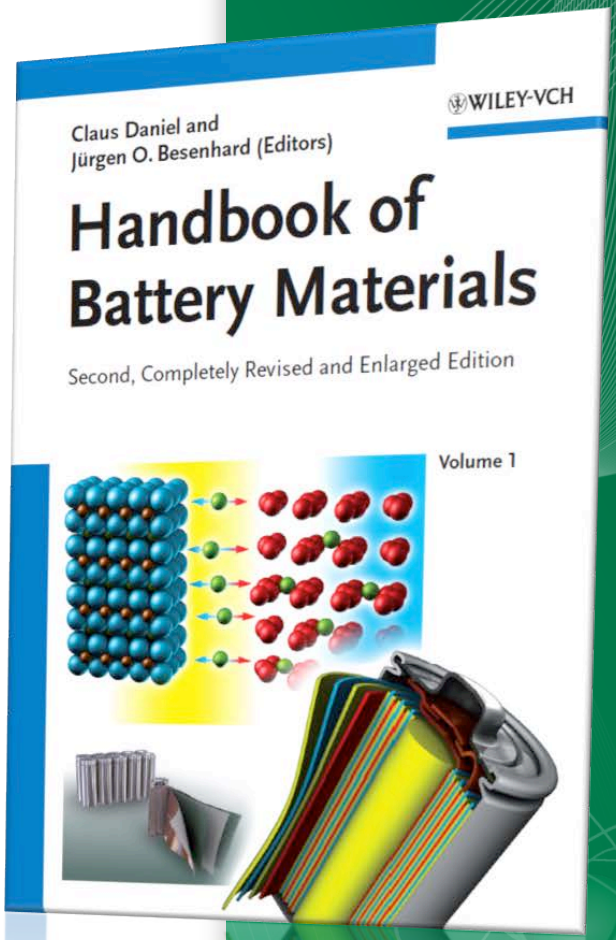
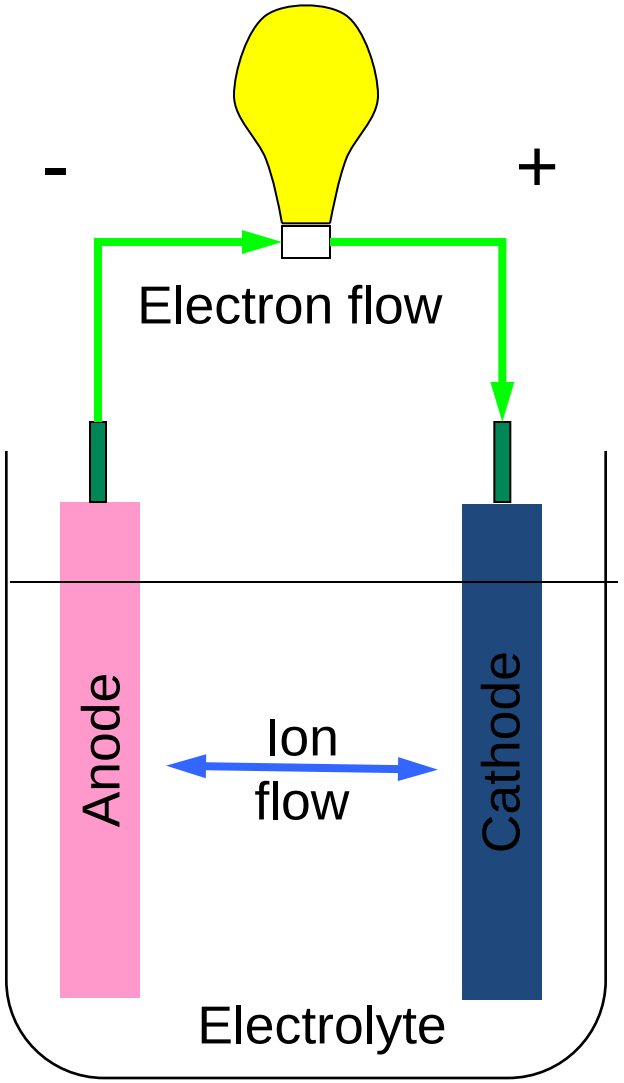
How to power your smartphone for a week!



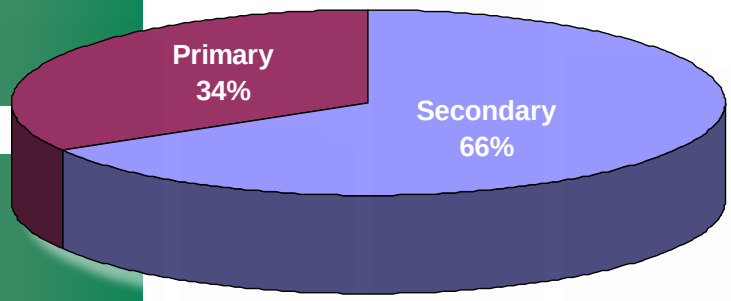
What is a battery?

