PSC 320
4/21/15

Problem Set 3

1) a) Maximum Power output: $P = \frac{work}{time}$ 1 HP = 746 W

254 mph = 1,001 HP

$1001 \text{ HP} \cdot \frac{746 \text{ W}}{1 \text{ HP}} = 746,746 \text{ Watts}$

My car (1998 Toyota 4runner) = 160 HP

$160 \text{ HP} \left(\frac{746 \text{ W}}{1 \text{ HP}}\right) = 119,360 \text{ Watts}$

Common car: Toyota Campry = 200 HP

$200 \text{ HP} \left(\frac{746 \text{ W}}{1 \text{ HP}}\right) = 149,200 \text{ Watts}$

b) Rate of Veyron's consumption of petroleum @ max power:

1.4 U.S. gallons / minute

3 miles / U.S. gallon

c) Chemical potential energy consumption rate? (watts)

gallon of gas = 1.3×10^8 J

$\frac{1.4 \text{ gallons} (1.3 \times 10^8 \text{ J})}{1 \text{ minute}} \left(\frac{1 \text{ min}}{60 \text{ sec}}\right) = 3,033,333 \text{ W}$

$\Rightarrow 3.03 \times 10^6 \text{ W}$

d) Efficiency of this engine @ max power:

$\frac{746,746 \text{ W}}{3.03 \times 10^6 \text{ W}} \times 100 = 24.9\%$ efficiency

e) Combustion temp of otto cycle:

$T_1 = 1830 \text{ K}$ $T_2 = 300 \text{ K}$

max efficiency: $1 - \frac{T_C}{T_H} = 1 - \frac{300 \text{ K}}{1830 \text{ K}} = 83.6\%$

f) Rate engine dissipates heat: $75.1\% (3.03 \times 10^6 \text{ W}) = 2.28 \times 10^6 \text{ W}$

= 22,756 100W light bulbs

Radiators are used to cool engines, so many would be necessary to combat the output of 2.28×10^6 W of heat

2) a) NGCC = Natural gas combined cycle
b) Coal has more impurities that release toxins when it is burned.
Toxins = CO_2, SO_2, NO_x, Mercury, Lead, carbon monoxide, VOC
c) Natural Gas CO_2 emission = 51 g CO_2/MJ
Coal CO_2 emission = 92 g CO_2/MJ
d) Why coal emitts more CO_2:
1. Coal emits more carbon
~~2. coal has more impurities~~

$\eta_{cc} > \eta_{Rankin}$

e) Portion of the world's coal consumed:
US = 904 mt / 7823 Mt = 11.6%
China = 3561 mt / 7823 mt = 45.5%
Portion of the world's Natural gas consumed:
US: 26,000 bil ft³ / 120,000 billion ft³ = 21.7%
China = 5,700 bil ft³ / 120,000 bil ft³ = 4.8%

see last pages for more complete answers

3) How much CO_2 for 100W on for a year: ÷ $\eta_{conversion}$
a) NGCC power plant: 3153.6 MJ $\left(\frac{51\text{ g}CO_2}{1\text{ MJ}}\right)$ = 160,830 g of CO_2
$100\text{ W} = 100\ \frac{J}{s}\left(\frac{60\text{ sec}}{1\text{ min}}\right)\left(\frac{60\text{ min}}{1\text{ hr}}\right)\left(\frac{24\text{ hr}}{1\text{ day}}\right)\left(\frac{365\text{ day}}{1\text{ yr}}\right) = 3.15\times10^9\text{ J} = 3153.6\text{ MJ/year}$
b) Old Coal-fired Rankin cycle: 3153.6 MJ $\left(\frac{92\text{ g}CO_2}{1\text{ MJ}}\right)$ = 290,130 g of CO_2 ÷ $\eta_{conversion}$
Combustion of what mass of fuels:
c) NGCC power plant: $\frac{40\text{ MJ}}{1\text{ kg}} = \frac{3153\text{ MJ}}{x\text{ kg}}$ x = 78.8 kg (51)
d) Old coal-fired Rankin cycle: $\frac{30\text{ MJ}}{1\text{ kg}} = \frac{3153}{x\text{ kg}}$ x = 105.1 kg

