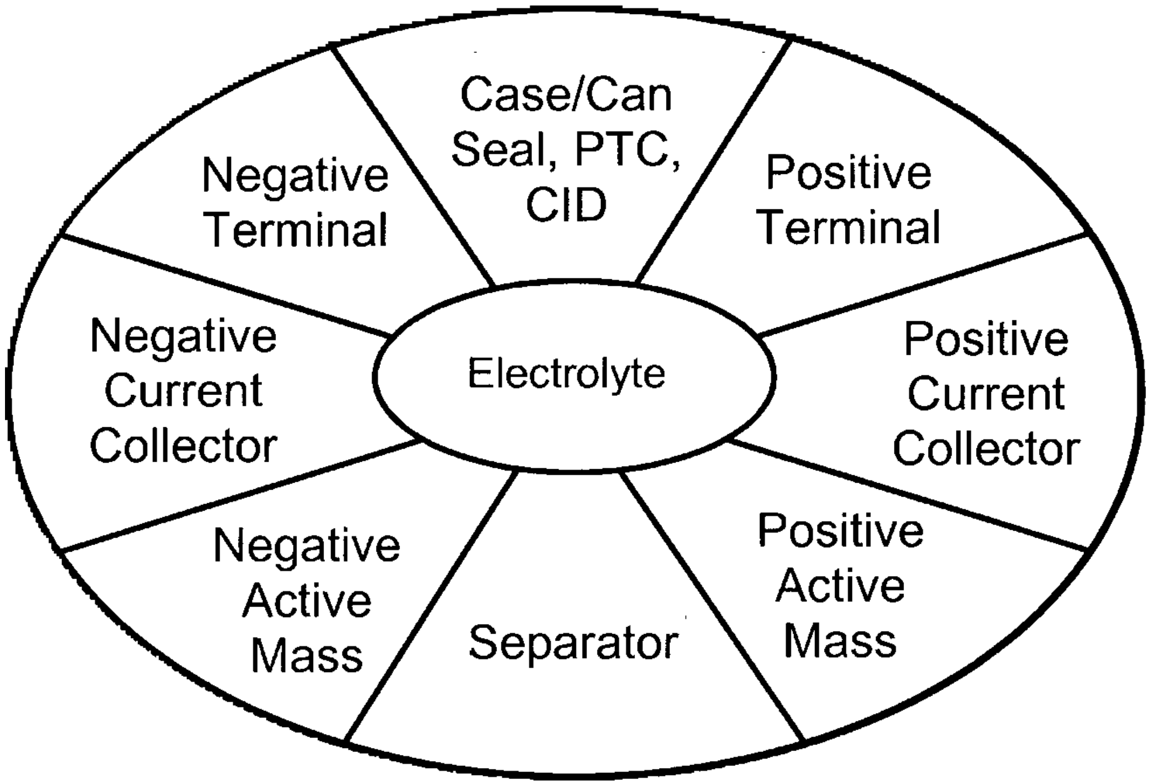
“Broddside”

Ralph Brodd
Broddarp of Nevada, Inc.

