A3PS Conference 2010
Vehicle Integration and System Optimization

Li-ion Battery: Development Status and Perspective in Electric Vehicles

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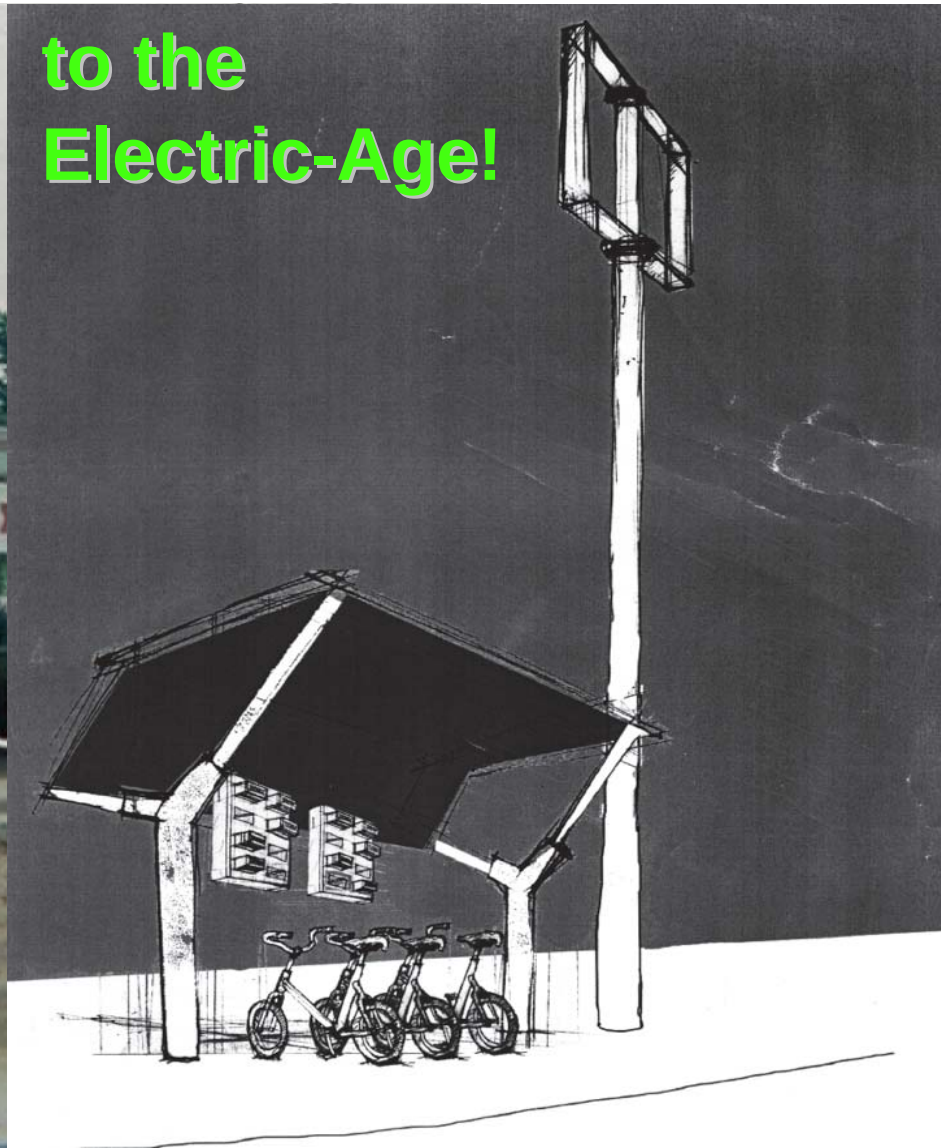
November 19, 2010

Contents

- EV System
- LIB Material Developments
- LIB Safety Improvements
- LIB System Developments for EV

From the
Oil-Age to the...
HELL
SUPER
CAY XANG


to the
Electric-Age!