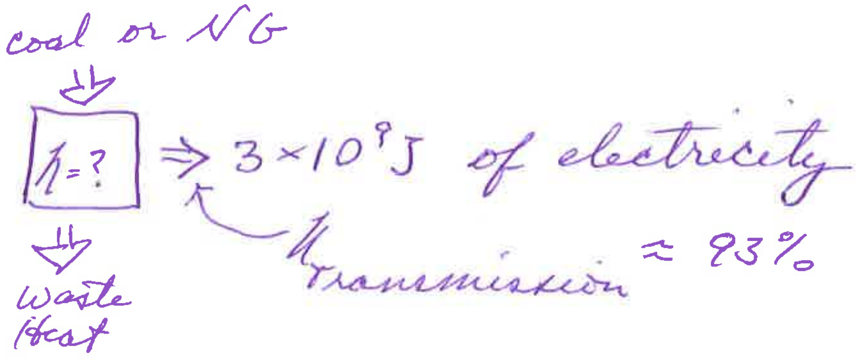
4) a) a-b have to increase to meet demands, voltage + frequency (b-d) decrease
b) Increase flow of fuel
c) a-b go back down, b-d increase

5) a) Transformers step voltage up & down to reduce line loss but still produce and consume at a certain voltage
b) AC is still mostly used b/c of the extensive infrastructure already in place, which is the biggest obstacle for DC use

3) Energy $= P \cdot t = 0.1\,\text{kW} \cdot 8760\,\text{hrs} = \underline{876\,\text{kWhr}}$

$\quad\quad 100\,\text{W} \cdot 1\,\text{year}$

$= 876\,\text{kWhr} \left(\frac{3.6\,\text{MJ}}{\text{kWhr}}\right) \approx 3000\,\text{MJ} = 3\times10^9\,\text{J}$



$$E_{\substack{\text{electricity}\\ \text{to consumer}}} = \underbrace{\eta_{\text{conversion}}\,\eta_{\text{transmission}}}\, E_{\text{Heat of coal or NG}}$$

$$\eta_{\text{coal}} \approx 30\% \qquad \eta_{NG} \approx 60\%$$

$$E_{\text{heat}} = \frac{E_{\text{electricity}}}{\eta} \approx \boxed{\begin{array}{l} 5\times10^9\,\text{J}_{\text{Heat}}\ (NG) \\ 1\times10^{10}\,\text{J}_{\text{Heat}}\ (\text{coal}) \end{array}}$$

a) NGCC Power Plant burns $5\times10^9\,\text{J}$ NG

Carbon intensity $\approx \frac{15\,\text{g (C)}}{\text{MJ}_{\text{Heat}}} \cdot \frac{44\,\text{g} (CO_2)}{12\,\text{g C}} = \frac{55\,\text{g} (CO_2)}{\text{MJ}}$

CO_2 Produced $= 5\times10^9\,\text{J} \times \frac{55\,\text{g} (CO_2)}{10^6\,\text{J}} \approx 275\,\text{kg}\,CO_2$

b) for coal: $\frac{25\,\text{g (C)}}{\text{MJ}} \cdot \frac{44\,\text{g} (CO_2)}{12\,\text{g (C)}} = \frac{92\,\text{g} (CO_2)}{\text{MJ}}$

CO_2 Produced $= 10^{10}\,\text{J} \cdot \frac{92\,\text{g} (CO_2)}{\text{MJ}} \approx 900\,\text{kg}\,CO_2$

Energy Density of NG $\approx \frac{55\ MJ}{kg}$

Coal $\approx \frac{24\ MJ}{kg}$

c) we need NG: $5 \times \cancel{10^9}\,10^3\ \cancel{J}\left(\frac{kg}{55\ \cancel{MJ}}\right) \approx 90\ kg$ NG

D) we need Coal $\approx 10 \times \cancel{10^9}\,10^3\ J\left(\frac{kg}{24\ MJ}\right) = 400\ kg$ Coal