Using Li-ion Battery for Intermittent Renewable Energy Storage: Requirements and Landscape

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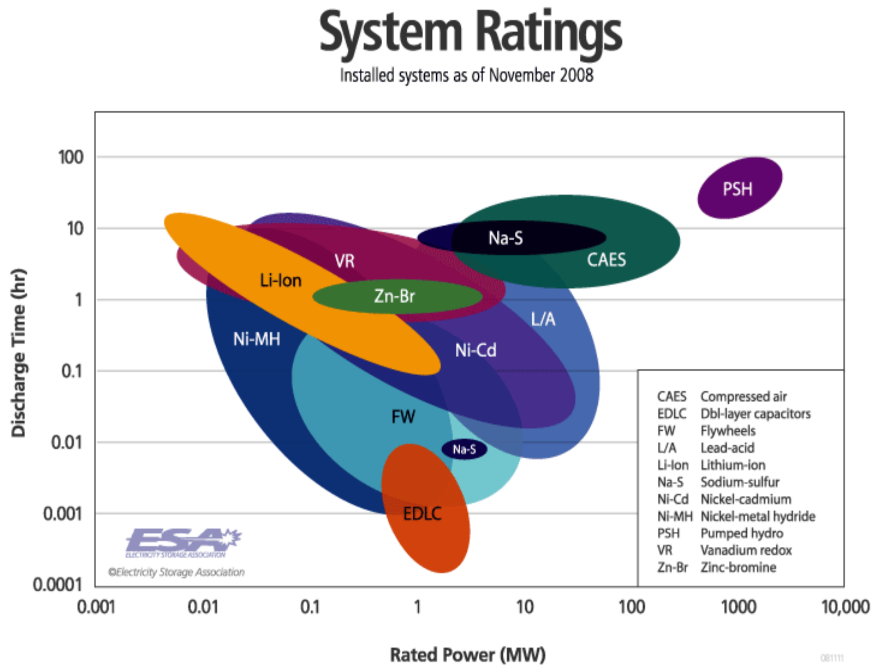
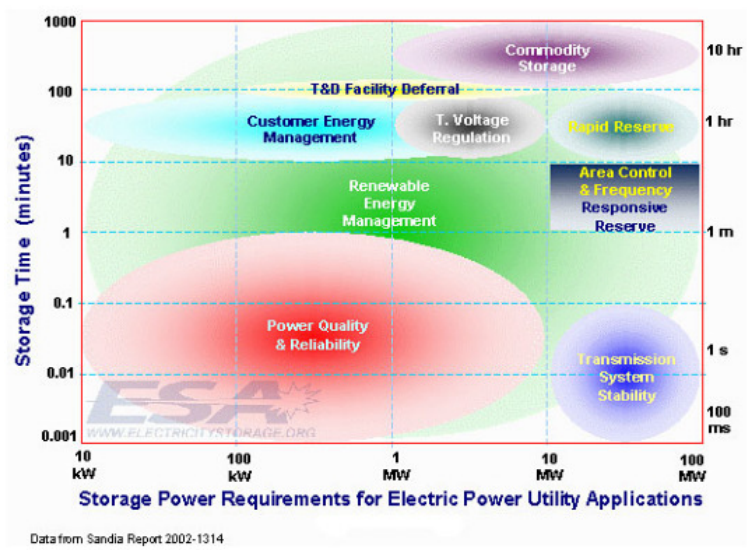
- Requirements and Landscape of LiB for Stationary Storage
- Role and Comparison of Current Materials and Chemistries
- Near term future: Very High Energy LiB Materials and Cells

Energy/Power Ratings for Intermittent Stationary Storage



Application Rating



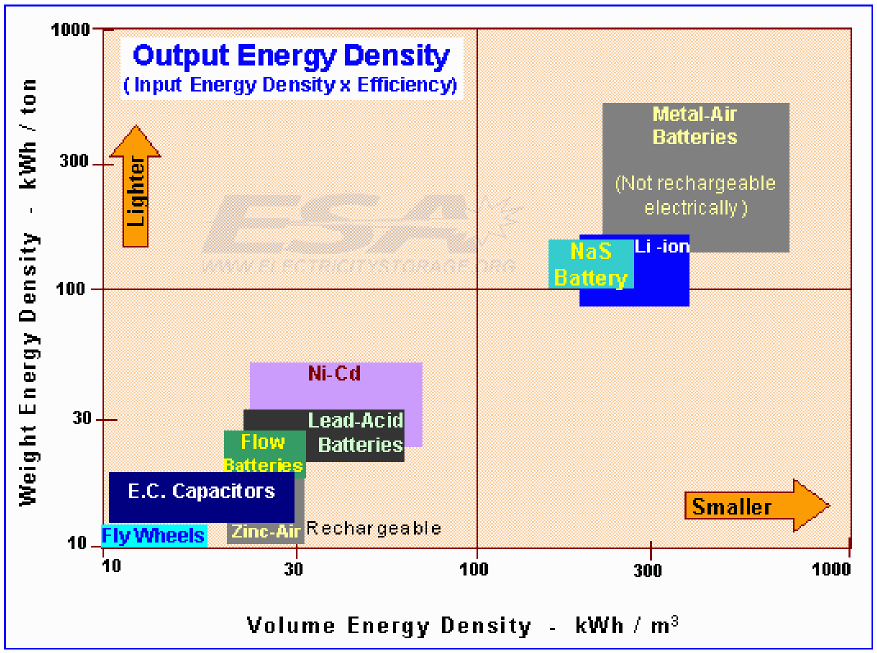
Power Quality:
Seconds or less as needed, Continuity of quality power

