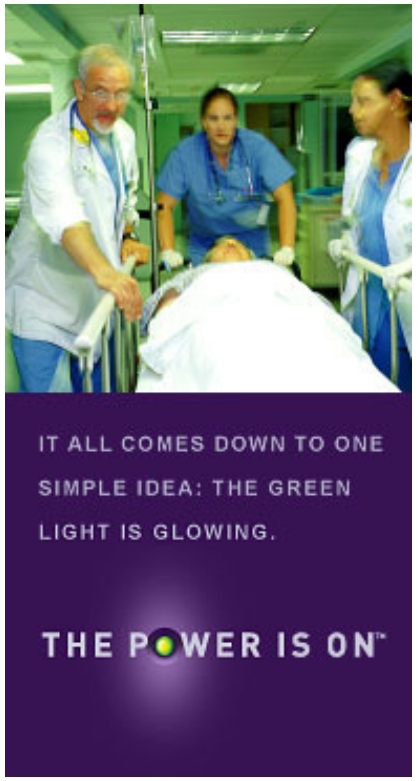
Safe Battery Design, Updates and Innovations from the Battery Industry

Agenda

- Micro Power Introduction
- Cell Selection
- Novel battery chemistries
- Safe battery manufacturing
- Conclusions and Questions

About Micro Power Electronics

- Battery packs and chargers
- Exclusive OEM customers
  - Medical
  - Military
  - Industrial
- Twenty years experience
- FDA Registered and ISO certified



Battery performance critical in our core markets

Creating strong demand for mission-critical battery systems

Portable Medical Equipment & Devices

- Defibrillators
- Patient Monitors
- Infusion Pumps
- Endoscopy

"Portable Patients"

Handheld AIDC & Rugged Computing

- Barcode Scanners
- RFID Readers
- Portable Printers
- Handheld Computing

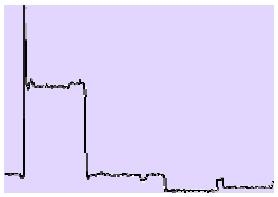
"Portable Data Collection"

Commercial Military & Industrial GPS

- Ruggedized Radios
- Troop Location Devices
- Asset Management
- Survey & Mapping Devices

"Portable Soldiers"

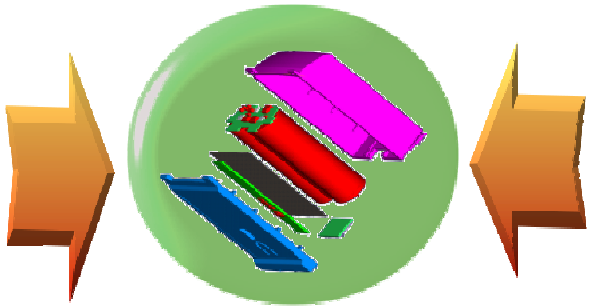
Today's feature-packed portables creating tougher demands