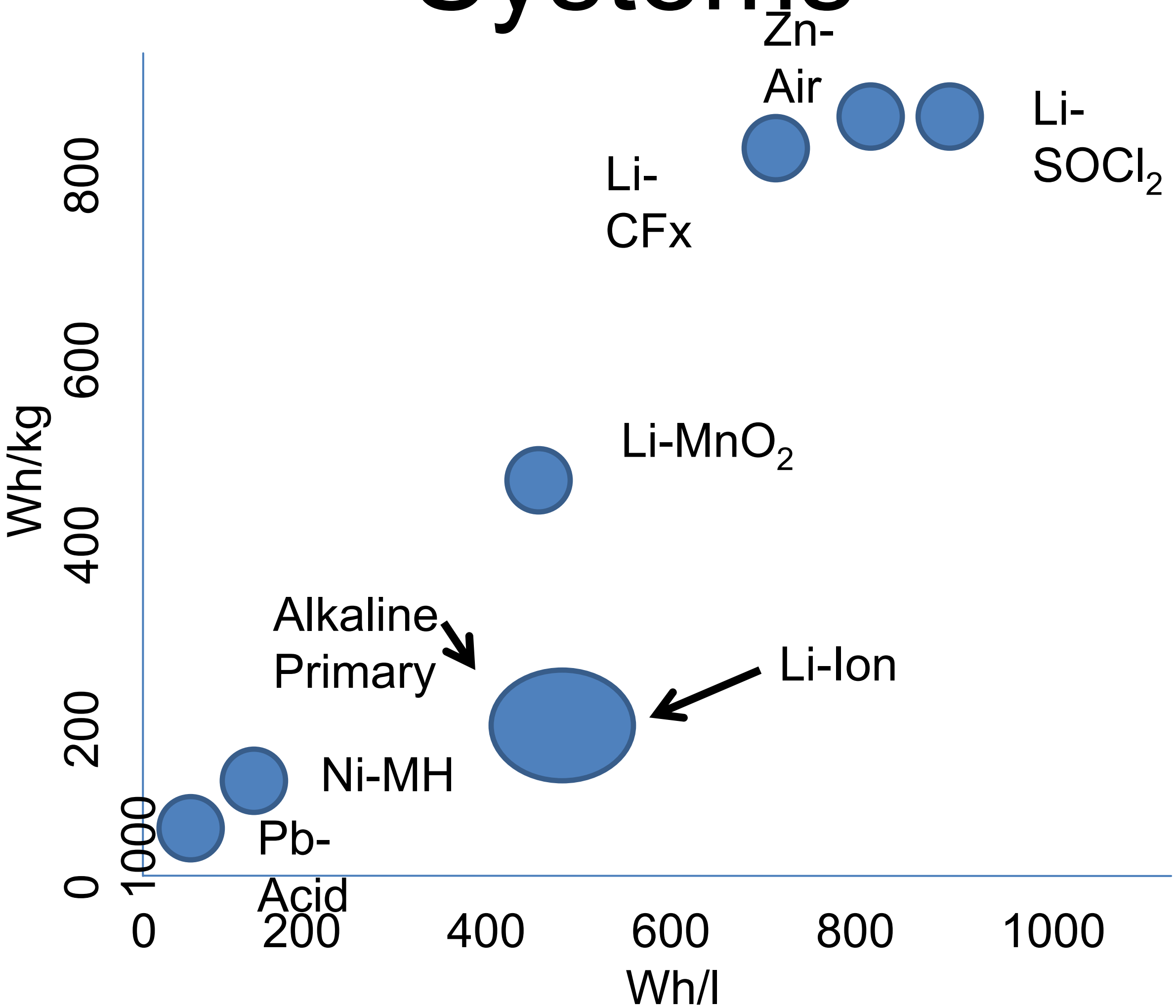
Anatomy of a Battery



Criteria for Rechargeable Batteries

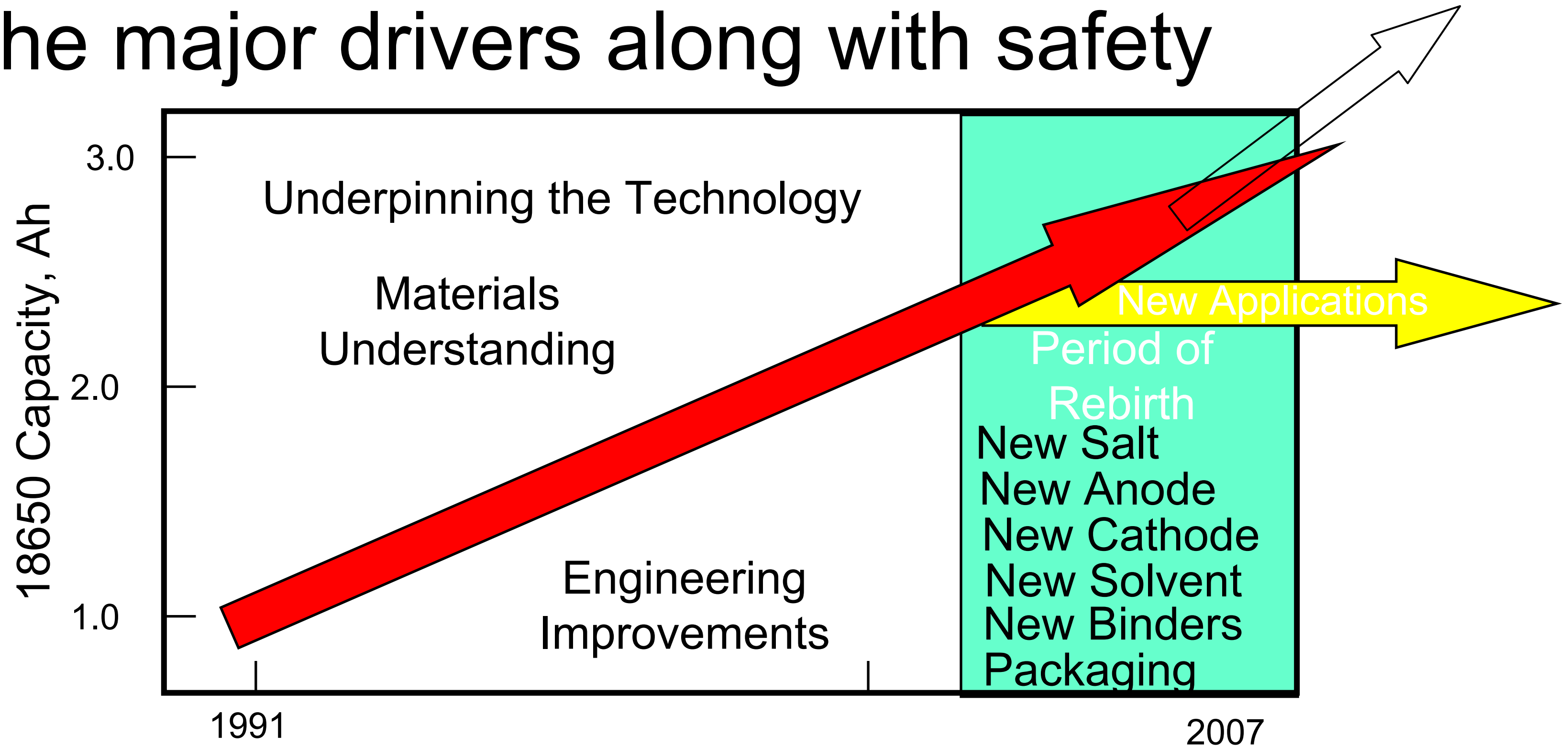
- Nine general characteristics of a rechargeable battery chemistry. These criteria limit the number of materials and reactions that qualify for use in battery technology.
- **1. Mechanical and Chemical Stability**
- **2. Ability to Recharge and Deliver Power:**
