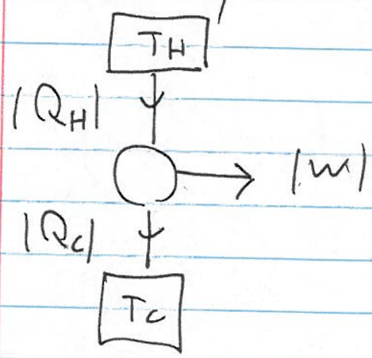
Lecture 10 Heat Pumps continued.

Note: text uses different notation for Q_H, Q_C, T_H; (T_1, T_0 etc)

Read ch. 5 start reading ch. 6

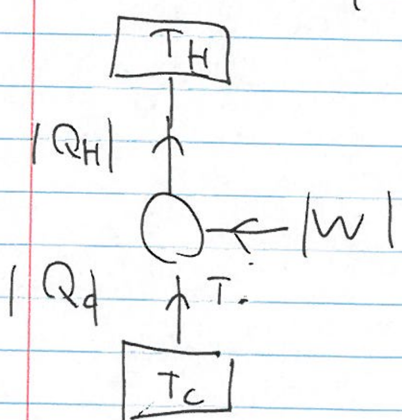
Efficiency of a heat engine:



$$\eta = \frac{|W|}{|Q_H|} = \frac{|Q_H| - |Q_C|}{|Q_H|}$$

$$\eta_{max} = \frac{T_H - T_C}{T_H}$$

Coefficient of performance of a heat pump or refrigerator



① Fridge or air conditioner

$$COP = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|}$$

$$COP_{max} = \frac{T_C}{T_H - T_C}$$

② Residential heat pump

$$COP = \frac{|Q_H|}{|W|} = \frac{|Q_H|}{|Q_H| - |Q_C|}$$

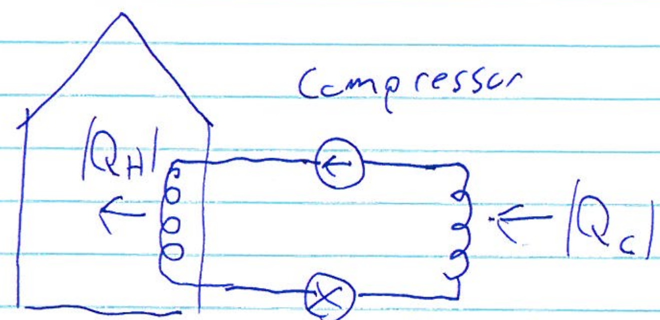
$$COP_{max} = \frac{T_H}{T_H - T_C}$$

Note:

COP decreases with increasing temp. difference ($T_H - T_C$)

Residential heat pumps

Air - Air

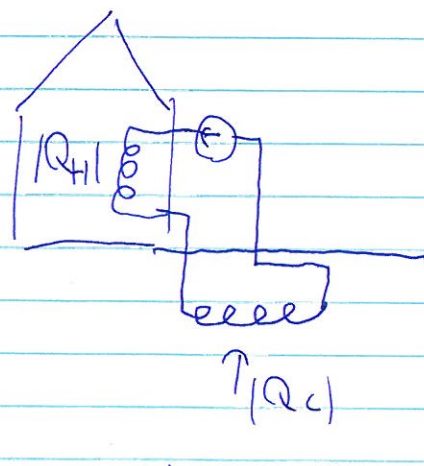


Advantage: - evaporator coils are in the air
$\therefore$ inexpensive

Disadvantage - outside air temp can be cold!

$$COP_{max} = \frac{T_H}{T_H - T_c}$$ } large $T_H - T_c$
$\Rightarrow$ low COP

Solution : Ground based heat pump
(mistakenly called "geothermal")



Advantage : ground temperature is much warmer than air (in winter) $\therefore T_H - T_C$ is smaller

Disadvantage : - cost $$$
- ground may freeze if too much heat is removed

Ch. 5 Health and Environmental Effects of Fossil Fuels

Direct impacts of fossil fuel use:

Pollution.