High Pulse Currents

Extreme Environments

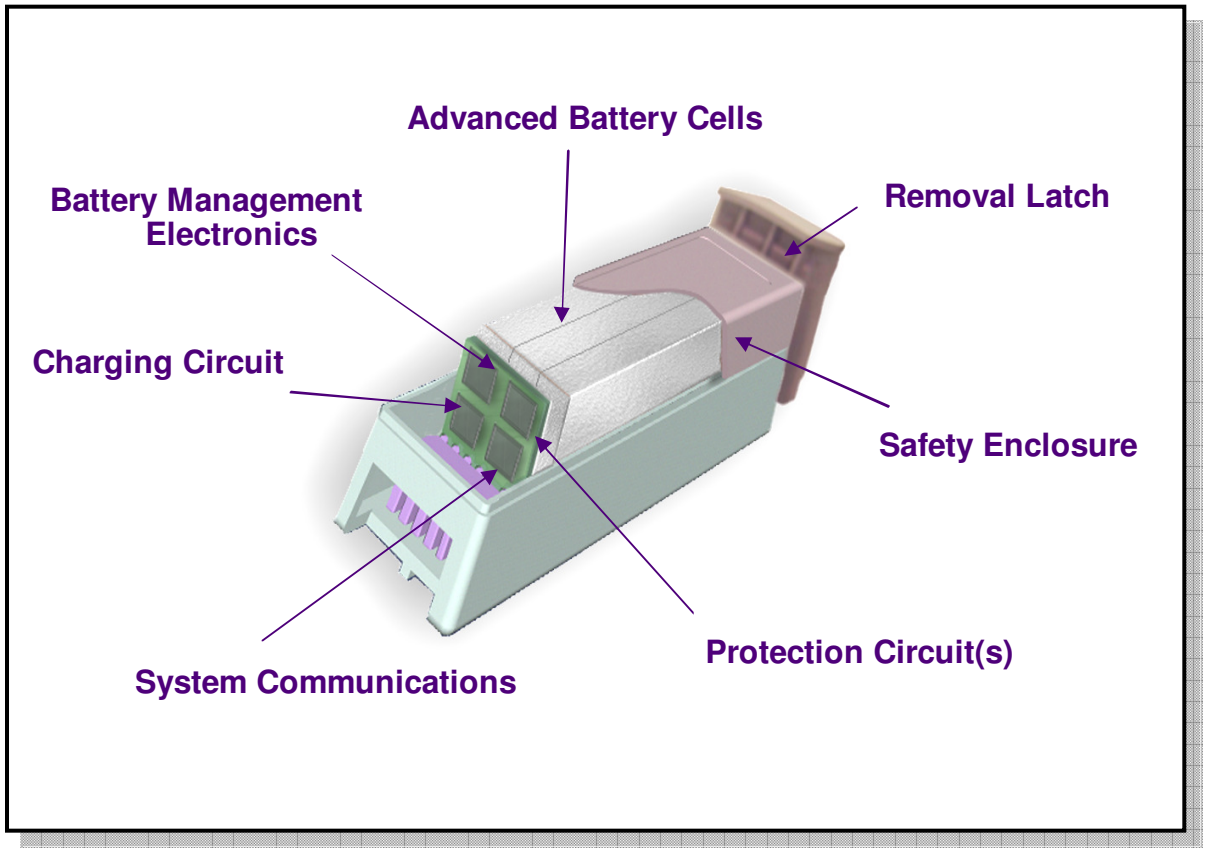
Full-Day Operation



Small Ergonomic Form Factor

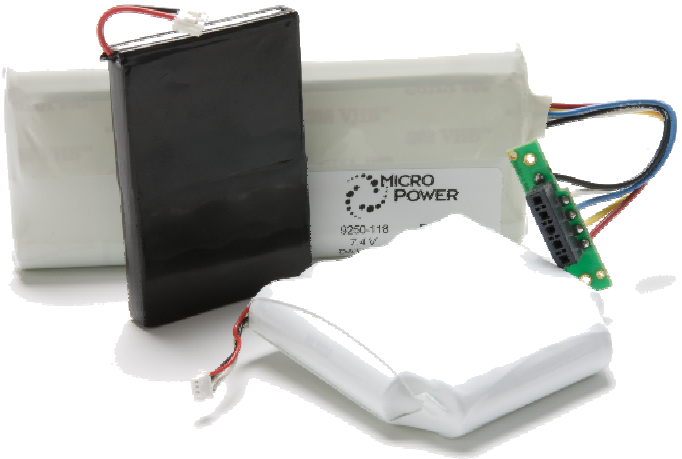
Battery Pack Features

Custom High Performance Battery System



Mechanical Options

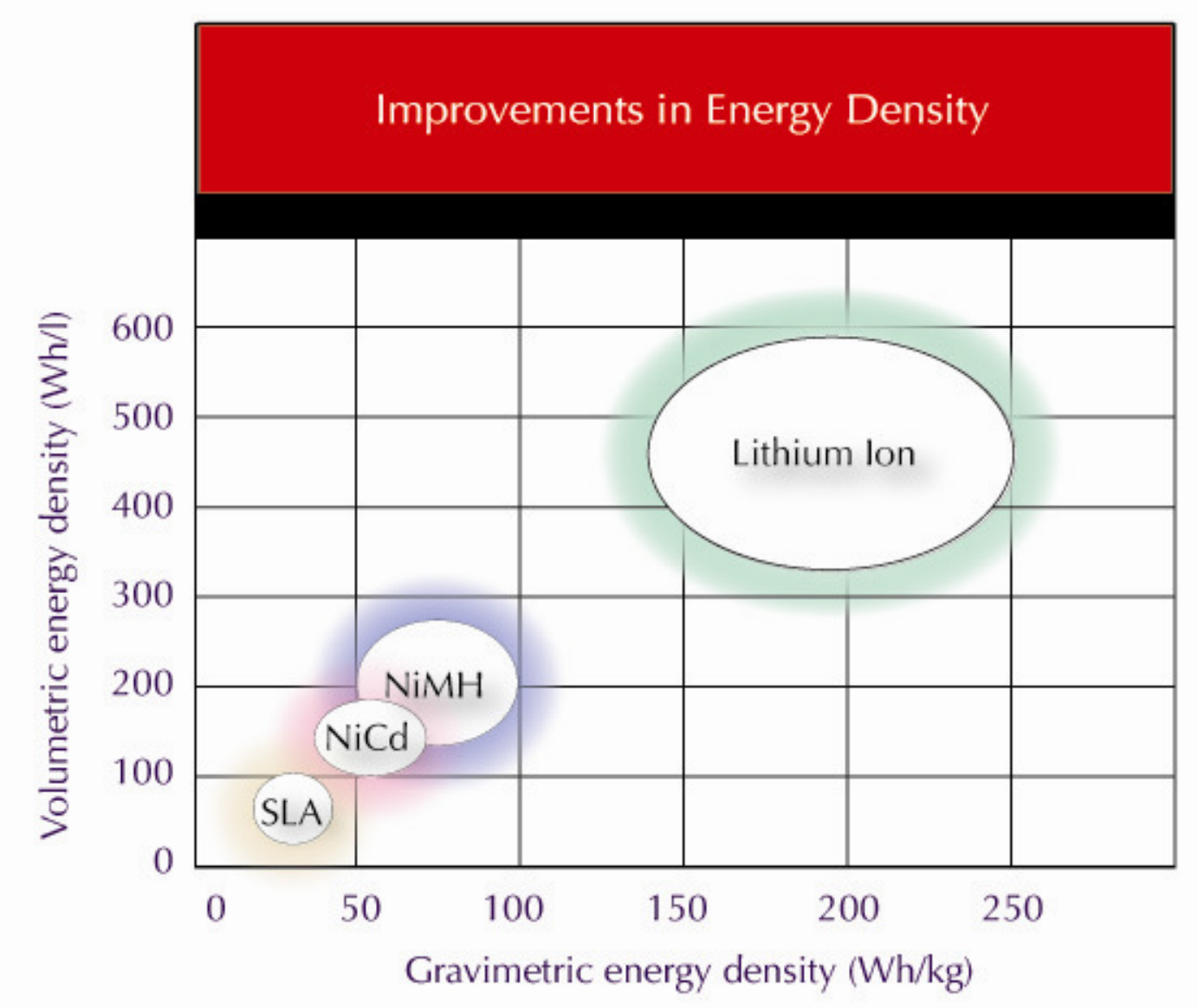
- **Full plastic enclosure with rigid frame**
  - Possible materials: PolyCarbonate (PC), ABS, PC/ABS blends, some with Fire Resistant (FR) additives, Nylon, or Acrylic
- **Shrink-wrap**
- **Connectors**
  - Typical kinds: Molex, Tyco, Mill-Max pogo-pins and Samtec PCB headers
- **Insulation**
  - Absorbs external shock and retain the positioning of internal components
- **Visual display or indicator**
  - LED's or on screen



Chemistry Selection

- **Battery pack configuration**
  - Cells can be added in series to increase voltage
  - Cells are added in parallel to increase capacity

	SLA	NiCd	NiMH	Li-ion
Operating Voltage (V)	2	1.2	1.2	3.6
Max. Series Cells (V)	12 (24V)	10 (12V)	10 (12V)	7 (25V)
Energy Density	35 Wh/kg 70 Wh/L	40 Wh/kg 125 Wh/L	70 Wh/kg 200 Wh/L	175 Wh/kg 500 Wh/L
Cycle Life	500-800	500-1000	500-1000	500
Advantage	Cost	High drain rates	Good value	High energy density
Disadvantage	Low capacity	Low capacity	Venting	Complicated Packs


Improvements in Energy Density
Volumetric energy density (Wh/l)
600
500
400
300
200
100
0
Lithium Ion
NiMH
NiCd
SLA
0
50
100
150
200
250
Gravimetric energy density (Wh/kg)

Advantages of Li-ion for Portable Devices

- ✓ **Higher energy density**
- ✓ **Lighter weight**
- ✓ **Longer cycle-life**
- ✓ **Superior capacity retention**
- ✓ **Faster charge**
- ✓ **Accurate fuel gauging**
- ✓ **More environmentally friendly**
  - No recycling restrictions for discharged cells
  - Regulations Restriction of Hazardous Substances (RoHS)

★ **Challenge: difference in charging regimen**

Cell Shape and Size Options for Li-ion

- **Cylindrical, Common sizes: 18mm diameter and 65 mm long**

Cylindrical	
Pros	**Cons**
Higher energy density	Not thin
Standard sizing	Tolerance issues
Wound electrodes	Capacity gains slowing
Lower cost per watt hour	Most development 18650

- **Prismatic, Common sizes: length 50, width 34mm and height 4-12mm**

Prismatic	
Pros	**Cons**
Thin profile	No standard
Al cans reduce weight	Swelling
Volumetric efficiency in pack	Fewer safety features
Rounded edges/ergonomic	Higher price per Watt hour

- **Li-ion Polymer Rechargeable (Secondary)**
  - Available in custom shapes, Thin (2.5-12mm), lightweight, slightly flexible, expensive

Comparison of Alkaline and Similar Li-ion and NiMH

	Alkaline (AA)	NiMH (Fat 4/3A)	Li-ion (18650)
Configuration	3S2P	3S1P	1S2P
Pack Operating Voltage (V)	3.6	3.6	3.6
Pack Capacity (Ah)	5.9	4.5	4.8
Pack Weight (g)	138	186	89
Operating Temp (C)	-20 -> +54	0-> +50	-20 -> +60
Pack Volume (cm^3)	63.6	66.6	43.5
Run time at 5W (hrs)	4.3	3.2	3.5

