Rechargeable Battery Market Trends and Technologies

Presentation Prepared the Staff of Progress Investments

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Overview

Performed a study of a variety of emerging battery technologies.

What was learned ?

There are several interesting market trends.

There are several competing technologies.

Gained an insight into the methods of selecting a battery technology tailored for an application.

There is still a lot to learn.

What is a Battery ?

- Batteries are active electrical energy storage devices.

- Primary Batteries: Non rechargeable.
- Secondary Batteries: Are rechargeable.

- All batteries use a Redox reaction (Reduction/Oxidation)

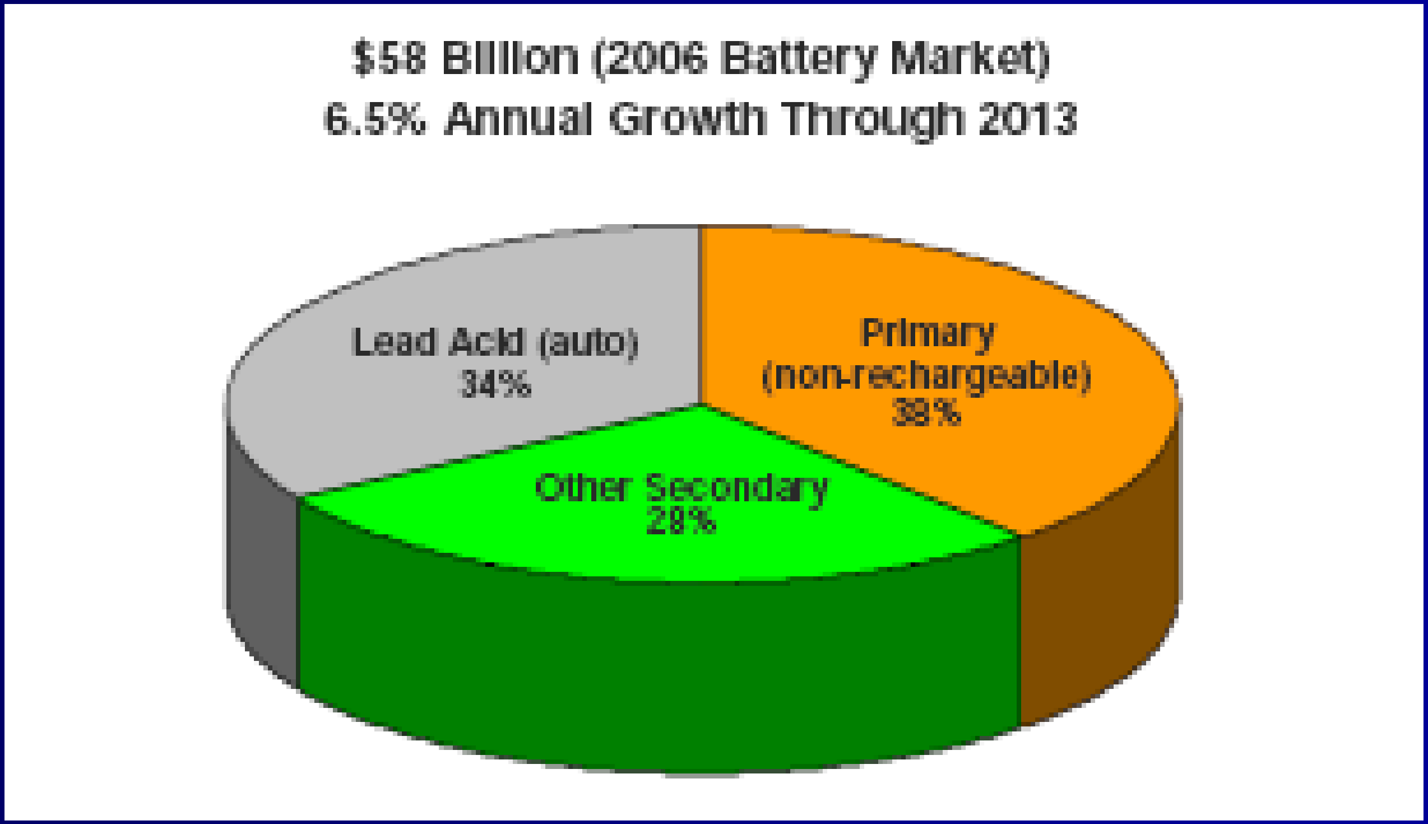
to supply electrical power. (Chemical Reaction).
Primary Batteries: Redox reaction is one way (can not be reversed).
Secondary Batteries: Redox reaction is reversible.

Chemistries types.

- Aqueous Chemistries. (Wet electrolyte ie acid) Example :SLA
- Gel chemistries. (Gel Electrolyte) Example: Lithium Polymer.
- Dry Chemitries: (Dry Electrolyte) Example: Zinc Air

Fuel Cells ? Reactants need to be continuously supplied. New technologies on the horizon
To store reactants in solid state.

World Battery Market

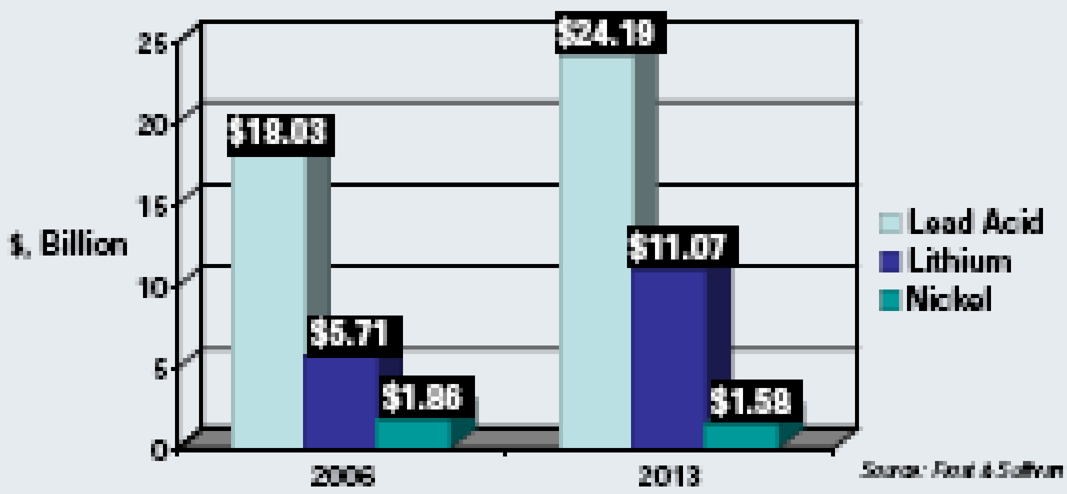


Rechargeable Battery Market

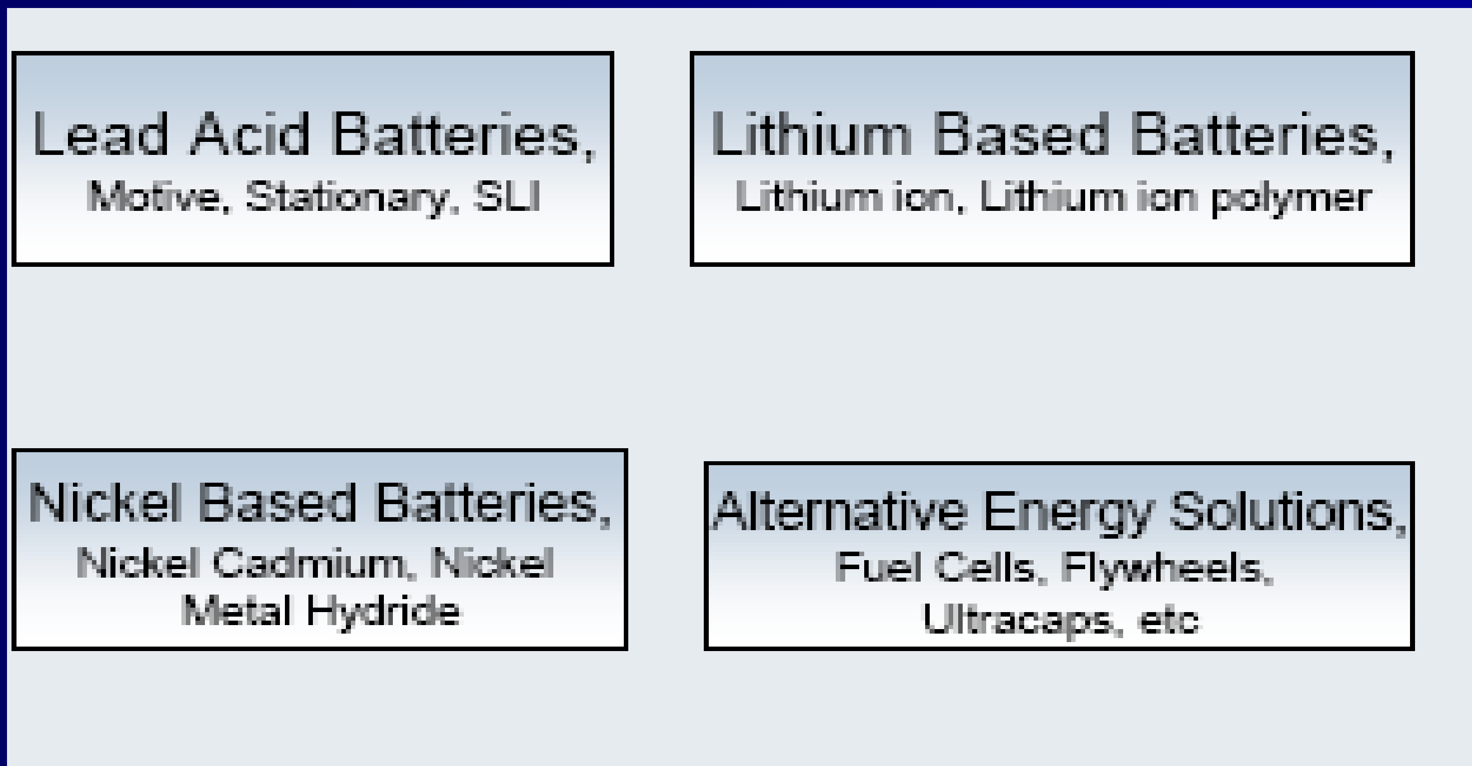
World Rechargeable Battery Market

- Worldwide rechargeable battery market is valued around $25.6 billion
- This market is projected to grow approximately 5.3 percent annum, reaching $36.8 billion in 2013.

Rechargeable Battery Market, World



Rechargeable Battery Market Segmentation



* Renewable Alkaline and Zinc based batteries are not considered to be a key Market Seg

Quick Comparison of Key Players

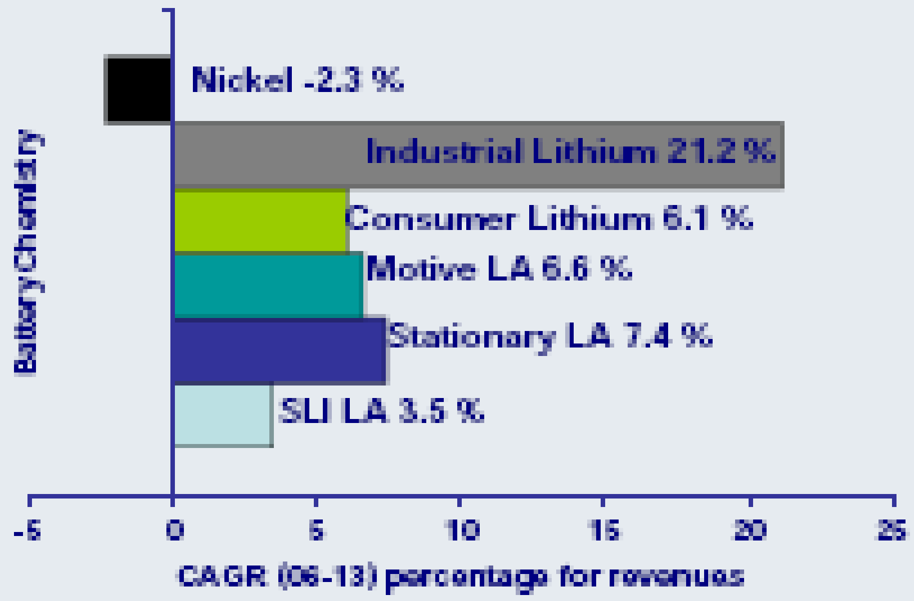
- **Nickel Cadmium** (NiCd) — mature and well understood but relatively low in energy density. The NiCd is used where long life, high discharge rate and economical price are important. Main applications are two-way radios, biomedical equipment, professional video cameras, and power tools. The NiCd contains toxic metals and is environmentally unfriendly.