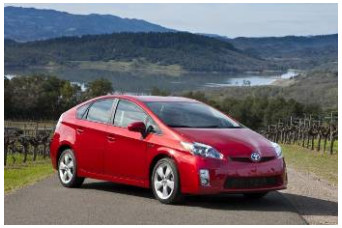
Revolution of Transportations

ICE Vehicles

Emission **Noise**

Energy Consumption

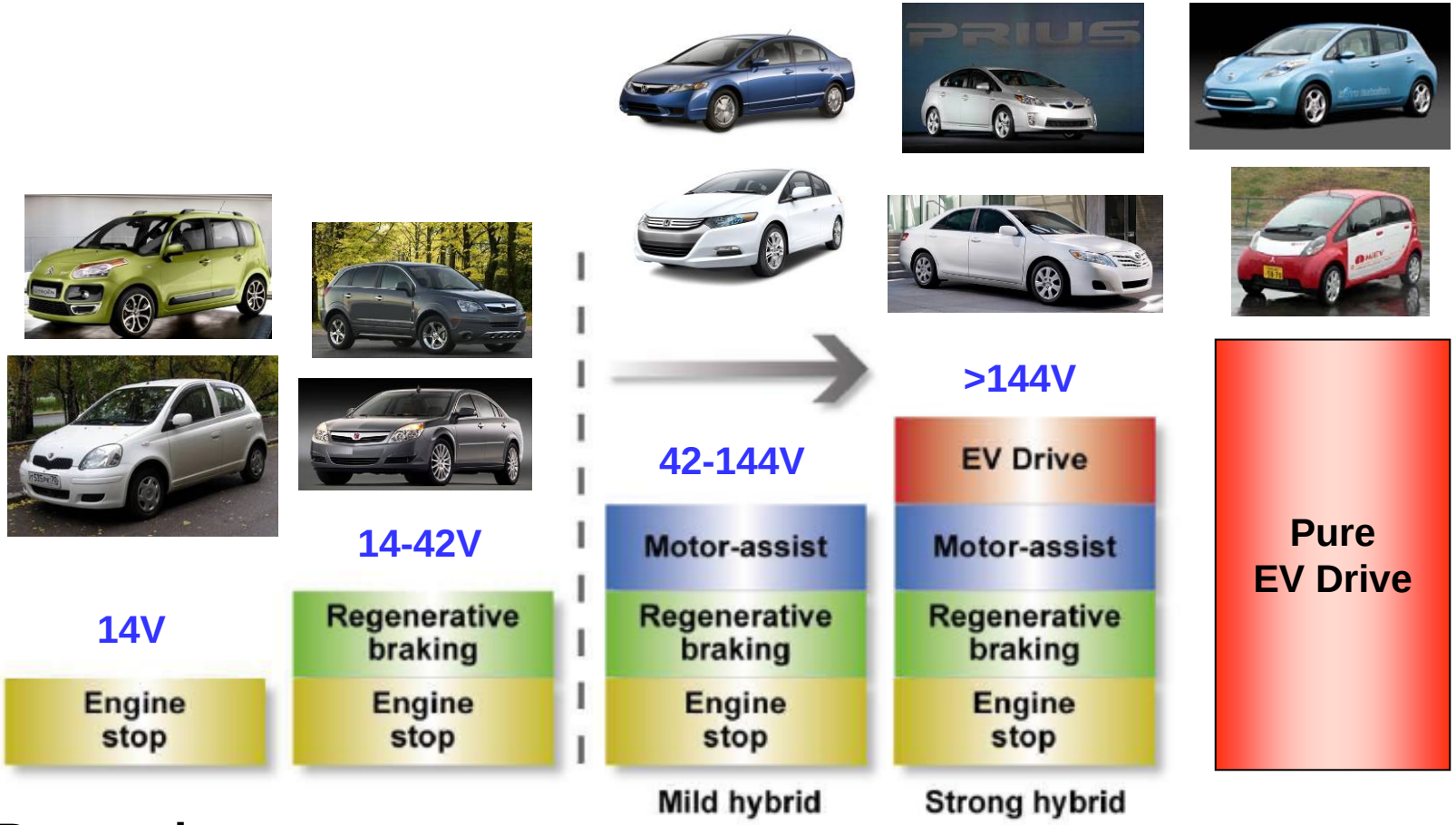
Electric Vehicles



Convenience **Energy Saving**

Safety **Environmental Friendly**

HEV/EV Segmentation



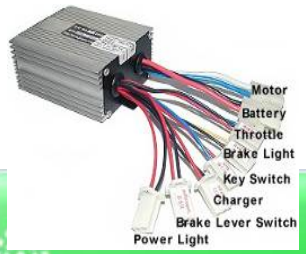
Battery Demand

Power ⟷ **Power + Energy**

data source: TOYOTA Motor Corp.

EV System

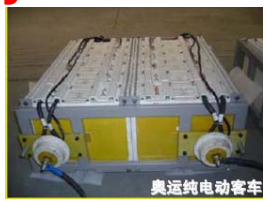
電動馬達與控制器
Electric motor & Controller



Power

Communication

電池與電池管理系統
Battery & Battery system



Power

Communication

Charger

key for EV - Batteries

Key for EV-Batteries Energy Storage System

Electric Vehicle?

Battery Vehicle?

Now We're Cooking With … Batteries, Newsweek, Dec., 2008

LIB Product Application Segments

行動電話

3Wh (0.4顆电池)

Ref. 18650 cell
2.2Ah, 8Wh

筆記型電腦

70Wh (8.8顆电池)

0.25-3kWh

輕型電動車

4-44台NB

1kWh (125顆电池)

>20kWh

電動車

>280台NB

20kWh (2500顆电池)

Vehicle vs Battery

Vehicle	Battery
Driving rang, Weight	Energy density（Wh/kg）
Starting, Acceleration, Climbing	Power density（W/kg）
Charging time	High charging rate
energy consumption when vehicle Idling	Self-discharge
Energy Efficiency	Charge-discharge efficiency
Cost	Cost
Operation cost ($/km)	Cycle life

From Material to Energy System

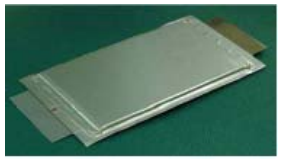
Electronic & Mechanical Tech.

Energy system control Tech.

Battery Tech.