① CO_2 : inherent, "intrinsic"
- toxic in large concentrations (implications for sequestration)
- greenhouse gas

② other pollutants: (trace contaminants)

CO : incomplete combustion = highly toxic

NO_x = nitrous oxides = inherent to combustion process

increases w/ temperature:

reaction of N_2 & O_2 in atmosphere

SO_2 = sulfur dioxide, highly toxic
- acid rain precursor
- sulfur is an impurity in all coal / hydrocarbons.
- highly variable sulfur contents

VOCs = volatile organics = e.g.: unburnt hydrocarbons

Particulates = "soot"
- PM 2.5 (< 2.5 μm particulates)
- respiratory irritant

Ozone = O_3 = reactive form of oxygen
- = photochemical reaction of VOCs & NO_x
- respiratory irritant

Note: Items ② can be scrubbed or mitigated with relatively low cost (see viewgraphs)

Breakdown of fossil fuel pollutants:

(1) $\underline{CO_2}$ carbon dioxide

- difficult to remove or "sequester" because of large quantities involved.

Example of CO_2 emissions : **Coal**

Attached table shows variation in chemical composition of coal

Lowest energy content : lignite (used in power plants)

~ 28.5 MJ/kg

Highest = anthracite (used in residential heating)

~ 35.0 MJ/kg

Note : - hydrogen content is low (compared w/ CH_4)
- sulfur 1 - 3% = big problem given (1) large volumes (2) toxicity of SO_2

CO_2 emission from coal : sample calculation

Assume ~70% carbon by mass

$\therefore$ 1 kg coal $\Rightarrow$ 0.7 kg carbon

Assume this reacts according to $C + O_2 \rightarrow CO_2$

Chemical Composition of Coal

Name	Volatiles %	C Carbon %	H Hydrogen %	O Oxygen %	S Sulfur %	Heat content kJ/kg
Braunkohle (Lignite)	45-65	60-75	6.0-5.8	34-17	0.5-3	<28470
Flammkohle (Flame coal)	40-45	75-82	6.0-5.8	>9.8	~1	<32870
Gasflammkohle (Gas flame coal)	35-40	82-85	5.8-5.6	9.8-7.3	~1	<33910
Gaskohle (Gas coal)	28-35	85-87.5	5.6-5.0	7.3-4.5	~1	<34960
Fettkohle (Fat coal)	19-28	87.5-89.5	5.0-4.5	4.5-3.2	~1	<35380
Esskohle (Forge coal)	14-19	89.5-90.5	4.5-4.0	3.2-2.8	~1	<35380
Magerkohle (Non baking coal)	10-14	90.5-91.5	4.0-3.75	2.8-3.5	~1	35380
Anthrazit (Anthracite)	7-12	>91.5	<3.75	<2.5	~1	<35300
Percent by weight						

http://en.wikipedia.org/wiki/Coal

Now lets calculate how much CO_2 this 1 kg of coal (700g of carbon) releases.

Assume $C + O_2 \rightarrow CO_2$

How many moles of carbon in 700g ?

$$n = \frac{700\,g}{12\,g/mole} = 58.3 \text{ moles}$$

1 mole of carbon yields 1 mole of CO_2

Molecular weight of $CO_2 = \left(12 \frac{g}{mol}\right) + \left(2 \times 16 \frac{g}{mol}\right)$
(C) (O₂ → O_2)

$= 44 \frac{g}{mol}$

$\therefore$ Mass of $CO_2 = (58.3\,mol)\left(\frac{44\,g}{mol}\right) = 2.57\,kg$

Overall 1 kg coal yields 2.57 kg CO_2

Note that this number depends on the grade of coal as per previous table.

World consumption of coal in 2000

6.13×10^9 metric tons (1 metric ton = 1000 kg)

This gives $(6.13 \times 10^9 \text{ tons})\left(\frac{2.57 \text{ kg } CO_2}{1 \text{ kg coal}}\right)$

$= 1.87 \times 10^{10}$ tons McFarland

Total number for <u>all</u> fossil fuels (2000)

$\sim 3.4 \times 10^{10}$ tons / year (McFarland)

Per person = world pop. (2000) $= 6 \times 10^9$

This gives $\dfrac{3.4 \times 10^{10} \text{ tons/year}}{6 \times 10^9 \text{ people}}$

$= 5.7$ tons / person / year

See attached to graph : figures for North America are much higher, ~ 25 tons/person /year