- **Nickel-Metal Hydride** (NiMH) — has a higher energy density compared to the NiCd at the expense of reduced cycle life. NiMH contains no toxic metals. Applications include mobile phones and laptop computers.

- **Lithium Ion** (Li-ion) — fastest growing battery system. Li-ion is used where high-energy density and lightweight is of prime importance. The technology is fragile and a protection circuit is required to assure safety. Applications include notebook computers and cellular phones.

- **Lithium Ion Polymer** (Li-ion polymer) — offers the attributes of the Li-ion in ultra-slim geometry and simplified packaging. Main applications are mobile phones.

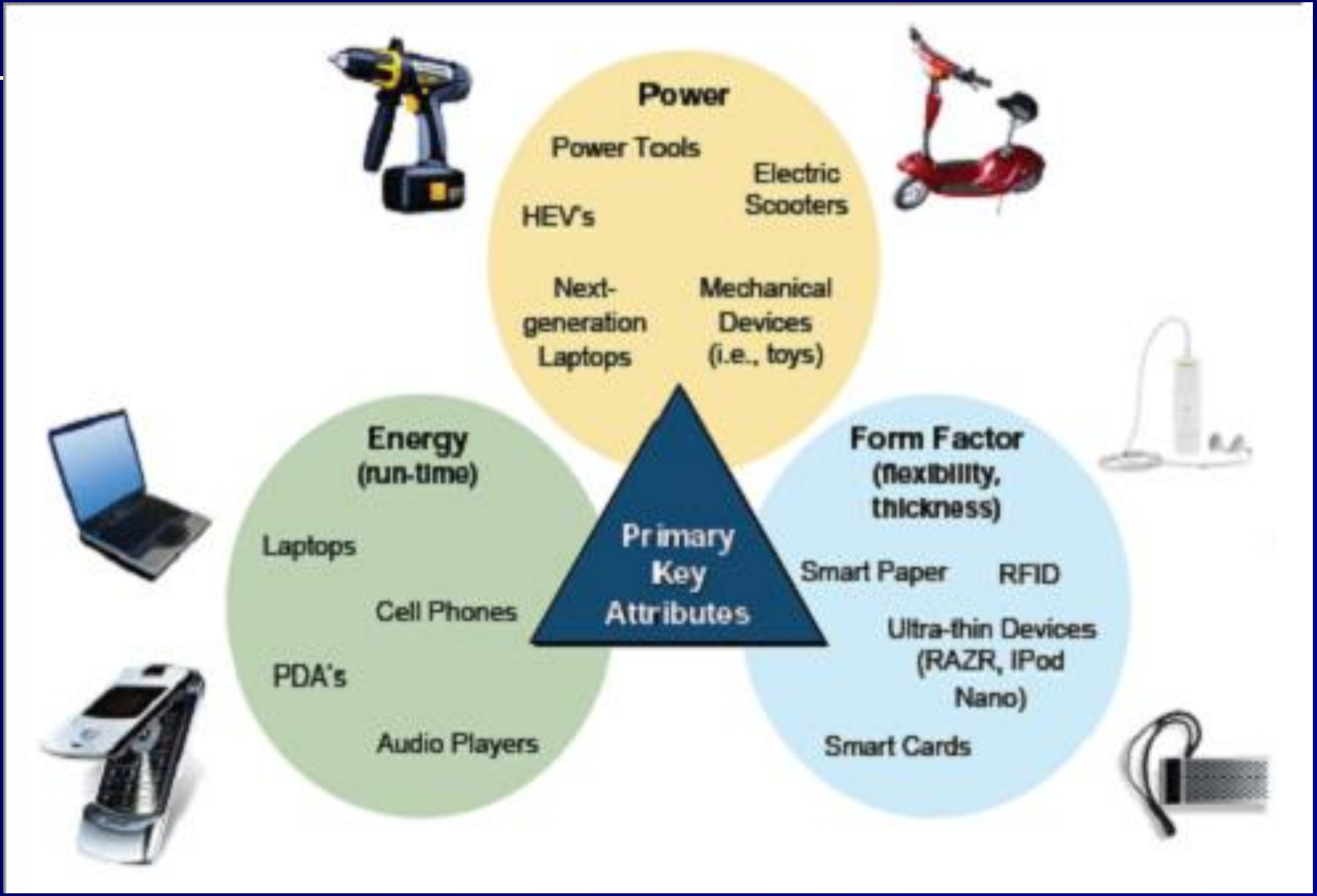
Market Growth Opportunities



- Industrial Lithium fastest growing segment – replacing traditional nickel battery technology.
- Due to its inherent benefits such as its energy density, environmentally safer, and fast charging capabilities.
- Opportunities in the data center space is driving demand for stationary lead acid batteries