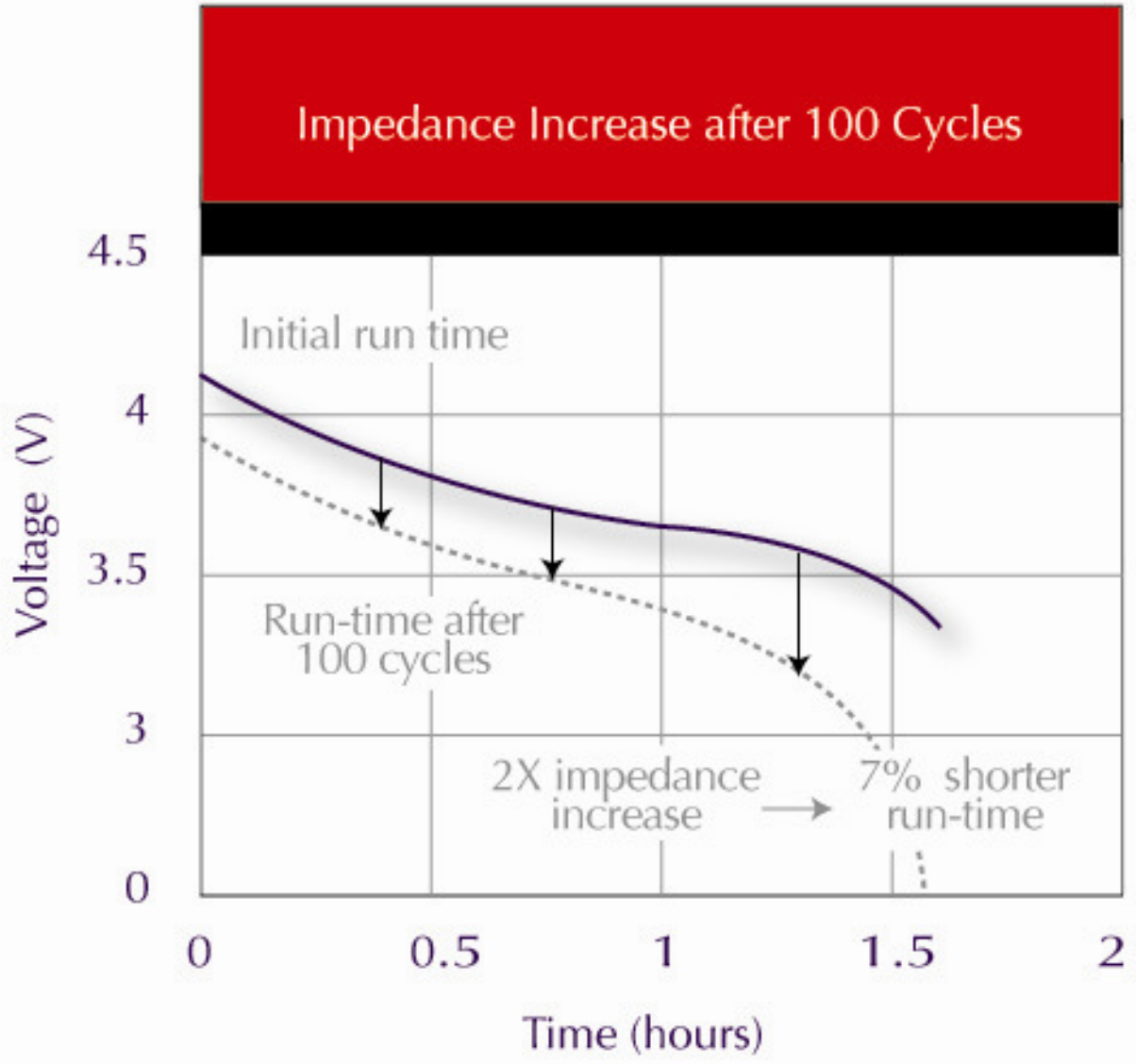
Replace a non-rechargeable with a rechargeable: Li-ion is 1/2 the weight and 2/3 the volume of the equivalent NiMH battery pack!

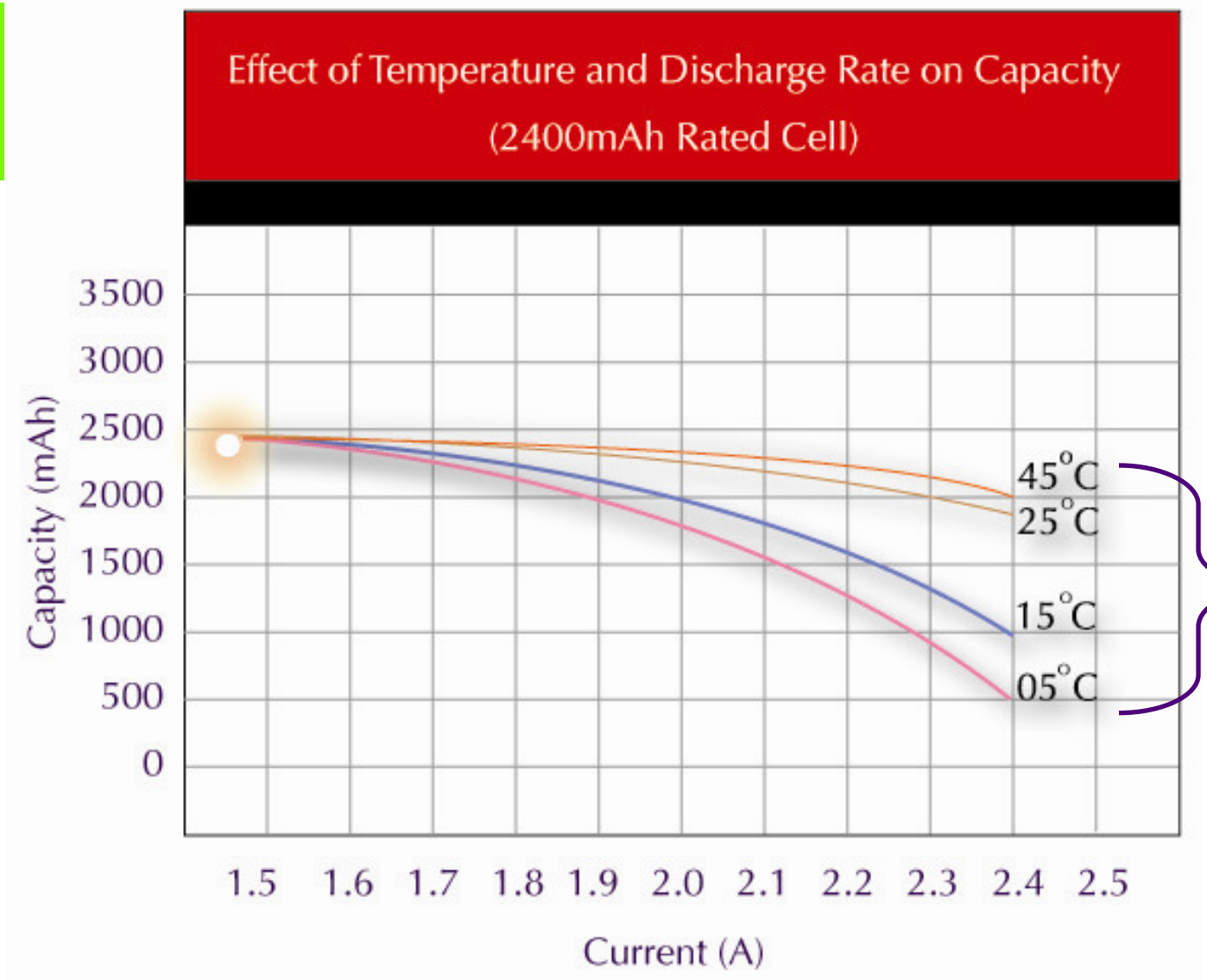
Comparison of Similar SLA and Li-ion packs

	SLA 2 x LC-RA127R2P	Li-ion 18650s	
Configuration	6S-2P	4S-4P	3S-6P
Volume [l]	1.85	0.34	0.38
Weight [kg]	4.94	0.67	0.76
Thickness [cm]	6.5	3.4	3.4
Voltage range [V]	10.5 –13.7	11.0 – 16.8	8.25 – 12.6
Run time at 12 W [hrs:min]	7:12	6:30	7:18
Run time at 14 W [hrs:min]	6:06	5:34	6:15
Run time at 16 W [hrs:min]	5:15	4:52	5:28

Replace a non-rechargeable with a rechargeable: Li-ion is 1/7 the weight and 1/5 the volume in order to achieve the necessary runtime!

