The Development of Lithium Ion Batteries for Energy Storage Applications

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Overview

- Lithium ion basics
- Electrochemistry and materials
- Construction
- Safety
- Operating Characteristics
- Availability and cost
- Energy storage applications
- Conclusions

Lithium Ion Basics

- Introduced in 1990 as commercial concept
- First significant shipments in 1993
- Already constitutes over 50% of portable battery market price
- Work on larger format cells driven by electric vehicle development

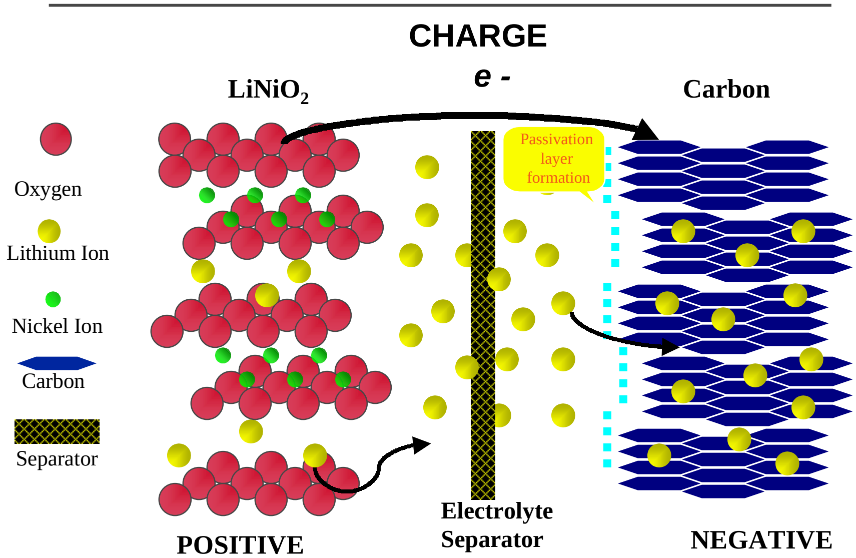
Lithium Ion Basics

- Li is light and the most highly reducing chemical element
  - Up to 4V nominal cells with high energy density
- Electrolyte is organic
  - Non aqueous system - no electrolysis during charge
  - Faradic charge efficiency is virtually 100%
  - Energy efficiency >95%
- Hermetically sealed
  - No gas production or electrolyte loss

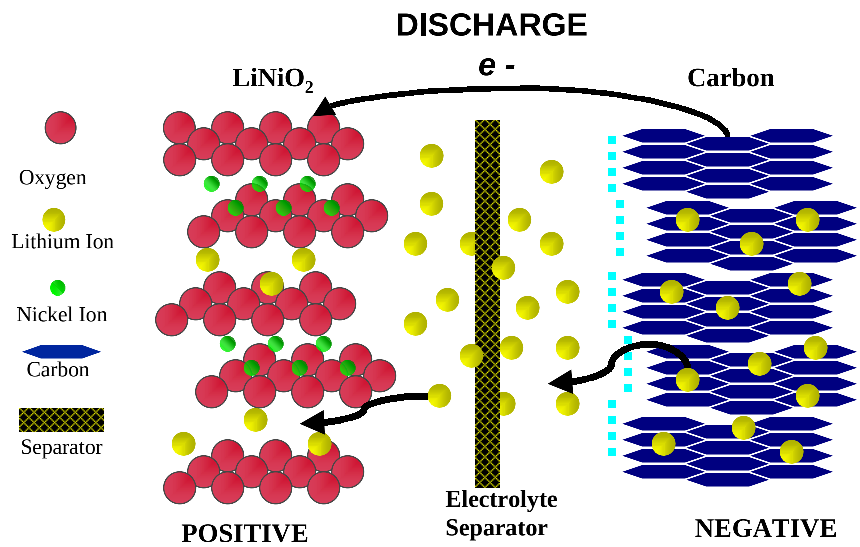
System Chemistry

- Positive: Metallic oxide containing lithium ions
  - Cobalt used in portable cells
  - Nickel based mixed oxide gives better cost and performance
- Negative: Lithium inserted in graphite
  - Avoids safety problems with metallic lithium
- Electrolyte: LiPF6 salt + organic solvent mixture (carbonates)
- All materials are recyclable

Lithium Ion Mechanism



Lithium Ion Mechanism



Construction

- Active materials coated onto metallic foils
- Prismatic designs with flattened coils possible
- Larger cells benefit from additional support
- Cylindrical format favored