- A device that stores chemical energy in its active materials and converts it, on demand, into electrical energy by means of an *electrochemical reaction*
  - *Electrochemical reaction* is a chemical reaction involving the transfer of electrons
- Batteries are made up of one or more basic electrochemical units called *cells.*
  - *Cells* are usually connected in series to increase the voltage.



Types of batteries

- *Primary batteries* are used once and thrown away, like the alkaline batteries used in portable CD players
  - Electrochemical reactions are not reversible and active materials cannot be restored to their original state.



- *Secondary (or rechargeable) batteries* can be used many times, like the battery in cell phones and laptop computers
  - The electrochemical reactions are reversible, and the active materials can be restored to their original chemical composition.

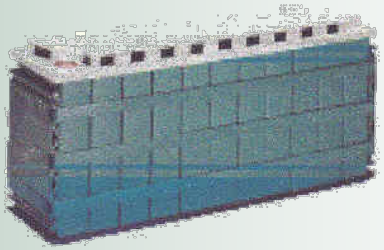
Widely used rechargeable batteries

Market share

- Lead acid (30-40 Wh/kg, 70-92% eff., 2V)
  - Over 100 years old, and still the most widely used rechargeable battery in the world.

51%

- Nickel metal hydride (30-80 Wh/kg, 66% eff., 1.2 V)
  - A high power battery chemistry similar to nickel cadmium, introduced in the 1980s. It is environmentally friendly, contains no toxic cadmium, and is replacing NiCd in many applications.



8%

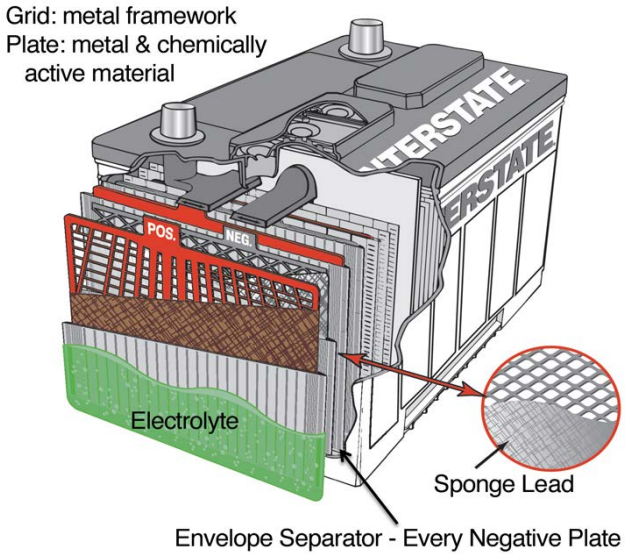
- Lithium ion (160 Wh/kg, 99.9% eff., 3.6-3.7V)
  - The newest and fastest growing rechargeable battery technology.
  - Theoretical capacity: 150-275mAh/g

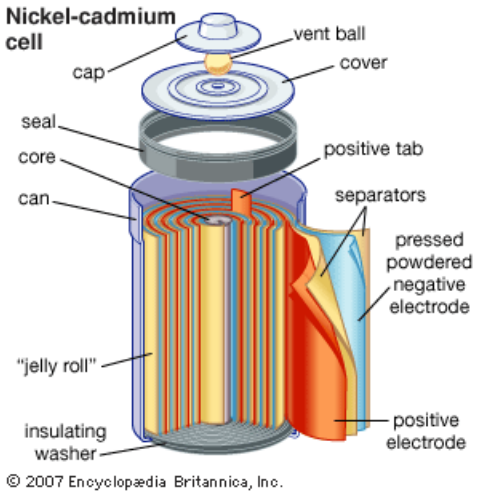
31%

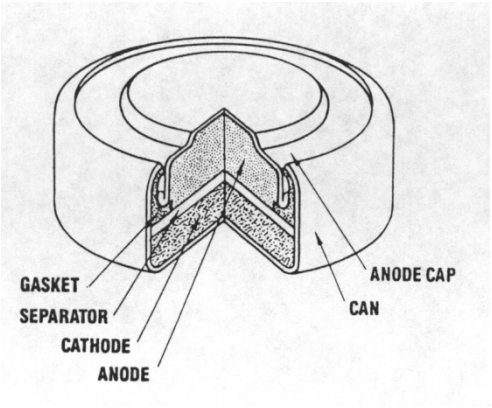
Main concerns: large volumes, liquid technology, leakage, and toxicity