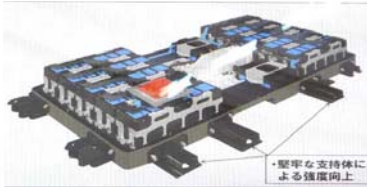
Materials

Cell



Module

Pack

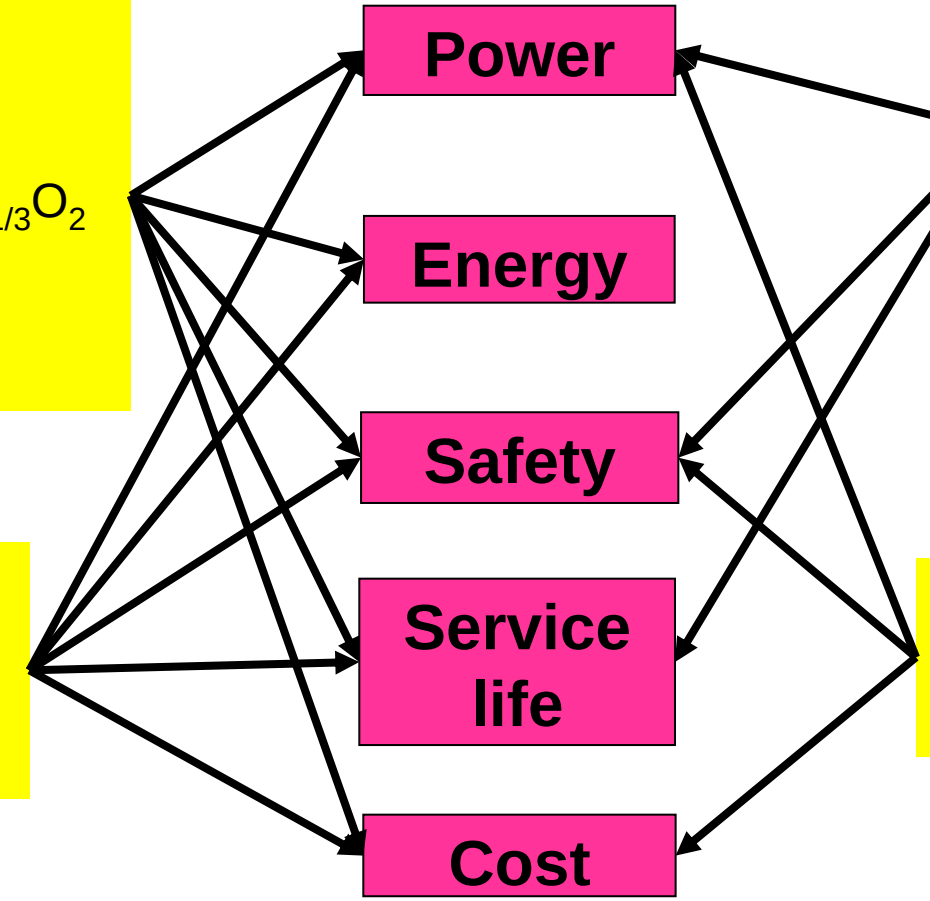


EV

LIB Material Developments

Cathode:
- $LiCoO_2$
- $LiCo_xAl_yO_2$
- $LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$
- $LiMn_2O_4$
- Blending
- $LiFePO_4$

Anode:
- Si-based
- Sn-based
- $Li_4Ti_5O_{12}$

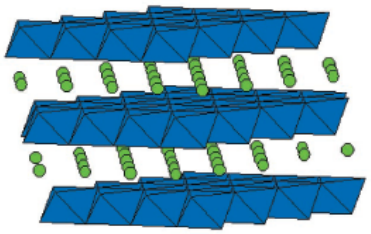


Electrolyte:
- Non-flammable,
- Ionic liquid,
- Polymer/Gel type
- Additives

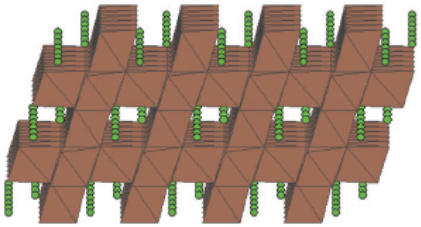
Separator:
- Ceramic coated separator
- Heat resistance separator

