

① Fuel Cell

$$\dot{W} = 129 \text{ kW}$$

$$m = 82 \text{ kg}$$

$$V = 0.0574 \text{ m}^3$$

V6

$$\dot{W} = 175 \text{ hp} = 130.5 \text{ kW}$$

$$V = 12960 \text{ in}^3 = 0.2124 \text{ m}^3$$

$$mg = 1000 \text{ lbf} = 4448 \text{ N}$$

$$m = 453.9 \text{ kg}$$

(a) Specific energy density

$$\text{Fuel Cell} = \frac{\dot{W}/m}{V} = \frac{129/82}{0.0574} = 27.4 \frac{\text{kW/kg}}{\text{m}^3}$$

$$V6 = \frac{130.5/453.9 \text{ kg}}{0.2124} = 1.354 \frac{\text{kW/kg}}{\text{m}^3}$$

(b) Power Density = $\frac{\dot{W}}{V}$

$$\text{Fuel Cell} = \frac{\dot{W}}{V} = \frac{129}{0.0574} = 2247.387$$

$$V6 = \frac{130.5}{0.2124} = 614.5 \frac{\text{kW}}{\text{m}^3}$$

(c) While a V6 costs \approx \$2000, a quick web search reveals that a fuel cell for automotive use can cost around \$50-\$100 per kW. Obviously, this makes the FC option much more expensive, despite the advantages of its high power density.

(Also, keep in mind that a Chevy 60 Degree 3.1 L V6 engine only weighs about 350 lbs.)

2) (These values are from charts, so may vary a little.)

a) $A = 300 \text{ cm}^2$
 @ max power, $I \approx \boxed{460 \frac{\text{mA}}{\text{cm}^2}} \cdot 300 \text{ cm}^2 = \boxed{138,000 \text{ mA} = 138 \text{ A}}$
 $\dot{W}_e \approx \boxed{82 \text{ W}}$ (power), $V \approx \boxed{0.6 \text{ V}}$ (potential)

(Double-check: $P = IV = (0.6)(138) = 82.8 \text{ W}$)

b) $\eta_{th} = ?$ $\eta = \frac{0.83 \times V}{V_L}$, where $V_L = 1.229 \text{ V}$. or $\eta = 0.675 \times V$

$\eta = \boxed{0.405}$

3) a) $HHV_{\text{Thermal}} = (700 \frac{\text{lbm}}{\text{hr}}) (23,881 \frac{\text{Btu}}{\text{lbm}}) (\frac{1 \text{ W} \cdot \text{hr}}{3.412 \text{ Btu}}) (\frac{1 \text{ MW}}{10^6 \text{ W}}) = \boxed{4.899 \text{ MW}}$

b) $LHV_{\text{Thermal}} = (700 \frac{\text{lbm}}{\text{hr}}) (21,526 \frac{\text{Btu}}{\text{lbm}}) (") (") = \boxed{4.416 \text{ MW}}$

c) Efficiency is output over input, so $\eta_{e,HHV} = \frac{2 \text{ MW}}{4.899 \text{ MW}} = \boxed{40.8\%}$

d) $\eta_{e,LHV} = \frac{2 \text{ MW}}{4.416 \text{ MW}} = \boxed{45.3\%}$

e) Heat rate is the amount of heat req'd to produce 1kW electricity.
 So, producing $3412 \frac{\text{Btu}}{\text{kW} \cdot \text{hr}}$ would be a 100% efficient process. Therefore,

Heat Rate_{HHV} = $\frac{\text{Perfect}}{\text{HHV eff.}} = \frac{3412 \text{ Btu/kW} \cdot \text{hr}}{0.408} = \boxed{8360 \frac{\text{Btu}}{\text{kW} \cdot \text{hr}}}$

(Alternately: $HR_{HHV} = \frac{\text{Input}}{\text{Output}} = \frac{700 \times 23881 \frac{\text{Btu}}{\text{hr}}}{2000 \text{ kW}} = 8360 \frac{\text{Btu}}{\text{kW} \cdot \text{hr}}$)

4) From any thermo book, $h_{\text{steam}} (150 \text{ psia}, 400^\circ\text{F}) \approx 1219.1 \frac{\text{Btu}}{\text{lbm}}$, $h_{\text{water}} (60^\circ\text{F}) = 28.6 \frac{\text{Btu}}{\text{lbm}}$

so the heat transfer is: $\dot{Q} = \dot{m} (h_{\text{out}} - h_{\text{in}}) = \dot{m} (h_{\text{steam}} - h_{\text{water}}) = (2 \frac{\text{tons}}{\text{hr}}) (\frac{2000 \text{ lbm}}{1 \text{ ton}}) (1219.1 - 28.6 \frac{\text{Btu}}{\text{lbm}})$

$\dot{Q} = 4.762 \times 10^6 \frac{\text{Btu}}{\text{hr}} = 1.396 \text{ MW}$

So the total heat + electrical output is $2 \text{ MW}_e + 1.396 \text{ MW}_e = 3.396 \text{ MW}$

and the HHV efficiency is:

$\eta = \frac{\text{Output}}{\text{Input}} = \frac{3.396}{4.899} = \boxed{69.3\%}$