Sentech, Wikipedia

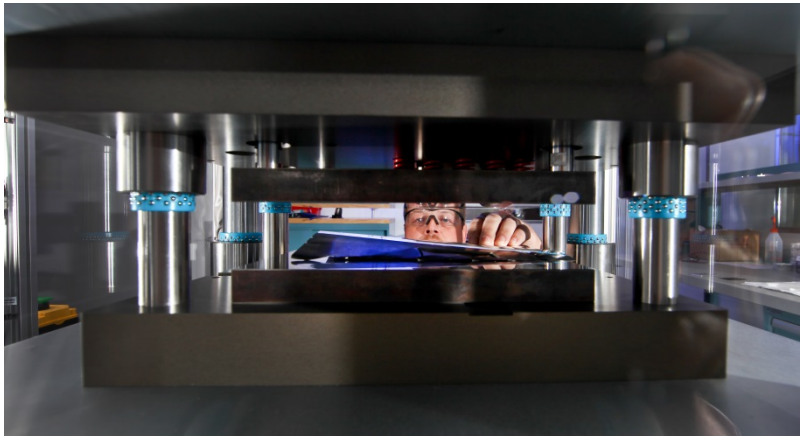
Real batteries



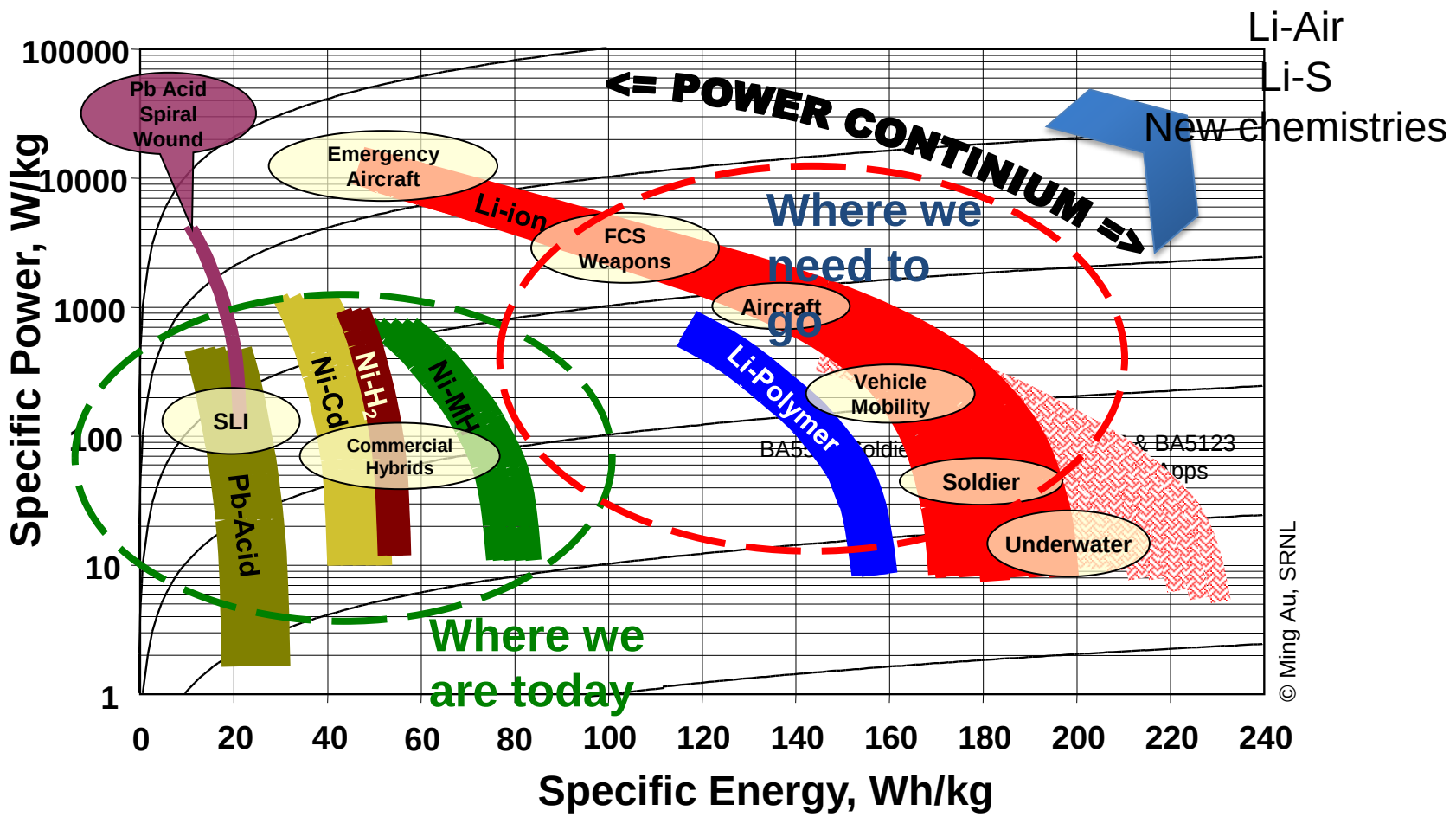




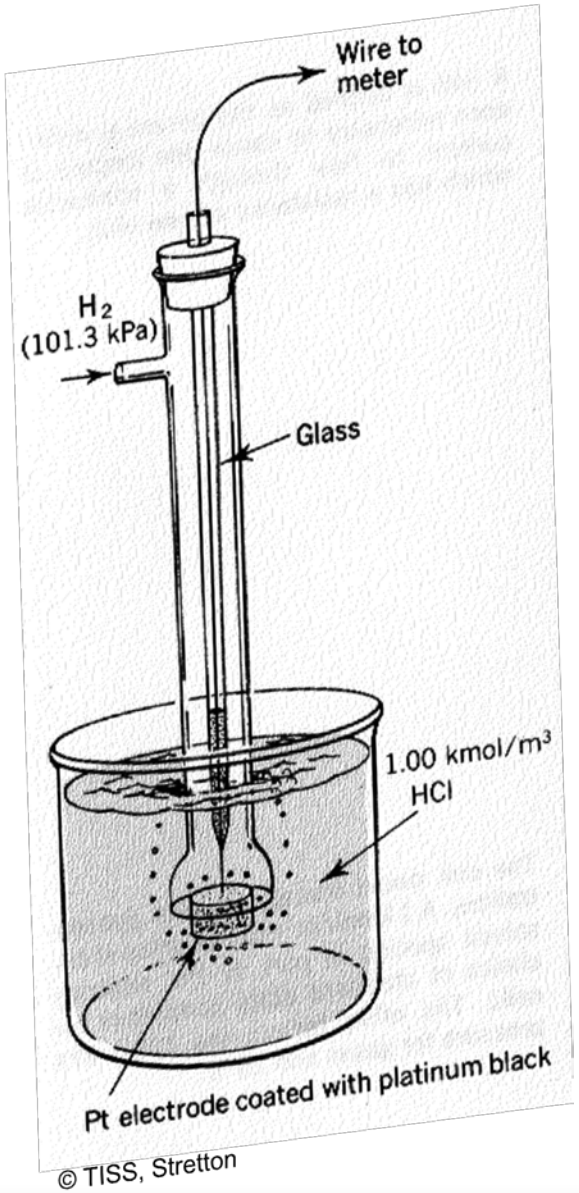
Research batteries at ORNL



Actual technology and materials



Cell potential



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Electrode	Oxidation reaction	Standard potential (volts)	Nature
$Li \mid Li^+$	$Li \rightarrow Li^+ + e^-$	+3.040	reducing agents
$K \mid K^+$	$K \rightarrow K^+ + e^-$	+2.924	
$Ca \mid Ca^{2+}$	$Ca \rightarrow Ca^{2+} + 2e^-$	+2.870	
$Na \mid Na^+$	$Na \rightarrow Na^+ + e^-$	+2.710	
$Al \mid Al^{3+}$	$Al \rightarrow Al^{3+} + 3e^-$	+1.660	
