

### Relationship between cell power, energy density, resistance, and capacity

**Batteries**

\[
P = E F \left(1 - E F\right) V_\text{nom}/R_{\text{cell}}, \quad E = V_\text{nom} \cdot \text{Ah}^1, \quad V_0 \quad \text{Max cell voltage}
\]

\[
P/W = 3/2 EF \left(1 - E F\right) \left(\text{Wh/kg}/R\right) \text{3600}, \quad \text{RC time constant}
\]

**Supercapacitors**

\[
P = 9/16 EF \left(1 - E F\right) V_0^2/R_{\text{oc}}, \quad V_0 \quad \text{Max rated voltage}
\]

\[
P/W = 3/2 EF \left(1 - E F\right) \left(\text{Wh/kg}/R\right) \text{3600}, \quad \text{RC time constant}
\]

### Battery and supercapacitor combinations

**HEV and PHEV applications**

<table>
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<tr>
<th>48V bat/cap</th>
<th>HEV FUDS</th>
<th>300V bat/cap</th>
<th>PHEV US06</th>
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<td>LiFePO4 Bat</td>
<td>ADVISOR simulations</td>
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### Conclusions

- Pulse efficiency is a key factor in stating W/kg of a battery.
- Supercapacitors can be used with bat. in HEVs and PHEVs
- The supercap reduces peak currents and battery stress by at least a factor of two.
- Use energy batteries with supercaps-not power batteries

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