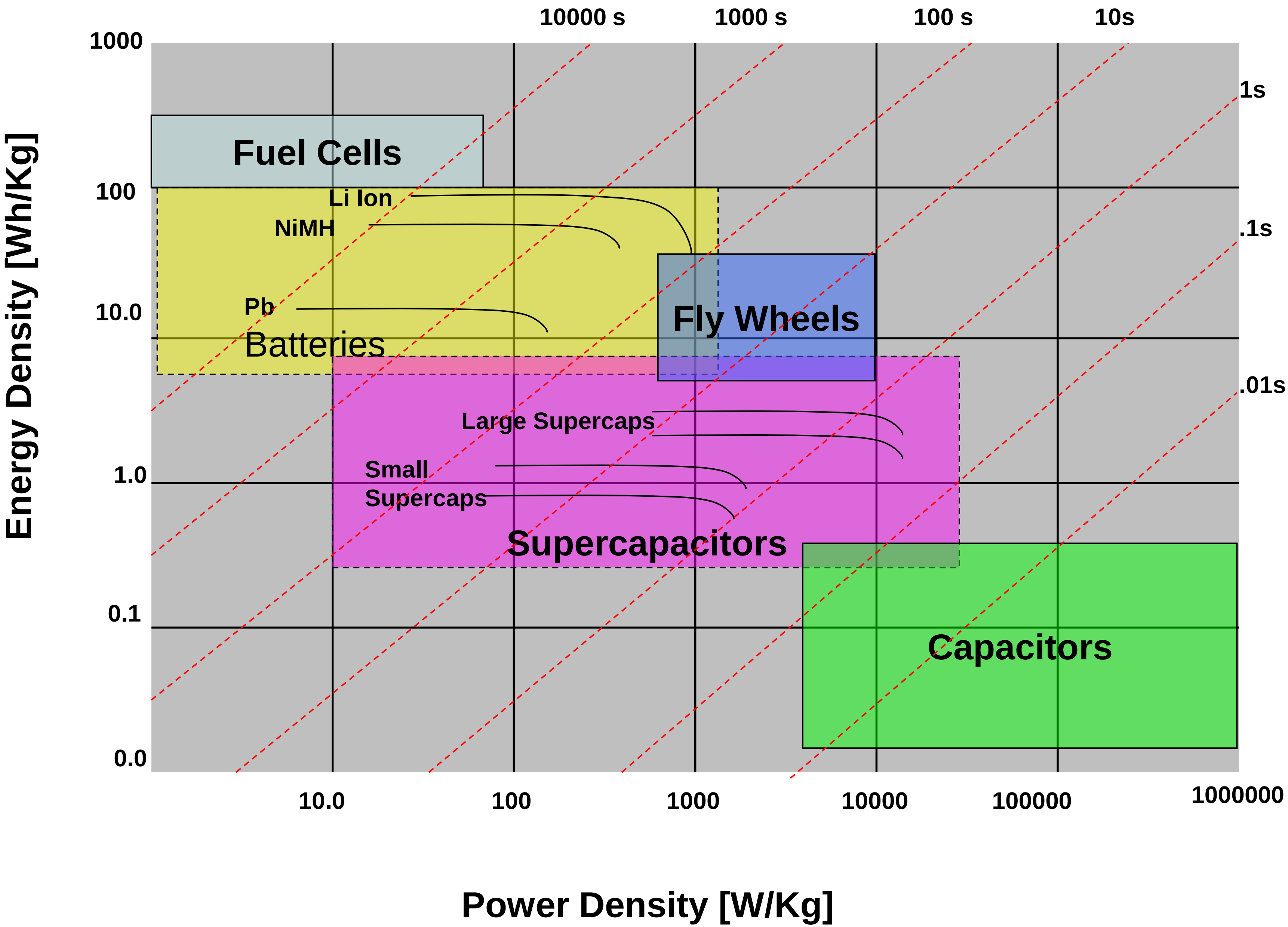
Source: Frost & Sullivan

Market Drivers for Batteries

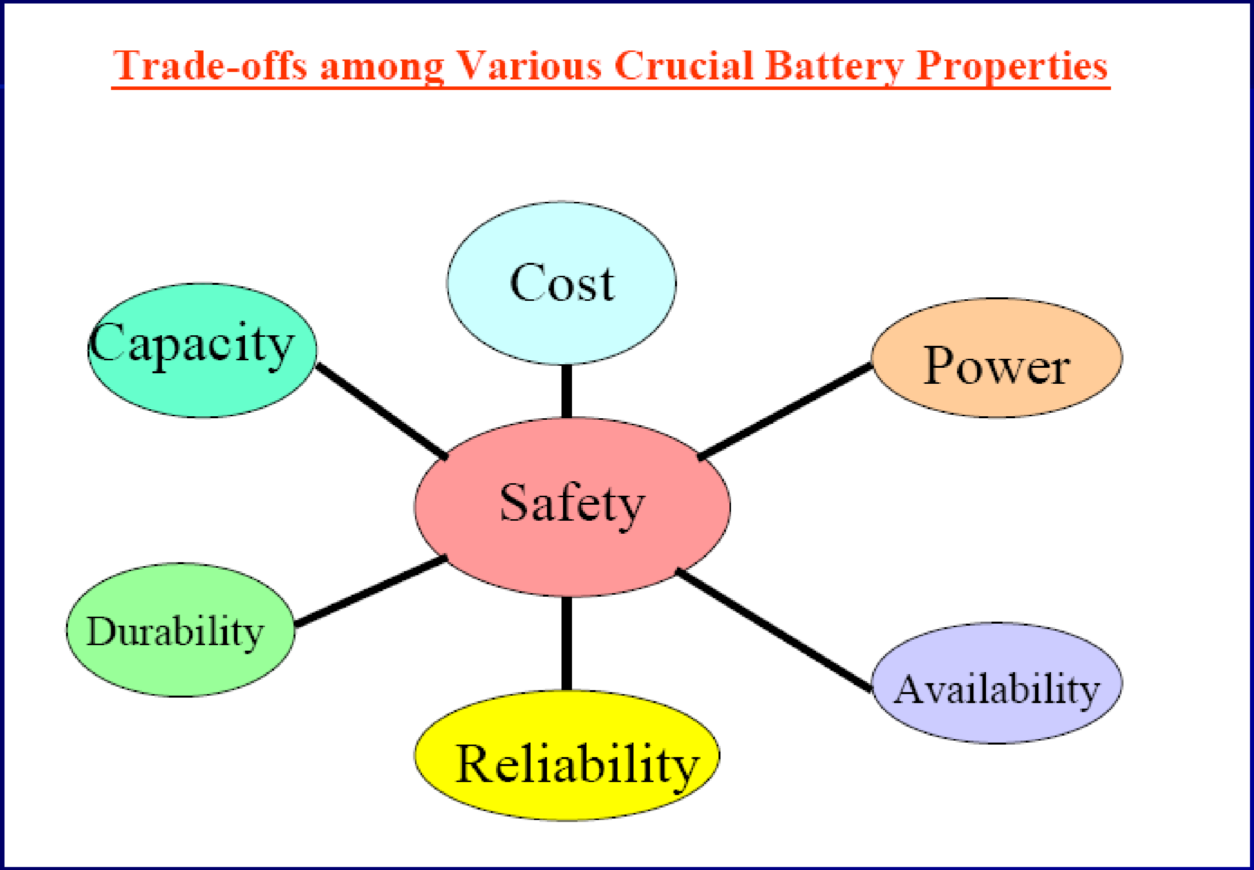


Many applications = Many Battery types

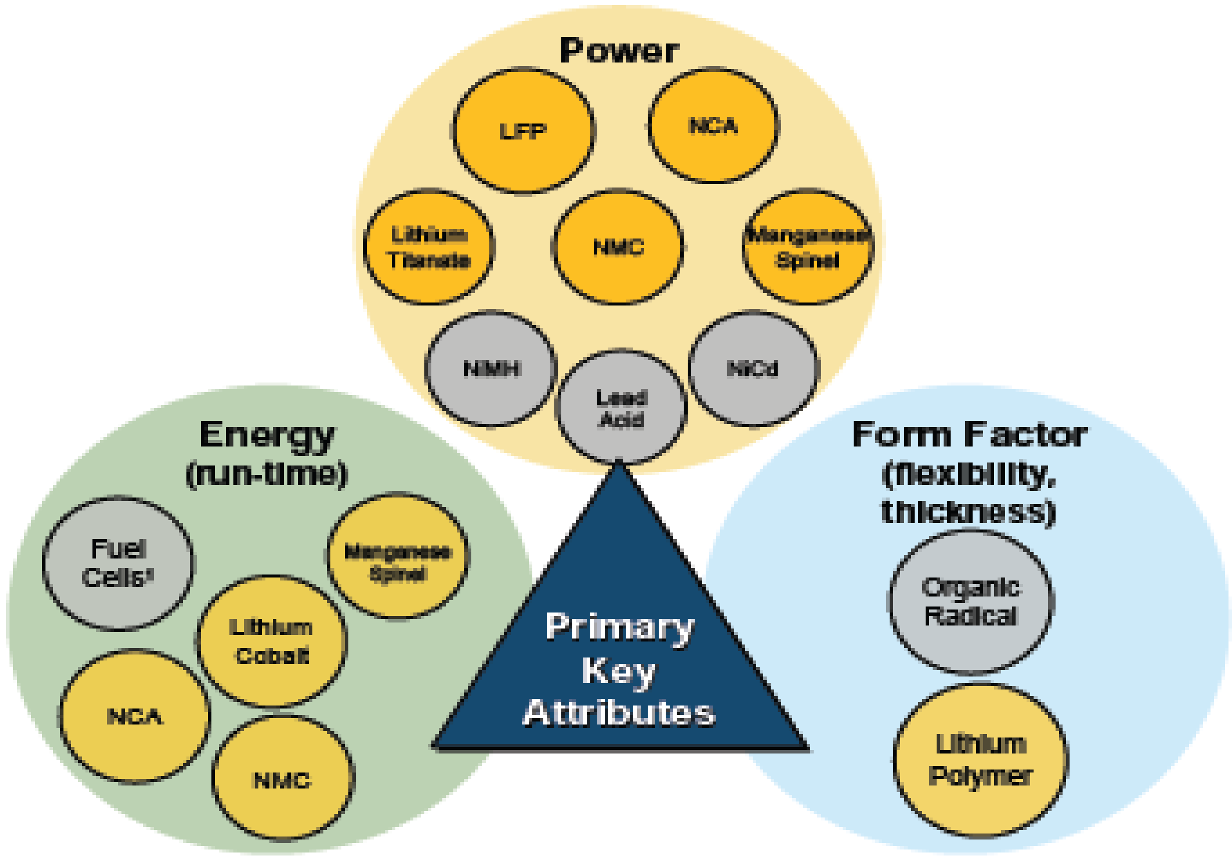
Comparing Storage Technologies



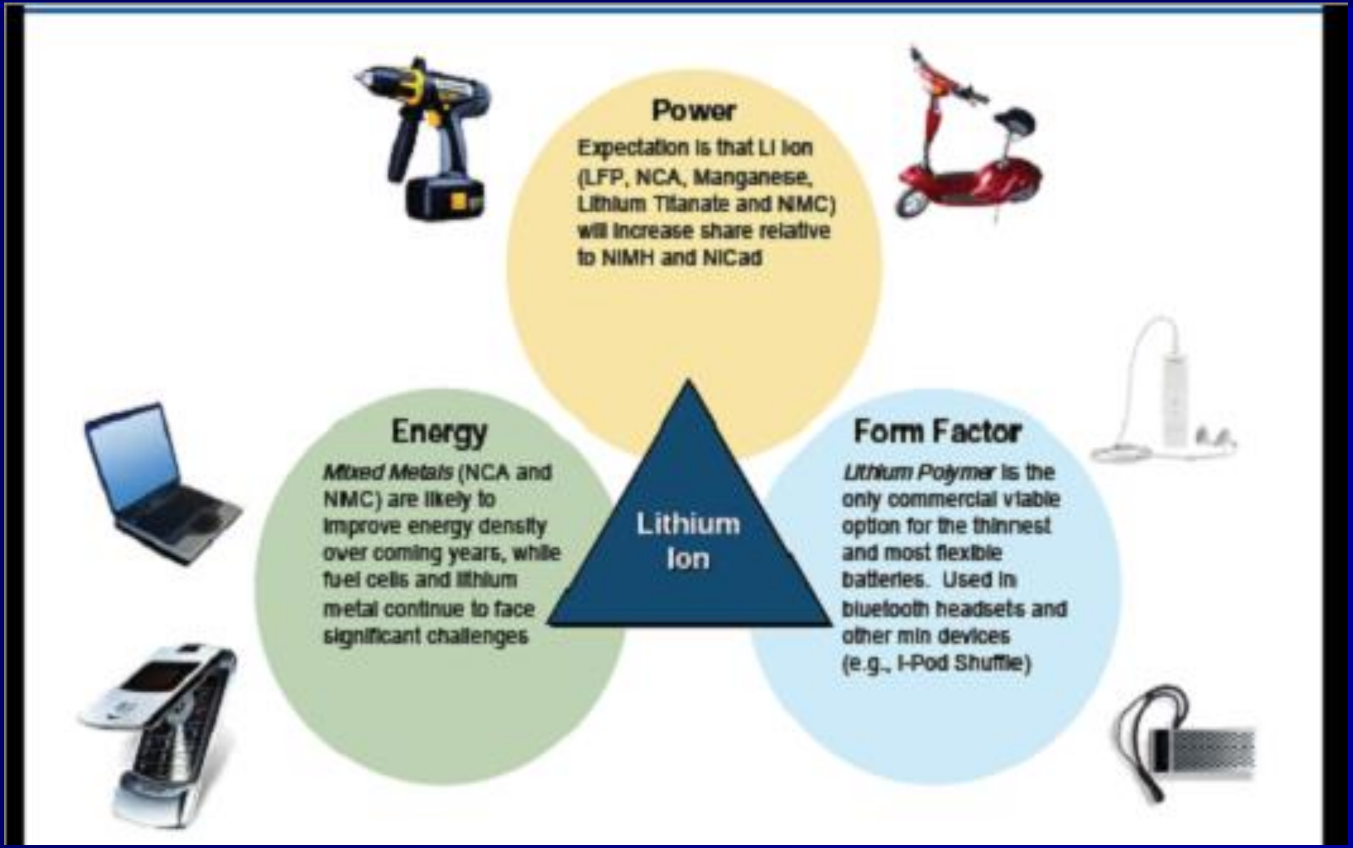
Key battery trade offs.



Where do the Battery Technologies fit ?



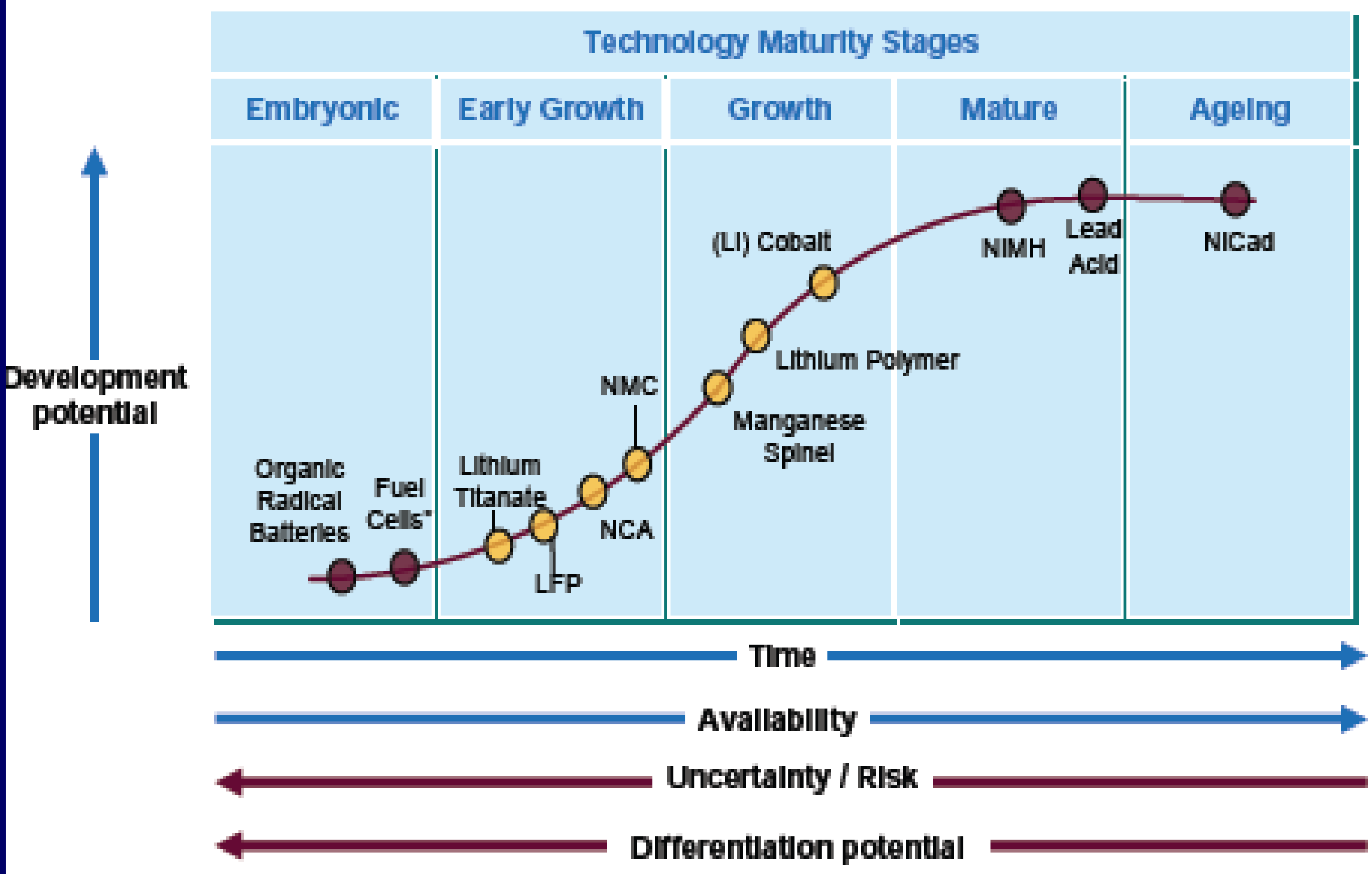
Where Lithium Ion is Headed



Lithium Ion Technologies Dominate Consumer Applications

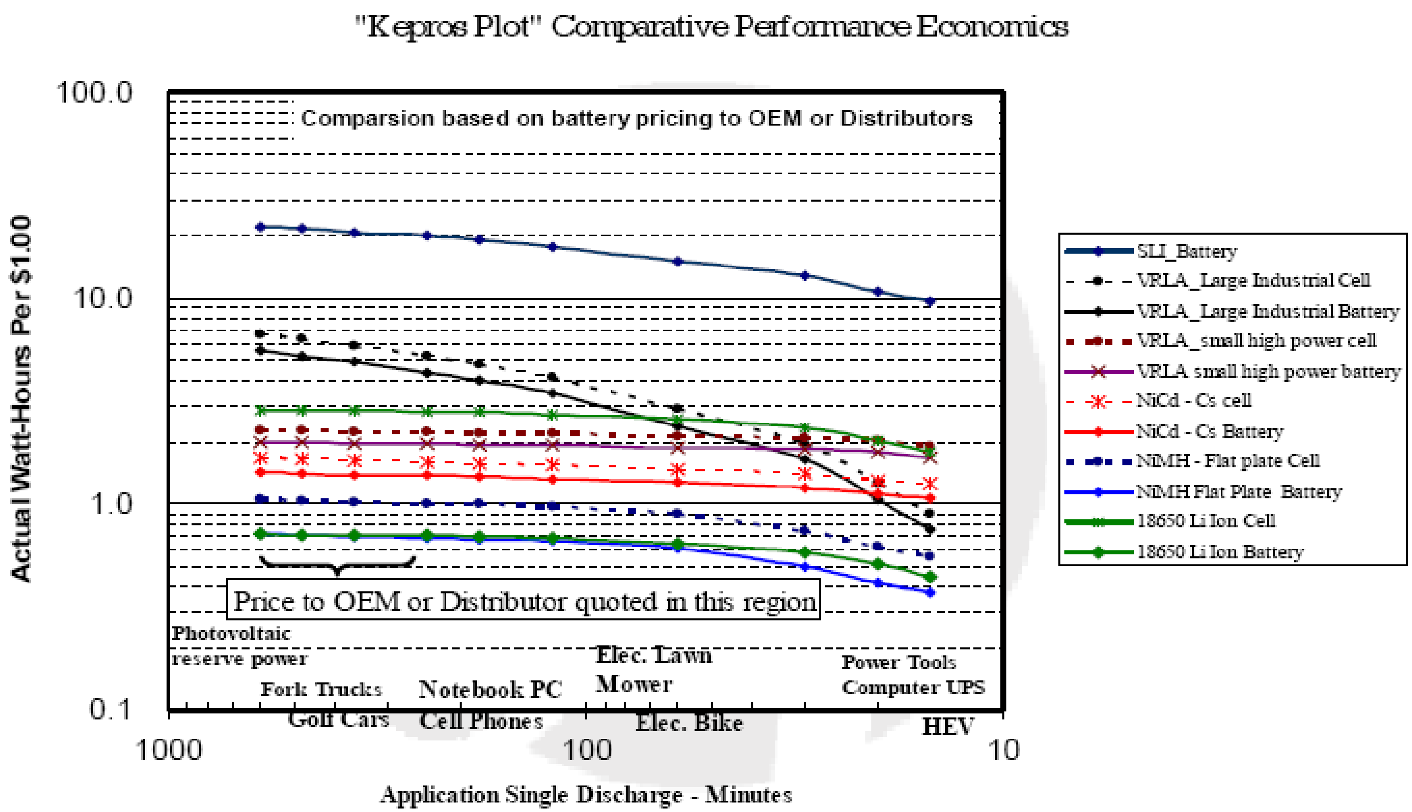
- Li-Ion based battery technology expected to continue dominate for the next 5 years.
- Soon to be integrated into the HEV market. (Toyota migrating to Lithium Ion technology).
- Demand is high, yet prices are not going down ?
- Lithium demand is keeping prices up ?