Cathode Materials

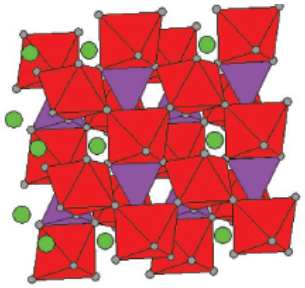
layered structure



spinel structure



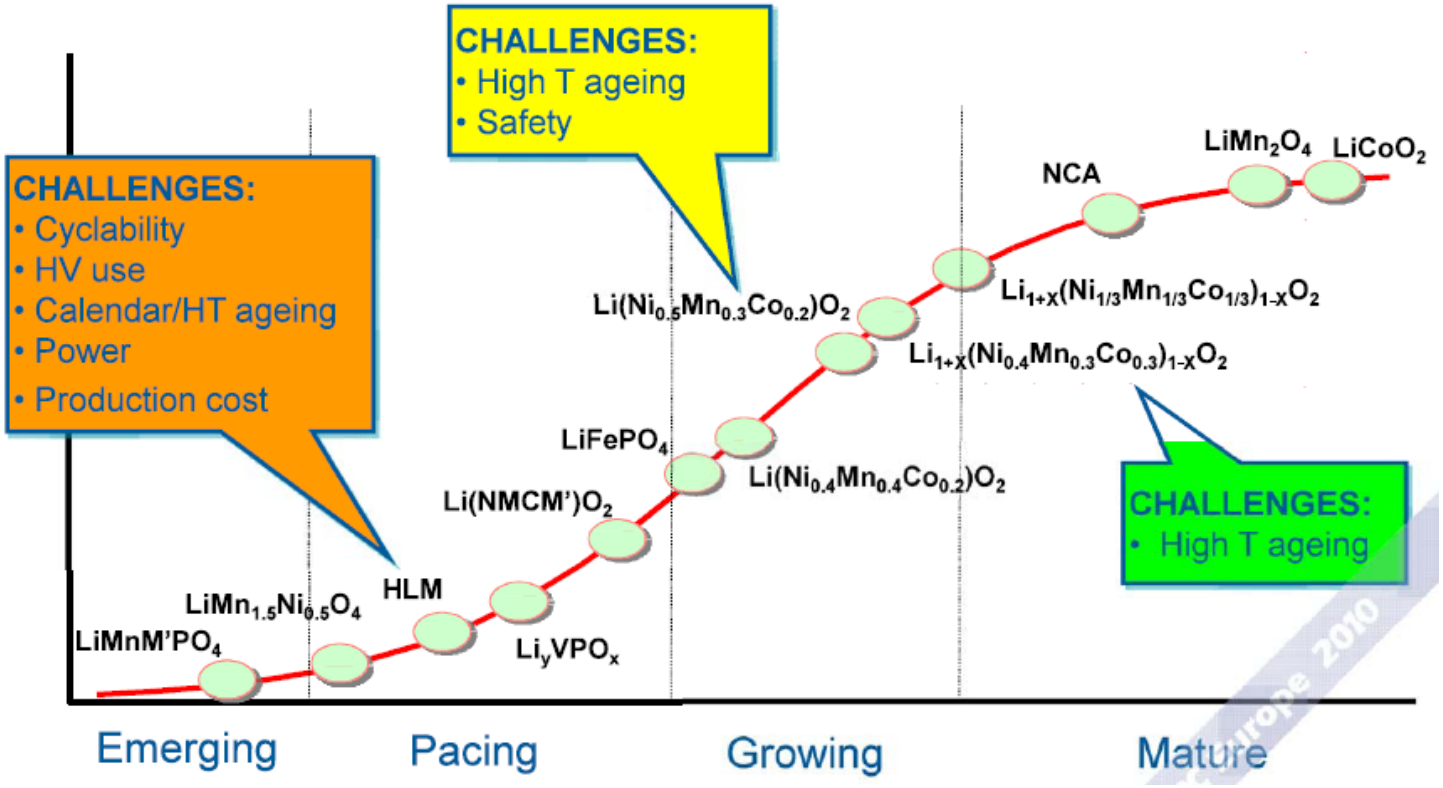
olivine structure



	Li diffusion	Material system	Capacity (mAh/g)	Nominal V. (V)	Safety	Cost
Olivine Structure	1D	$LiFePO_4$	160	3.4	excellent	low
Layered structure	2D	$LiCoO_2$ $Li(Co\text{-}Ni)O_2$ $Li(Ni\text{-}Mn)O_2$ $LiCo_{1/3}Ni_{1/3}Mn_{1/3}O_2$	160 180 160 190	3.6~3.7	accept	high
Spinel Structure	3D	$LiMn_2O_4$	110	3.7	good	low

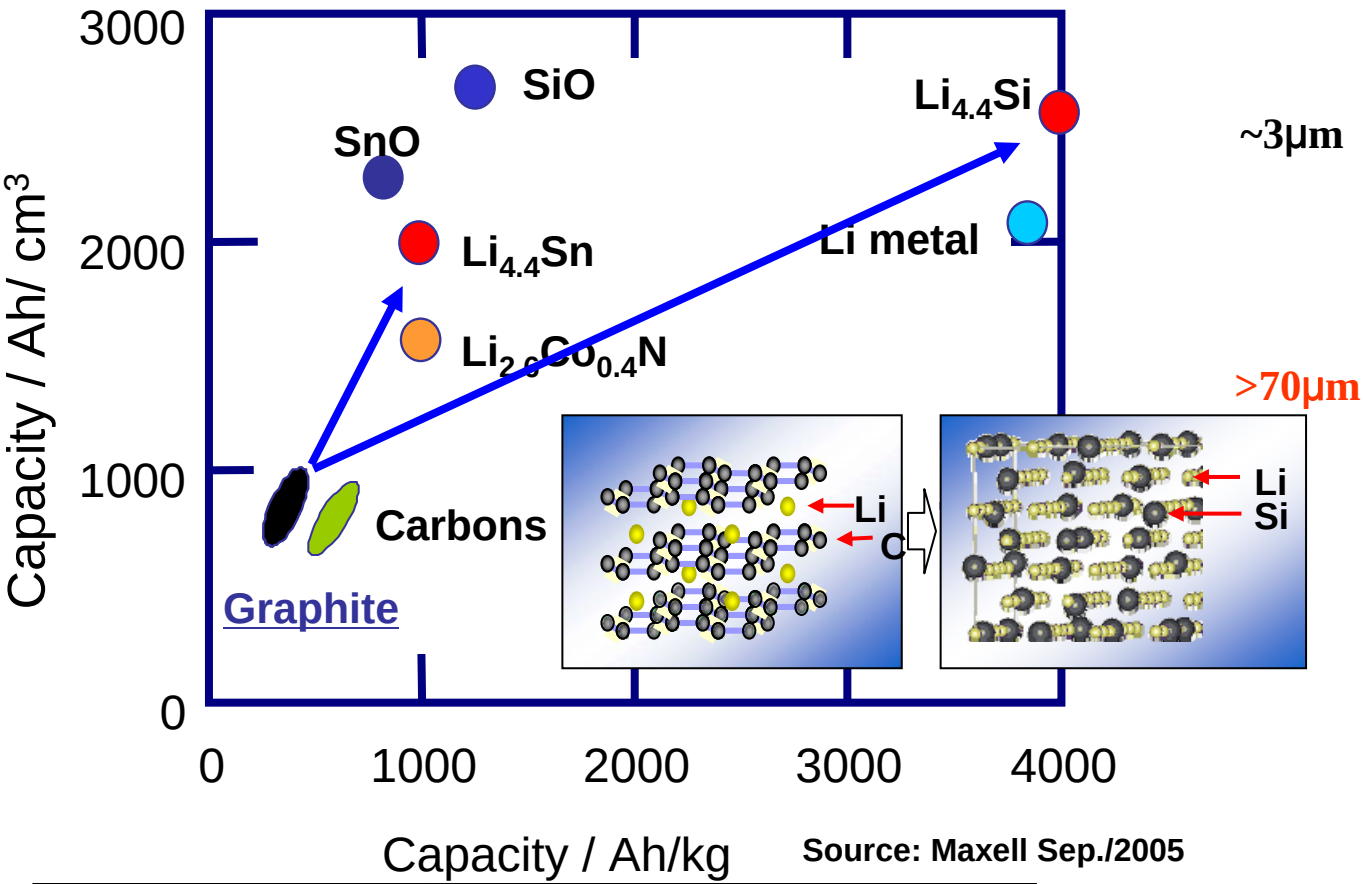
Cathode Materials

Current level of development



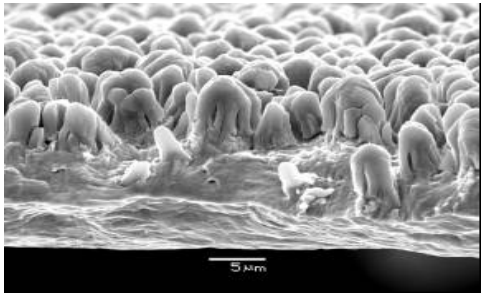
Data source: Umicore, AABC 2010, Germany

