Lunch Speaker: Ralph J. Brodd

The Future of Batteries

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Hot News Flash - Water on Mars

Rechargeable Market Snapshot

- Lead acid dominates with total sales of >$30 billion
- Li-Ion sales are $6+ billion in portable electronics with double digit growth
- Japan/Korea/China control Li-Ion technology and production
- Global economics apply for all chemistries
- Ni-MH continues in HEV, AA-size for cameras, etc.
- Electrochemical capacitors "emerging" for pulse power
- Fuel cells are still in the wings!!
  - **An energy source, need battery for HEV regen. and accel**
  - **Expensive, short life, repeat of the '70s with PEM? .**

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Battery Industry Time Lines

- Lead Acid – Plante 1860
- Carbon Zinc – Leclanche 1860
- Ni-Fe, Ni-Cd – Junger, Edison 1900
- Ag-Zn, Rechar. Andre; Zn-Hg Rubin, Zn-Ag 1950
- Alkaline Zn-MnO_2, Fuel Cells 1960
- Lithium Primary 1975 – 1980
- Ni-MH 1980
- Lithium Ion 1991 $Li_xC/Li_{1-x}CoO_2$
  - **Various Flavors: Alloy anodes (4+), Phosphate (3+), Cathodes (6+), Fuel cells**

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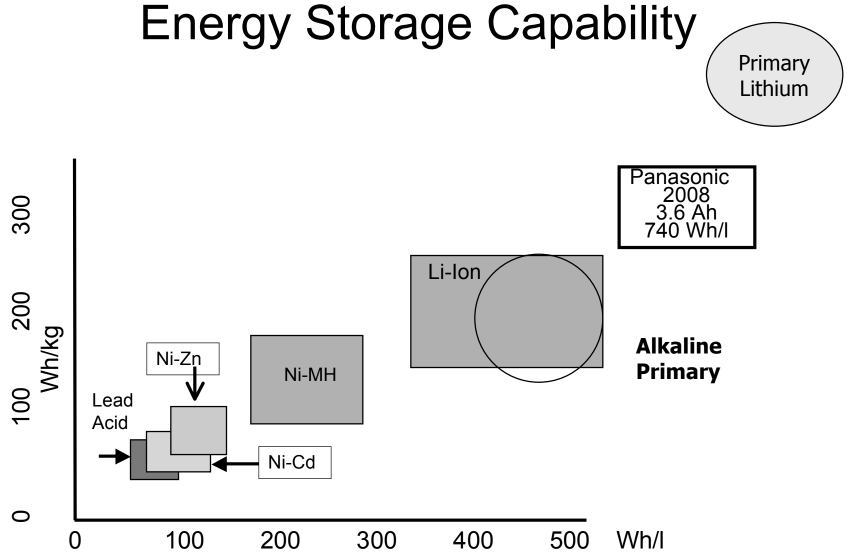
Energy Storage Capability



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Lead Acid - Alive and Kicking

- Strong manufacturing base and market presence
  - **Global Infrastructure and Production**
  - **Good example of why replacement is difficult**
- Controls SLI, Motive Power and UPS Markets
- Reinventing itself with transition to VRLA for sealed, longer, more reliable service
  - **Market is receptive to improved performance, conversion to VRLA at somewhat higher pricing**
- Low cost vs. Li- Ion, but lead price increases are leveling the market
- Recycling (98% in U.S.) makes it a “green” technology

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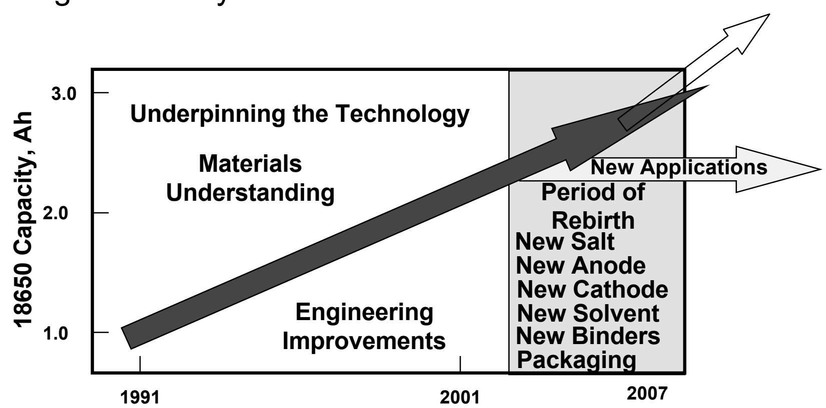
Li-Ion Review !!! The Future ???

Today, high rate capability and cost are the major drivers along with safety



What Does "Lithium Ion" Mean?