$Zn \mid Zn^{2+}$	$Zn \rightarrow Zn^{2+} + 2e^-$	+0.762	
$Fe \mid Fe^{2+}$	$Fe \rightarrow Fe^{2+} + 2e^-$	+0.441	
$Cd \mid Cd^{2+}$	$Cd \rightarrow Cd^{2+} + 2e^-$	+0.403	
$Ni \mid Ni^{2+}$	$Ni \rightarrow Ni^{2+} + 2e^-$	+0.236	
$Sn \mid Sn^{2+}$	$Sn \rightarrow Sn^{2+} + 2e^-$	+0.140	
$Pb \mid Pb^{2+}$	$Pb \rightarrow Pb^{2+} + 2e^-$	+0.126	
$Pt \mid H_2 H^+$	$H_2 \rightarrow 2H^+ + 2e^-$	0.000	
$Cu \mid Cu^{2+}$	$Cu \rightarrow Cu^{2+} + 2e^-$	-0.337	oxidising agents
$Ag \mid Ag^+$	$Ag(s) \rightarrow Ag + e^-$	-0.799	
$Hg \mid Hg^+$	$Hg(l) \rightarrow Hg^{2+} + 2e^-$	-0.920	
$Cl_2 \mid Cl^-$	$2Cl^- \rightarrow Cl_2(g) + e^-$	-1.359	