Bridging Power:
Seconds-Minutes
Continuity of Service when Switching

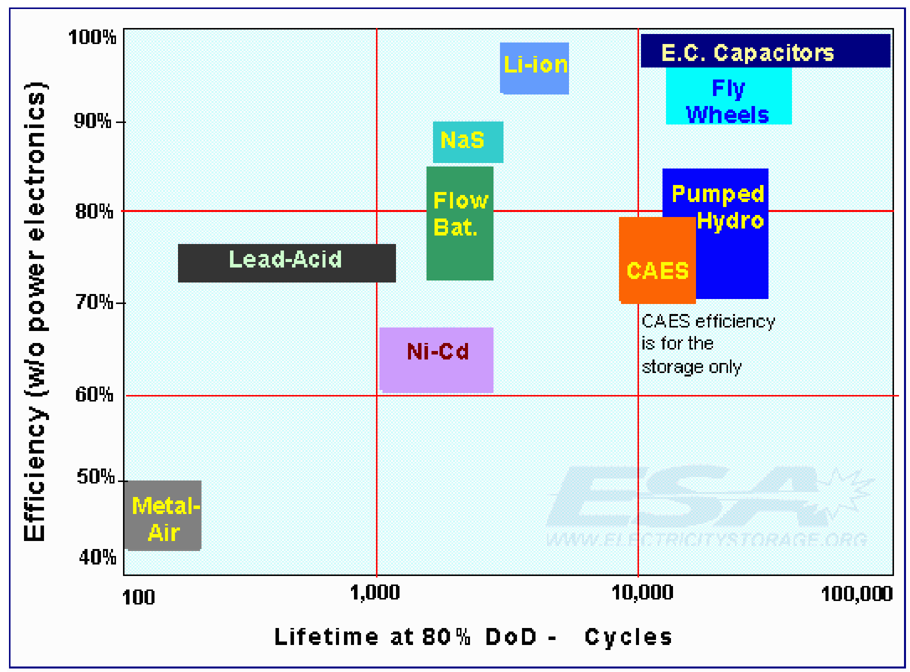
Energy Management.
Decouple the Timing of Generation and Consumption of electrical energy.
~ Load leveling
~ Cost Optimization
~ Revenue Arbitrage
~ Grid-independency for many hours.