MPE Advanced Systems Lab


Impedance Increase after 100 Cycles
4.5
4
3.5
3
0
Voltage (V)
Initial run time
Run-time after
100 cycles
2X impedance
increase
7% shorter
run-time
0
0.5
1
1.5
2
Time (hours)

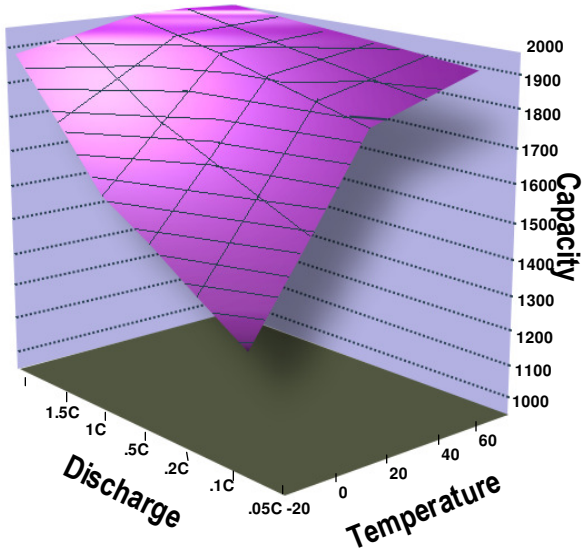


65% variation in capacity

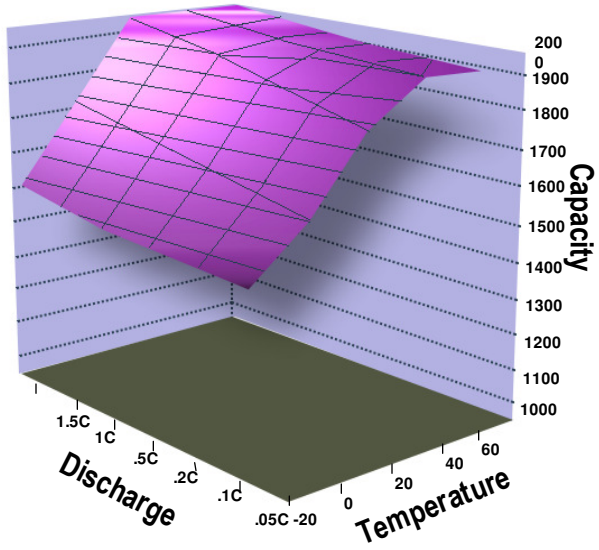
Makes predicting run time difficult

Test similar cells from multiple manufacturers

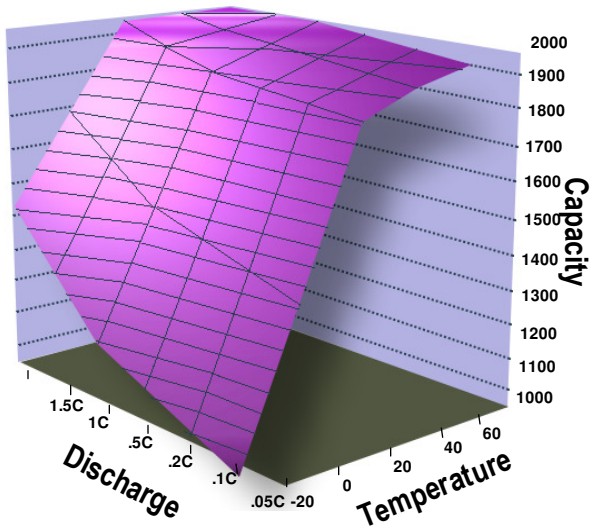
Cell Manufacturer A



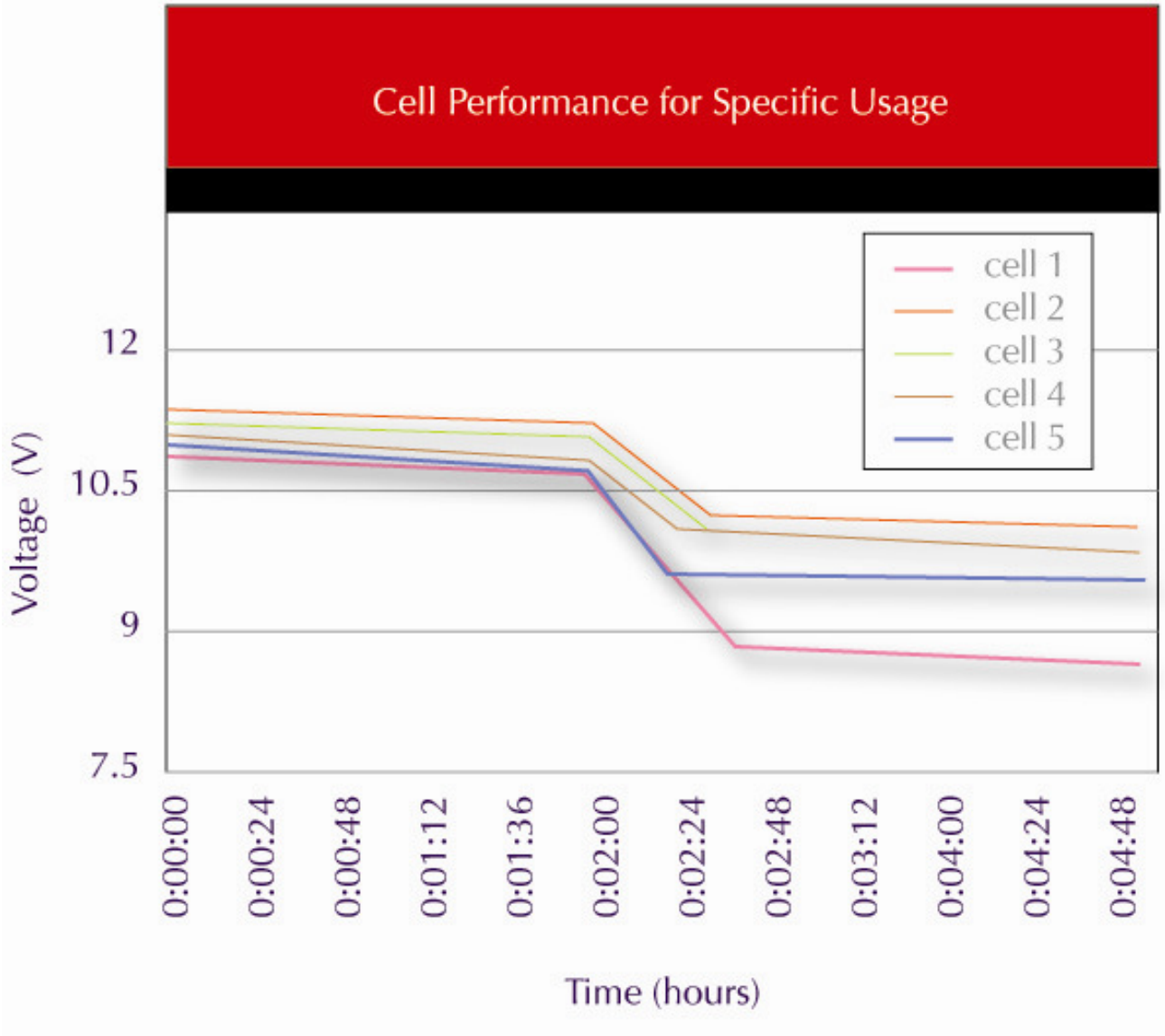
Cell Manufacturer B



Cell Manufacturer C



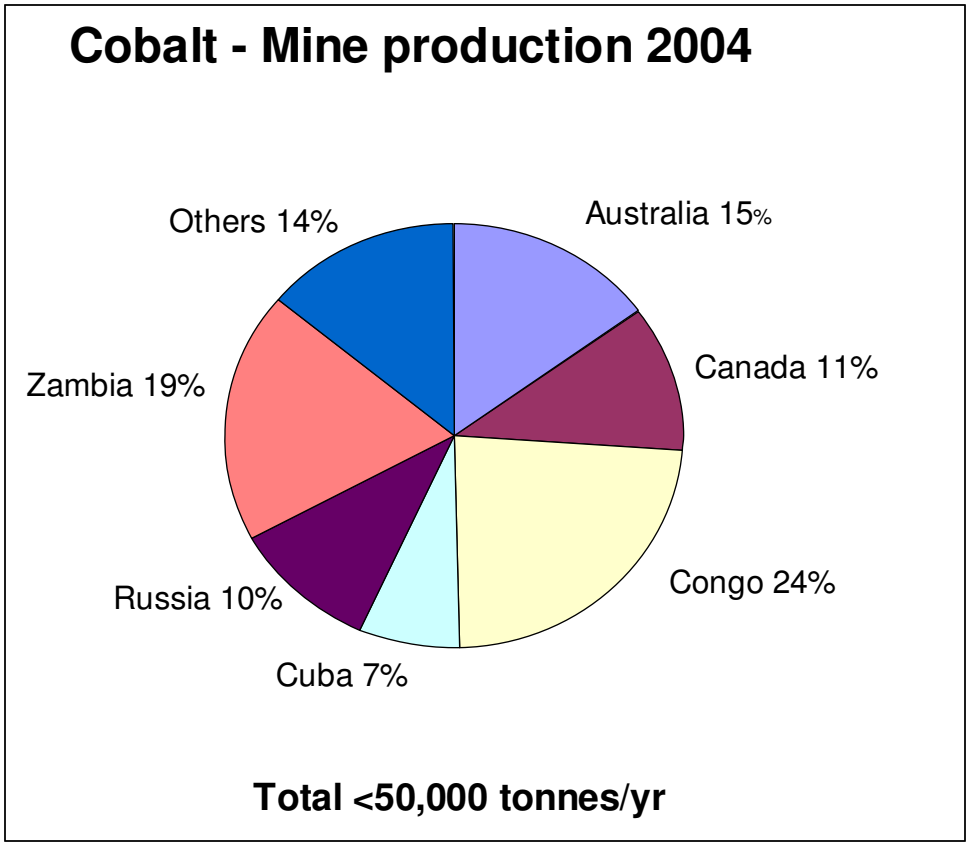
Source: MicroChip



Cutoff voltage

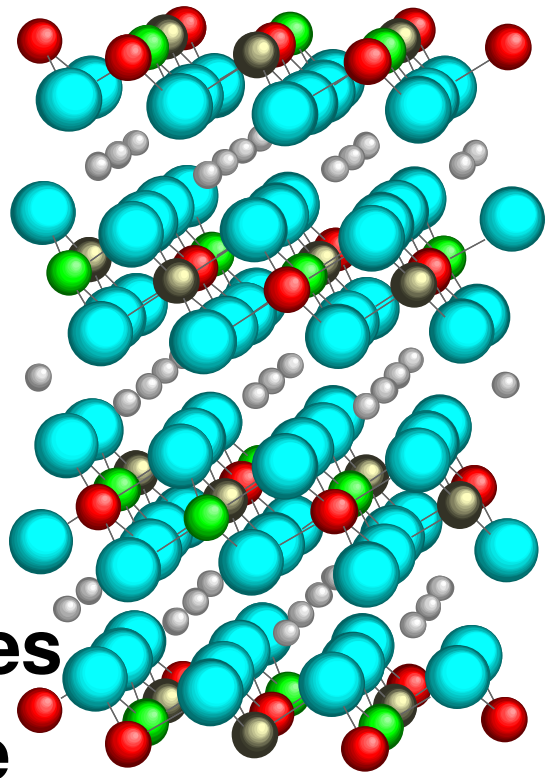
Future direction - away from Cobalt

- **Cobalt Cathode**
  - Cobalt is considered a “Strategic Metal”