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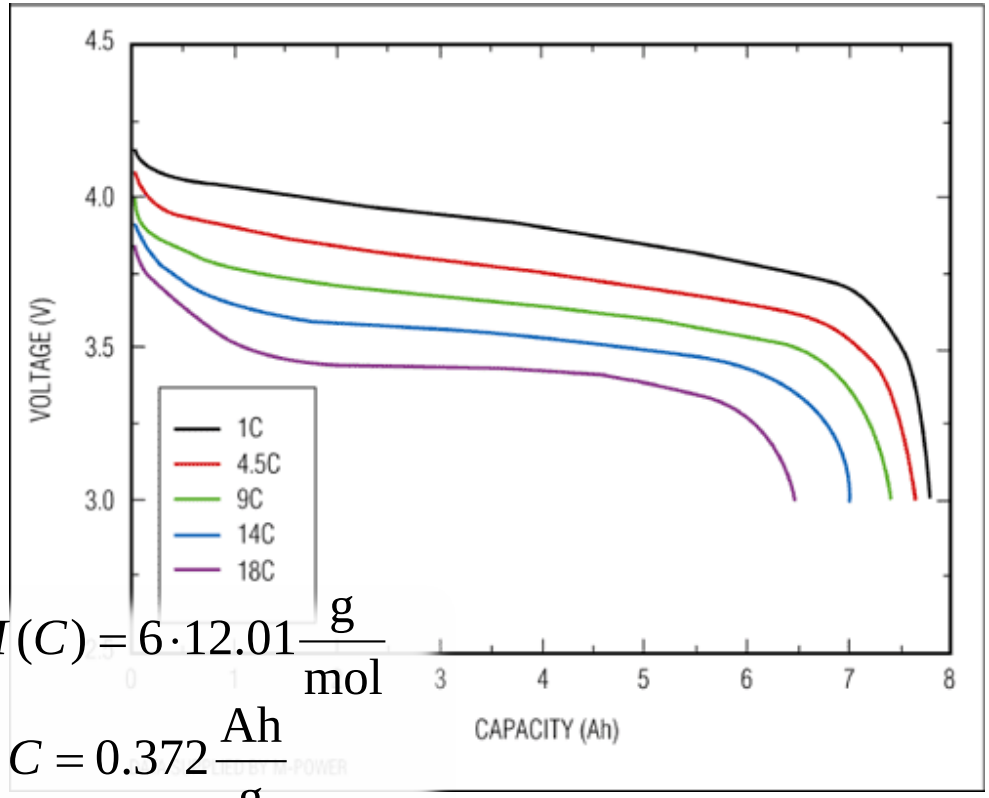
Cell capacity

$$F = \frac{It}{n} = \frac{C}{n} = N_A e$$

$$C = \frac{zF}{M}$$



$$LiC_6 \leftrightarrow Li^+ + 1e^- + C_6$$

$$z = 1;\ M(C) = 6 \cdot 12.01 \frac{\text{g}}{\text{mol}}$$

$$\Rightarrow C = 0.372 \frac{\text{Ah}}{\text{g}}$$

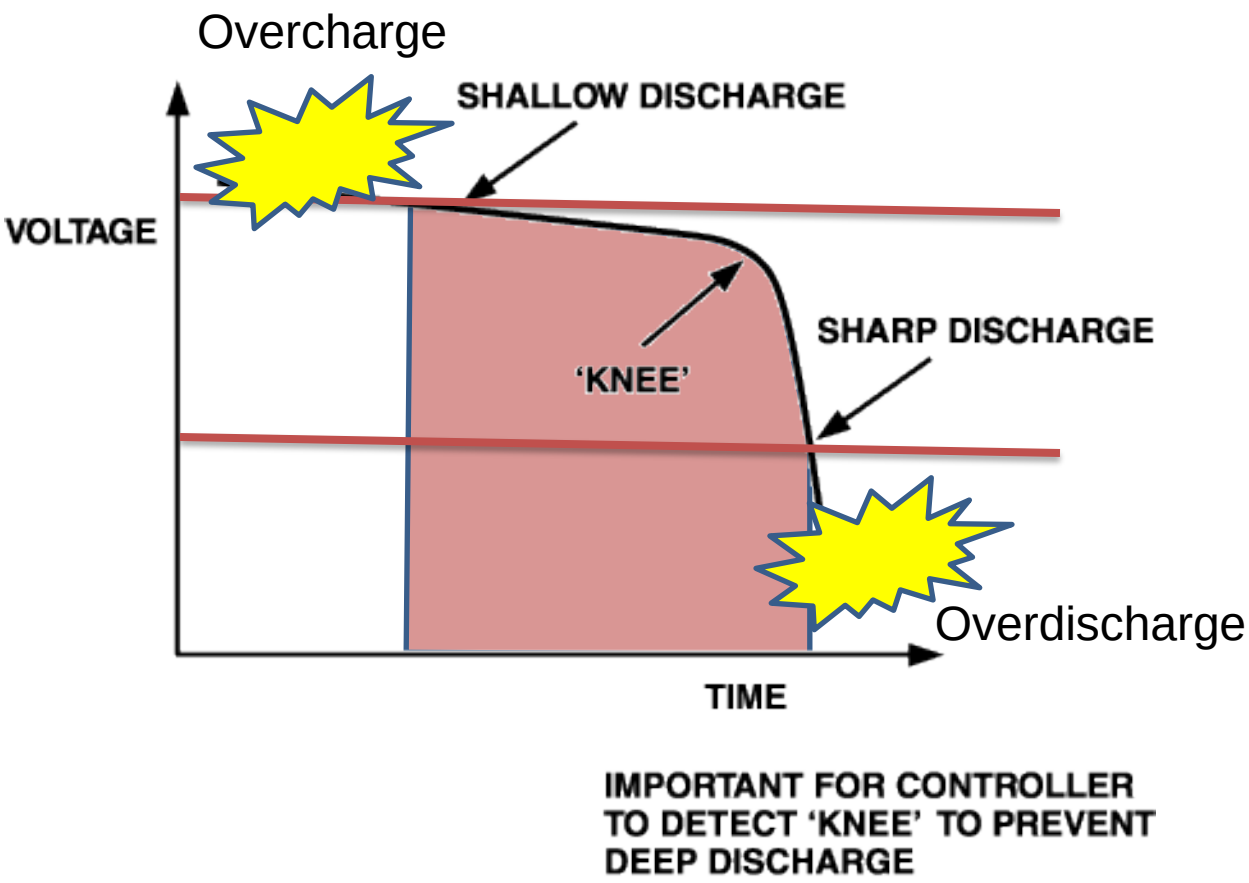
$$Li_{22}Si_5 \leftrightarrow 22Li^+ + 22e^- + Si_5$$