The Technology Maturity Curve.



Watt Hours per Dollar

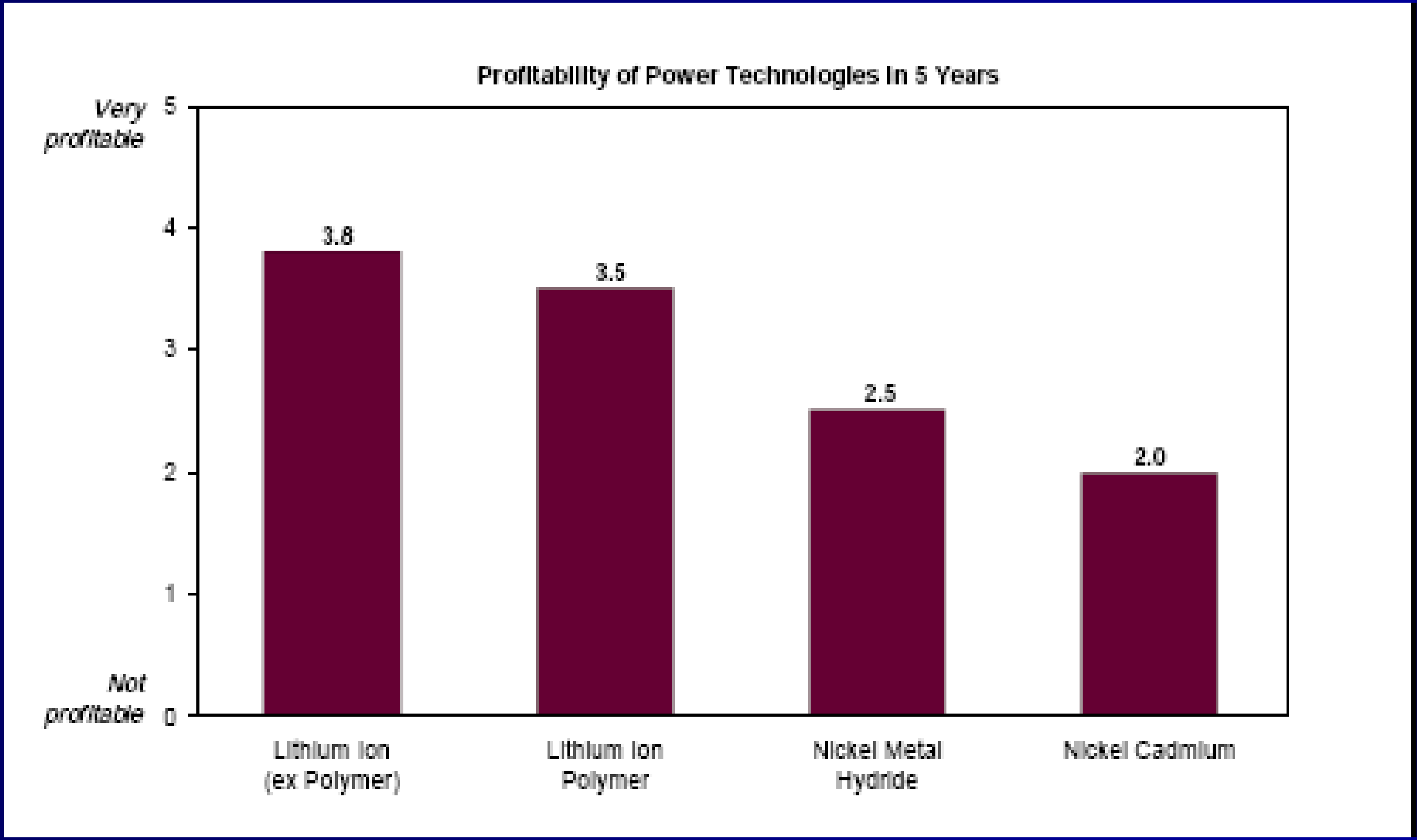
The cost of energy storage. $$$



Comparing Costs of Key Battery Technologies

Battery Type	Cost $ per Wh	Wh/kg	Joules/kg	Wh/liter
Lead-acid	$0.17	41	146,000	100
Alkaline long-life	$0.19	110	400,000	320
Carbon-zinc	$0.31	36	130,000	92
NiMH	$0.99	95	340,000	300
NiCad	$1.50	39	140,000	140
Lithium-ion	$4.27	128	460,000	230

Profitability Comparison of Rechargeable Technologies



Current Li ion R&D Paradigm

R&D Efforts

- Current R&D focus is energy density.
- R&D efforts are shifting to improving power density.
- Advanced modeling techniques are being used to research new cathode materials.
- Improvements are occurring at a rate of 2 to 3% per year. (Definitely not following Moore's Law)
- Lithium not reaching full potential due to safety.

Challenges

- Portable electronics are reaching ergonomic limits of the technology.
- Form factor is becoming an issue.
- New and more rigorous regulations and testing standards are soon to have an impact.

Short term Focus of Rechargeable Manufacturers

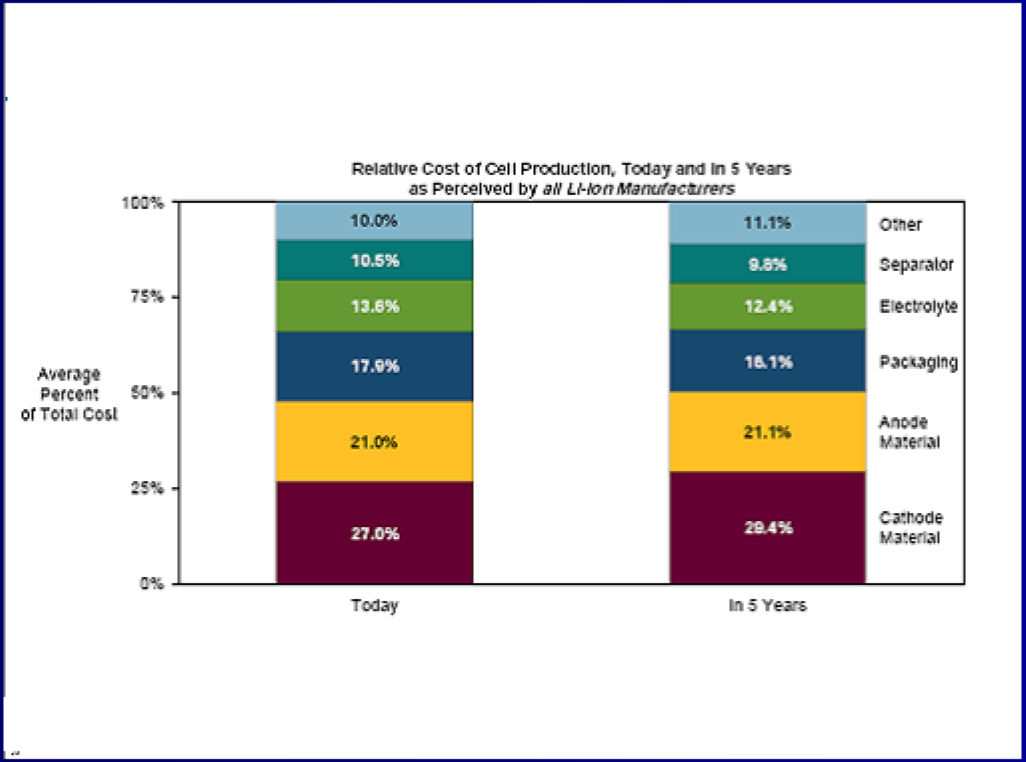
Cost Reduction

- Reducing costs of basic cell components.
- Anode/Cathode account for 50% of battery cost. (Seperator and electrolyte account for 20%)
- Manufacturers are moving operations out of areas with high labor cost, such as Japan, and moving to China, Korea, and India.

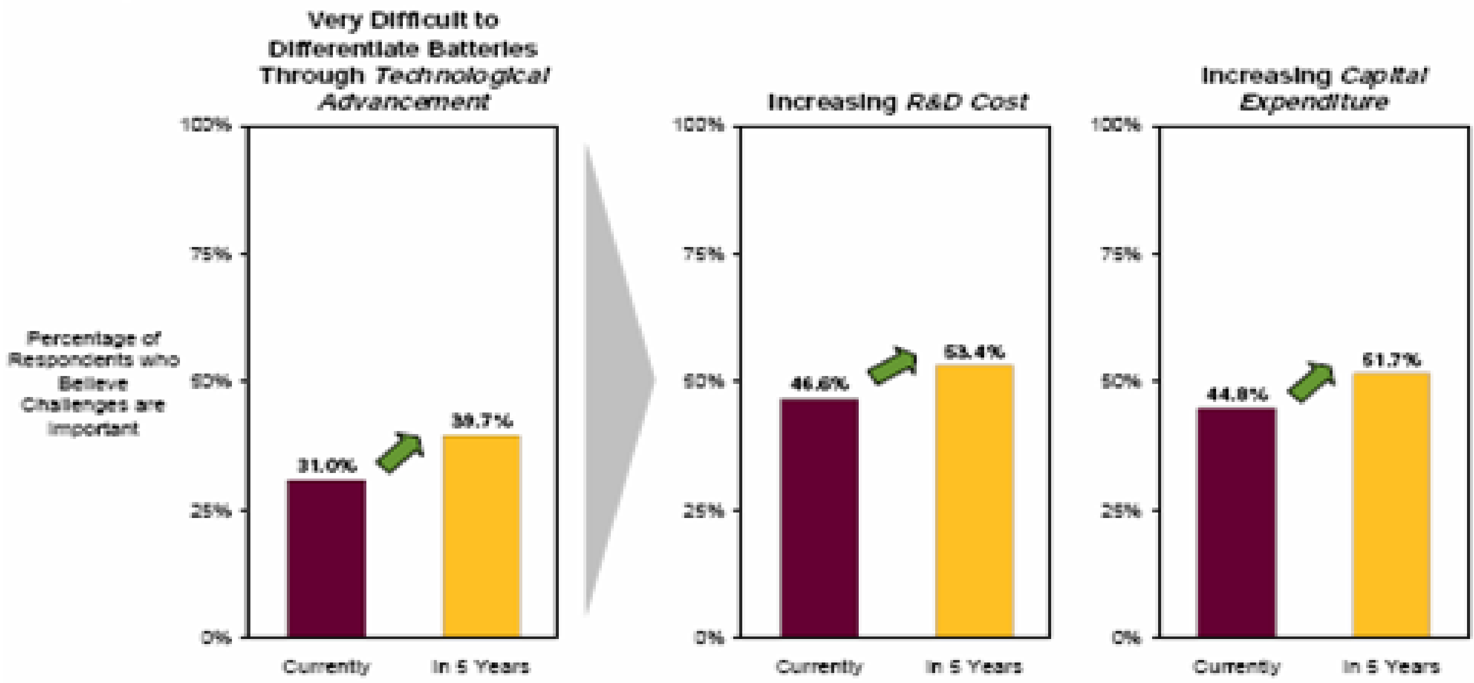
Challenges

- Margins average at 5%.
- Price Wars !
- Battery manufacturers need to differentiate themselves.
- Striving for operational excellence.
- Improved customer service.