Size/Weight and Efficiency Considerations

Size and Weight Consideration

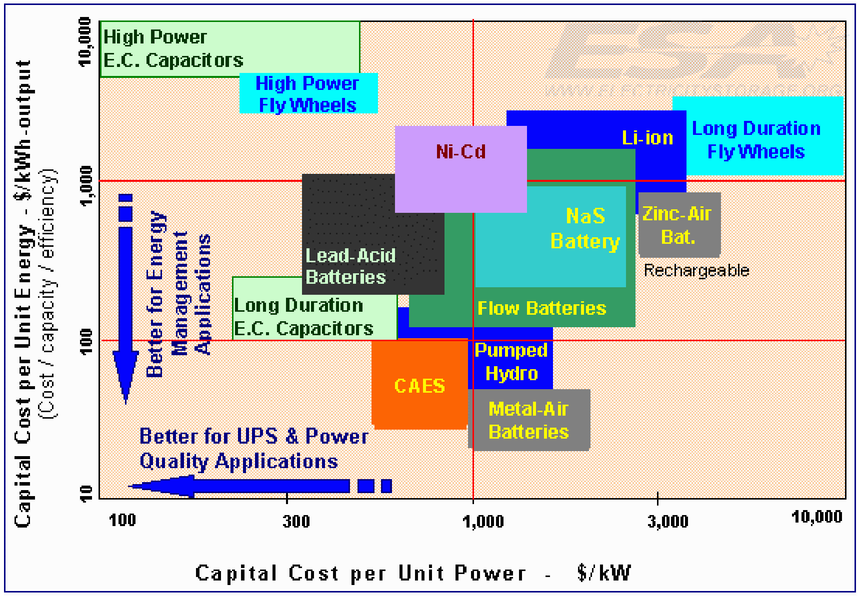


Cycle Life Efficiency

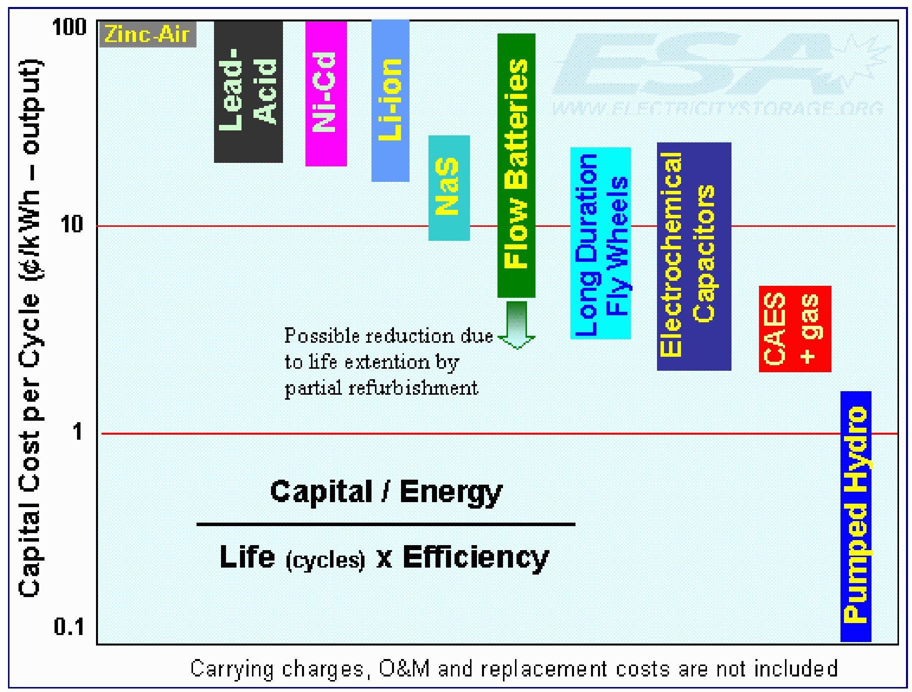


Cost Considerations

Capital Cost/Unit Energy-Power



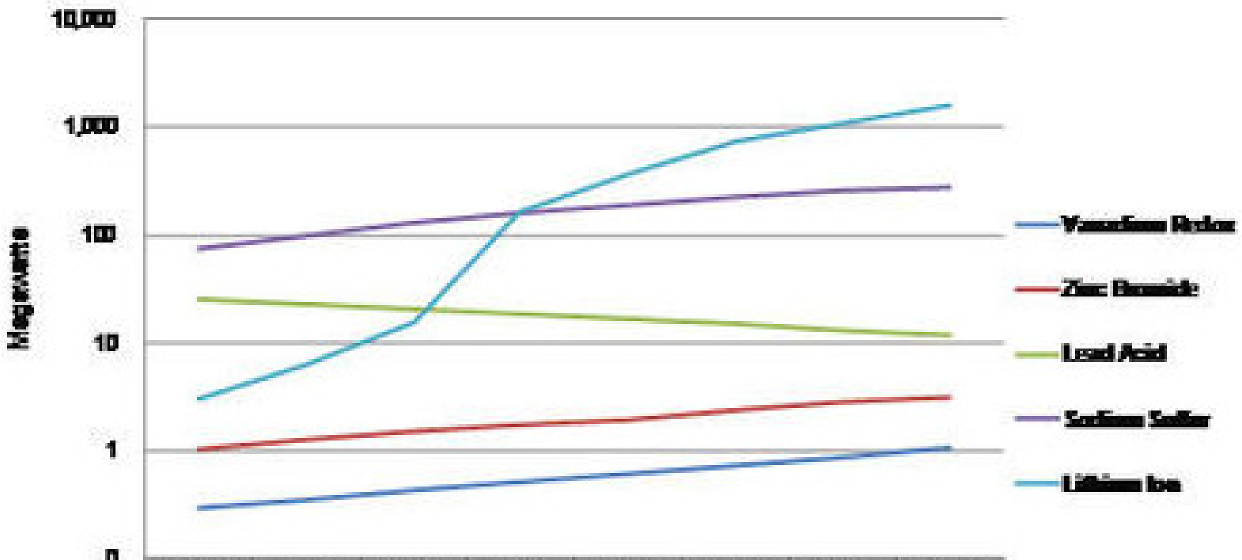
Per Cycle Cost of Stored Energy



Cost basis: 2002 and Changing Fast

Market Considerations: Projections

Stationary Utility Battery Storage Technologies, World Markets: 2008-2015



	2008E	2009	2010	2011	2012	2013	2014	2015
Vanadium Redox	0	0	0	1	1	1	1	1
Zinc Bromide	1	1	2	2	2	2	3	3
Lead Acid	25	23	20	18	16	15	13	12
Sodium Sulfur	75	98	132	160	194	234	257	283
Lithium Ion	3	6	15	168	363	737	1,093	1,548

(Source: Pike Research)

Different Battery Technologies : Materials and Chemistries

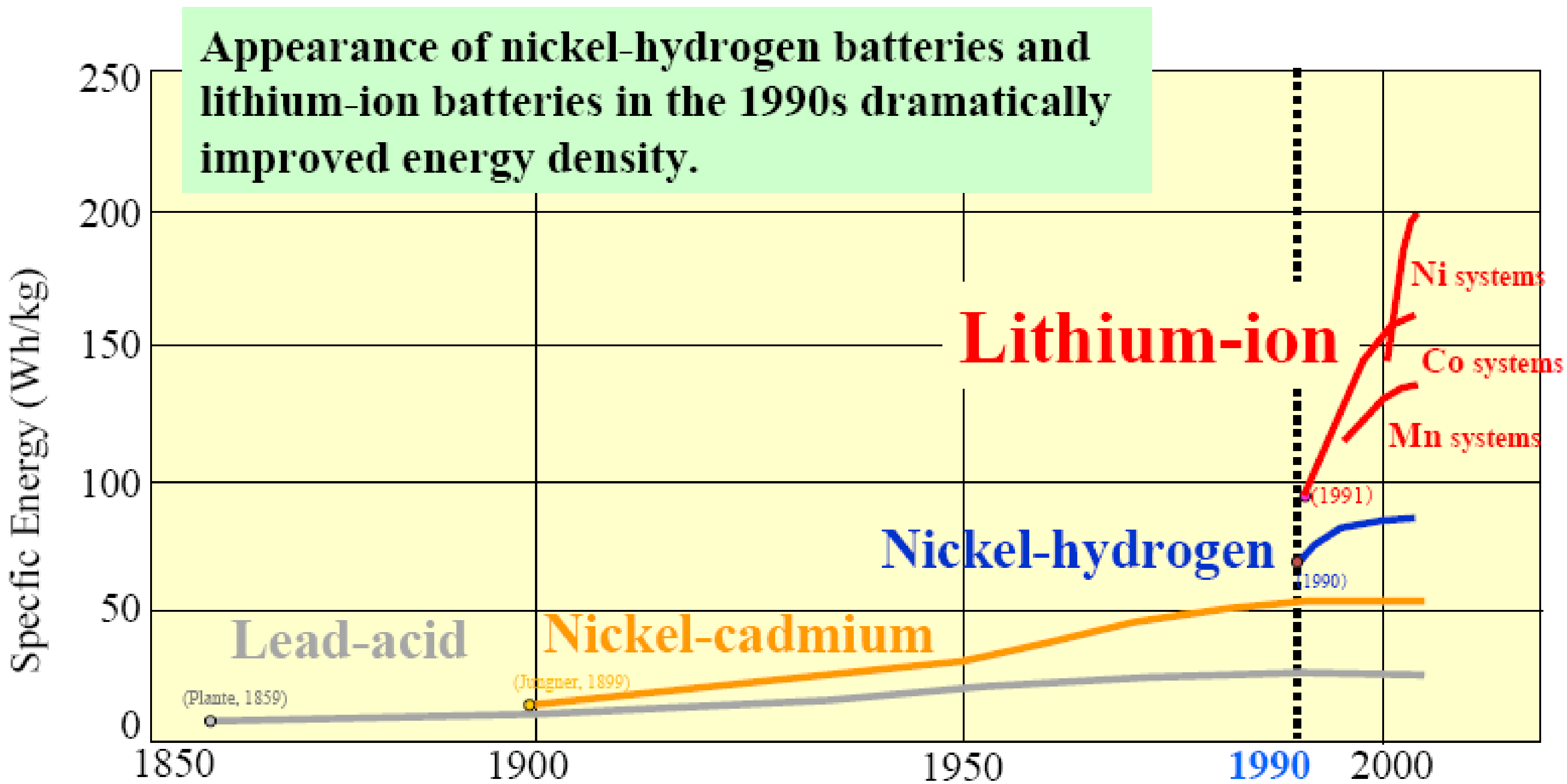
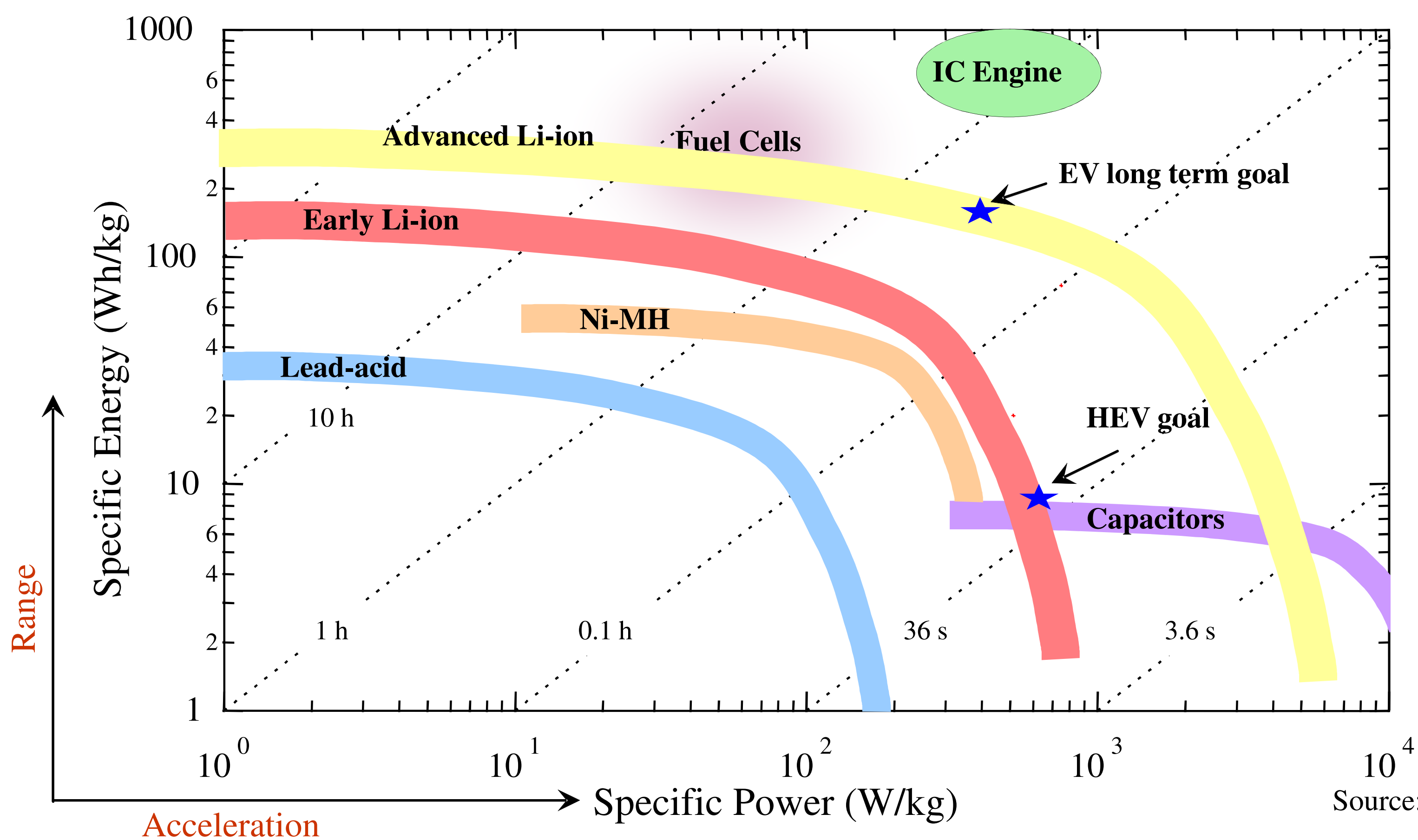