$$z = 22;\ M(Si) = 5 \cdot 28.09 \frac{\text{g}}{\text{mol}}$$

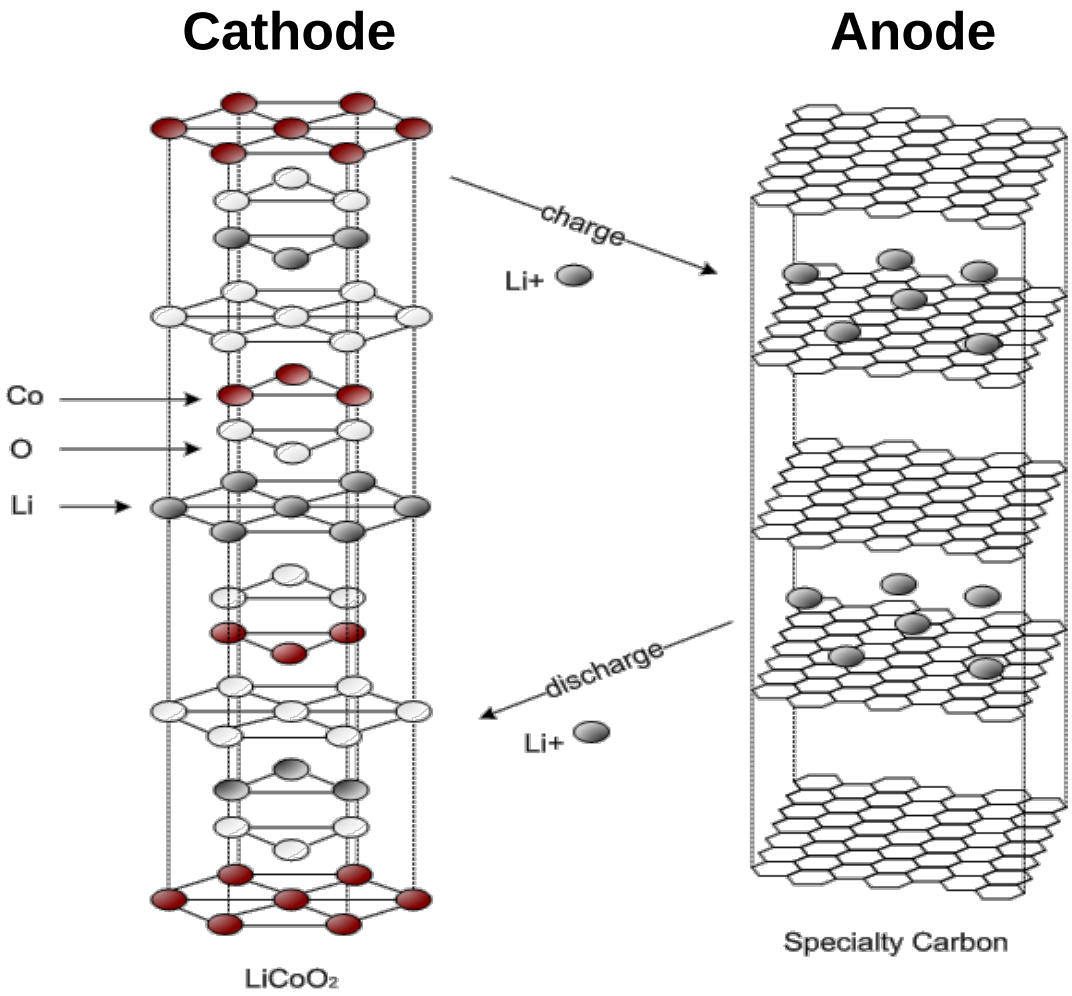
$$\Rightarrow C = 4.200 \frac{\text{Ah}}{\text{g}}$$