- **3. Cycle Life:**
- **4. Temperature Range of Operation: -40 to+85C**
- **5. Low Self-Discharge**
- **6. Shape of the Discharge Curve:**
- **7. Cost:**
- **8. Charge Time:**
- **9. Overcharge/Overdischarge Protection:**

Energy Storage of Present Systems



Li-Ion Progression

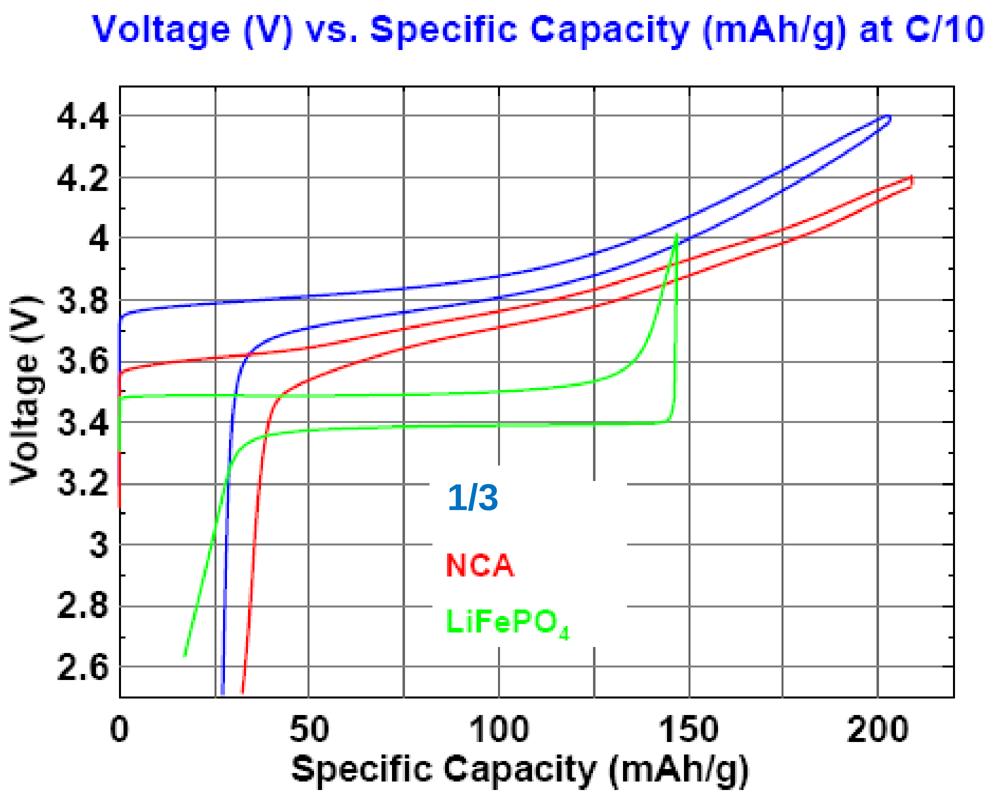
Today, high rate capability and low cost are the major drivers along with safety



