① Fuel Cell

$\dot{W} = 129\ kW$

$m = 82\ kg$

$\forall = 0.0574\ m^3$

V6

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

$\forall = 12960\ in^3 = 0.2124\ m^3$

$mg = 1000\ lb_f = 4448\ N$

$m = 453.9\ kg$

(a) Specific energy density

$$\text{Fuel Cell} = \frac{\dot{W}/m}{\forall} = \frac{129/82}{0.0574} = 27.4\ \frac{kW/kg}{m3}$$

$$V6 = \frac{130.5/453.9\ kg}{0.2124} = 1.354\ \frac{kW/kg}{m3}$$

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

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

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

(c) While a V6 costs ≈ \$2000, a quick web seach 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.) 2/2

a) $A = 300\ cm^2$

@ max power, $I \cong \boxed{460\ \frac{mA}{cm^2}} \cdot 300\ cm^2 = \boxed{138{,}000\ mA = 138\ A}$ ← current

$\boxed{\dot{W}_e \cong 82\ W}$ ← power, $\boxed{V \cong 0.6\ V}$ ← potential

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

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

$\boxed{\eta = 0.405}$

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

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

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

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

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

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

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

4 From any thermo book, $h_{steam}(150\,psia, 400°F) \cong 1219.1\ \frac{Btu}{lbm}$; $h_{water}(60°F) = 28.6\ \frac{Btu}{lbm}$

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

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

So the total heat + electrical output is $2\ MW_e + 1.396\ MW_t = 3.396\ MW$

and the HHV efficiency is:

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