New Anode Material Candidates



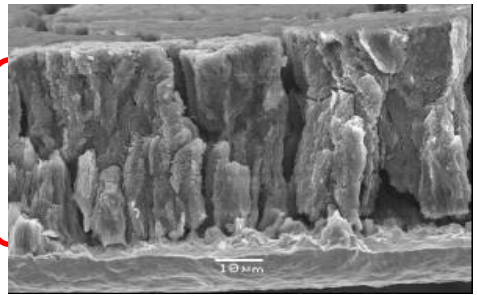
Source: Maxell Sep./2005

~3μm



CS of cycled Si thin-film

>70μm



CS of faded Si thin film

	Si	Sn
Cost ($/kg)	54	80
Capacity(Ah/kg)	4200	980
Sp. Cost ($/Ah)	0.013	0.082

Key issue

Mechanical degradation by volume expansion (fracture & disconnection)

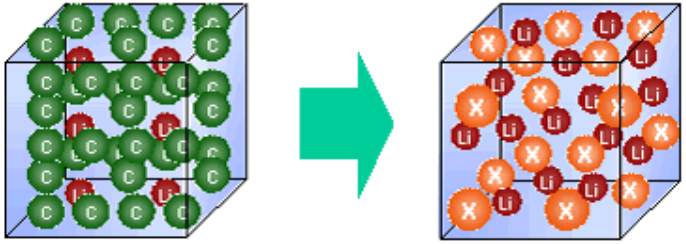
Sony-Nexelion

Model：14430

Item	Spec/material
Nominal Capacity(0.2C) ave.	910mAh 3.15Wh
Rated Capacity (0.2C) mini.	865mAh 3.00Wh
Anode Material	Co-Sn-C Amorphous
Cathode material	Li-CoO2,Li-(Ni,Co,Mn)O2
Energy density Volumetric（Wh/ l)	478Wh/l
Internal Impedance	70mΩ
Cycle performance (0.5C discharge)	60% @300cycles