Present Li-Ion Anodes and Cathodes

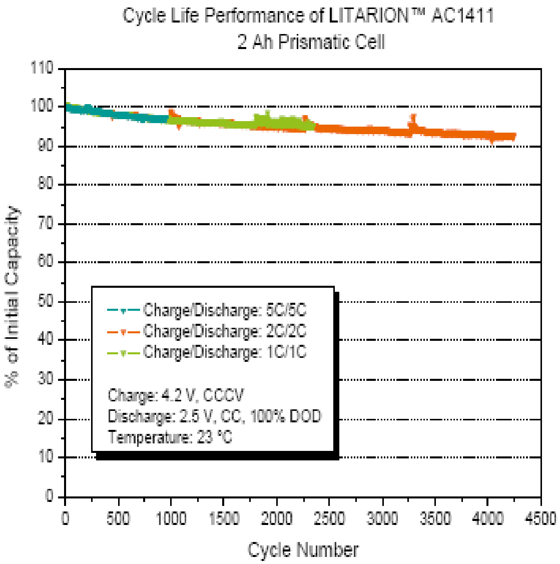
- Anodes:
  - Graphite
  - Hard carbons
  - Lithium Titanium Phosphate
- Cathodes
  - $LiCoO_2$,
  - $LiMn_2O_4$
  - $LiFePO_4$
  - $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$
  - $LiMn_{0.33}Ni_{0.33}Co_{0.33}O_2$
  - $Li_3V_2PO_4$
- Electrolytes
  - $LiPF_6$ + aliphatic carbonates + additives
  - LiBOB
  - Ionic liquids