Fig. Improvement in specific energy of secondary batteries

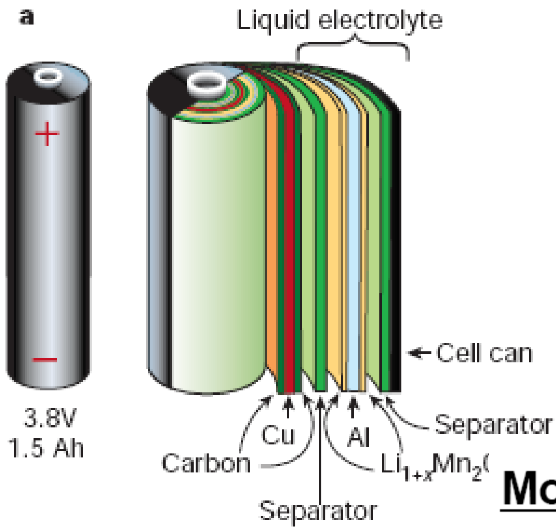
Nissan Presentation (2008)

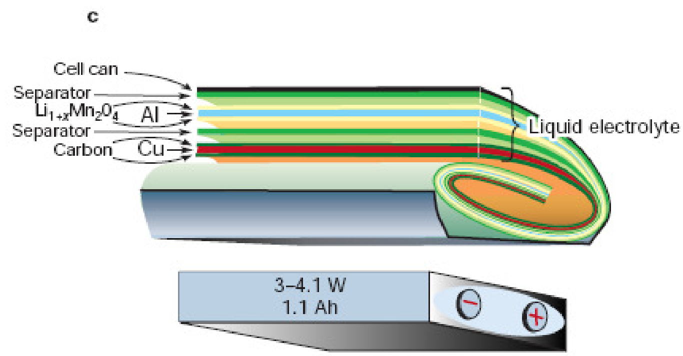
Specific Energy vs Specific Power: Ragone Plot