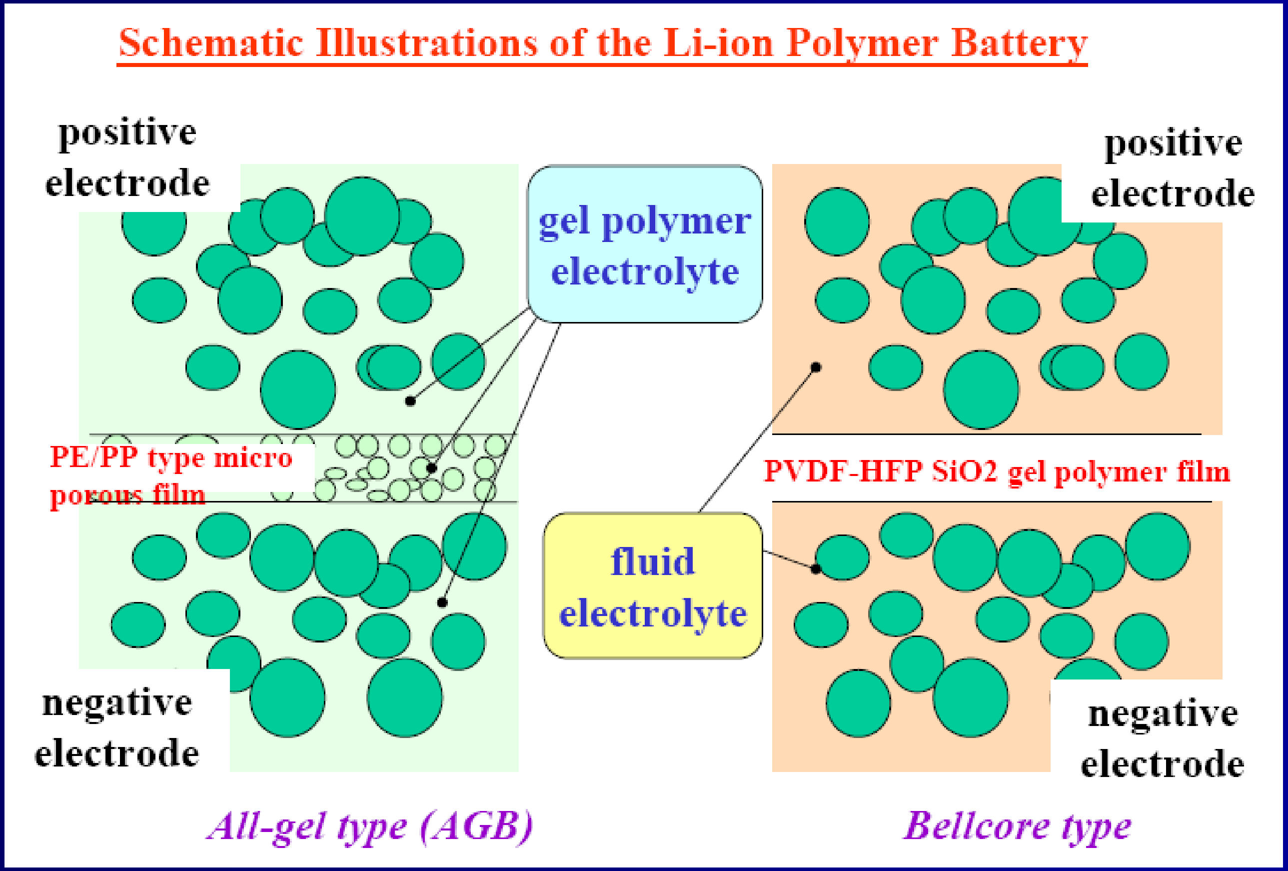
Cost Stack up of Li-ion Batteries



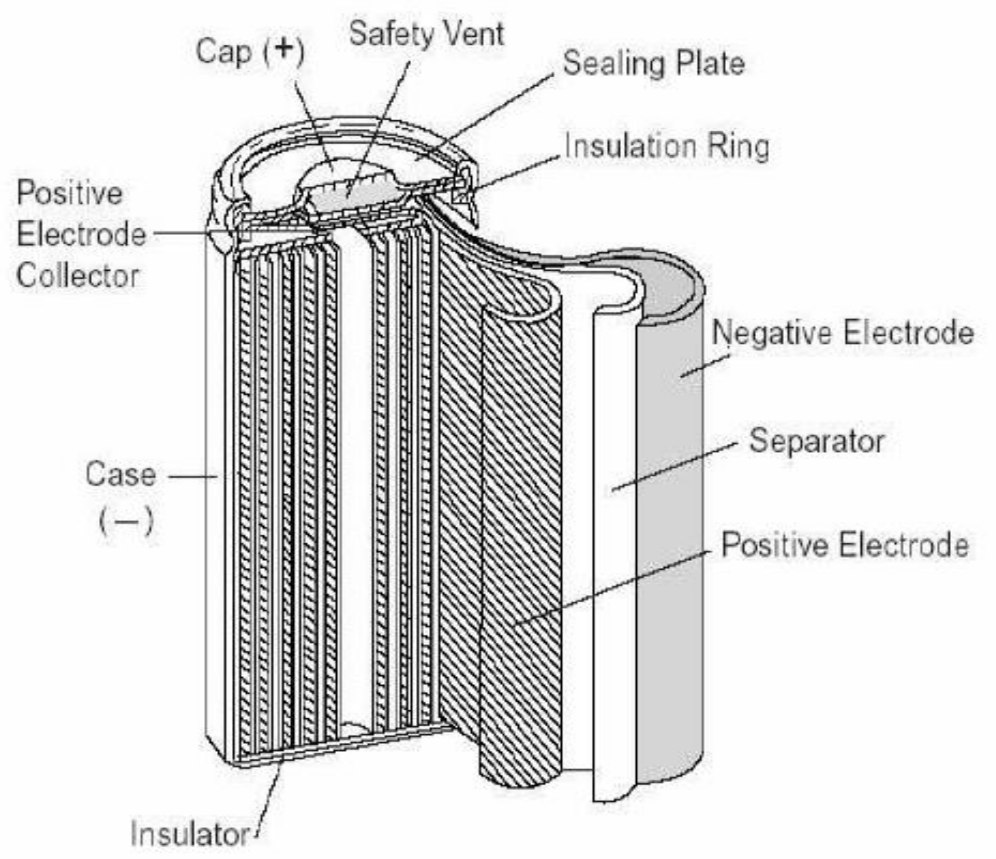
Summary of Challenges to the Battery Industry



Inside a Lithium Polymer Battery



Inside of a NiMh Battery



Cylindrical Type

Advancements to Watch For

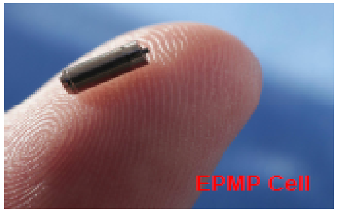
- Lithium Ion Technology in Medical devices
- Silver-Zinc
- Lead Acid
- Nickel Zinc
- Rechargeable Alkaline
- Thin Film Batteries

Lithium Ion Technology in Medical Devices

EaglePicher™
Medical Power

Background

Implantable medical batteries

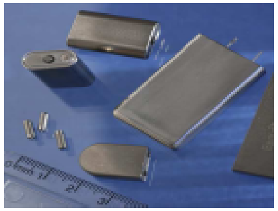


- Most important features: reliable performance, high energy density and long service life

- Primary/secondary lithium cells, like Li/MnO_2, Li/CF_x and Li-ion systems, can meet the requirements

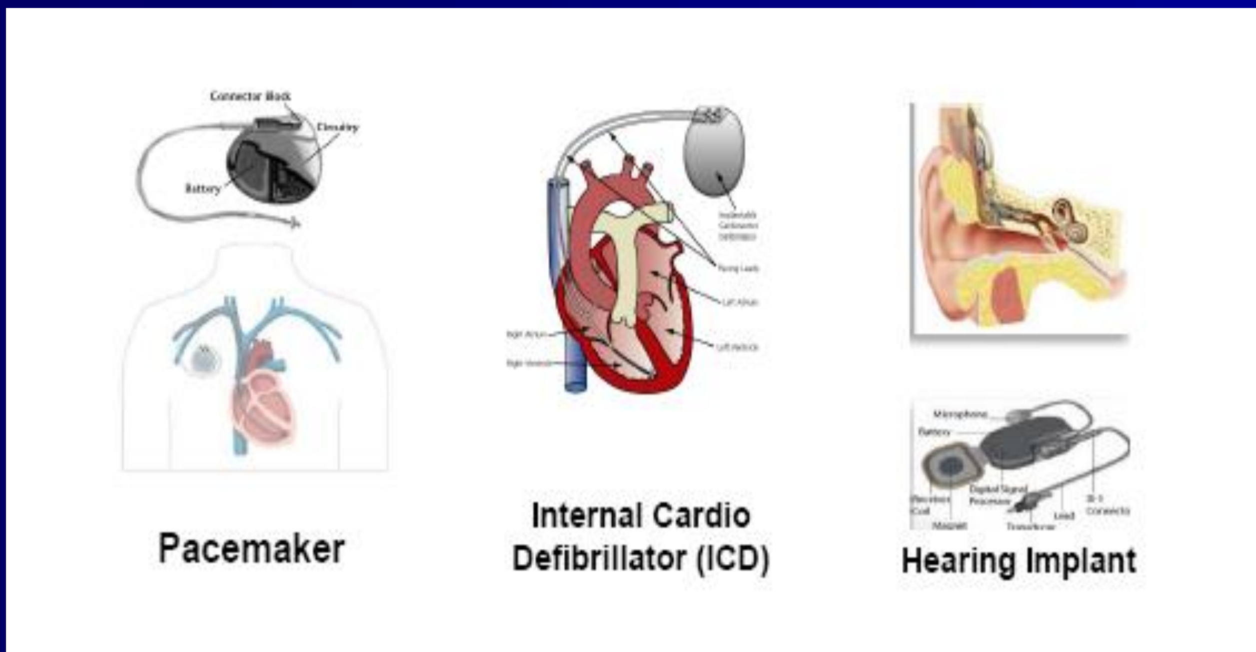
- Lithium-ion cells are a better choice for many medical power applications due to their high energy and safety characteristics

- EPMP has successfully introduced the industry's first modular lithium-ion implantable battery



EPMP Li-ion Cells

Medical Applications



Requirements:

Long life and or rechargeable.
Safety

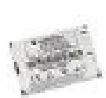
Silver Zinc

Only a handful of rechargeable battery technologies have had a commercial impact on the marketplace. Zinc Matrix Power is the next step in the evolution to make batteries lighter, smaller, and longer lasting

1801 Volta
Zn-Cu

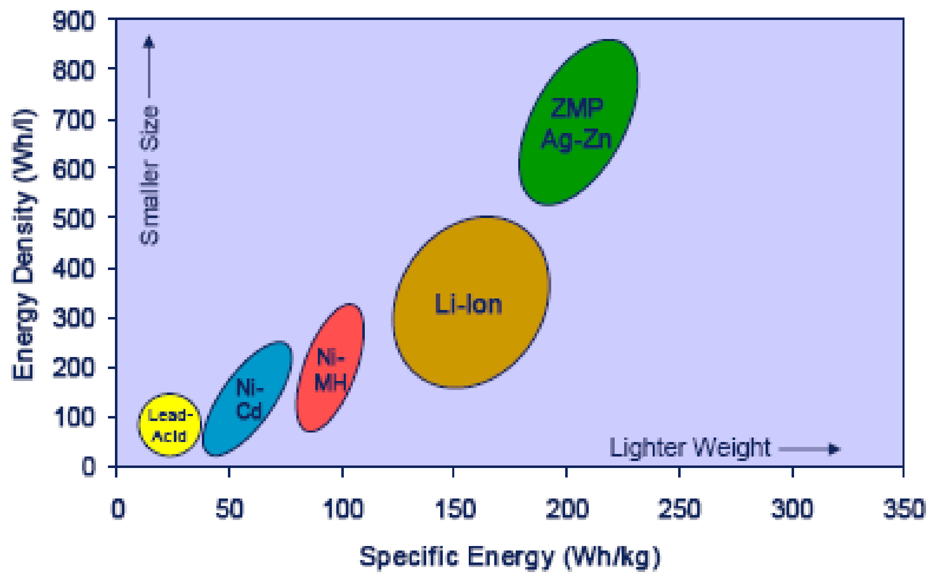
1839	Fuel Cell
1859	Pb Battery
1899	Ni-Cd
1973	Li-Metal
1975	Ni-MH
1979	Li-Polymer

