{Coal train}=1.46\times 10^7 \text{ kg}\times\frac{\text{mole}}{1.906\text{kg}}=7.61\times 10^6 \text{ moles}$$

Converting from $C_{135}H_{96}O_9NS$ to CO_2?

$$2\ C_{135}H_{96}O_9NS + 313\ O_2 \rightarrow 270\ CO_2 + 96\ H_2O + 2\ NO_2 + 2\ SO_2$$

2 moles $C_{135}H_{96}O_9NS$ = 270 moles CO_2

Molar mass of CO_2?

1x12.0 g = 12.0 g
2x16.0 g = 32.0 g
= 44.0 g/mol CO_2

$$7.61\times 10^6 \text{ moles Coal}\times\frac{270 \text{ moles } CO_2}{2 \text{ moles Coal}}\times\frac{44.0 \text{ g } CO_2}{\text{mole } CO_2}=4.52\times 10^{10} \text{ g } CO_2$$

$(1\text{Gt} = 1\times 10^{15} \text{ g})$

6.6 Gt=150,000 coal trains

Other Greenhouse Gases and their Relative Effects

Table 3.2 Greenhouse Gases–Concentration Changes and Lifetimes

	CO_2	CH_4	N_2O
Preindustrial concentration (1750)	278 ppm	0.700 ppm	0.270 ppm
2005 concentration	385 ppm	1.75 ppm	0.314 ppm
Average rate of concentration change, 1990–2005	1.5 ppm/year	0.007 ppm/year	0.0008 ppm/year
Global atmospheric lifetime	50–200 years*	12 years	114 years

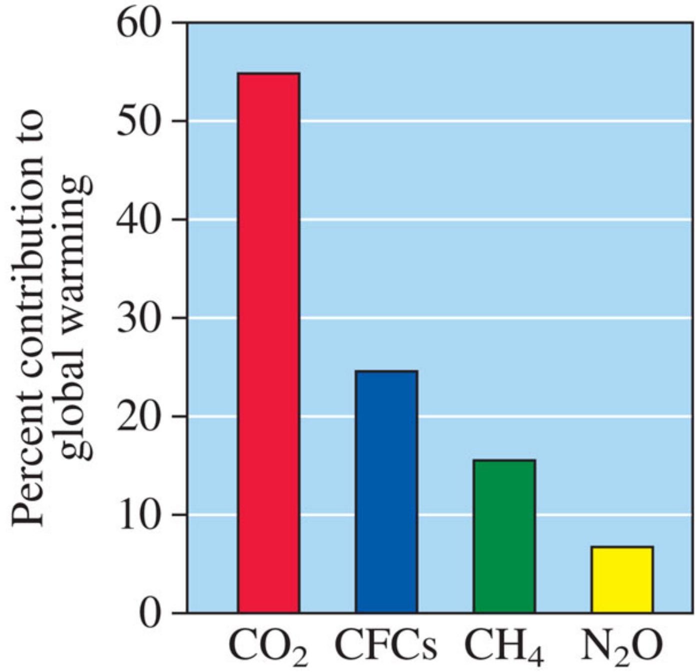
*A single value for the atmospheric lifetime of CO_2 is not possible. Different removal mechanisms take place at different rates, leading to variation in atmospheric lifetime.

Table 3.3 Global Warming Potential for Three Greenhouse Gases

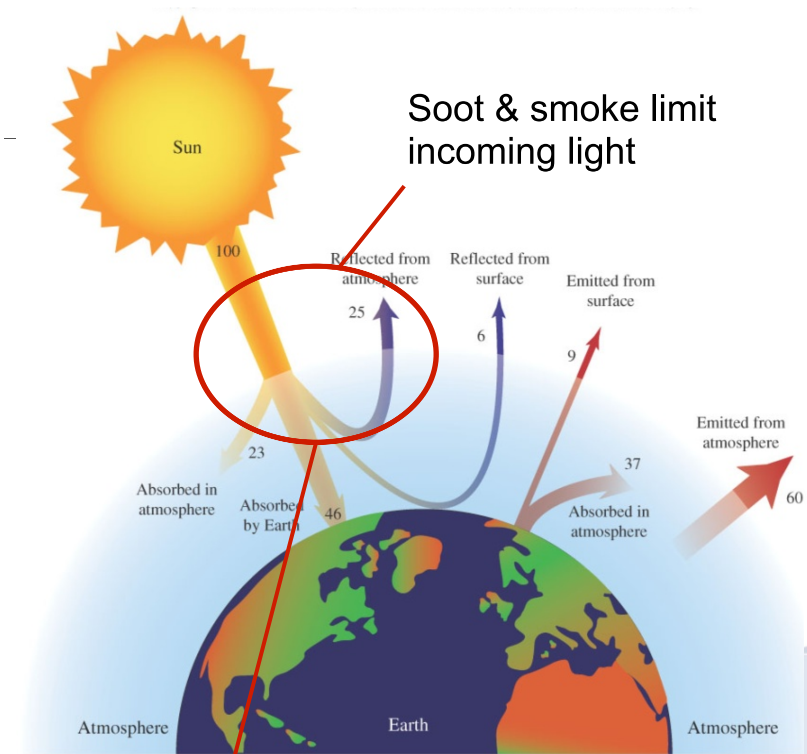
Substance	Global Warming Potential (GWP)*	Tropospheric Abundance (ppm)
CO_2	1	385
CH_4	23	1.8
N_2O	296	0.31

