Homework 5 - Solutions

a) The size of the system is linearly dependent on the operating time, because the longer the system is required to produce electricity, the more fuel it needs. The fuel cell system has a fixed-size fuel cell (0.4 litres) but the battery system is assumed to only consist of the battery itself. The linear dependencies for the system lifetimes versus the system sizes are

$$t_1 = 3400\mathrm{Wh/L} \cdot 0.2/20\mathrm{W} \cdot V_{1,\mathrm{storage}} \tag{1}$$

for the fuel cell system and

$$t_2 = 200\mathrm{Wh/L} \cdot 1/20\mathrm{W} \cdot V_{2,\mathrm{storage}} \tag{2}$$

for the battery system. Here t_1 and t_2 represent the operating times of the systems (in hours) and V_1 and V_2 the sizes of the systems (in litres).

From these equations we get impressions for the system lifetime with respect to the system size:

$$V_{1,\mathrm{system}} = V_{1,\mathrm{storage}} + V_{1,\mathrm{FC}} = t_1/34 + 0.4 \tag{3}$$

and

$$V_{2,\mathrm{system}} = V_{2,\mathrm{casing,etc}} + V_{2,\mathrm{battery}} \approx V_{2,\mathrm{battery}} = t_2/10. \tag{4}$$

These lines intercept at a point [5.7;0.57], which means that the battery is a better option up until a lifetime of 5.7 hours, after which the fuel cell is a better option. The plot is shown in Figure 1.

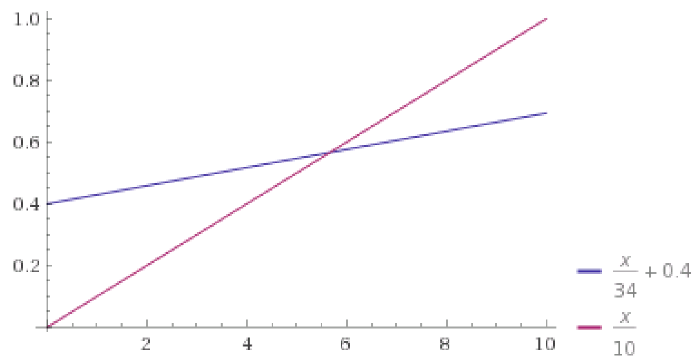

Figure 1: Fuel cell and battery system operating time dependency on system size (y axis system size (litres), x-axis system lifetime (hours)). Blue line is the fuel cell system and red line the battery system.

b) Ragone plot shows the trade-offs between system power density and energy density. It can be used to compare different energy-storing devices. An example of a typical Ragone plot for various devices is shown in Figure 2. The desired characteristics of the system can be optimized with the help of the diagram. A system that needs to be as low-weight as possible should have a high power density and a system with small size a high energy density. The plot shows different operating times as dashed lines. Based on these three main characteristics in the plot one can choose the appropriate energy storing device for different needs. The lifetime of the device can be directly seen from the x and y axis values: t = energy density/power density.

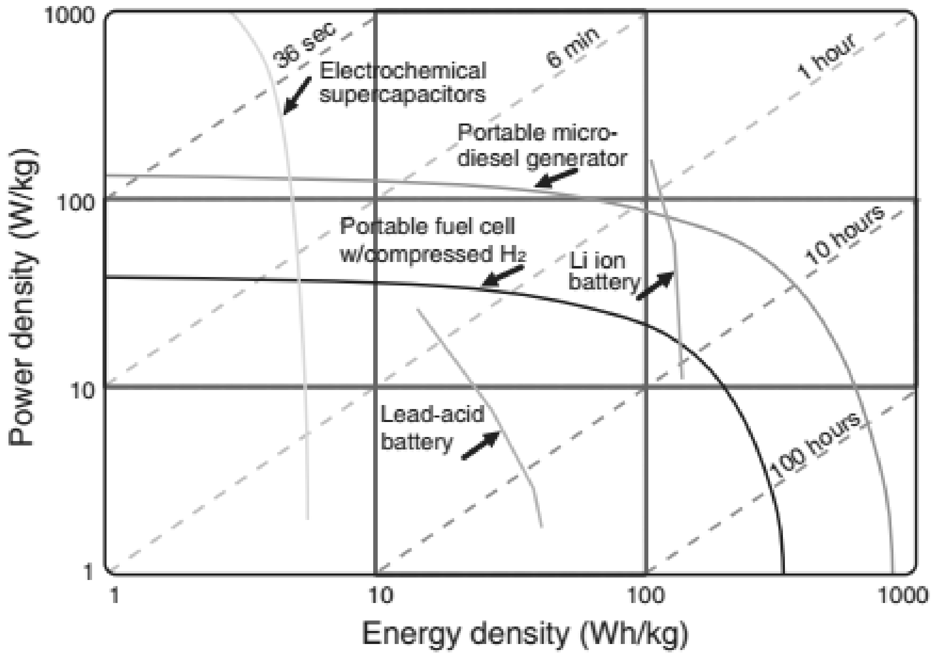

Figure 2: An example of a Ragone plot (From O'Hayre et al, 2016)

c) Some chosen portable fuel cell power sources are listed in Table 1. Typical lithium ion battery systems on the other hand have power densities of 300-2400 W/kg and energy densities of 70-110 Wh/kg. This means that the lithium ion battery power densities are over 20 times larger than for the fuel cell systems, but the energy densities can be lower or in the same neighborhood. (Source: "Rechargeable Energy Storage Systems for Plug-in Hybrid Electric Vehicles—Assessment of Electrical Characteristics", Energies 2012)

Table 1: Different fuel cell systems and their weight, power, energy capacity, gravimetric power density, energy density and run time. https://www.electrochem.org/dl/interface/wtr/wtr08/wtr08_p40-45.pdf

FC system	Weight(kg)	P(W)	E cap.(Wh)	P dens.(W/kg)	E dens.(Wh/kg)	Runtime(h)
SFC Jenny	1.66	25	480	15.1	289.2	19
EFOY 1600-M10	15.7	65	9100	4.1	579.6	140
Ultra-cell XX25	1.37	25	166	18.2	121.1	7