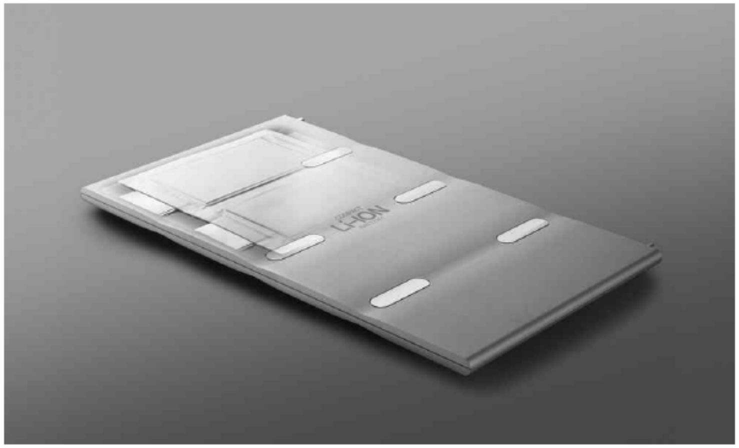
Source: Product data sheets

Li-ion Battery Cells



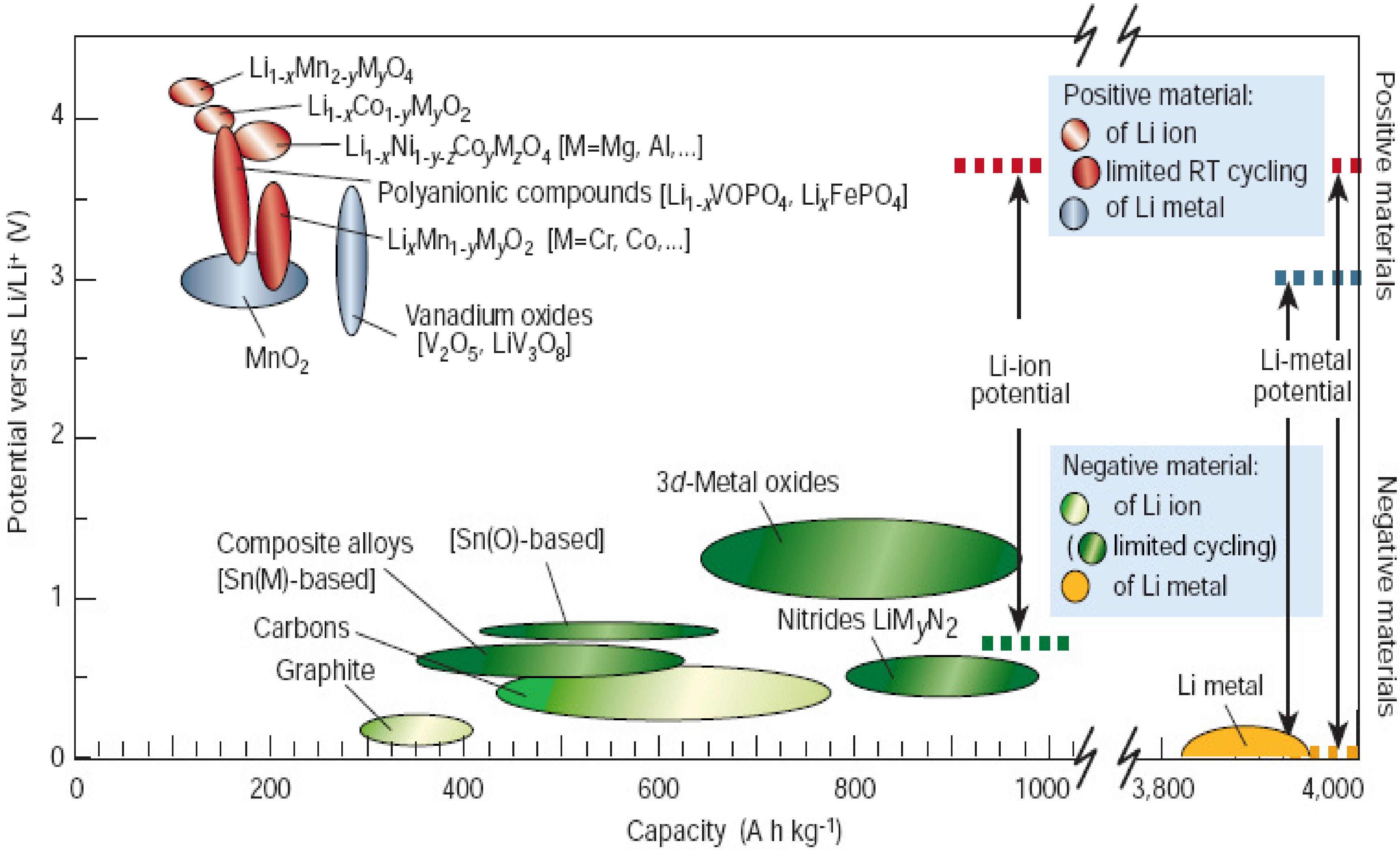


Module of compact Li-ion battery



Tarascon et. al, Nature (2001)

Li-ion Battery: Role of Materials and Chemistries

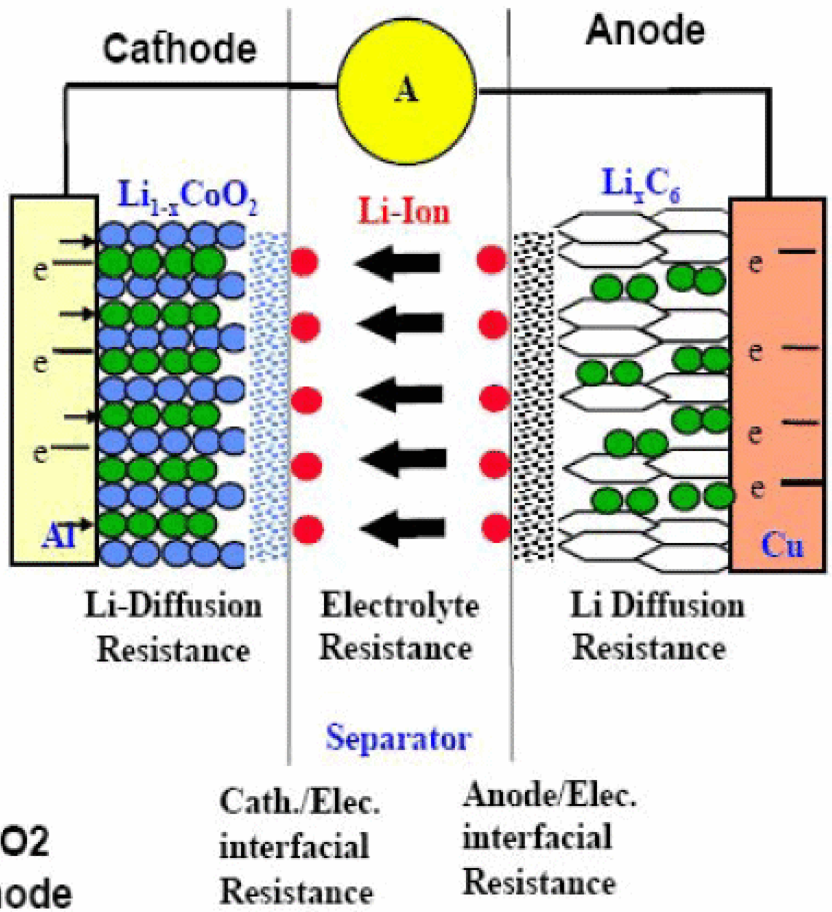


Tarascon et. al, Nature (2001)