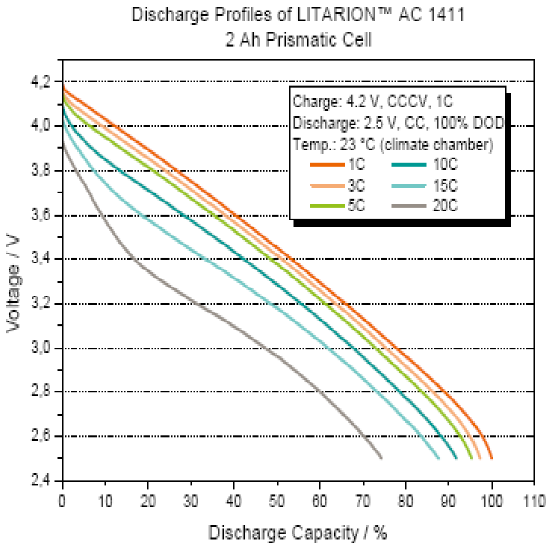
Charge-Discharge of Selected Cathodes



J. Jiang, 24th International Power Sources Conference, Ft. Lauderdale, March, 2007

Expected Cycle Life



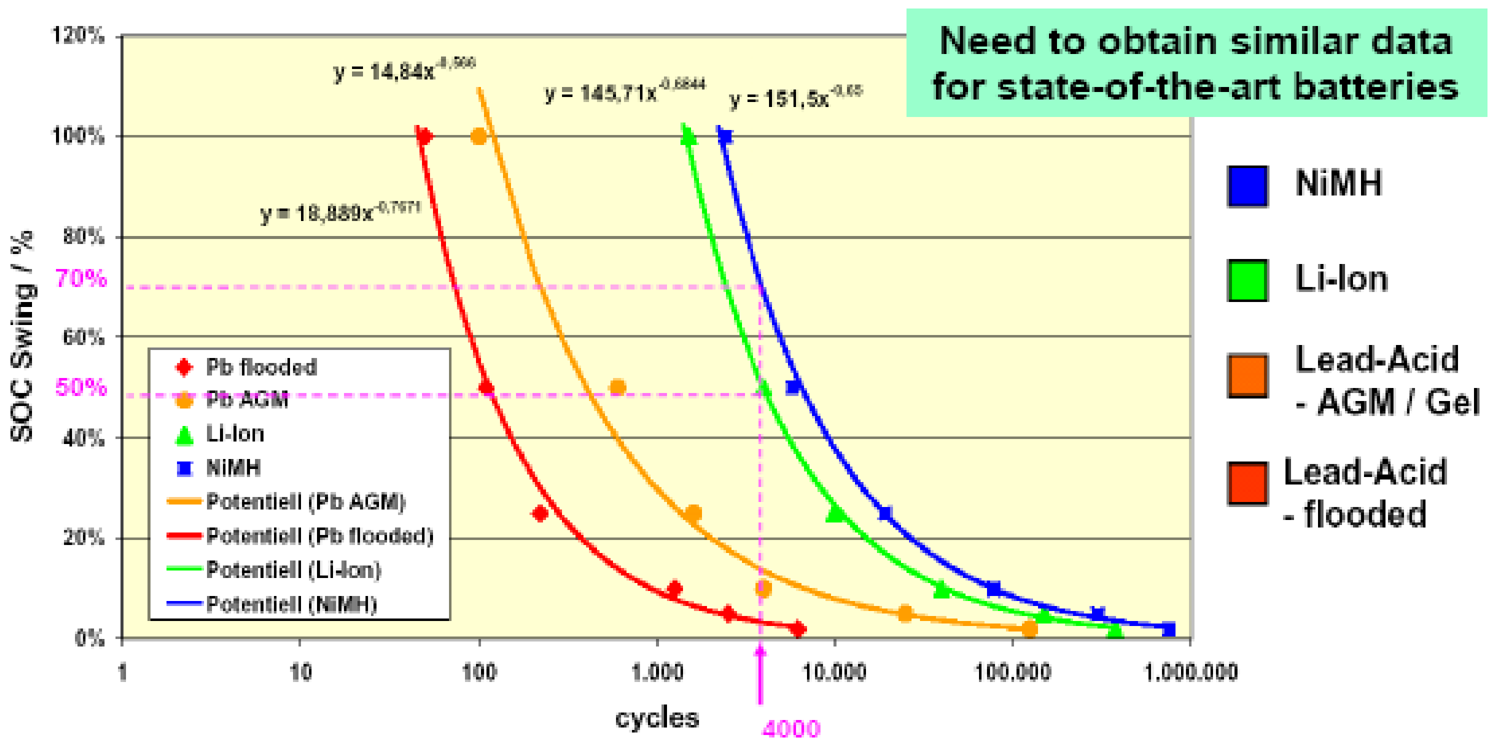


Forecast 12,000 100% DOD cycles for 1/3 compound

Veit, 2007 IBA

Battery Life - Depth of Discharge

- PHEV battery likely to deep-cycle each day driven: 15 yrs equates to 4000-5000 deep cycles
- Also need to consider combination of high and low frequency cycling



Source: Christian Rosenkranz (Johnson Controls) at EVS 20, Long Beach, CA, November 15-19, 2003