*GWP values are given for the estimated direct and indirect effects over a 100-year period and are relative to the assigned value of 1 for CO_2.

Important factors:
- Concentration
- Lifetime (connected to concentration & reactivity)
- Light absorption efficiency



Projecting the Future: Climate Models



Soot & smoke limit incoming light

Albedo-ratio of radiation reflected relative to the amount incident on the surface-impacted by what's on the surface. Deforestation, melting snow, etc.

Photosynthesis dependent upon CO_2 concentration & temperature

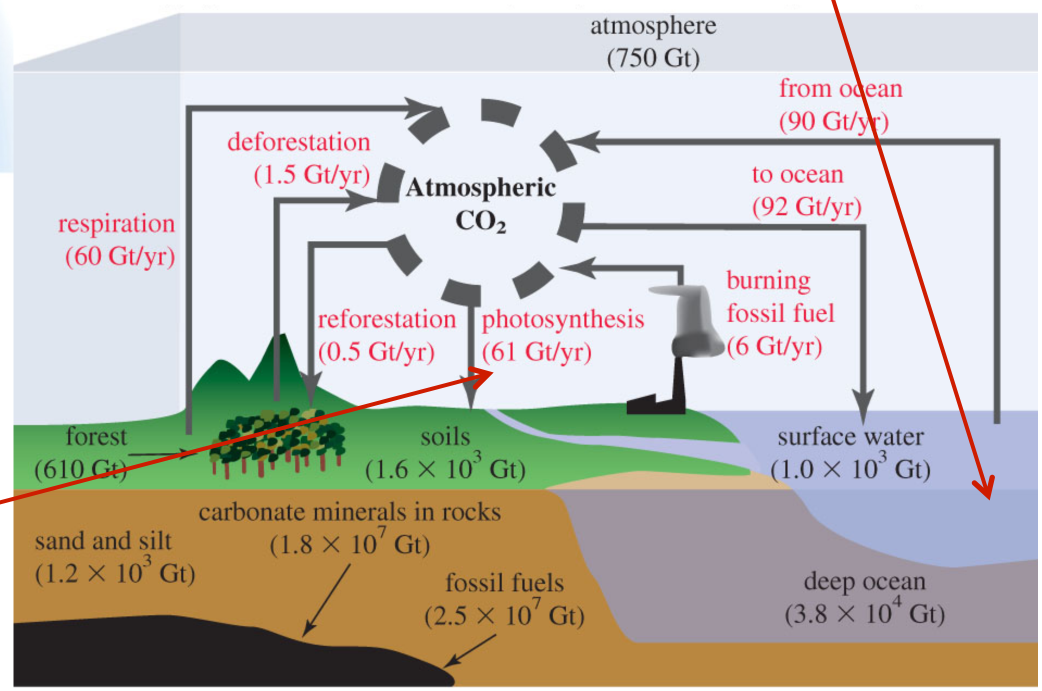
equilibrium

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

Carbonic acid, the carbonate of carbonated beverages

Product favored by pressure, higher concentration in deep ocean

Reactants favored by higher temperatures…



Soda Siphon

Demonstrates:

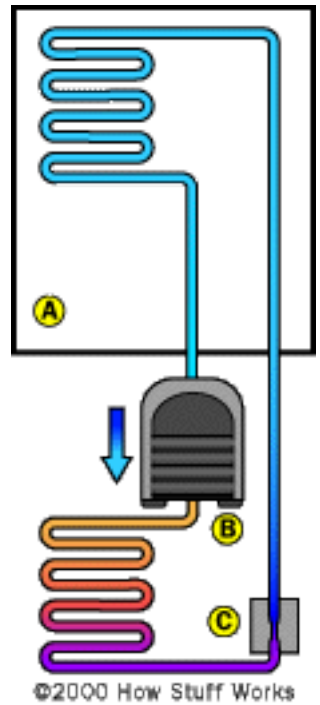
- Refrigeration/steam turbine
- Temperature/Pressure dependence of CO_2 dissolving in oceans equilibrium
- Acids & Bases