  - 64% of known deposits in Congo and Zambia – political stability ?
  - Price fluctuation $5.50 to $25/lb with spot prices at $50/lb
  - Chemically more volatile than other potential cathode materials
- **Alternative Cathode Materials**
  - Nickel – Much less volatile than Co, both economically and chemically. Also, much less efficient at charge cycling
  - Manganese – Cheap and safe with very good rate capabilities. Poor energy density and slightly soluble in electrolyte



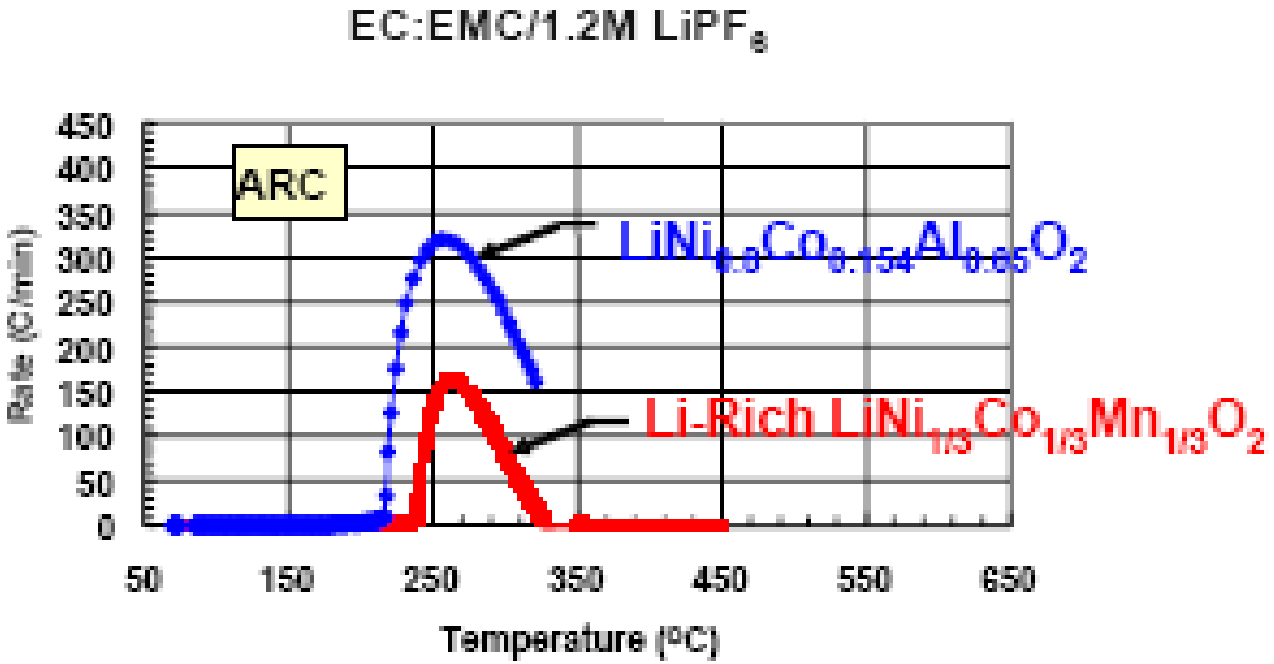
Introduction of New Cathode Materials

- **$LiCoO_2$ is standard**
- **$Li(CoMnNi)O_2$ and $Li(CoAlNi)O_2$**
- **$LiFePO_4$ and $LiMn_2O_4$**
- **Benefits**
  - Increased safety
  - Less raw metal price fluctuations
  - Rate capability
- **Solid solution from many sources**
- **Others most likely single source**