1990
Sony
Li-Ion



2000
Bellcore
Plastic
Li-Ion

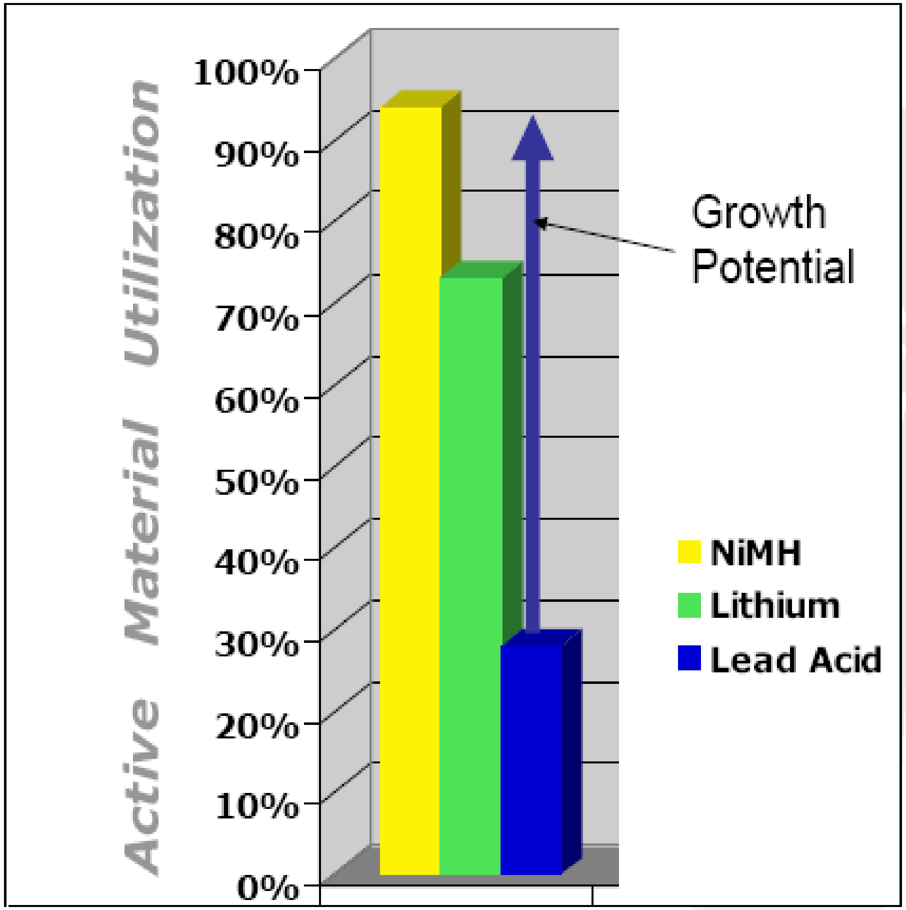
2008
ZMP
Ag-Zn



Source: Avicenne 23rd IBSE

Zinc Matrix Power

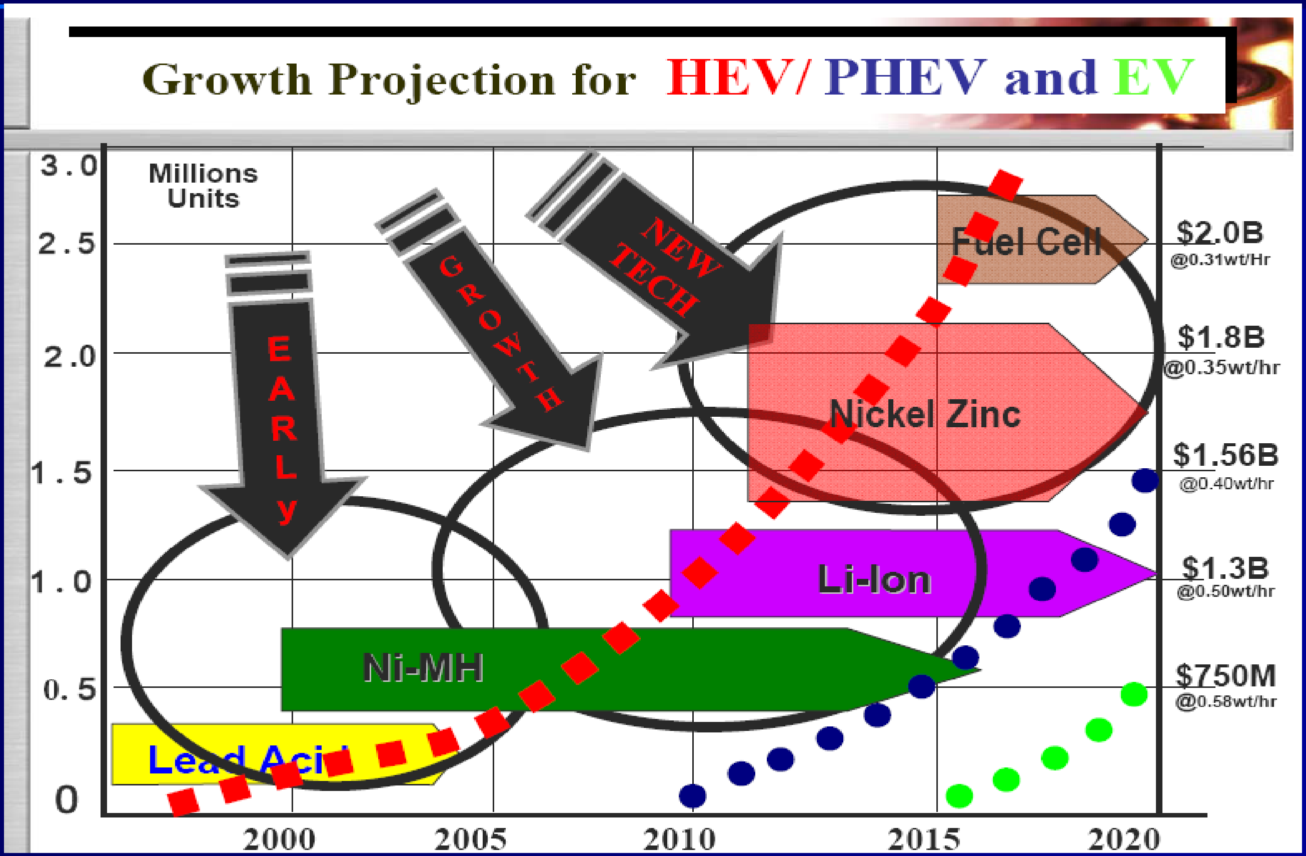
Reinvigorating Lead Acid



Tremendous Opportunity to Re-invigorate the Power of Lead Acid Chemistry

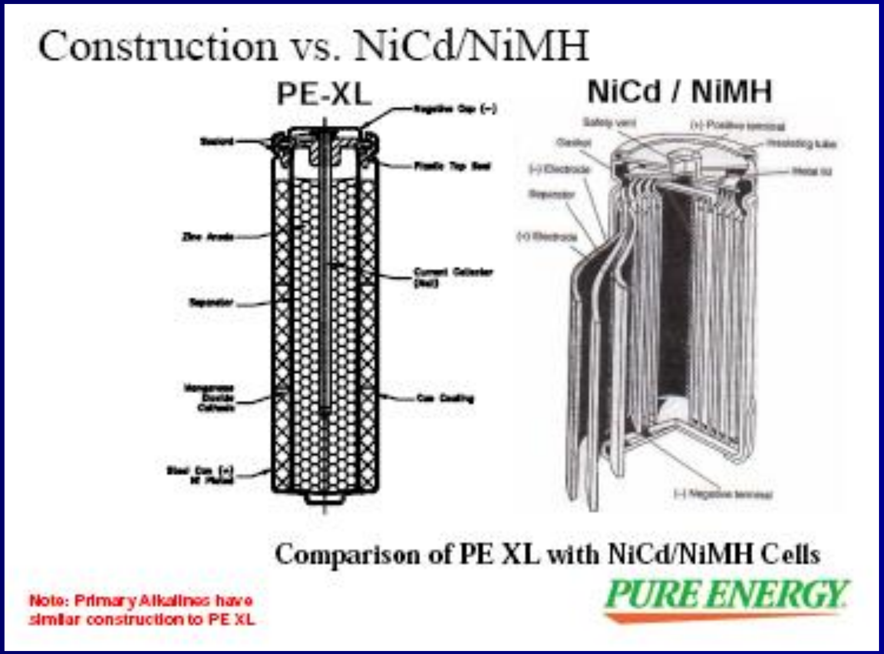
Advancements are being achieved by increasing the active surface are of the electrodes. Similar concept to that is used in Supercaps.

Nickel Zinc

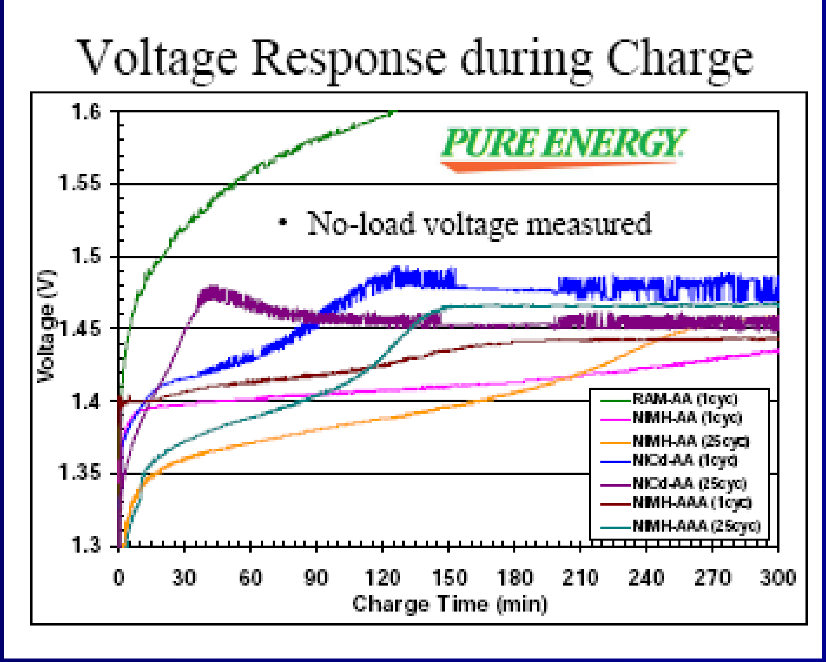


Growth Projection for HEV/ PHEV and EV
Millions Units
3.0
2.5
2.0
1.5
1.0
0.5
0
EARLy
GROWTH
NEW TECH
Fuel Cell
Nickel Zinc
Li-Ion
Ni-MH
Lead Acid
$2.0B
@0.31wt/Hr
$1.8B
@0.35wt/hr
$1.56B
@0.40wt/hr
$1.3B
@0.50wt/hr
$750M
@0.58wt/hr
2000
2005
2010
2015
2020

Rechargeable Alkaline: Replacement for NiCd



Fast Charge with Alkaline



Low Cost Materials

XL RA Material Cost

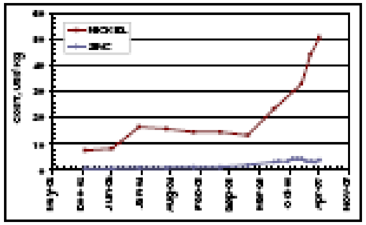
PURE ENERGY

Main ingredients are readily available low cost materials:

- Steel, Manganese Dioxide, Graphite, Zinc, Aqueous Potassium Hydroxide Solution, Separator Paper, Nylon

Unlike unstable Nickel pricing situation for Ni-based batteries:

- LME Ni cost in US$/Kg:
  - Jan-2003: \$7.56/Kg → Ratio: 1
  - Jan-2005: \$16.5/Kg → Ratio: 2.2
  - Jan-2007: \$33/Kg → Ratio: 4.4
  - May-2007: \$50/Kg → Ratio: 6.6
  - Jan-2009: ???