Energy Density of NMC Material and Other Materials

Li-ion Cell and Materials

Cathode Materials	Energy Density (mAh/g)
LiCoO2	137
Doped LiCoO2	124-137
LiMnO2	110
LiMnCoO2	120
LiMnCoNiO2	160
LiMnNiO2	150
LiFePO4	< 110



Anodes Materials	
Carbons	Energy Density (mAh/g)
Graphite	320-370
MCMB	300
MCMF	300
HC	400-500
HC:SC	350-450
Si-C	>700
Inter-metallic	
LiSi	2000
LiSn	>800
CuSn	700-800
Li-metal	3800

Current Li-ion Cells Use Graphite & LiCoO2 Based Anode & Cathode

Source: Motorola Portable Energy

Example: Li-ion Battery for Stationary Storage

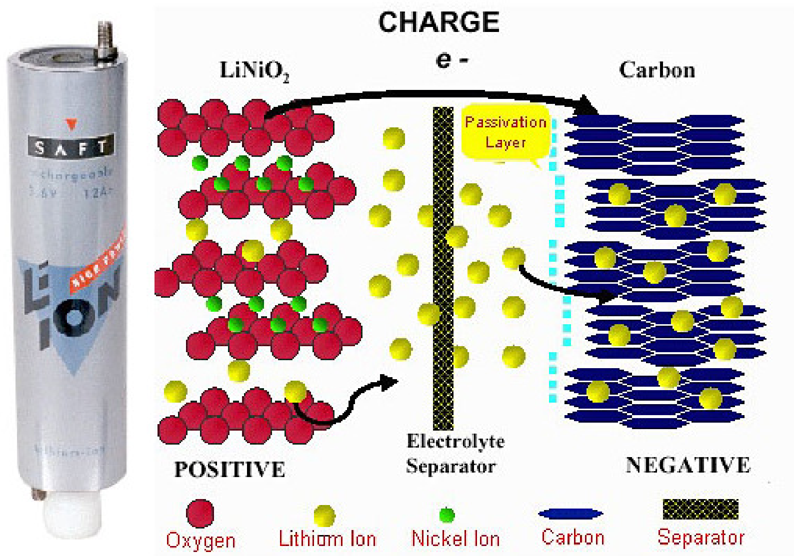


Photo Courtesy of SAFT America

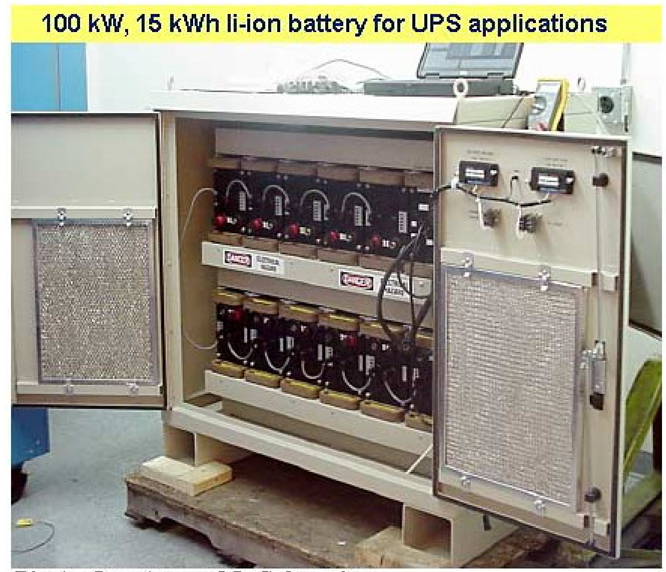
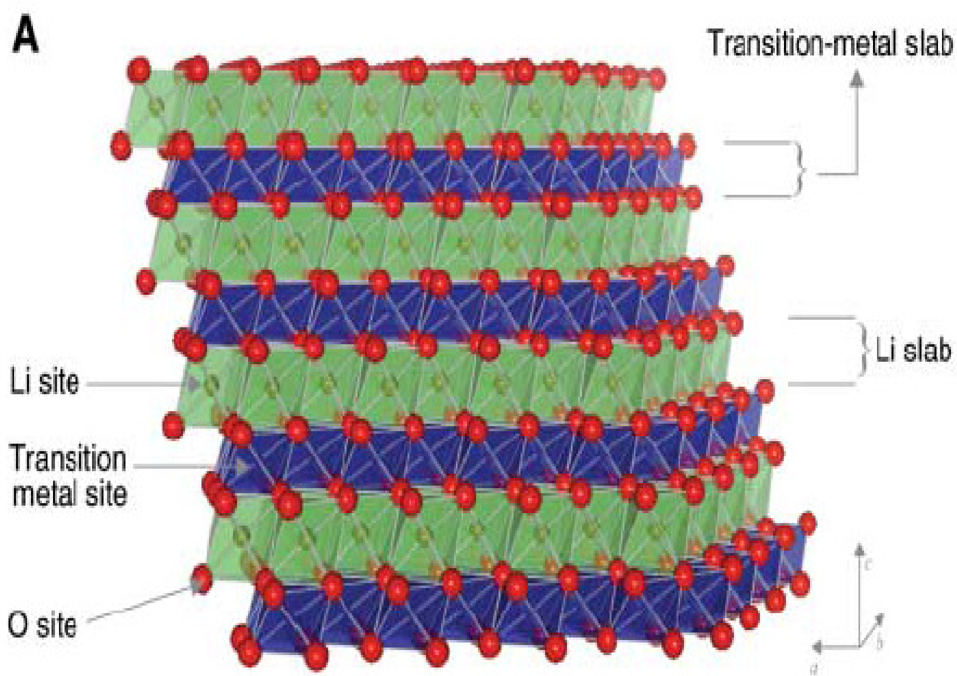


