

## Energy Density

By Bob Smith

This is a term which is used to express the efficiency of a re-chargeable battery in terms of its ability to store energy per unit weight. We usually simplify it slightly by using electrical units for the energy (watt hours) rather than absolute units (joules) but it is simply the battery discharge capacity (amps x volts x hours) divided by its weight. We also need to specify the rate of discharge in terms of current draw (usually constant) as the battery performance changes with increased current so the simple approach is to measure values at a 1C discharge (3.2 amps for a 3200 mAh battery). This 1C discharge rate is usually (but not invariably) the rate used by the manufacturer to determine the specified capacity of a battery, so this is consistent.

As the discharge of a battery proceeds the voltage changes and we get the typical voltage V time curve shown in graph 1. Since our calculations have to include the current and voltage it is better if we look at the watts V time curve as in graph 2, and then the energy density of the battery is the area under this curve (amps x volts x time) divided by the weight of the battery. For electric flight we have used NiCd and NiMH cells for several years with LiPo and LiIo cells now becoming very popular. The introduction of lithium batteries has been very swift because we quickly realised that these gave us the same level of energy/power at lower weights (or greater energy/power at the same weight). One of the strange features of this conversion has been that little attempt has been made to quantify the relative energy densities of the two systems. The calculations are simple to make but I have seen few numerical comparisons of different makes and types of flight batteries in these terms. The information is available within the specifications of the cells and so I have extracted this for a number of typical cells and calculated the values given in the following tables.

I have not had time to carry out discharge tests for each cell (as I would need to do to obtain accurate voltage drop curves at 1C discharge) so I have assumed average voltage figures of 1.2 volts for the nickel and lead systems and 3.6 volts for the lithium ones. At least any errors arising from these assumptions are constant throughout the table. The figures in the table are for single cells (1S), but for the Lithium table, some examples are based on a subdivision of data for larger packs e.g. the data from a 4S pack with the voltage, weight and thickness divided by 4. There will be some variations due to cable size and length and in cases where a circuit board is included, and the weights and thicknesses are therefore approximate. The make and size of cells has been chosen at random but you will see from the table that the variation in energy density between brands is lower than I expected. The clearest variation is in terms of size where, perhaps unsurprisingly, the energy density increases as the size of the cell increases, simply meaning that larger cells are more efficient

In the case of the second table covering various other battery types, the situation is simplified by the use of standard case sizes (e.g. D, C, sub-C, etc) but there are still slight variations in the cell size and weight. Although the energy densities are well down on the Lithium cells, the ratios are not as high as you might expect with 2/1 being an average comparison.

As I have mentioned above, there are a number of simplifications involved in the calculation of this data but it does give a broad-brush impression of where we are. There are many other factors involved in battery performance which I have deliberately ignored in this comparison. I have not considered the ability of the different cells to discharge at higher rates than 1C, especially since this involves a voltage drop throughout the discharge, nor have I included the effect of temperature as all of the data in the tables can be considered to be applicable to normal ambient conditions (20 degrees C). The importance of such additional factors is very much dependent on the application (sports flying, competitions, etc.) where they can sometimes outweigh the simple energy density comparison, but it is an interesting area of consideration.

### Energy Density for Lithium Polymer Cells

| <u>Make of Cell</u> | <u>Capacity mAh</u> | <u>Weight gms</u> | <u>Approx.Dimensions</u><br>L x W x T mm | <u>Energy Density</u><br>Whrs/Kg |
|---------------------|---------------------|-------------------|--|----------------------------------|
| <b>Kokam</b>        | 360                 | 11                | 52 x 34 x 3                              | 118                              |
| <b>Kokam</b>        | 910                 | 23                | 59 x 34 x 6                              | 142                              |
| <b>Kokam</b>        | 1500                | 35                | 70 x 38 x 7                              | 154                              |
| <b>Kokam</b>        | 3200                | 83                | 128 x 44 x 8                             | 139                              |
| <b>Tornado</b>      | 360                 | 13                | 53 x 34 x 5                              | 100                              |
| <b>Tornado</b>      | 1500                | 40                | 86 x 34 x 7                              | 135                              |
| <b>Tornado</b>      | 3200                | 100               | 138 x 42 x 9                             | 115                              |
| <b>Polypro</b>      | 800                 | 21                | 65 x 36 x 4                              | 137                              |
| <b>Polypro</b>      | 1500                | 38                | 100 x 32 x 5                             | 140                              |
| <b>Polypro</b>      | 3300                | 85                | 142 x 45 x 6                             | 142                              |
| <b>Flightpower</b>  | 400                 | 14                | 76 x 37 x 3                              | 102                              |
| <b>Flightpower</b>  | 1500                | 41                | 101 x 31 x 6                             | 132                              |
| <b>Flightpower</b>  | 3300                | 85                | 146 x 48 x 6                             | 140                              |
| <b>EnErG Pro</b>    | 1200                | 35                | 115 x 35 x 6                             | 123                              |
| <b>EnErG Pro</b>    | 3200                | 85                | 135 x 45 x 8                             | 135                              |
| <b>AirPower</b>     | 800                 | 25                | 67 x 35 x 5                              | 115                              |
| <b>AirPower</b>     | 2000                | 58                | 102 x 35 x 8                             | 124                              |
| <b>BRC Hobbies</b>  | 1500                | 42                | 86 x 33 x 7                              | 128                              |
| <b>BRC Hobbies</b>  | 3300                | 80                | 137 x 35 x 7                             | 148                              |