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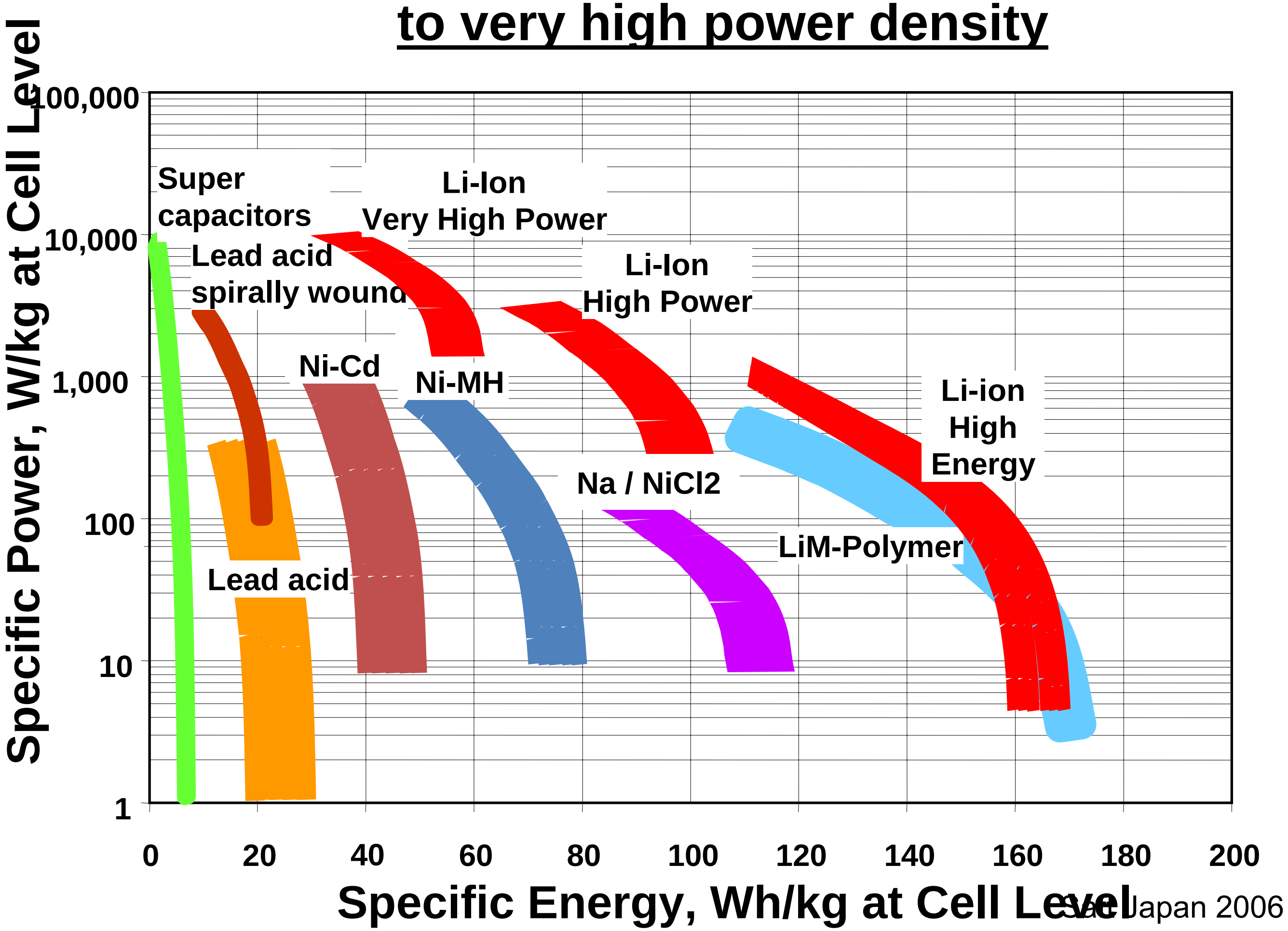