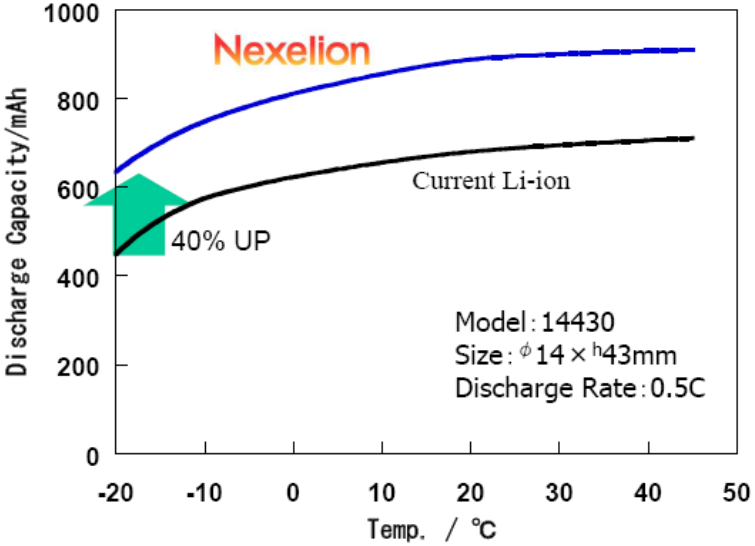
Nexelion

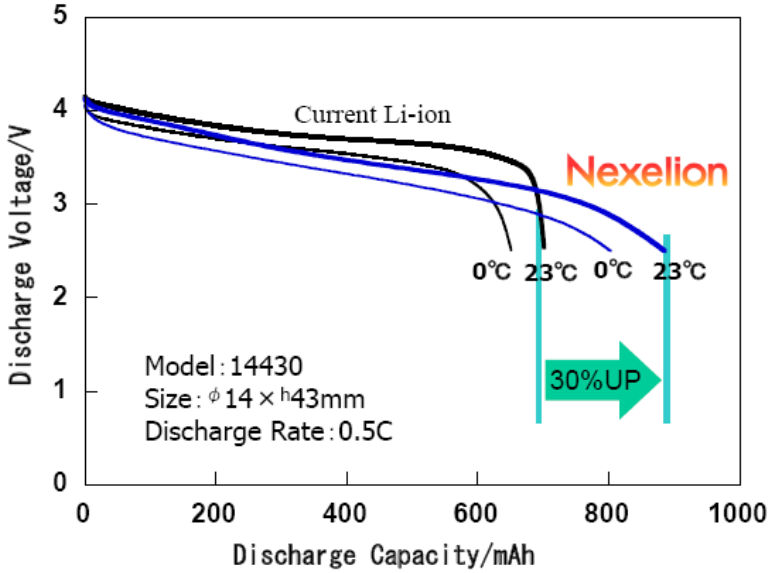
Diagram representing high-density anode



Graphite anode　　Tin-based amorphous anod

Sony-Nexelion

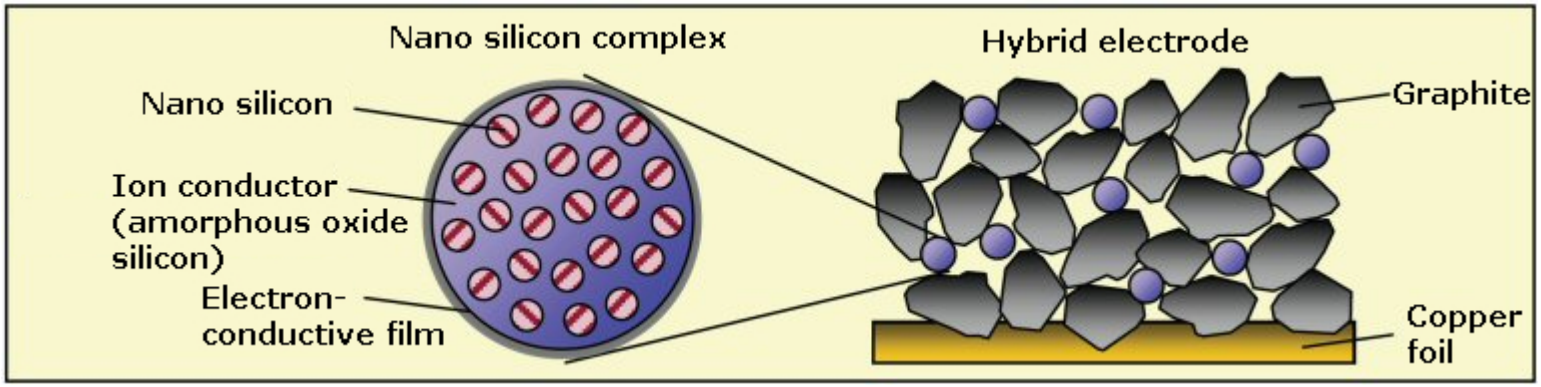




30% higher capacity than current Li-ion battery

Hitachi Maxell

Hitachi Maxell to Launch Li-ion Battery Using Si-based Anode Material



- "nano silicon complex" - made by dispersing silicon grains with a size as small as several nanometers in amorphous oxide silicon (SiO). The amorphous SiO mitigates the distention and contraction of silicon.
- SiO grains are coated with carbon so that their electron conductivity is enhanced. And they are mixed with graphite, which is a common negative-electrode material.

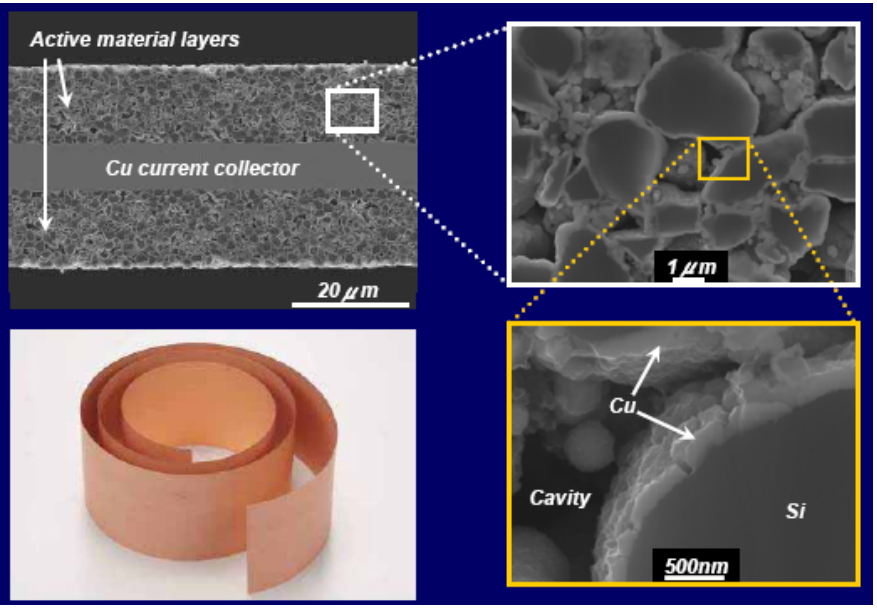
Capacity +20%

Charging time -30%

SILX® Technology-Mitsui

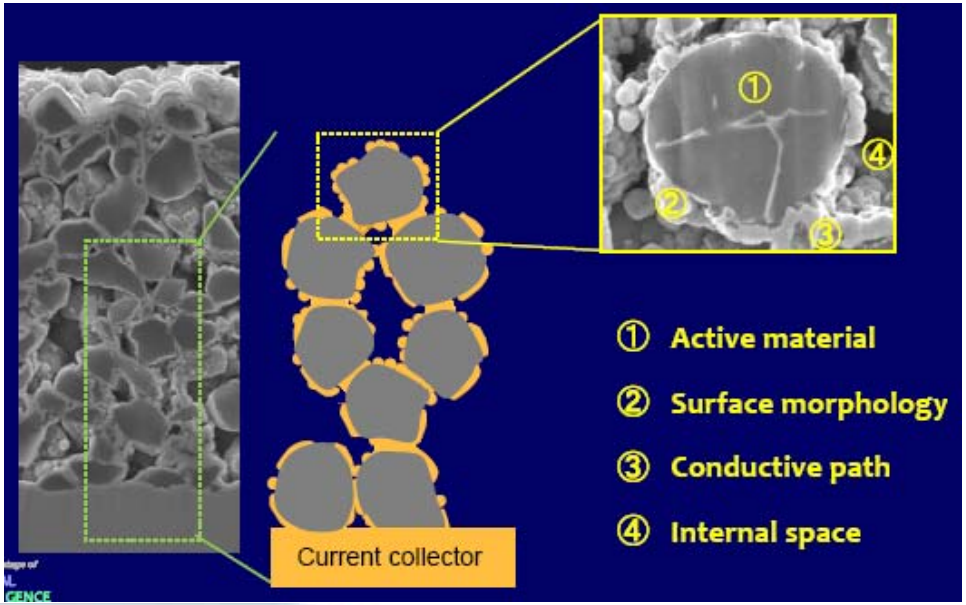
SILX® Technology

- Consists of unique network structure utilizing Silicon and Copper
- Provides significant improvement over proposed technologies