Cell energy

- Capacity x voltage
- Cut off voltage is controlling available energy but also limiting access for safe operation



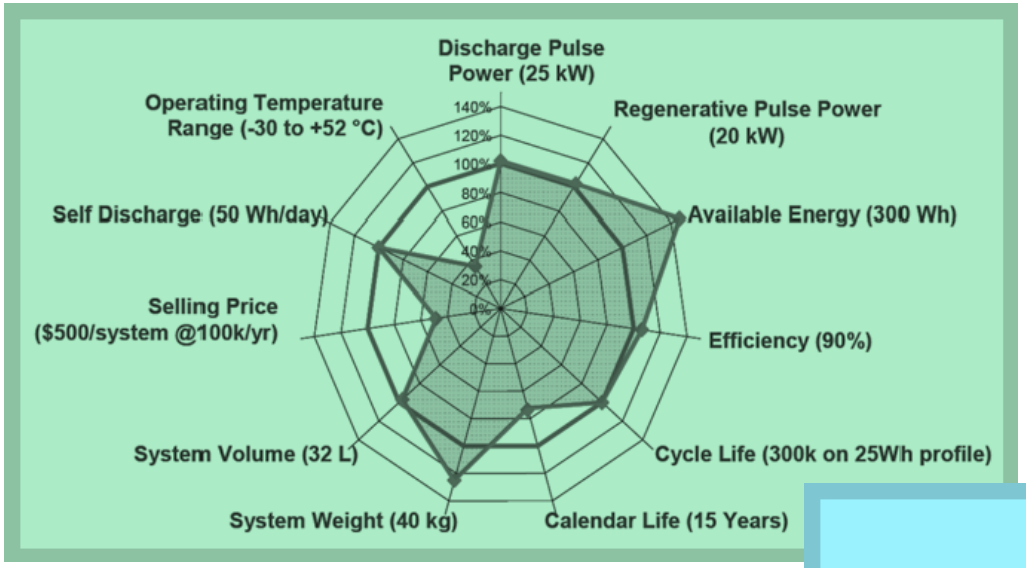
Lithium ion battery principle



Discharge reaction:

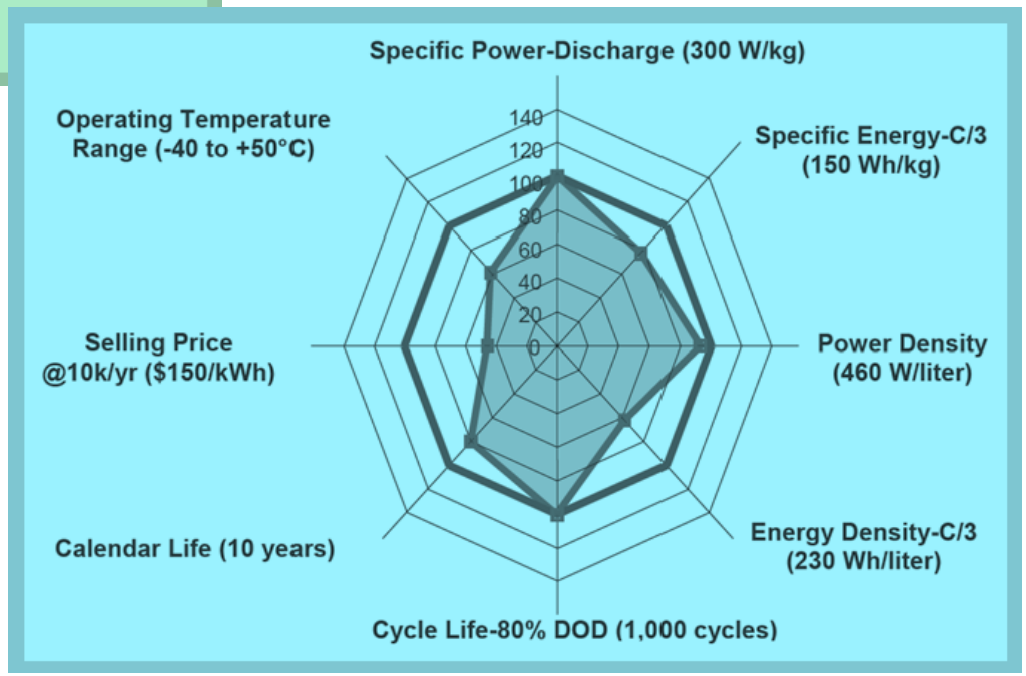
$$Li^+ + e^- + MeO_2 \rightarrow LiMeO_2 \qquad LiC_6 \rightarrow Li^+ + e^- + C_6$$