- **Li-Ion does not define a "unique" chemistry**
  - **$LiCoO_2$, $LiMn_2O_4$, NCA, $LiNi_{1/3}Mn_{1/3}C_{1/3}O_2$, $LiNi_{1/2}Mn_{1/2}O_2$, $LiFePO_4$**
  - **Graphite, hard carbon, mesophase pitch, titanate, alloys, silicon nanotubes**
  - **Original $LiCoO_2$–hard carbon–$LiPF_6$–aliphatic carbonates**
  - **Cell capacity growth (18650, 1.0 Ah → 2.6+ Ah)**
- **Portable market continues double digit growth**
- **Safety issues continue to be a problem**
  - **Stored energy content - 4 volts, 2.6Ah = 600ºC or more**
  - **Safety incidents rated at ~1 – 10 in 10 million**
  - **Manufacturing defects, cell design, system defect or abuse?**
  - **Problems MUST be resolved or government safety action is threatened (U.S. concern for fire on aircraft)**

Markets for Li-Ion

- Portable electronics drives improved performance
- Satellites, Aeronautics, Military
- Stationary energy storage
- Power tools
- Automotive starting, lighting, ignition (SLI)?
  - **Li-Ion more expensive, Life of the car opportunity**
- HEV, PHEV, EV – will dwarf other markets when implemented
- Low cost structure possible for Li-Ion!!
  - **Natural graphite (treated), PC electrolyte, Mn cathode**
  - **Lower energy but safer**

HEV/PHEV Ballpark Structure

- Assume facility cost about \$4 per 10 Wh 18650 cell, or \$0.40/Wh/cell (cylindrical cells only)
- Takeshita – in 2007 3 x 10^9 cells, then present Investment of \$1.2 x 10^{10} in production facilities.
- Selling price depends on chemistry and capacity but assume \$1/Wh for a high end cell for HEV and PHEV.
- HEV 1.5 x 10^3 Wh/car x 300,000 cars = 4.5 x 10^8 Wh
  - **Facility cost of \$180 million, Sales of \$450 million/year**
- PHEV 10 kWh/car x 3 x 10^5 cars = 3 x 10^9 Wh
  - **Facility cost of \$1.2 billion and sales of \$3 billion/year**
- These costs are for cells not packs

Recent activity worldwide (5/08)

- .**Automotive Energy Supply Corp**. (JV, Nissan and NEC) will spend $115 million over the next three years to build its first Li-Ion battery plant. NEC Tokin allocated $105 million to produce lithium-manganese electrodes.
- **Toyota-Panasonic** will spend $675.5 million to: 1) expand present Ni-MH production plant, 2) build a new Ni-MH facility and 3) build a new Li-Ion facility.
- **Sanyo** plans to spend $769 million over the next seven years on Li-Ion plant facilities based on the 1/3 cathode, with proprietary additives, etc.
- **European** Li-Ion development program with €360 over 5 years

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Motive Power (HEV-EV-PHEV)

- Near term, Ni-MH in HEV, no reason to change
- About 325,000 HEVs sold in 2007
- PHEV needs higher capacity cell, production capability lacking, but battery performance OK
- PHEV market penetration will be slow – 3% in 2013 (JD Powers), others more optimistic at 10-15% in 2013
- Surveys of potential buyers express concerns on HEV and PHEV; Owners really like the HEVs
- Ultracapacitors?
- Lead acid for SLI, HEV??

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Can Li-Ion meet the Performance

- Cell performance is design related,
  - **Active materials, electrolyte additives,**
  - **internal cell design, current collection scheme, coating quality**
  - **electronic control concept/design**
- Safety issues dependent on quality control of manufacture and cell assembly
- Saft data show long life for NCA cathode
- Sanyo show long life for 1/3 cathode

Yes It Can

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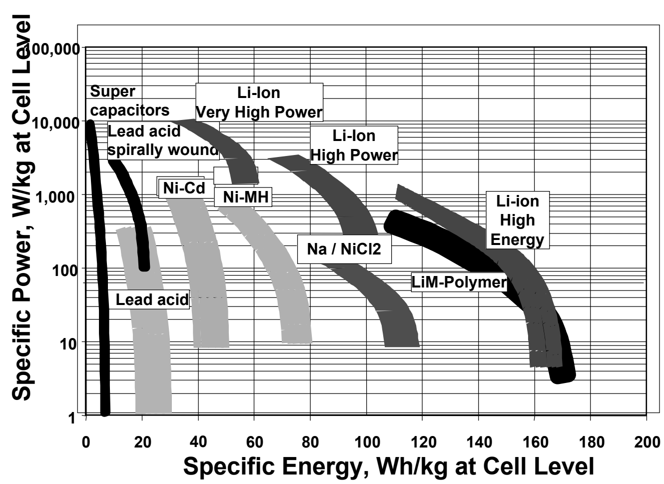
Can Li-Ion power HEVs and EVs?



Saft, 2006

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Li-Ion - Very Active R&D Area

- **Higher energy cathode materials/coating technology reduce thermal runaway**
  - **NCA, $LiMn_{1/3}Ni_{1/3}Co_{1/3}O_2$ and $LiMn_{1/2}Ni_{1/2}O_2$ – high capacity**
  - **$LiFePO_4$ - Low cost, high rate with exceptional safety**
- **Higher capacity anode compositions**
  - **Alloy anodes with higher capacity, graphites for low cost**
  - **Titanate materials very high rate, BUT, 1.6 volts loss vs. graphite gives lower energy system**
- **New components from DOE programs**
  - **Have developed new active anode and cathode materials with superior performance**
  - **Higher performance electrolytes and additives**
  - **New separator materials**

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Summary

- Li-Ion poised to power the emerging EV, HEV and PHEV applications
- In portable electronics, Li-Ion won over Ni-MH because it was lighter and smaller, even though it cost more
- Li-Ion has demonstrated ability to meet the requirements for HEV, PHEV and EV applications
- Li-Ion cost structure, can be competitive given choice of electrode materials and cell design.
- Capital Investment to meet needs of US production not forthcoming
- Technology developed in the US being implemented overseas

Comment: “It is manufacturing that generates wealth”

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Thank You

The End

(or just the beginning
of a new era?)