Safety

- Lithium ion batteries much safer than early rechargeable lithium types
- Unlike aqueous batteries, do not emit gas
- Materials used in construction are flammable
  - Carbon negative
  - Organic electrolyte
- Temperature must be maintained below 150°C
  - Electronic controls necessary to prevent overcharging
  - Also prevent damage to battery through overdischarging

Smart Batteries

- Electronic controls for safety and to prevent battery damage
- Monitoring of cell voltage and charge current
- Built-in monitoring system
  - External communications interface
  - State of health monitoring

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Operating Characteristics

- Energy density
- Discharge characteristics
  - High power capability
- Cycling
- High and low temperature operation
- Float charging

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Energy Density

	Cell Voltage	Energy Density (Wh/liter)
Vented lead-acid	2.0V	25
Vented Ni-Cd	1.2V	27
VRLA	2.0V	54
Ni-MH	1.2V	135
Li dry polymer	2.5V	117
Li ion	3.6V	230

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Discharge Characteristics

	Ni-MH 100Ah	Li Ion HE-44Ah	Li Ion DM-30Ah	Li Ion HP-12Ah
		Energy	→	Power
Energy density (Wh/l)	133	308	220	150
Power density (W/l)	320	642	2100	2900
Ratio	2.4	2.1	9.5	19.3

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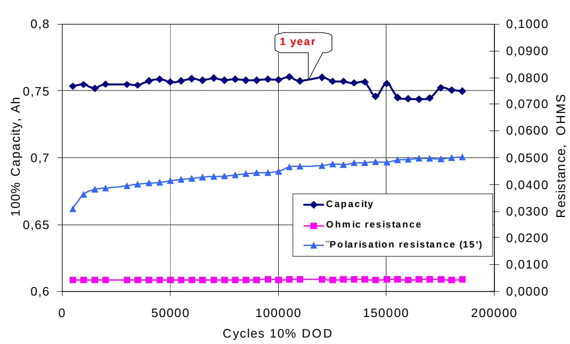
Cycling

- **Very good deep discharge capability**
  - **3000 cycles to 80% DoD**
- **100% charge efficiency and high charge rates critical for battery availability**
- **Shallow cycling capability is outstanding**



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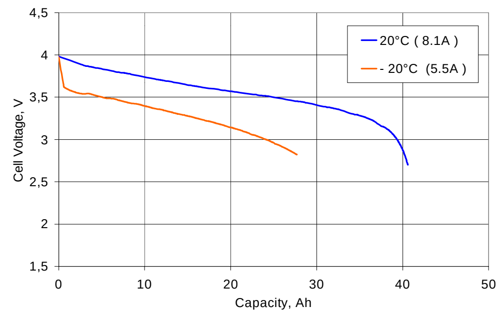
High & Low Temperature Operation

- High temperature tests show life has very little dependence on temperature
  - Climate control not required - energy savings
- Low temperature operation to about –20°C
  - Reformulation of electrolyte may yield improvements



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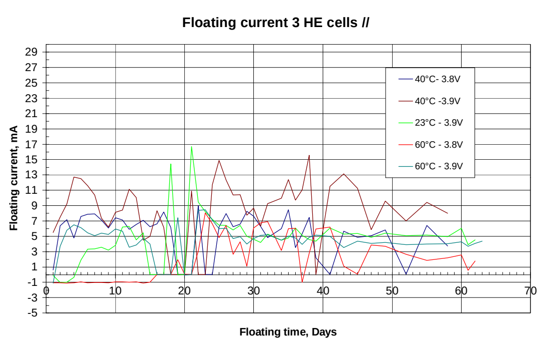
Float Charging

- Electronics will be designed for compatibility with existing constant potential ‘float’ chargers
- Life on float in outdoor cabinets expected to be at least 15 years
  - May not improve much for ideal conditions



Availability and Cost

- Production currently at pilot plant level
- Electronics to be designed and produced
- Industrial production expected in ~3 years
- Initial cost will be quite high
- Cost highly volume-dependent
  - No other industrial applications for many materials
- Eventual life cycle cost similar to lead-acid

Lithium Ion in Energy Storage Applications

- High energy density
  - Less real estate for multi-megawatt hour installations
- High performance
  - High power capability for peak shaving/power quality
- Excellent cycling capability
  - Long life for load leveling/frequency control
- Zero routine maintenance
  - Built-in monitoring and diagnostics
- High charge efficiency
  - Energy losses are minimized
- Excellent operation at temperature extremes
  - Energy costs for heating/cooling are minimized

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Conclusions

- Very good long term outlook for lithium ion batteries in energy storage
- Industrial production ~3 years away
  - Several years longer to realize volume-related cost savings
- Long term cost effectiveness vs. lead-acid

- **Lithium ion will become a major player in the energy storage market**