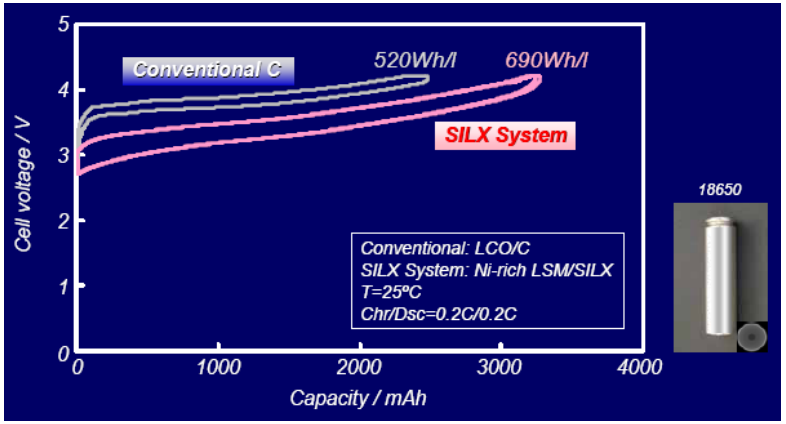
the nano-designed surface copper can stabilize the electrode

1. giving conductivity to each silicon particle,
2. preventing Si particles from isolation and keeping the bette conductivity through whole electrode even after cycling.

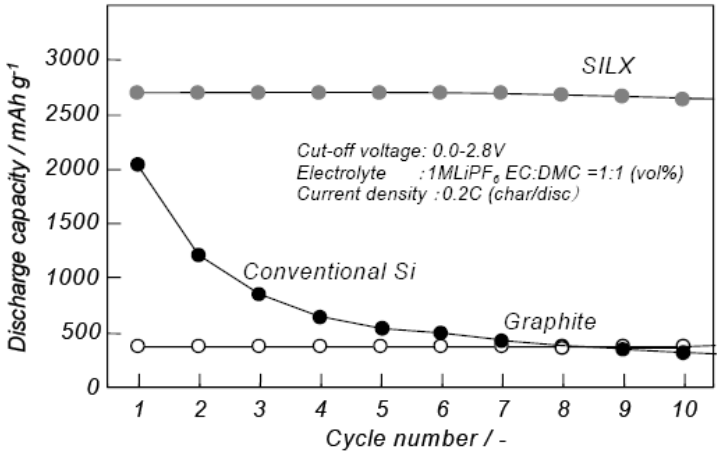


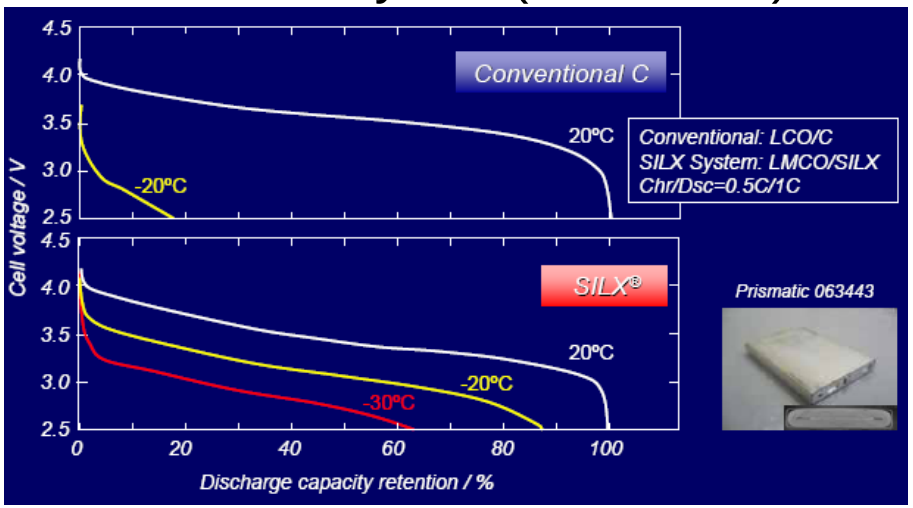
Data source: Mitsui Mining & Smelting Co., Ltd. Japan

SILX® Technology-Mitsui



- **Capacity density**
  1000Ah/l at charged state (SILX)
- **Energy density**
  3300mAh, +690 Wh/L (cylindrical 18650)
- **Rate performance**
  +88% at -20ºC, +65% at -30ºC at 1C
- **Cycle life**
  +80% at 500cycles (Coin 2032)