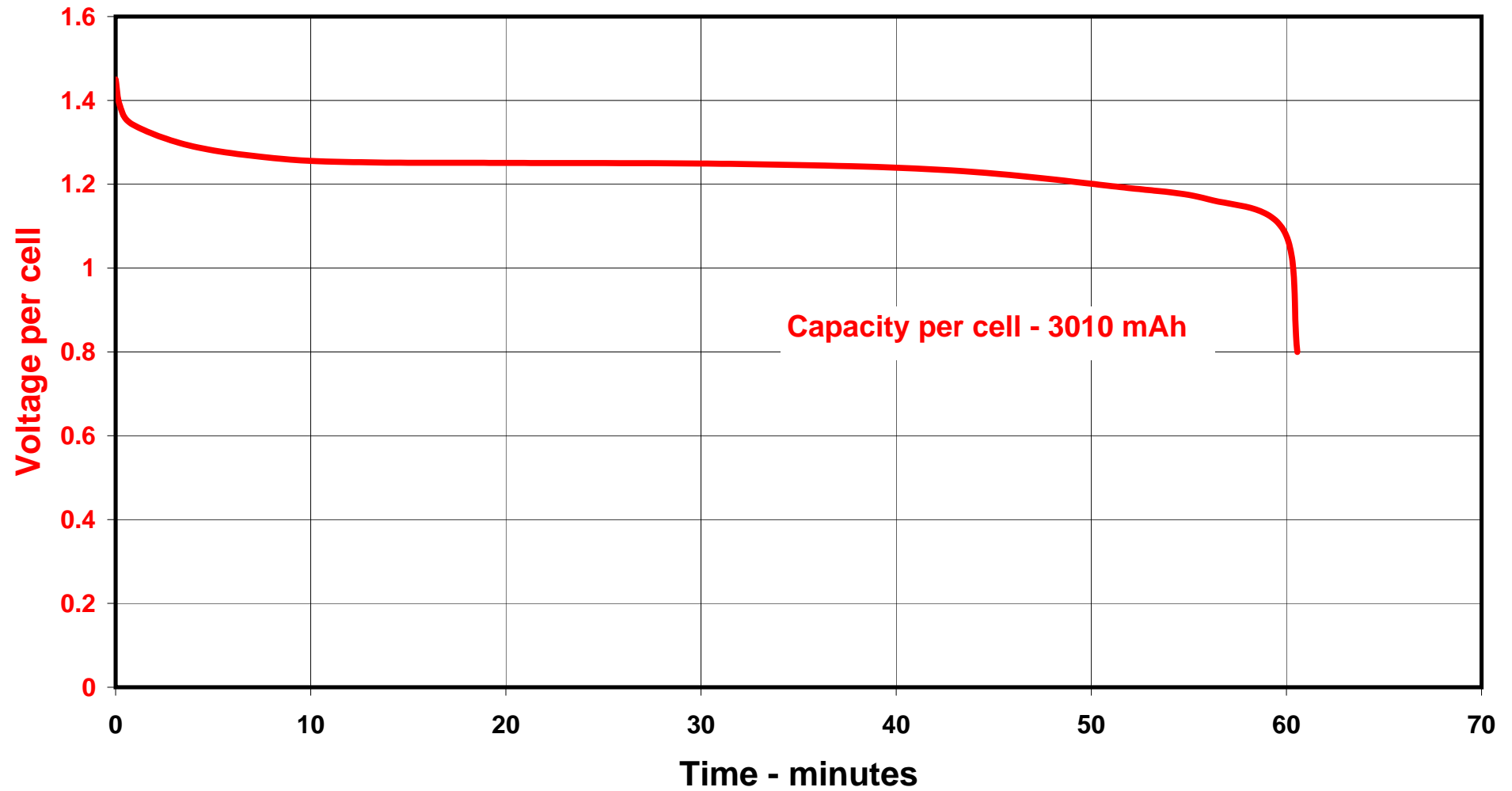
### Energy Densities for Other Battery Types

| <u>Make/Type</u>         | <u>Size</u> | <u>Capacity</u><br><u>mAh</u> | <u>Weight gms</u> | <u>Energy Density</u><br>Whrs/Kg |
|--------------------------|-------------|-------------------------------|-------------------|----------------------------------|
| <b>Intellect NiMH</b>    | 2/3 AF      | 1400                          | 23                | 73                               |
| <b>Intellect NiMH</b>    | Sub C       | 4200                          | 67                | 75                               |
| <b>Sanyo NiMH</b>        | D           | 10000                         | 175               | 68                               |
| <b>Sanyo NiCd</b>        | Sub C       | 2400                          | 58                | 49                               |
| <b>Sanyo NiCd</b>        | C           | 3000                          | 85                | 42                               |
| <b>Sony LiIo</b>         | 4/3 AF      | 1100                          | 48                | 80                               |
| <b>Lead Gel</b>          | 6 volt      | 12000                         | 1850              | 39                               |
| <b>Leisure Lead Acid</b> | 12 volt     | 80000                         | 20000             | 48                               |

### Photograph title

An assortment of typical batteries as included in the tables.

**Graph 1 - Discharge at 1C - Constant 3 amps**



**Graph 2 - Discharge at 1C - Constant 3 amps**