Soda Siphon: Refrigeration

5. Cold HFC gas is sucked up by the compressor, and the cycle repeats

1. Compressor (B) compresses HFC gas. (compressed gas heats up as it is pressurized (orange))

2. Coils on the back of the refrigerator dissipate HFC gas heat. The HFC gas condenses into HFC liquid (purple) at high pressure



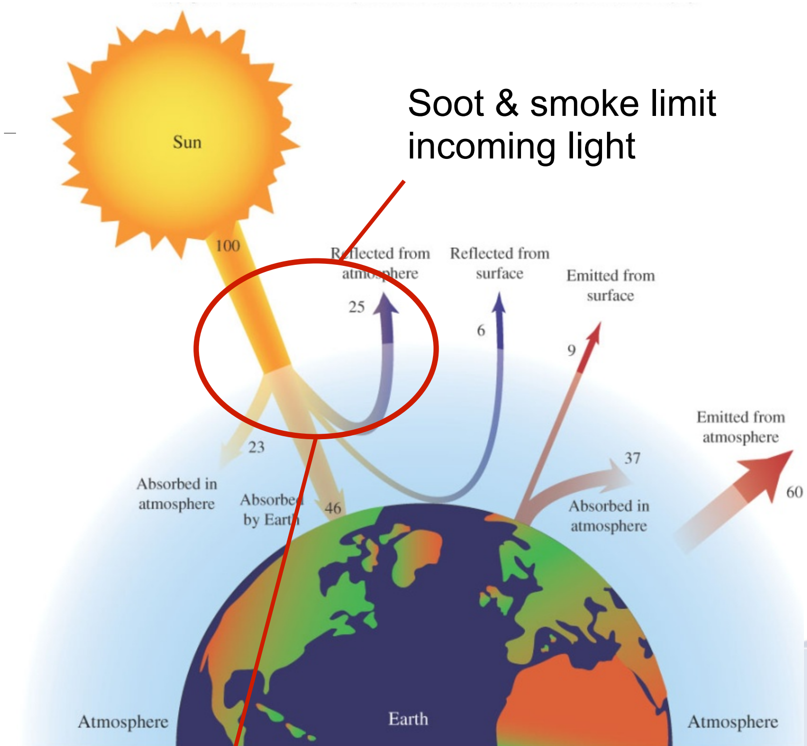
4. Liquid HFC vaporizes (light blue), its temperature dropping to -27 F. This makes the inside of the refrigerator cold (A)

3. High-pressure HFC liquid flows through the expansion valve (C). (a small hole). On one side of the hole is high-pressure HFC liquid. On the other side of the hole is a low-pressure area (the compressor is pumping gas out of that side).

In the Soda Siphon, a small needle punctures the high pressure CO_2 cartridge. Expansion into our relative “vacuum” cools the CO_2 gas and the cartridge

Projecting the Future: Climate Models

Soot & smoke limit incoming light



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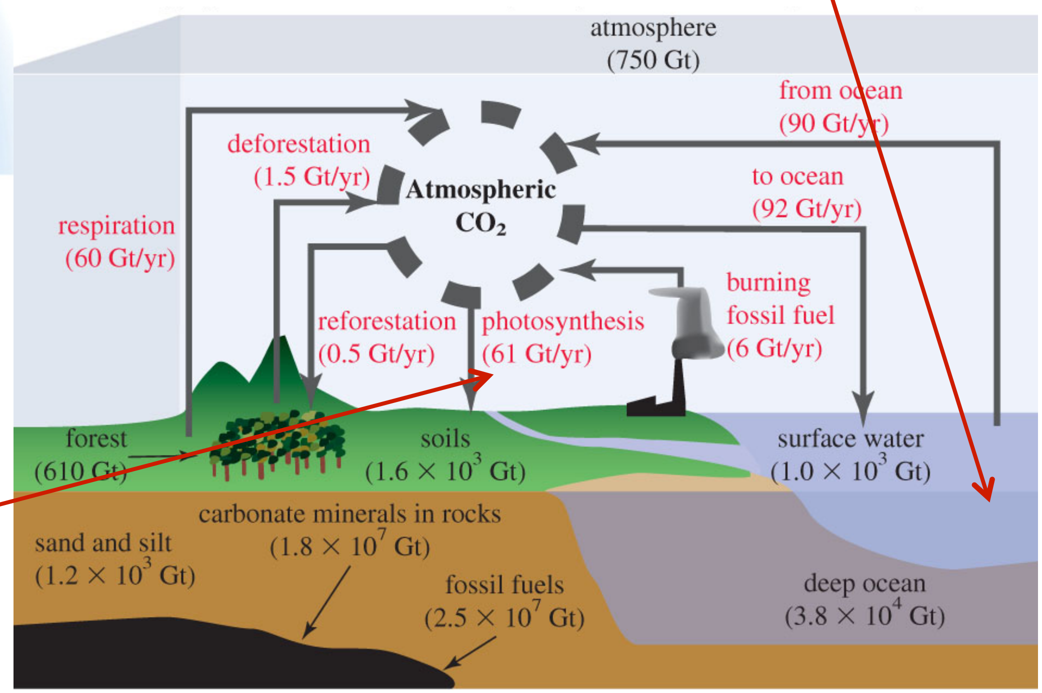