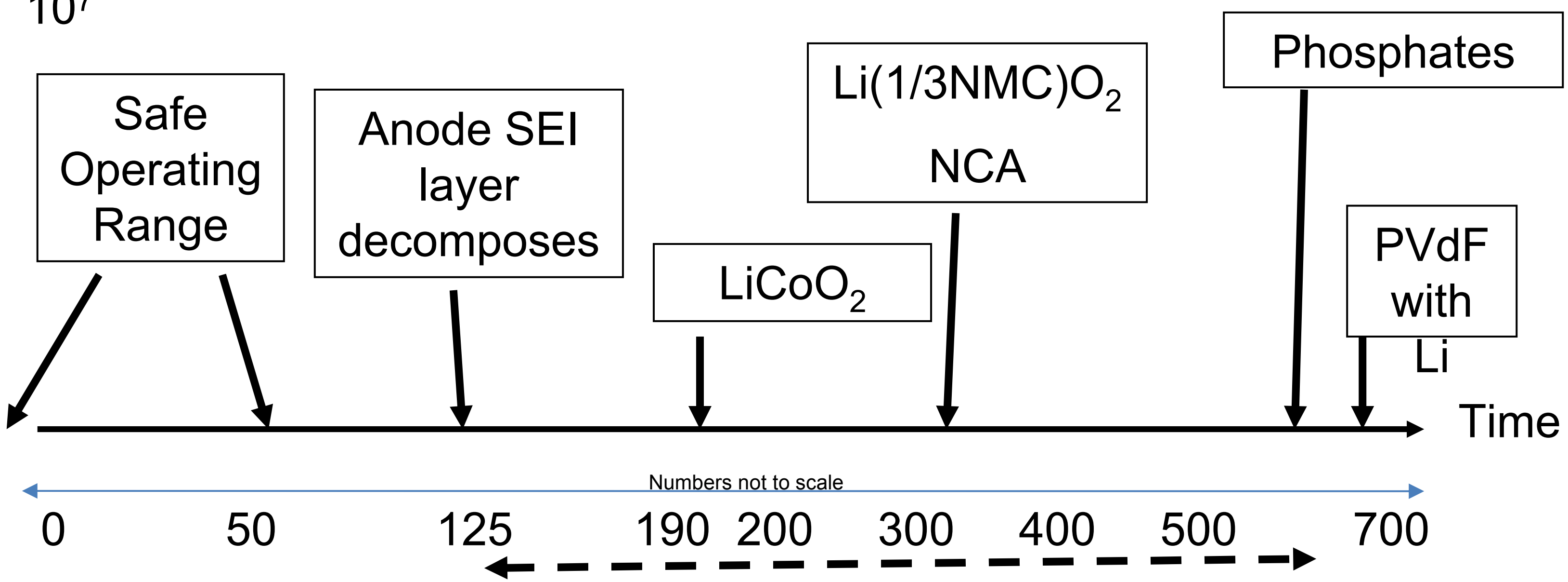
Why using Li ion in HEVs ?