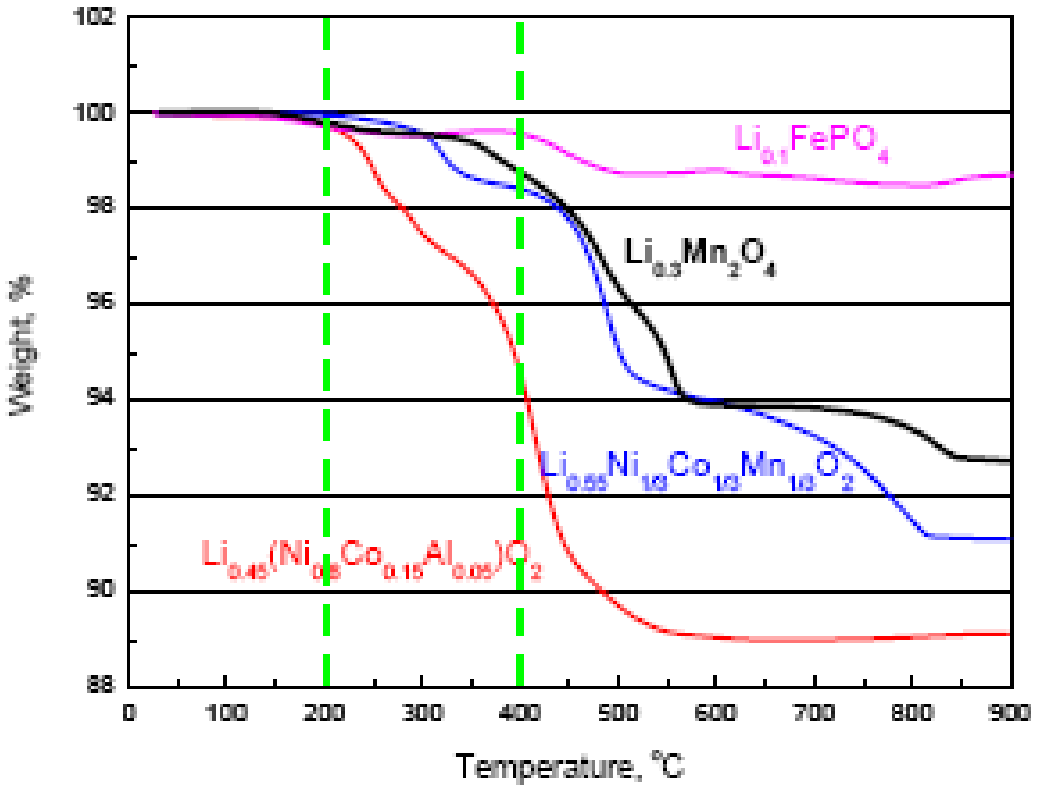
ARC Test of 18650s

- ARC test shows that although all cells have the same graphite anode and same electrolyte, their thermal behaviors are different.
- Cathode impact on overall cell thermal behavior is dominant.



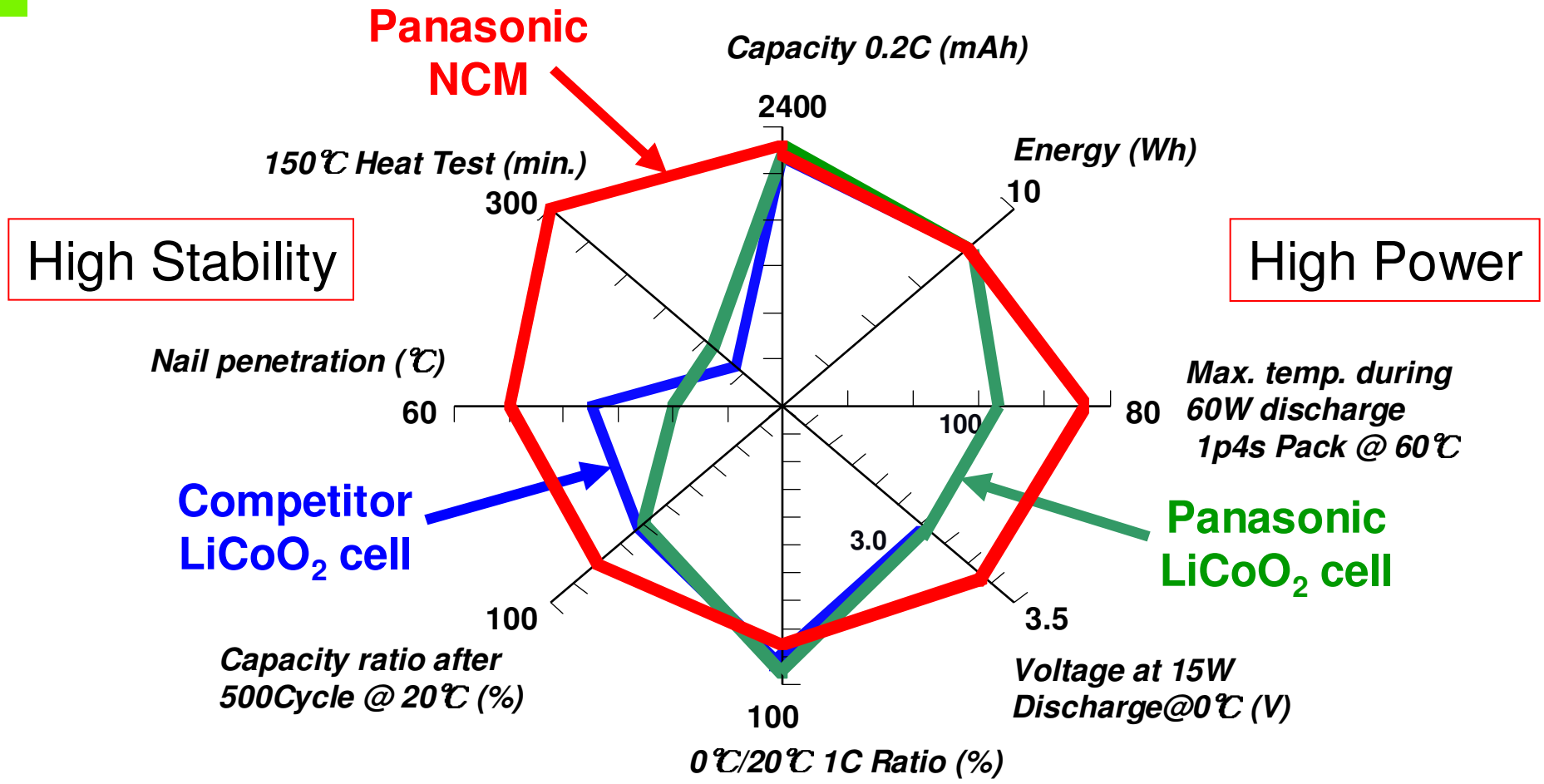
Advanced Cathodes

- **TGA indicates thermal volatility**
- **In order of safety**
  - Olivine
  - $LiMn_2O_4$
  - $LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$
  - $LiNi_xCo_yAl_zO_2$