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Soda Siphon: Acid-Base Chemistry

While discussing the carbon cycle, we talk about carbon going into the ocean & coming out of the ocean & that this was an equilibrium (Fig. 3.17)

- Gaseous CO_2 dissolves in the water & vaporizes from water

$$CO_2\ (g) + H_2O\ (l) \rightleftharpoons CO_2\ (aq)$$

- Dissolved CO_2 reacts with H_2O forming H_2CO_3 (carbonic acid)

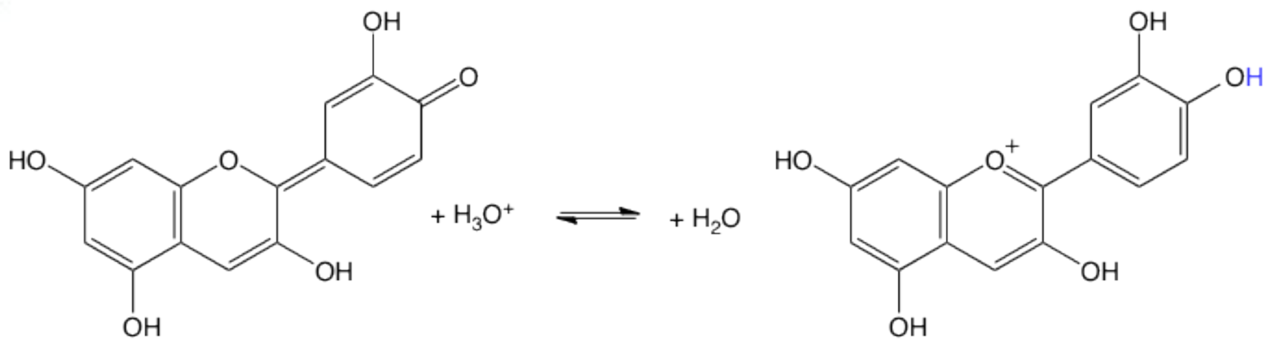
$$CO_2\ (aq) + H_2O\ (l) \rightleftharpoons H_2CO_3\ (aq)$$

- Dissolved H_2CO_3 reacts with H_2O forming HCO_3^- (bicarbonate) and H_3O^+ (hydronium ion)

$$H_2CO_3\ (aq) + H_2O\ (l) \rightleftharpoons HCO_3^-\ (aq) + H_3O^+\ (aq)$$

Our definition of an **acid** is a substance that forms hydronium ions (H_3O^+) when dissolved in water

- Hydronium ion reacts with anthocyanin, the product is a different color



Blue-green

red

Concentration of Acid

Each CO_2 cartridge: $$8.0\ g\ CO_2 \times \frac{mol\ CO_2}{44\ g\ CO_2} = 0.18\ moles\ CO_2$$

0.18 moles CO_2 in 1 L aqueous solution = 0.18 M CO_2

$[CO_2]$=0.18M

If the CO_2 equilibria reproduced below were to all favor products then we would have ~0.18 M H_3O^+ (this would correspond to a pH of ~0.7)

$$CO_2\ (g) + H_2O\ (l) \rightleftharpoons CO_2\ (aq)$$

$$CO_2\ (aq) + H_2O\ (l) \rightleftharpoons H_2CO_3\ (aq)$$

$$H_2CO_3\ (aq) + H_2O\ (l) \rightleftharpoons HCO_3^-\ (aq) + H_3O^+\ (aq)$$

In reality $[H_3O^+]$ = ~1.9×10^{-4} M, corresponding to a pH of ~3.72 (at the pressure of our Seltzer bottle)

At atmospheric pressure $[H_3O^+]$ = ~2.5×10^{-6} M (a pH of ~5.6)