Photo Courtesy of Saft America

High energy density (300 - 400 kWh/m3, 130 kWh/ton)
High efficiency (near 100%)
Long cycle life (3,000 cycles @ 80% depth of discharge)

Based on LCO or LMO type cathodes and Graphitic/Carbon type Anode and LiPF6 salts dissolved in carbonate electrolyte

Changing the LiB Oxide Cathode Materials Chemistry



Generic Structure of Layered Oxide Material

- **Change the end group**
- **Change the transition metal**
- **Ease of Li storage and dynamics with in the lattice ~ capacity and power**
- **Difficulty of removing O from the lattice ~ safety**
- **Difficulty of Li – transition metal exchange with in the lattice ~ cycling**
- **Ionic size ~ structural stability**
- **Intercalation voltage ~ voltage**
- **Cost**

Ceder, MIT 2006

LiB Materials Chemistries: Oxide Cathode

Table II: Effect of metal substitution on the average intercalation voltage in the α-$NaFeO_2$ structure

M in $LiMO_2$	Ti	V	Cr	Mn	Fe	Co	Ni	Cu
av. voltage (V) for MO_2 / $LiMO_2$	2.33	2.93	3.22	2.95	3.52	3.73	3.32	3.7

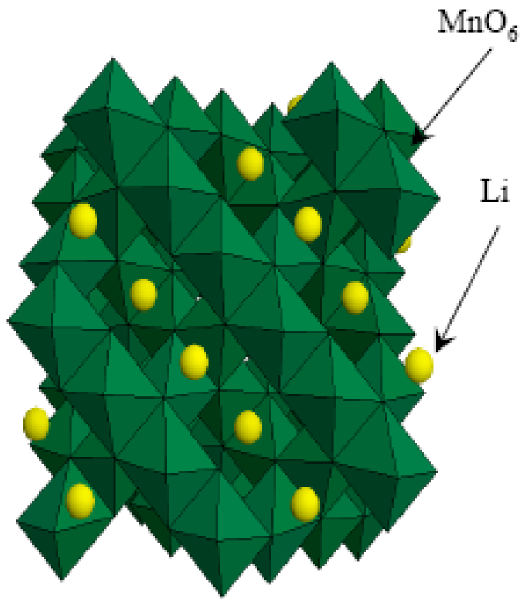
Table III: Effect of anion substitution on the average intercalation voltage of $LiCoX_2$ in the α-$NaFeO_2$ structure

X in $LiCoX_2$	O	S	Se
av. voltage (V)	3.75	2.04	1.46

California ZEV Panel Report: 2007

LiB Materials Chemistries: The Spinel $LiMn_2O_4$ Cathode

The $LiMn2O_4$ Spinel System



Manganese Spinel / Carbon-based

- Well-studied system that has a high power capability and excellent safety, but has low energy
  - Capacity is 110 mAh/g, vs. 180 mAh/g for the nickel-based systems
- Known cycle life problems because of manganese dissolution, exacerbated at higher temperatures
  - Use a mixture of spinel and nickelate to enhance life and increase energy, while maintaining safety
- Could satisfy PHEV-10 energy requirements, but meeting PHEV-40 requirements may be more problematic

Low energy and poor life are key challenges for use in PHEV-40

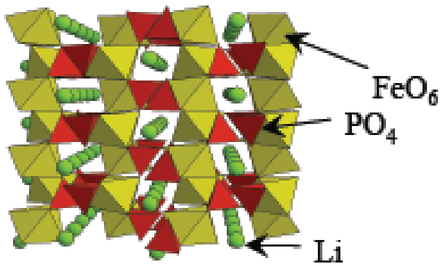
Ideas Being Pursued

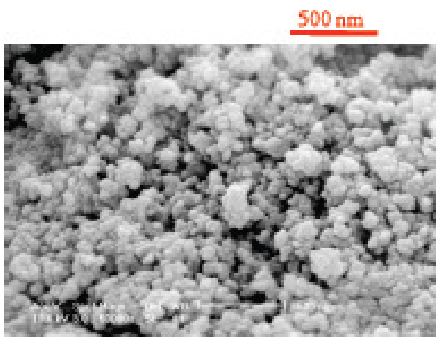
- Use electrolytes that prevent dissolution of manganese
- Move to higher energy anodes (without sacrificing life)

T. Duong DOE, 2008

LiB Materials Chemistries: Li-Iron-Phosphate Cathode

$LiFePO_4$ / Carbon-based





- Best chemistry in terms of safety characteristics
- Excellent power capability due to nanosize
- However, energy is low because of low cathode voltage (3.4 V vs. 3.8 V for nickel-based system)
- Cycle life unknown, with conflicting reports and limited data
  - Life appears to be related to impurities formed during material synthesis, and could be prevented
- Flat voltage leads to cell balancing and SOC determination problems