Lithium-ion technology: From very high energy density to very high power density



Anatomy of an Incident

The 18650 Li-Ion cell has sufficient energy to self heat to over 600°C. Today, the incidents are mostly related to manufacturing defects: one ~ 10^7



Self heating Reactions

Autocatalytic

Cathode Dependent

Anode and Cathode with Electrolyte

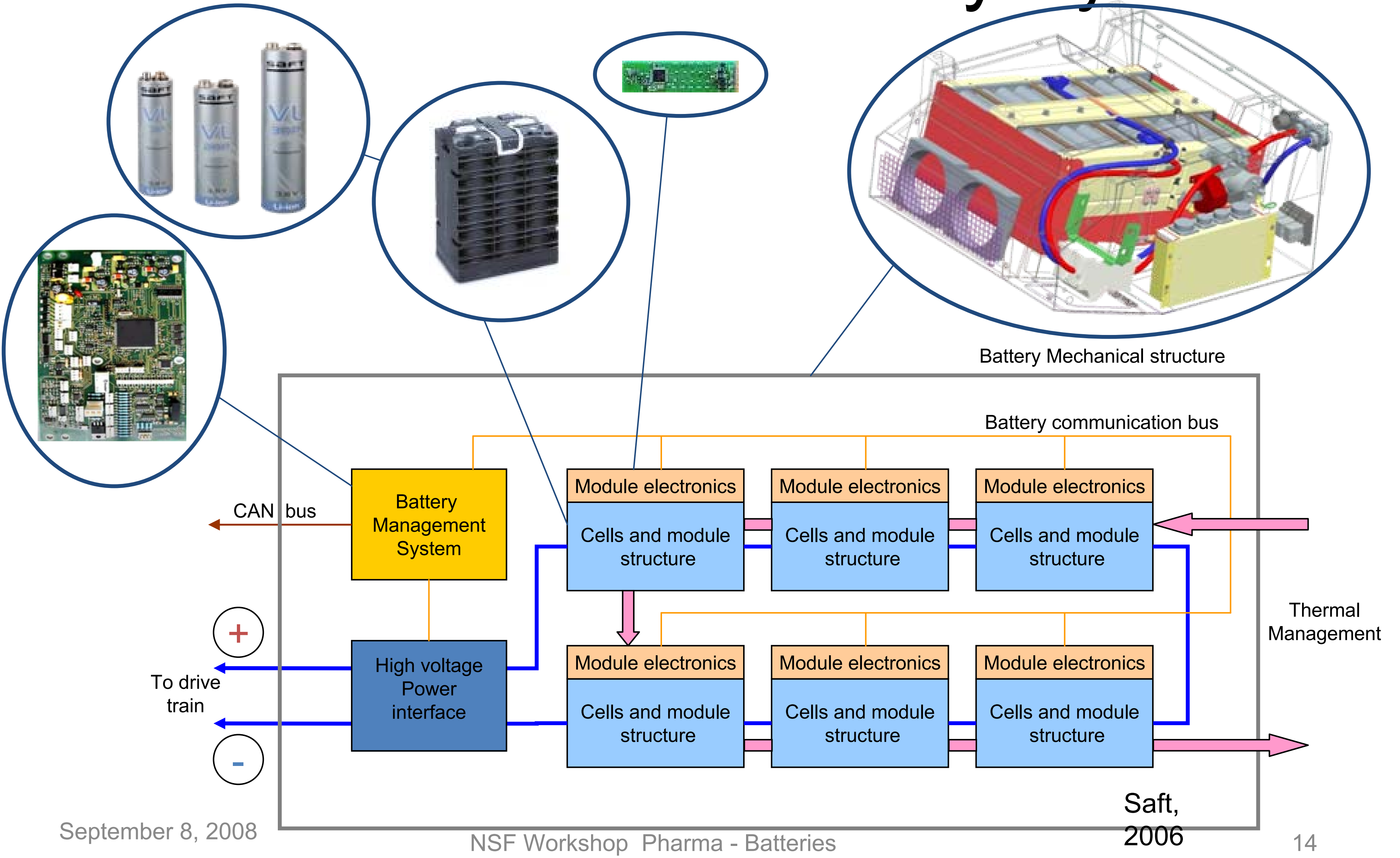
A Little History

- Prediction of reaction distribution in electrode structures, lead acid, carbon zinc (1960's and 1970's), Li-Ion (2000)
- Engineering models of electrode performance are reasonably accurate, based on fundamental data, i_o, ρ, etc.
- DOE workshop on Electrochemical Energy Sources, circa 1978 where Al Bard suggested *ab initio* calculation of H-Metal interaction for fuel cell catalysts
- Oh yes, Eyring Absolute Rate Theory. Quantum mechanics to calculate the activated complex and the reaction rate constant, K. At equilibrium, I_o - exchange current = $KC_{processes}$
- Today, just beginning to use structure calculations effectively: Cedar, Chiang, etc. – doping $LiFePO_4$ to improve conductivity

Present Situation

- **Over 3 billion cells annually**
- **Success - Li-Ion must address safety and cost**
  - Must have basic research on safety issues
  - Emphasis on cell design and manufacturing controls
  - Requirements: Long life, very high rate, low cost
- **Anode:**
  - Treated natural graphite
  - Hard carbon, lower capacity, higher rate, safer , long cycle life
  - Titanate, for safety but ~30% lower energy storage, very long cycle life
- **Cathode:**
  - Stabilized Mn Spinel
  - Phosphates, lower energy
  - ⅓, ½ Mn compounds, higher capacity, increased voltage
- **Cell design-balance, temperature**
- **Control circuitry**

Saft Lithium-ion Battery Systems



Identifying New Battery Systems

- Edisonian – keep trying
  - Expensive method
  - Requires luck to succeed
- Identify promising systems through calculation
  - Combine calculations with experimental verification
  - Comparatively inexpensive
  - Ionic liquids open up high voltage systems
  - Organic redox couples present a relatively untouched area
- Key investigator with proven track record
  - Patience
  - Encouragement
- Remember higher energy storage brings significant safety issues
- Starters - Replace graphite with Li metal, 370 → 3800 mah/g