Part 3: How do we evaluate battery performance?

By using some of the electrochemical reaction tools outlined in Part 2: "How do we measure electrochemical reactions" we can gather key performance parameters of batteries and other electrochemical experiments.

Energy

A typical question for a battery is how much energy does it store? This would allow you to realise how far your electric car might be able to travel on a single charge. We can calculate the energy (E) expressed in watt-hours (Wh) stored in a battery as equal to the product of the voltage (V) and the capacity (Q) measured in amp hours.

$$E = Q * V$$

If the energy is 1Wh this corresponds to 1 watt of power sustained for 1 hour. The voltage (V) of a battery is essentially the electric difference between the cathode and anode electrodes within the battery.

Power

Another question you might ask your car dealer is how fast will the electric car go? This translates to the power (P) expressed as watts of the battery which is the product of the voltage (V) and the current (I).

$$P = V * I$$

The current (I) of a battery is the number of the electrons passing from one electrode to the other electrode outside the battery.

Capacity

The capacity (Q) of a battery is a common value used to compare the performance of batteries. The capacity is a measure of the charge stored by the battery and represents the maximum energy which can be extracted from the battery. This value gives a better understanding of how much the electrodes (cathode and anode) can take the ions from the electrolyte. Capacity (Q) is given by the product of the current (I) measured in amps and time (t) measured in hours.

$$Q = I * t$$

C-rate

The C-rate is used to show how fast your battery will charge/discharge. This is important for knowing how long you will need to charge your electric car at a charging station. The C-rate is given as the inverse of the runtime (t) of the battery.

$$t = 1 / \text{C-rate}$$

Using the equation for capacity (Q) and runtime (t), the discharge current (I) of a battery is then equal to the product of the C-rate and the capacity (Q).

I = C-rate * Q

A C-rate of 1C will means your battery will discharge/charge in 1 hour. On the other hand, if the C-rate is 2C it means your battery will discharge/charge in 0.5 hours (30minutes). However, if the C-rate is 0.2C it means your battery will discharge/charge in 5 hours.

Ragone plot

Sometimes we want to compare different batteries or energy storages which work on different electrochemical processes. For this reason, we want to compare how much energy and power is being produced per weight. This is important if you want your electric car to go quickly, the major component of the car will be the battery which can weigh a considerable amount. It is all well if your battery produces a lot of power, however if it weighs tons of kilograms then the car won't move very fast.

We can therefore define the energy density (Wh/kg) which is simply the energy (Wh) divided by the weight of the battery (kg).

Energy density = E / weight

Similarly, the power density (W/kg) is the power (W) divided by the weight of the battery (kg).

Power density = P / weight

With the energy densities and power densities we can plot these on a graph known as a Ragone plot as in figure 1. This plot can be used to compare how different batteries are useful.

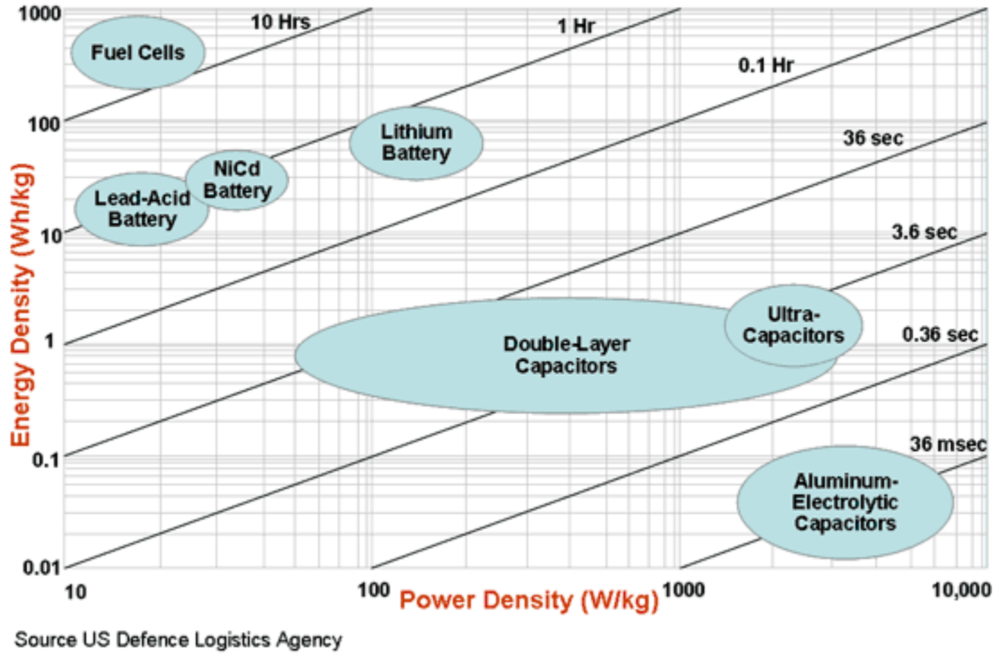

Figure 1. A typical Ragone plot of different energy storage solutions. The sloping lines show the time taken to charge/discharge the device.