From battery and Fuel Cell Technology for Portable Devices 2006

Comparison of Panasonic Cell Characteristics

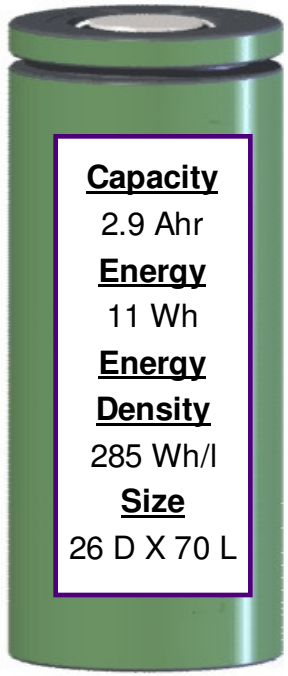


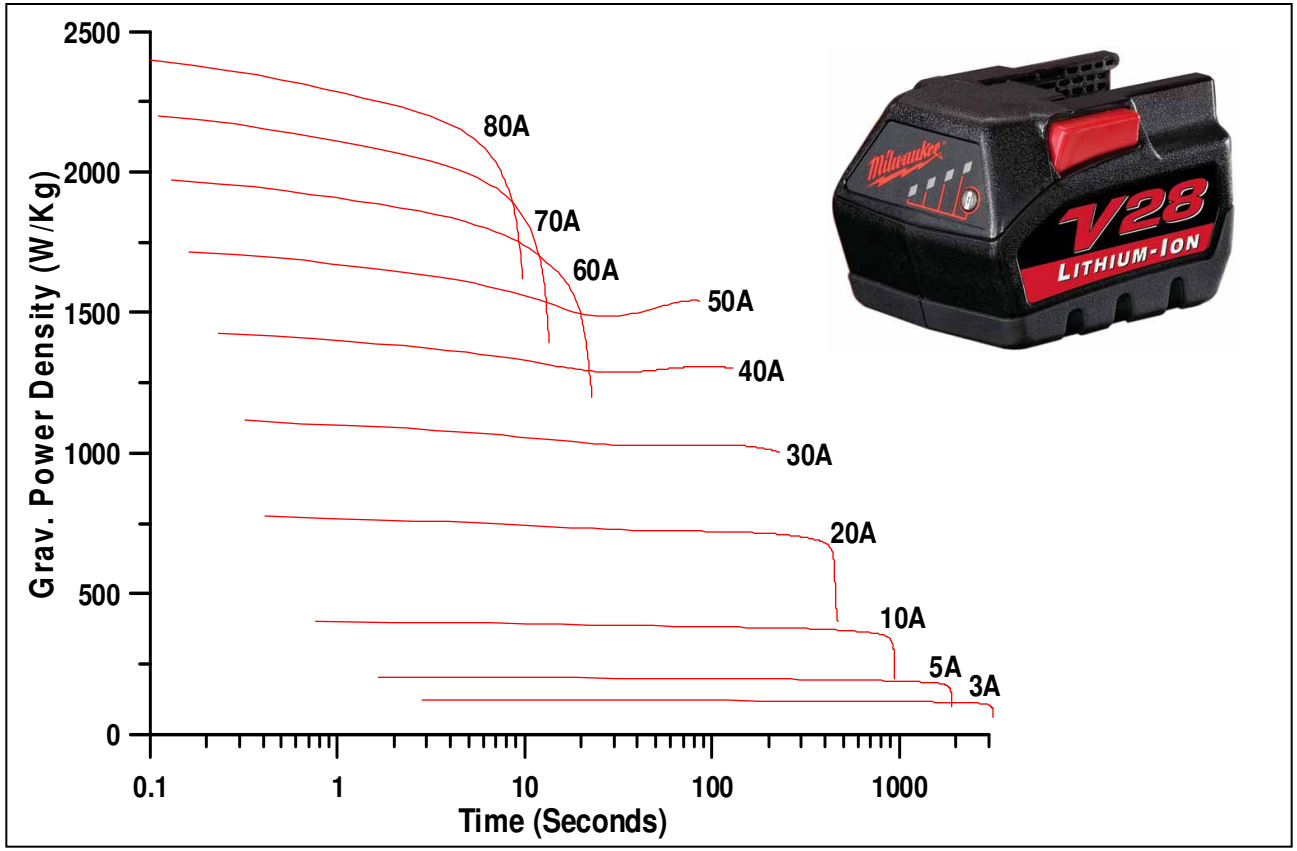
Summary of NCM Formulation

- **Advantages**
  - Potential for lower cost cells
  - Safer
  - Higher rate capability than standard $LiCoO_2$ cells
  - Lower operating temperature than $LiCoO_2$ cell at high discharge rates
  - Supported by many vendors
  - Potential for increased energy density

- **Disadvantages**
  - Variations in formulations may yield differences between vendors standard offerings

Introduction of High Power (W/Kg) Lithium Ion





- NiCd being phased out due to RoHS & WEEE legislation
- Alternative solutions being sought, including $LiMn_2O_4$ and nano-particulate BAM's
- Challenging NiCd in select high drain applications (i.e. power tools)

A123 Product: The 26650 High Power Cell

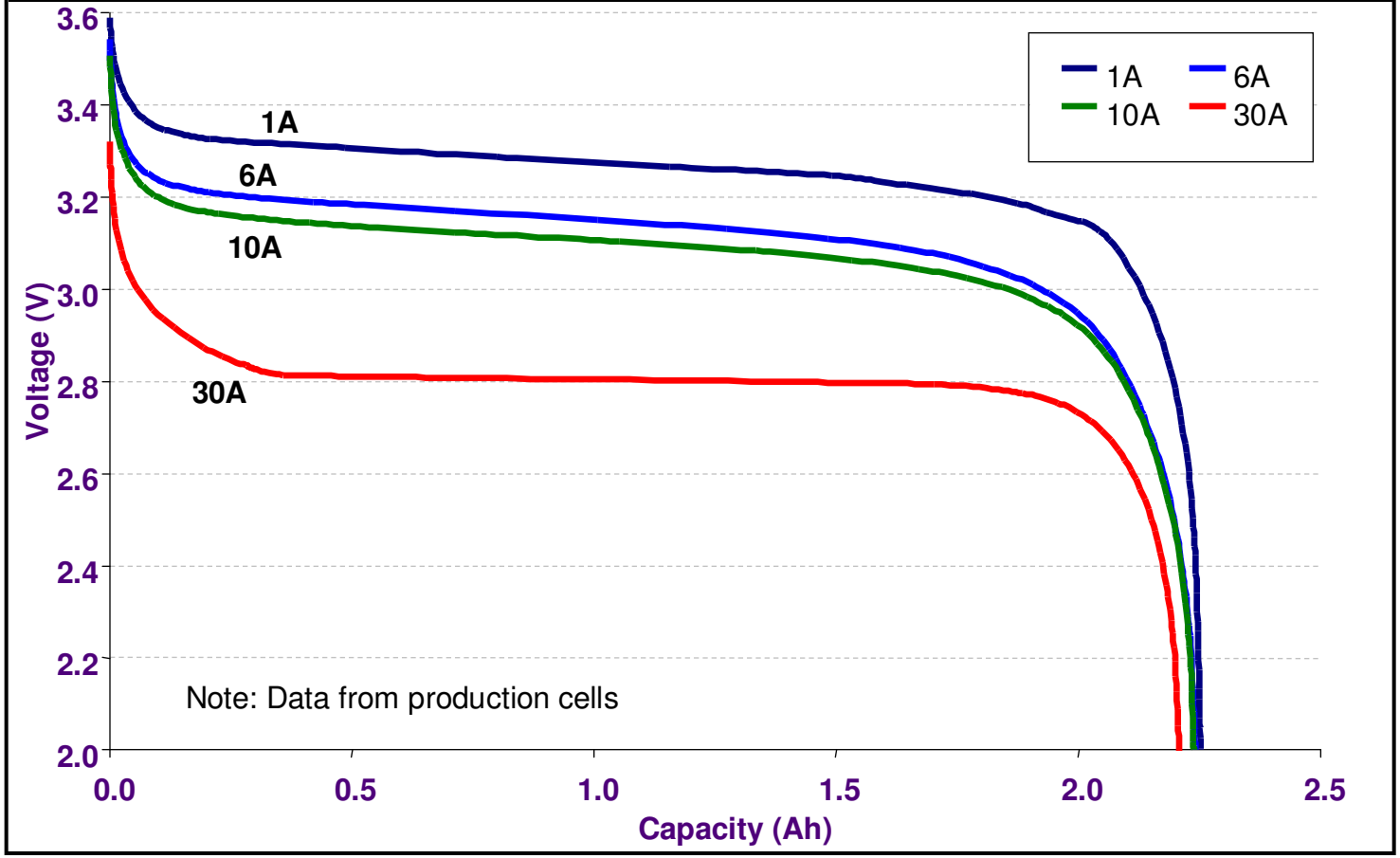
Features

- Power: **120Wh/kg, 230Wh/L and 100C pulse discharge capability**
- Safety: **Intrinsically safe cell and environmentally friendly**
- Life: **Significant improvement in life vs. other high power cells**