Development targets and accomplishments



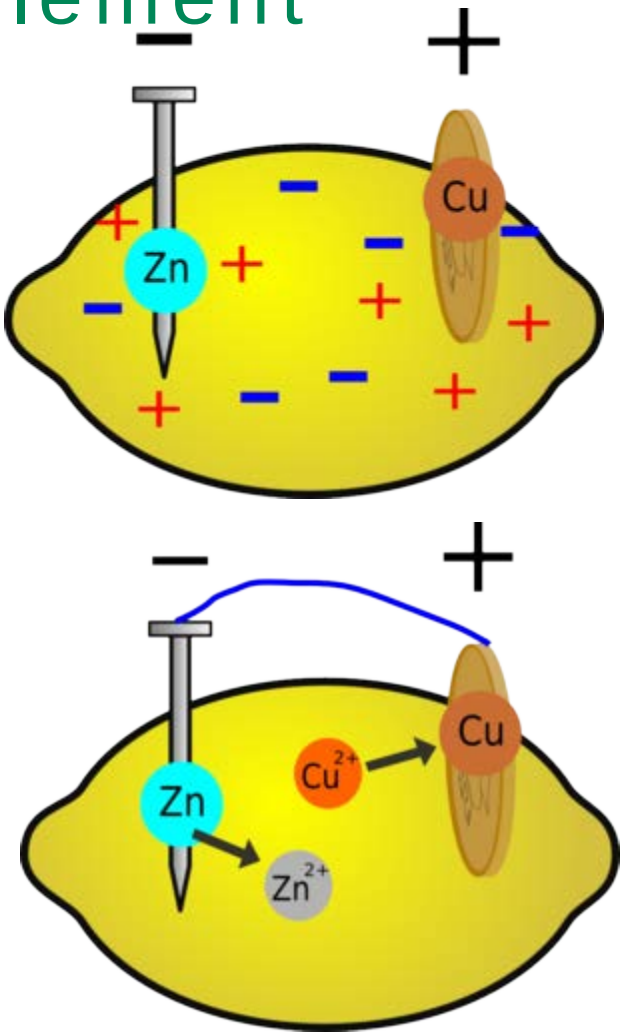
Hybrid electric vehicles (HEV)

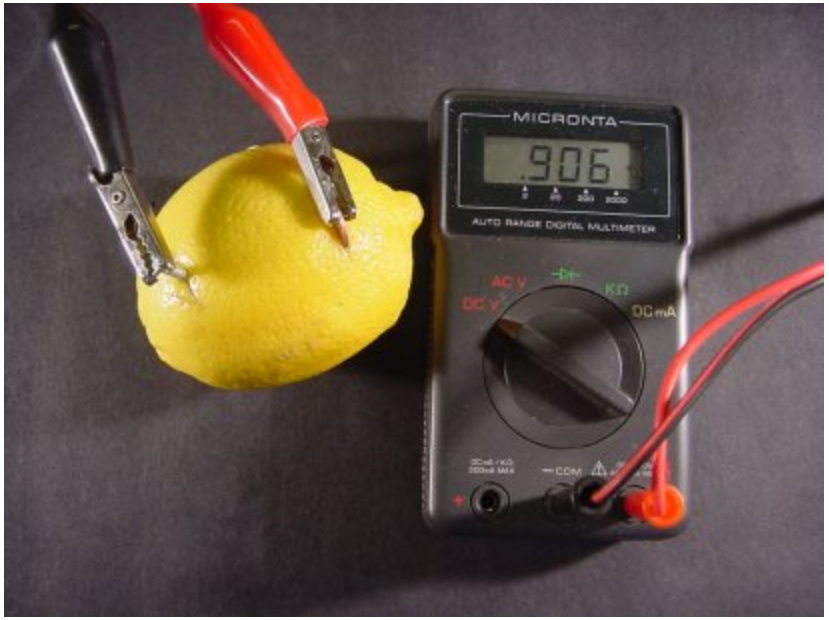
Plug-in Hybrid electric vehicles (PHEV)



- D. Howell, Energy Storage Research and Development, Annual Progress Report 2006
- FreedomCAR and Fuel Partnership and United States Advanced Battery Consortium, Electrochemical Energy Storage Technical Team Technology Development Roadmap (Southfield, MI: USCAR, 2006).

Fruit battery – Natural galvanic element





Have fun and stay safe!