PS2.1: Counting Dentists

- U.S. population ~ 300 million
- Each person visits the dentist twice a year
- A dentist can do 2 visits/hour ~ 16 visits/d
- Dentists work 5 d/wk, 50 wk/y ~ 250 d/y

$$\left[300 \cdot 10^6 \text{ people}\right]\left[\frac{2 \text{ visits}}{\text{person} \cdot \text{y}}\right]\left[\frac{\text{dentist} \cdot \text{d}}{16 \text{ visits}}\right]\left[\frac{\text{y}}{250 \text{ d}}\right]$$

$$\sim 150{,}000 \text{ dentists}$$

PS2.2: Exhausting Fossil Fuels

Time to exhaust the stock assuming constant consumption at current rates, given the remaining stock in Harte and rate of consumption given by BP:

$$T_{OIL} = \frac{10 \cdot 10^{21} \text{J}}{158 \cdot 10^{18} \text{J/y}} \approx 60 \text{ y}$$

$$T_{GAS} = \frac{10 \cdot 10^{21} \text{J}}{101 \cdot 10^{18} \text{J/y}} \approx 100 \text{ y}$$

$$T_{COAL} = \frac{250 \cdot 10^{21} \text{J}}{116 \cdot 10^{18} \text{J/y}} \approx 2200 \text{ y}$$

PS2.3: Mercury in Coal

$$\left[\frac{90 \cdot 10^{18} \text{ J}}{\text{y}}\right]\left[\frac{t_{coal}}{29.3 \cdot 10^9 \text{ J}}\right]\left[\frac{10^{-7} \; t_{Hg}}{t_{coal}}\right] \approx 300 \frac{t_{Hg}}{\text{y}}$$

In first class, Hg emission due to oil and coal burning ~3000 t/y. More careful analysis gives global Hg emissions from coal at ~1500 t/y:

– average energy content of ~ 25 GJ/t
– average Hg content of coal ~ 400 ppb
(40 ppb US, 300 ppb EU, 500 ppb China)

PS2.4: Global Ice Melt

The oceans cover about 360 million square kilometers; if this area did not change, the melting of all the world's ice would raise sea level by:

$$\left[29 \cdot 10^{15} \text{ m}^3\right]\left[\frac{1}{360 \cdot 10^6 \text{ km}^2}\right]\left[\frac{\text{km}^2}{10^6 \text{ m}^2}\right] \approx 80 \text{ m}$$

~270 ft. For comparison, Van Munching Hall is about 125 ft above current sea level.

PS2.4: Global Ice Melt

Complication: as sea level rises, land is flooded and ocean area increases, resulting in a slightly smaller increase in sea level.

PS2.5: Hot Water for Electricity

	Coal	Geothermal	Ocean
T_H	840	520	300
T_C	300	350	277
ΔT	540	170	23
$\varepsilon_{max} = \frac{\sqrt{T_H} - \sqrt{T_C}}{\sqrt{T_H}}$	0.40	0.18	0.039
MJ_{th}/s	2500	5600	26,000
MJ_{th}/m^3	2300	710	96
m^3/s	1	8	270

PS2.5: Hot Water for Electricity

MJ_{th}/s of heat to produce 1000 MW_e using coal:

$$\left[1000\ MW_e\right]\left[\frac{MJ_e}{MW_e \cdot s}\right]\left[\frac{MJ_{th}}{0.4\ MW_e}\right] = 2500\frac{MJ_{th}}{s}$$

MJ_{th} of heat extracted from 1 m^3 of water:

$$\left[\frac{10^6\ g}{m^3}\right]\left[\frac{1\ cal}{g \cdot {}^\circ C}\right]\left[\frac{4.184\ J}{cal}\right]\left[540\ {}^\circ C\right] = 2300\frac{MJ_{th}}{m^3}$$

PS2.5: Hot Water for Electricity

Flow of water needed:

$$\left[\frac{2500\ MJ}{s}\right]\left[\frac{m^3}{2300\ MJ}\right] \sim 1\frac{m^3}{s}$$

In general: $F = \frac{P}{4.2\ \varepsilon\ \Delta T}\ \frac{m^3}{s}$

Complications: coal and geothermal use steam; “latent heat of vaporization” ~ 2 MJ/kg; specific heat of steam less than liquid water; these largely offset.

PS2.6: Caesar's Last Drink

- On average, how many of the hydrogen atoms in Julius Caesar's last drink of water will be in your next drink of water?
- How many hydrogen atoms in a drink? Drink ≈ 1 cup ≈ 0.25 L = 250 g

$$\left[\frac{250\ g_{H_2O}}{drink}\right]\left[\frac{2\ g_H}{18\ g_{H_2O}}\right]\left[\frac{mole}{1\ g_H}\right]\left[\frac{6\cdot 10^{23}\ atoms}{mole}\right] = 1.7\cdot 10^{25}$$

$$\left[\frac{250\ g_{H_2O}}{drink}\right]\left[\frac{mole_{H_2O}}{18\ g_{H_2O}}\right]\left[\frac{2\ mole_H}{mole_{H_2O}}\right]\left[\frac{mole}{1\ g_H}\right]\left[\frac{6\cdot 10^{23}\ atoms}{mole}\right]$$

Caesar's Last Drink

- $1.7\cdot 10^{25}$ H atoms in your next drink. What fraction were in Caesar's last drink?
- $1.7\cdot 10^{25}$ H atoms in Caesar's last drink. These are mixed throughout all the water molecules in the world: $1.4\cdot 10^{21}$ kg

$$\left[\frac{0.25\ kg_{H_2O}}{1.4\cdot 10^{21}\ kg_{H_2O}}\right] = 1.8\cdot 10^{-22}\ \frac{CLD\ H\ atoms}{H\ atom}$$

$$\left[1.7\cdot 10^{25}\ \frac{H\ atoms}{drink}\right]\left[1.8\cdot 10^{-22}\ \frac{CLD\ H\ atoms}{H\ atom}\right] = 3000\ \frac{CLD\ H\ atoms}{drink}$$