Novel cell design IP

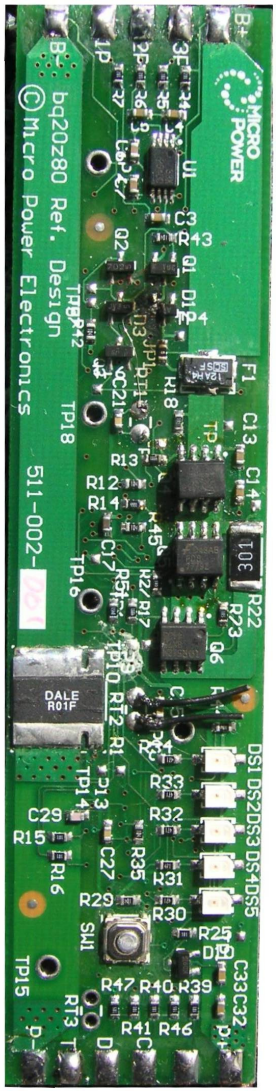
- **New mechanical cell design (5 distinct design features with patents applied for)**
- **High charge rate without high voltage anode**
- **Ultra low impedance electrode design**

26650 high power cells: 100% continuous discharge 1A, 6A, 10A, 30A at 25°C



Reasons for Battery System Failures

- Aftermarket Battery Packs
- Substandard cells
- Mismatched or substandard circuitry
- No current/voltage protection circuitry
- No thermal protection circuit
- No allowance for swelling
- No gas vents
- High temperature use

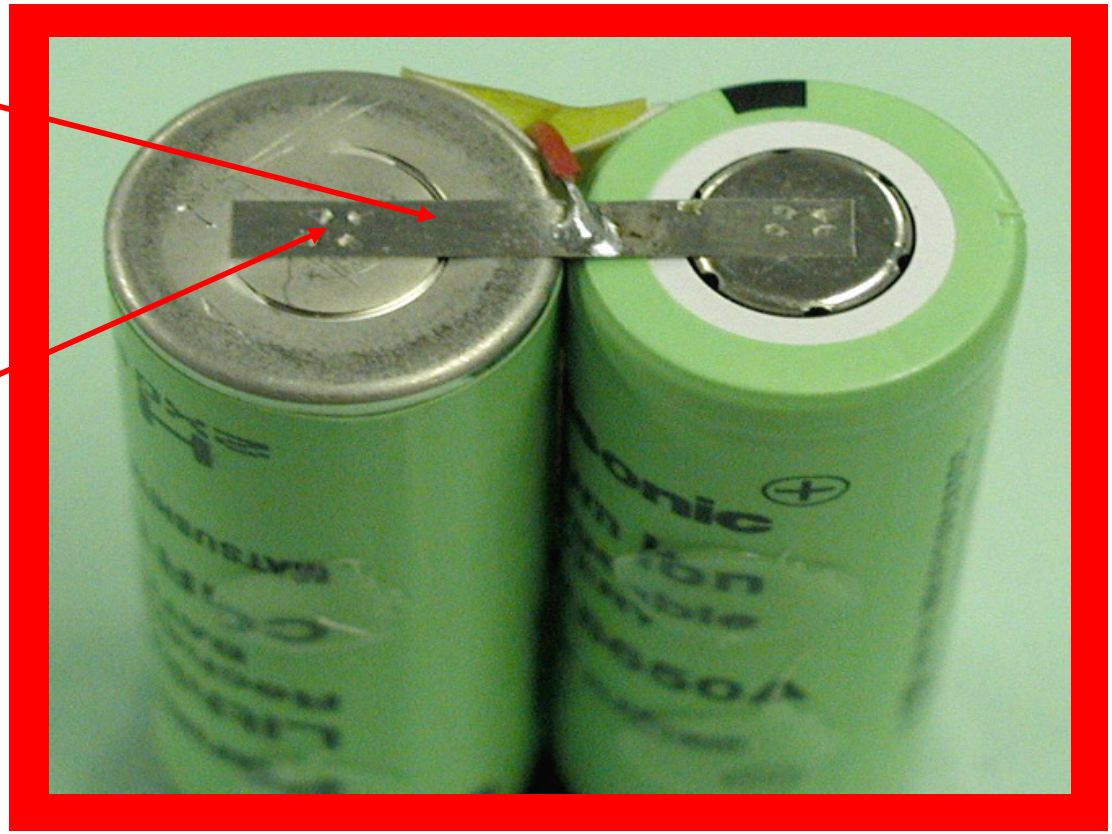


Insulating Material

Resistance Welding

Cell safety vent at negative end covered, compromising effectiveness of safety vent

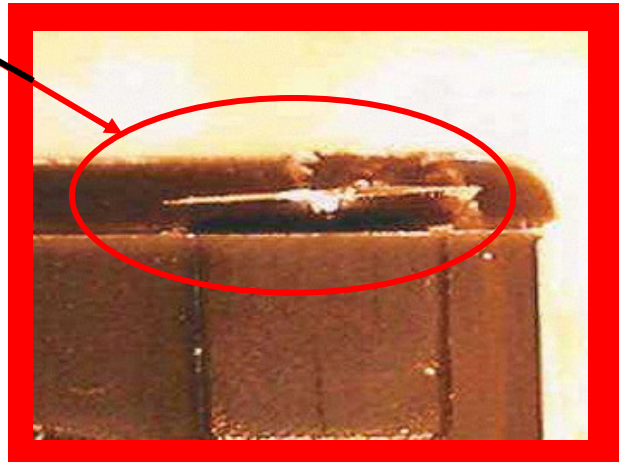
Cell was welded in middle of cell where can is very thin. This increases the possibility of an internal short

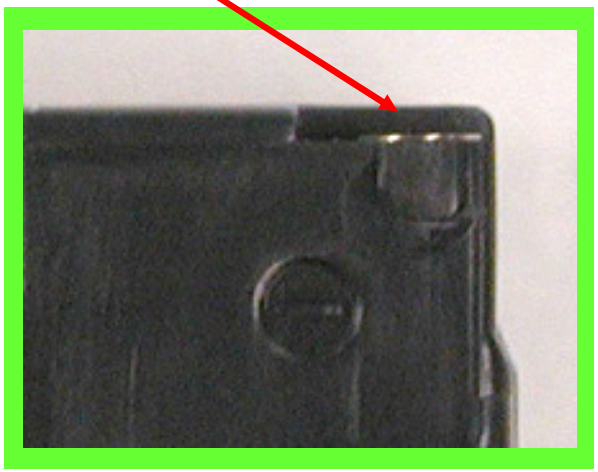


Connector Alignment and Placement

External contacts should not protrude from pack enclosure

Safe contacts are recessed to prevent shorting hazard





Crooked contacts cause fit issues with end unit, which can cause intermittent contact and data loss

Conclusions and Questions