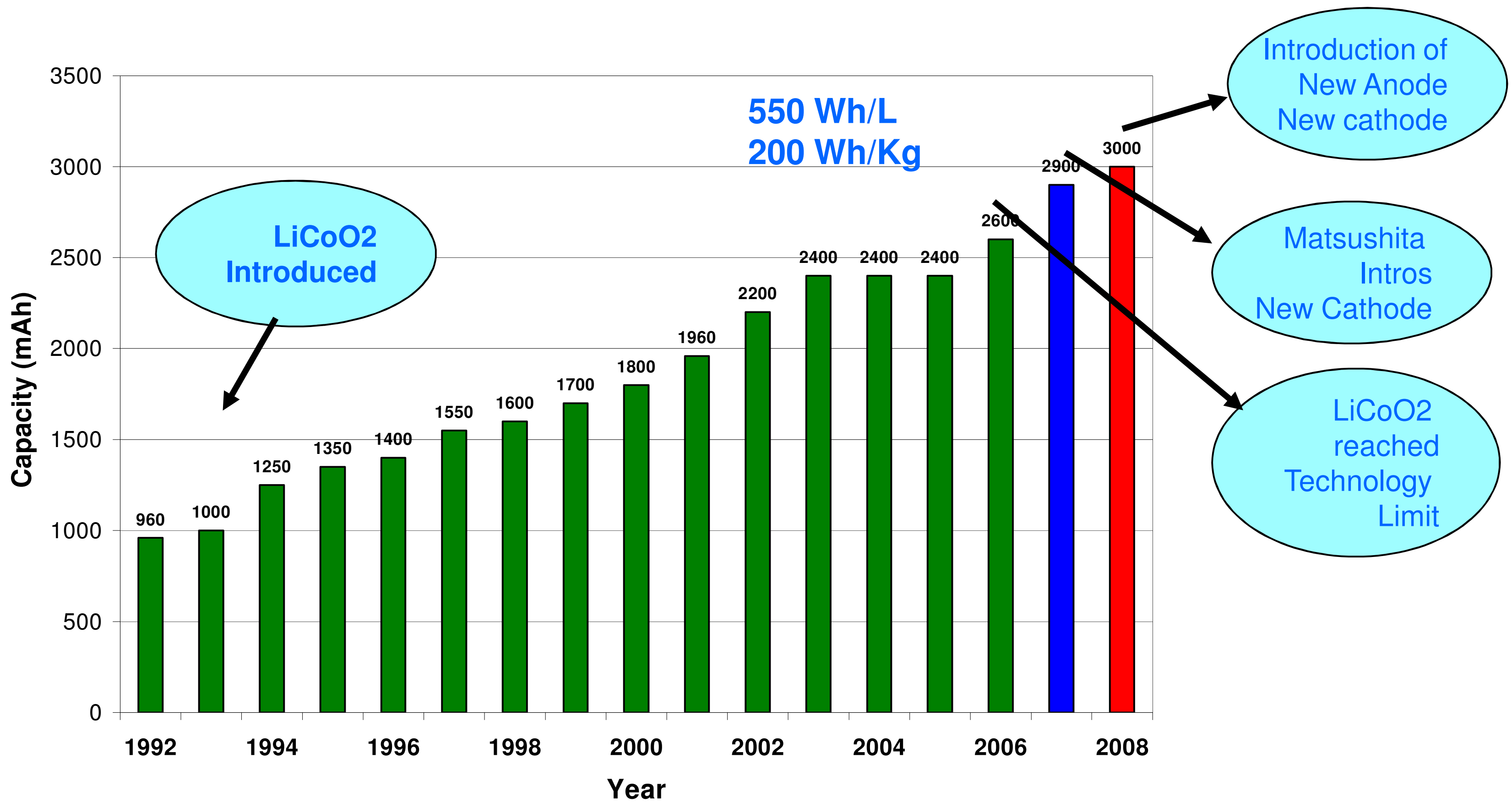
Low energy could impede use in PHEV-40

Ideas Being Pursued

- Move to prismatic designs to increase specific energy and energy density
- Tailor size of nanoparticle to increase tap-density (g/cc of active material)
- Move to alternative phosphates ($LiMnPO_4$) that have higher energy while maintaining safety

T. Duong DOE, 2008

The Lithium-Ion Technology is at the Crossroads



Typically 3-5% performance improvement unless new chemistry or material is introduced

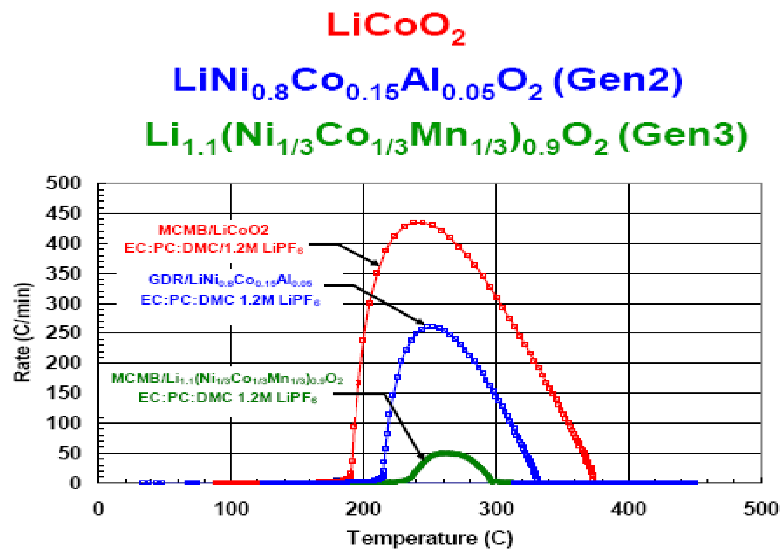
Source:IIT

Gen-3 layer-layer NMC Cathode Materials

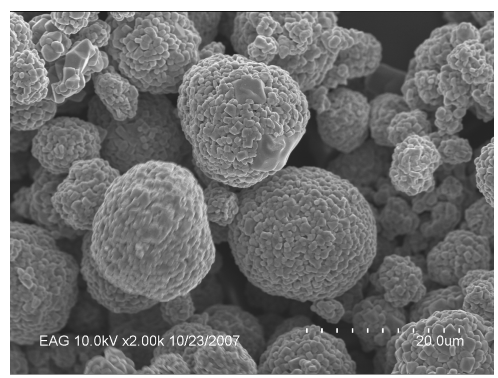
Cathode Materials	Energy Density (mAh/g)
LiCoO2	137
Doped LiCoO2	124-137
LiMnO2	110
LiMnCoO2	120
LiMnCoNiO2	160
LiMnNiO2	150
LiFePO4	< 110

Higher Capacity or Energy Density !

Fundamental IP Licensed From Argonne National Laboratory



Better Safety than LCO and NCA via Less Heat Generation!



Li-ion Battery for Stationary Energy Storage: Comments

- LiB is an advanced competitive technology in the Bridging Power and Energy Management areas

- Current Applications ratings are especially suitable for:
  - ➔ Re-newable Energy Management/Efficiency
  - ➔ Customer Energy Management
  - ➔ Up to 1MW power rating and Minutes-Hours Interruption

- The above specifications are based on LMO/ Graphite based Chemistries

- Higher power rating (1-10MW) are possible and starting to happen with Olivine (LFPO) and Spinel (LMnO) type cathode and LTO type anode Chemistries

- Nex-gen LIB Cells based on very high energy density composite cathode and Si-alloy based anodes will be game changer and booster in stationary energy storage area by 3-4x improvement in gravimetric energy density and 2x improvement in volumetric energy density at similar or lower cost

- Coating technology needs significant improvement to increase the discharge time ratings to below few minutes interruption