Comparison of CO_2 emissions per energy source

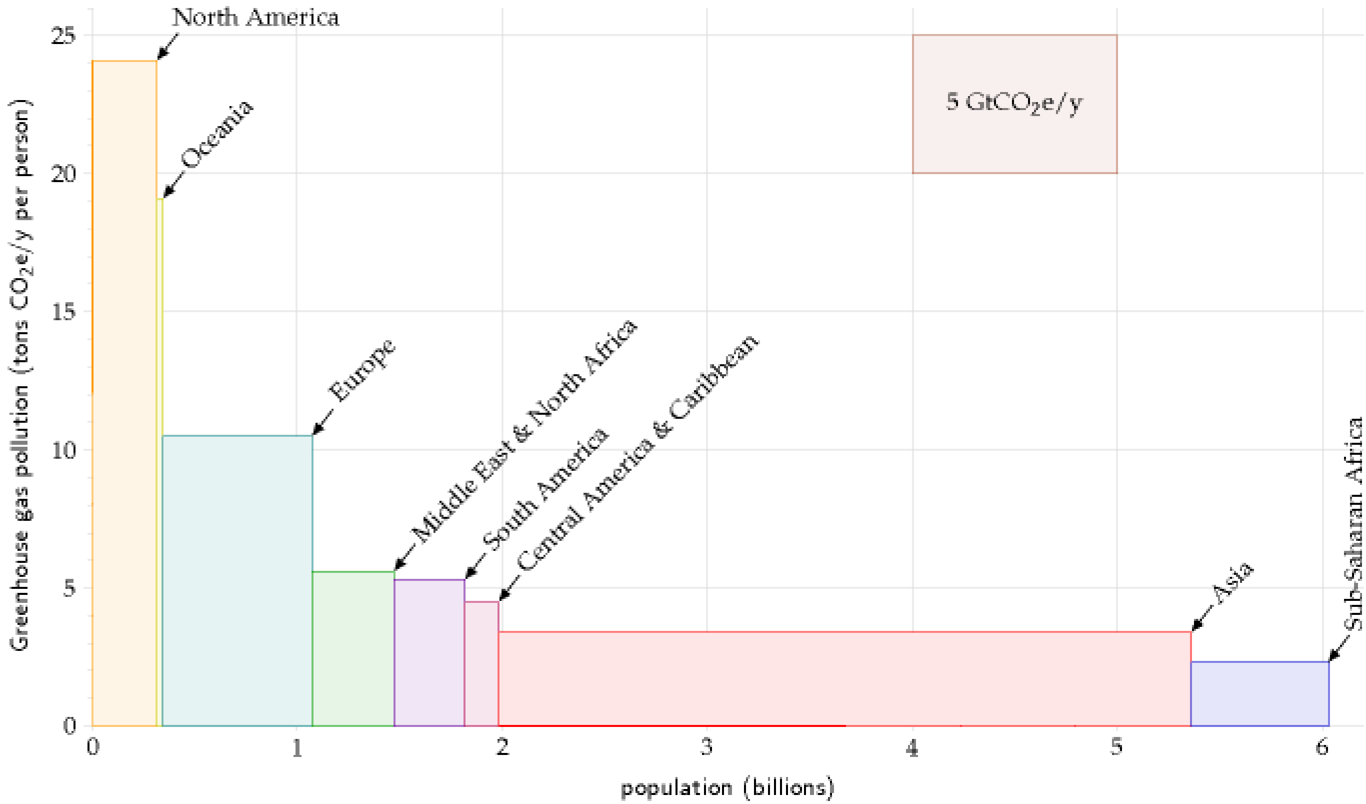
Fuel	Primary component	CO_2 emitted / unit energy
Coal	Carbon	~ 0.3 kg / kwh
Oil	Hydrocarbons: $C_x H_y$	~ 0.27 kg / kwh
Natural gas	Methane CH_4	~ 0.18 kg / kwh

Note that hydrocarbons emit <u>less</u> CO_2 per unit of energy delivered.

This is because of <u>hydrogen</u>

Some of the hydrogen forms H_2O which has a large heat of reaction

Per capita CO_2 emissions by region



Source: McKay, Sustainable Energy without the hot air, page 12