- About 30-40 wt.% of NiMH batteries are Ni-compounds

Good Performance

PURE ENERGY

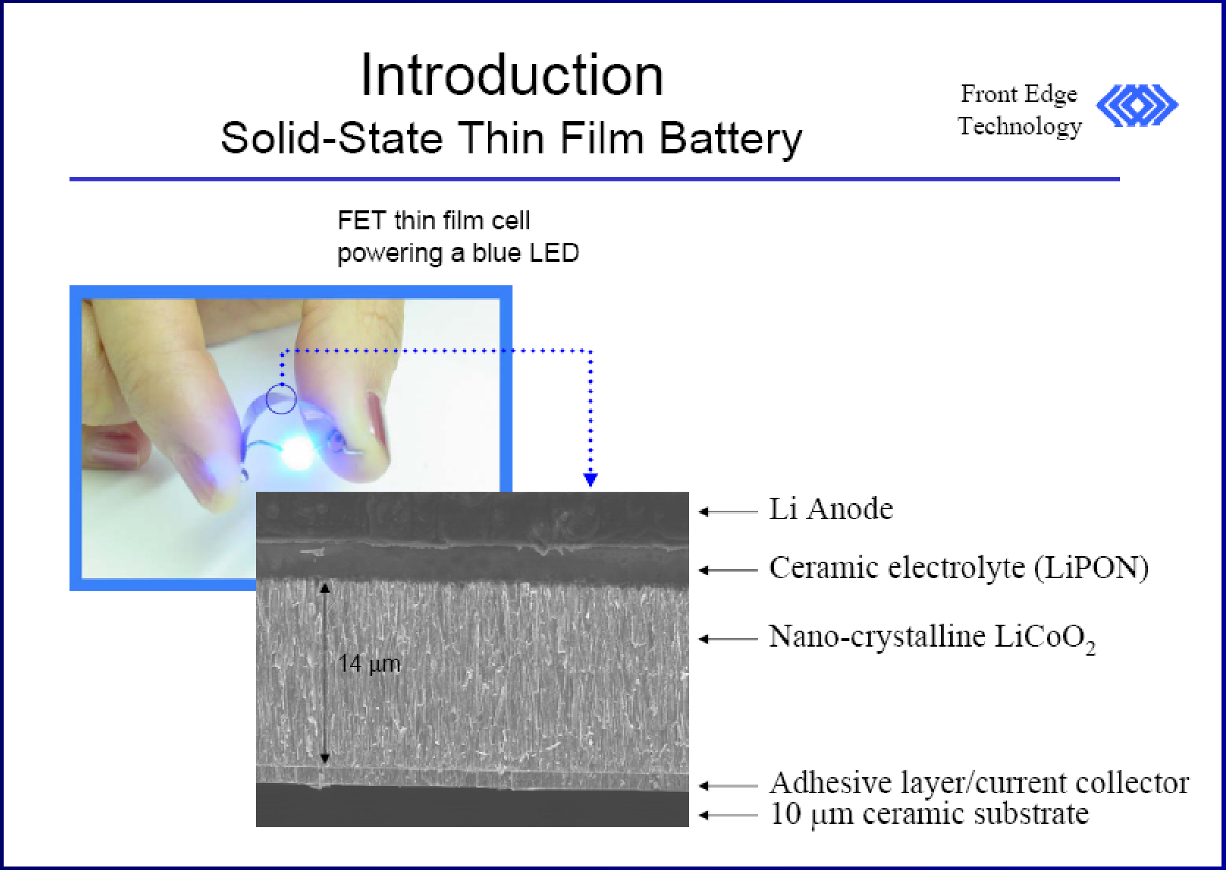
Initial Performance Comparison - AA

Rechargeable XL Alkaline vs. NiMH vs. NiCd

IEC Application Test	PE-XL	NiMH [2100mAh]	NiCd [600mAh]
Radio [43Ω, 4hpd to 0.9V]	75 hrs.	72 hrs.	21 hrs.
% of NiMH	104%	100%	29%
Personal Cassette Player [10Ω, 1hpd to 0.9V]	16 hrs.	16.5 hrs.	5 hrs.
% of NiMH	97%	100%	30%
Motor / Toy [3.9Ω, 1hpd to 0.8V]	6.0 hrs.	6.5 hrs.	2 hrs.
% of NiMH	92%	100%	31%

PE XL Cells provide about 3 times the service time of NiCd
and are competitive w/ NiMH rechargeables at medium to low rate!!!

Thin Film Batteries



Energy Density for Thin Film

Factors affecting energy density

Front Edge Technology

- Energy density of the active area:

  >1200wh/liter; >350wh/kg

- With 90% surface utilization:

  >1000wh/liter; >300wh/kg

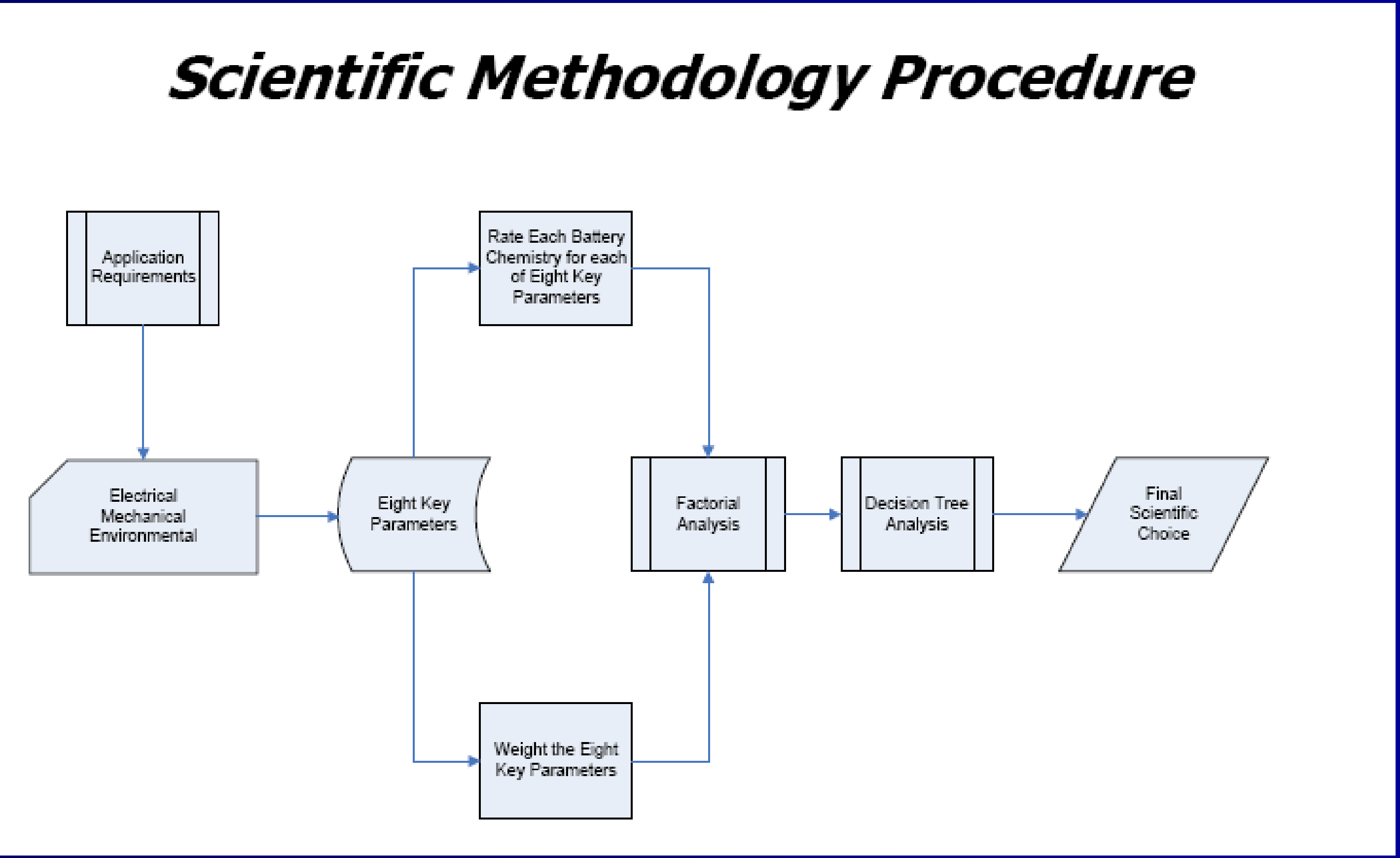
- After stacking and sealing

  2007 targets: >600wh/liter; 300wh/kg

The Future is coming

- Amorphous silicon solar cells combined and combined with thin film polymer batteries.
- Fuel cells advancements with new Hydrides for hydrogen storage.

Methodology for Selecting a Battery



Similar to hazard and failure analysis techniques.

Use of Weighting

Application Requirements Feed Into Factorial Analysis Weighting

- From Application Requirements we generated:
  - List of eight key parameters
  - Weighting factors for each parameter

		Shelf Life			Shipping			Safety			Energy Density			Power Capability			High Voltage			Disposal			Cost		
		a	(0.30)	+	b	(0.20)	+	c	(0.20)	+	d	(0.10)	+	e	(0.10)	+	f	(0.05)	+	g	(0.025)	+	h	(0.025)	
1.00	=	1.00	(0.30)	+	1.00	(0.20)	+	1.00	(0.20)	+	1.00	(0.10)	+	1.00	(0.10)	+	1.00	(0.05)	+	1.00	(0.025)	+	1.00	(0.025)	

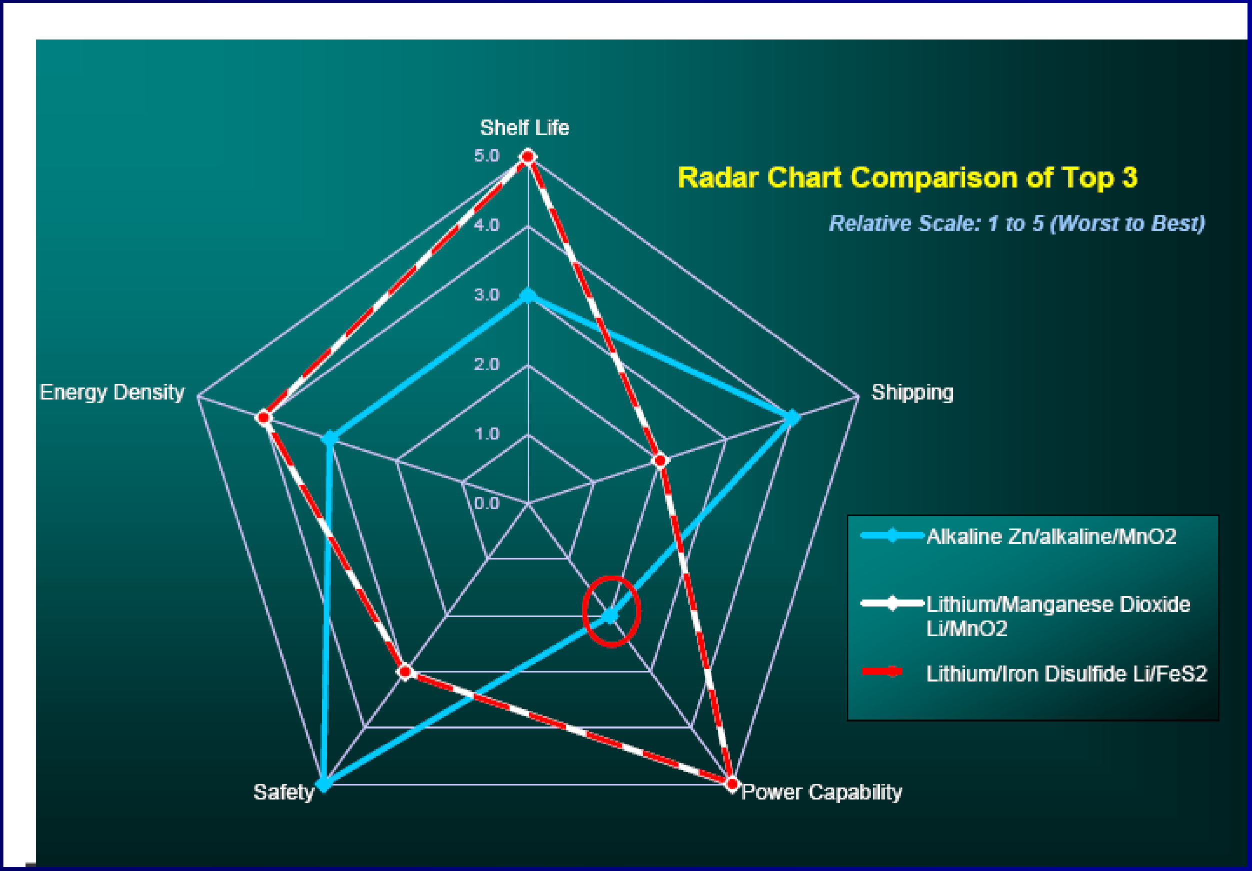
Rating categories.

Battery Chemistries Rated for Each Parameter

- Battery chemistries are rated for each of the eight parameters:
  - Shelf life
  - Safety
  - Shipping
  - Energy Density
  - Power Capability
  - High Voltage
  - Disposal
  - Cost

- Comments and values entered into master table, then translated into a 1 to 5 rating for each battery chemistry

Radar Chart

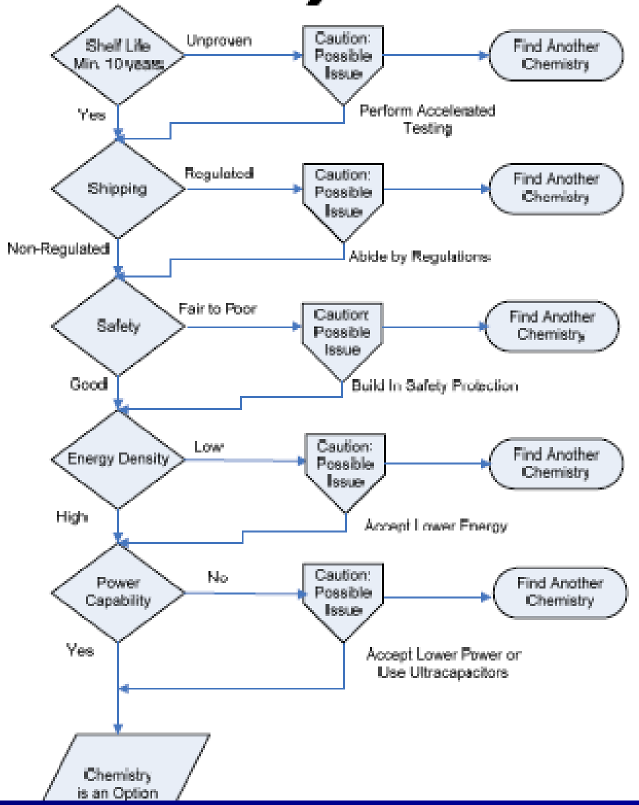


Radar Chart Comparison of Top 3
Relative Scale: 1 to 5 (Worst to Best)
Shelf Life
5.0
4.0
3.0
2.0
1.0
0.0
Shipping
Power Capability
Safety
Energy Density
Alkaline Zn/alkaline/MnO2
Lithium/Manganese Dioxide Li/MnO2
Lithium/Iron Disulfide Li/FeS2

The Decision Tree

Decision Tree Analysis

- Decision Tree includes top five ranked criteria
- Each chemistry is put through Decision Tree
- Used to differentiate between similar scores in Factorial Analysis
- Green = OK
- Yellow = Caution
- Red = Problem



When this happens !

February 2007 Battery
Incident on JetBlue Plane

.Gov and .org to The Rescue!

The Past 15 Months

- Feb. 2006: UPS plane fire at Philadelphia airport
- July 2006: NTSB hearing on UPS incident
- August-Sept 2006: Recalls
- Sept.-Oct. 2006: Several new lithium ion battery standard setting initiatives announced (IPC, IEC, IEEE, UL)
- Nov. 2006: CPSC issues report on *Safety Testing of Lithium Ion Cell Phone Batteries*
- Dec. 2006: UN Subcommittee adopts more stringent lithium battery dangerous goods transportation regulations
- January 2007: New Thai battery standard goes into effect

PRBA
PORTABLE RECHARGEABLE BATTERY ASSOCIATION

More regulation.

The Past 15 Months

- Feb. 2007: Battery incident on JetBlue aircraft
- Feb. 2007: DOT “battery safety” meeting
- March 2007: ICAO proposals on lithium ion batteries; US DOT issues Safety Advisory
- April 2007: Japan Electronics and Information Technology Industries Association–Battery Association of Japan issue *Safe Use Manual for Lithium Ion Rechargeable Batteries in Notebook Computers*
- May 2007: PRBA-DOT meeting on lithium ion standards and regulations

PRBA
PORTABLE
RECHARGEABLE
BATTERY
ASSOCIATION

More Testing Standards for Lithium Ion Batteries

Lithium ion Battery Standards Comparison

	Design	Testing	Manufacturing
System	IEEE UL6950 UL60745 JEITA/BAJ	IEEE UL6950 UL60745	IEEE UL FUS UL60745
Pack	IEEE UL2054 IEC/ANSI BAJ	IEEE UL2054 IEC/ANSI UN	IEEE UL FUS
Cell	IEEE UL1642 IEC/ANSI JEITA/BAJ	IEEE UL1642 IEC/ANSI UN JEITA/BAJ	IEEE UL FUS

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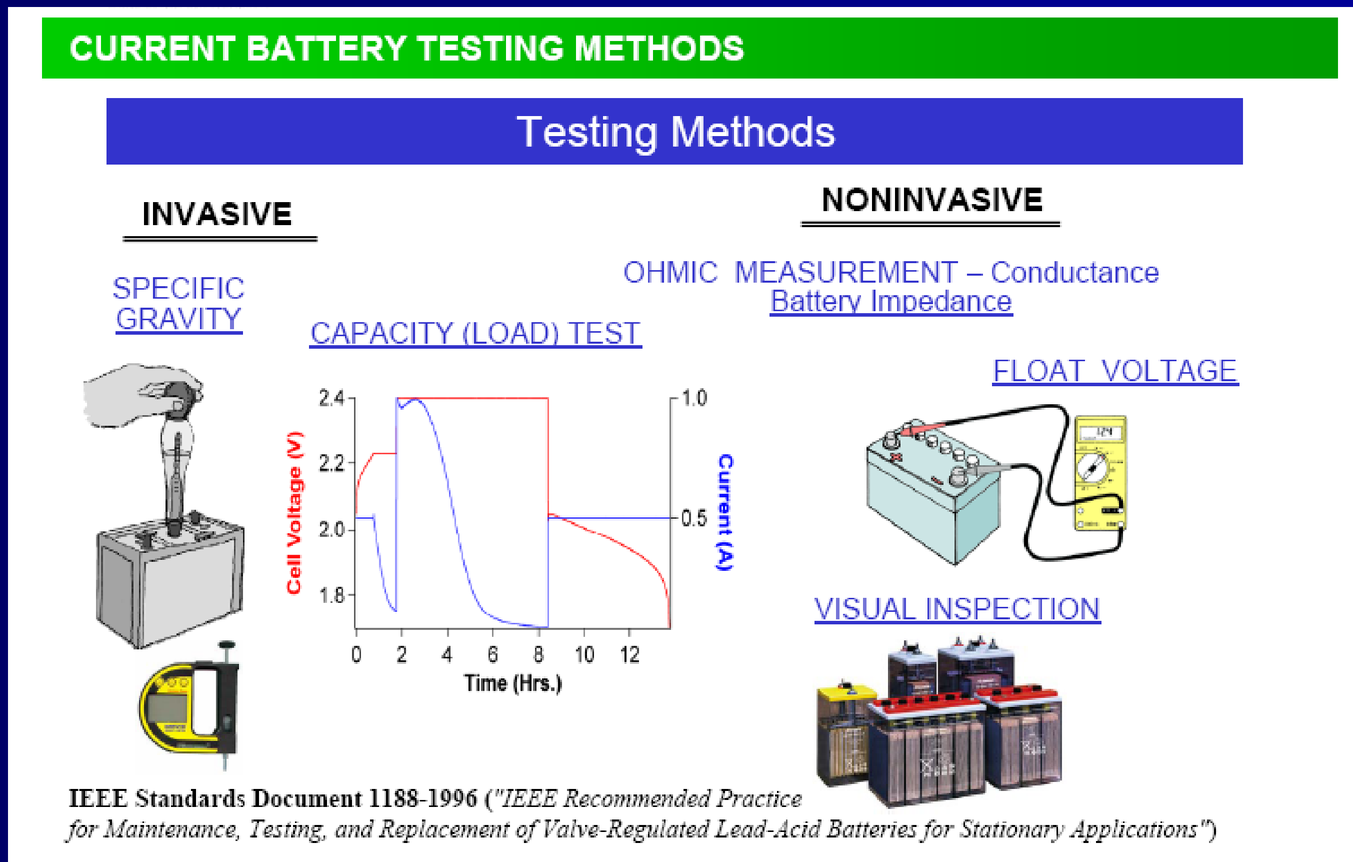
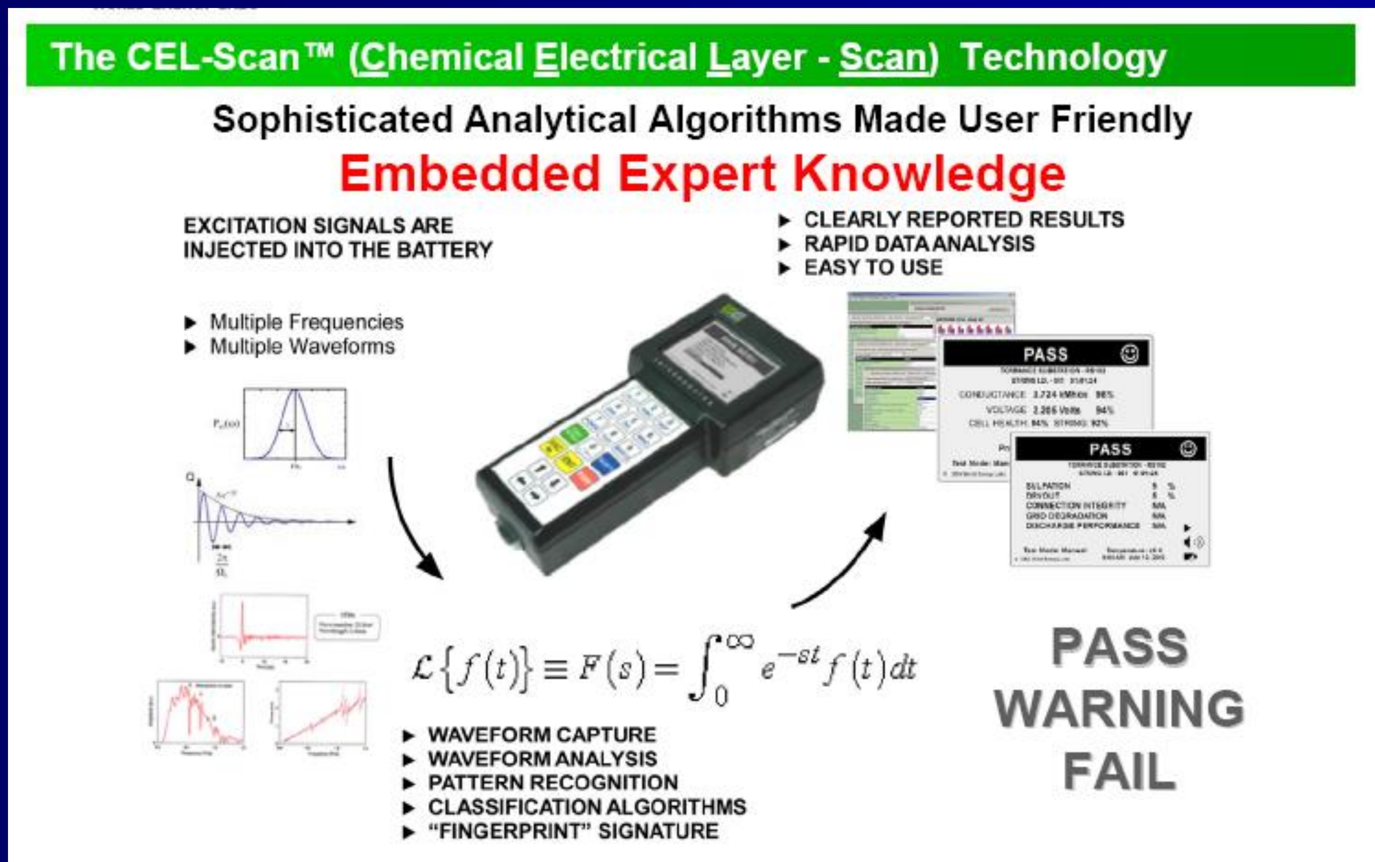
Testing Batteries for SOH



Impedance Spectroscopy to Measure "SOH"



Summary and Predictions

Summary

- Lithium Ion will dominate in growth markets for the near term.
- Lithium Polymer is near form factor limits.
- Advancements will occur with exotic metal mixes within the cathode/anode.
- New Electrode configurations will reinvigorate old battery technologies.
- Manufacturers will face material shortages and price pressure.
- Regulatory pressures and green initiatives will have impacts on all battery technologies.

Predictions

- There will be consolidation in the battery industry.
- Ventures/mergers between startup R&D and manufacturers will increase.