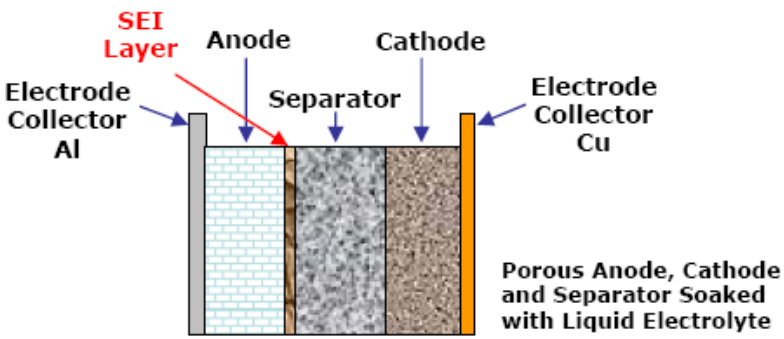




Data source: Mitsui Mining & Smelting Co., Ltd. Japan

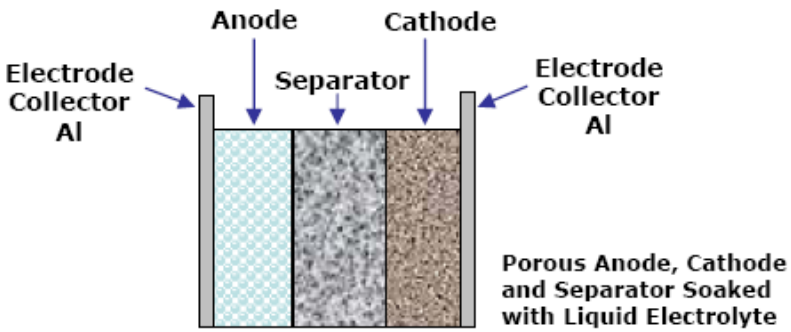
Anode Material-$Li_4Ti_5O_{12}$

$LiCoO_2$/C



SEI: Solid Electrolyte Interphase

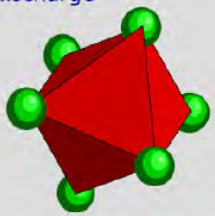
$LiCoO_2/Li_4Ti_5O_{12}$



No SEI formation

n-LTO($Li_4Ti_5O_4$) based Anode

- n-LTO is a stable 3-D crystal structure (spinel)
  - Lithium can insert from any angle – *fast kinetics*
- Retains fast 3-D kinetics at low temperatures
- Stable crystalline morphology
  - Near zero deformation from charge / discharge
- Stable to 700°C
- High capacity - 160 mAh/g
- Voltage vs. Lithium
  - Eliminates lithium metal formation
  - Eliminates SEI formation
  - Allows aluminum current collector
  - Reduces electrolyte side reactions



- **Low resistance (IR)**
- **High thermal stability**
- **No SEI decomposition heat**

Toshiba-SCiB

SCiB (Super Charge ion Battery)

Long Life
>5000 cycles

Excellent Safety
-no explosion
-no fire

Rapid Charging
>90% SOC in 5 min

High Power
>5000W/kg

Cryogenic Operation
Work at -30℃

Battery Manufacturing Process

Cathode

Electrode

active material
+binder +solvent

Mixing

Paste —**Coating**→ Electrode —**Pressing**→ Electrode
Al foil — **Slitting**

Separator

Paste —**Coating**→ Electrode —**Pressing**→ Electrode
Cu foil — **Slitting**

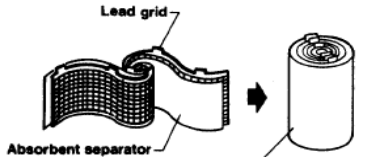
Mixing

active material
+binder +solvent

Anode

Assembly

Winding or Stacking



Jerry roll
or stack

Jerry roll
or stack in can

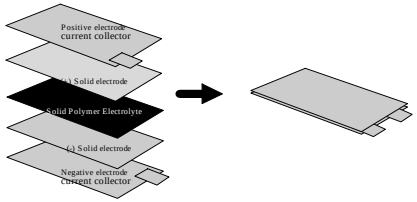
Electrolyte filling

Sealing

Cell

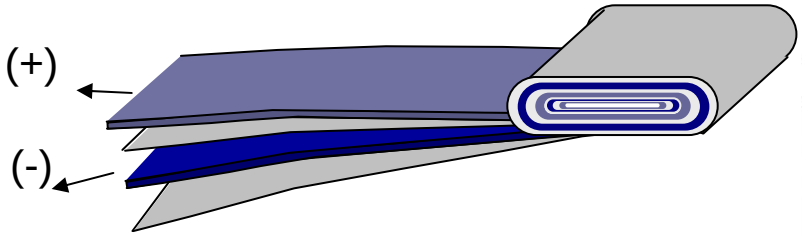
Formation

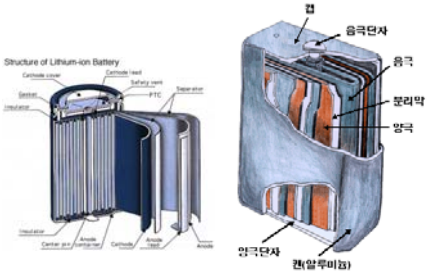
Cell



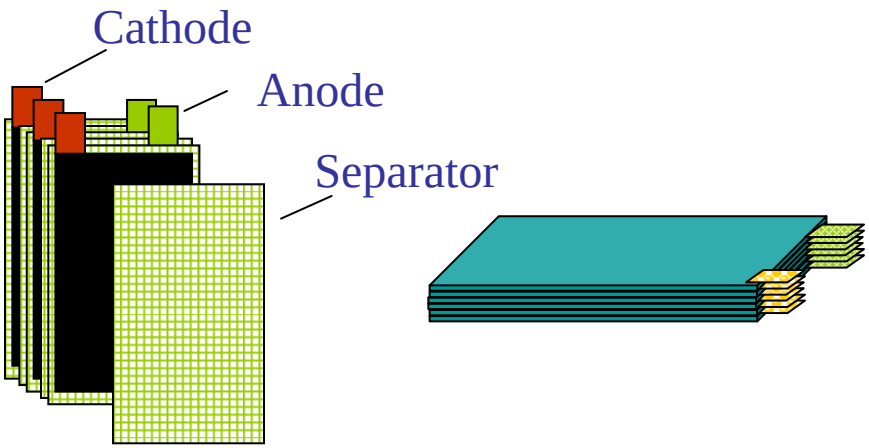
Electrode Assembly

Winding

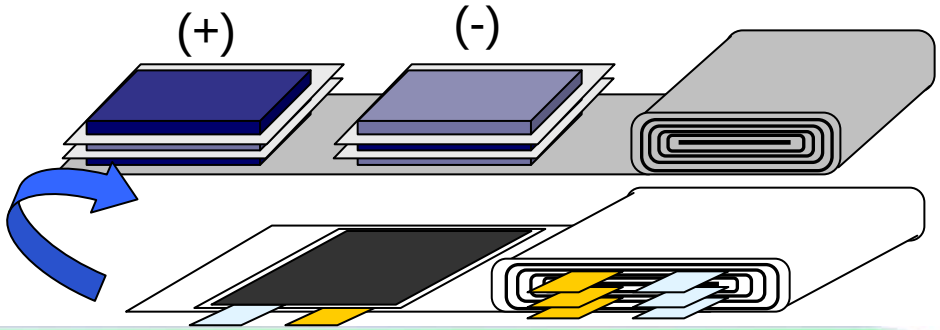




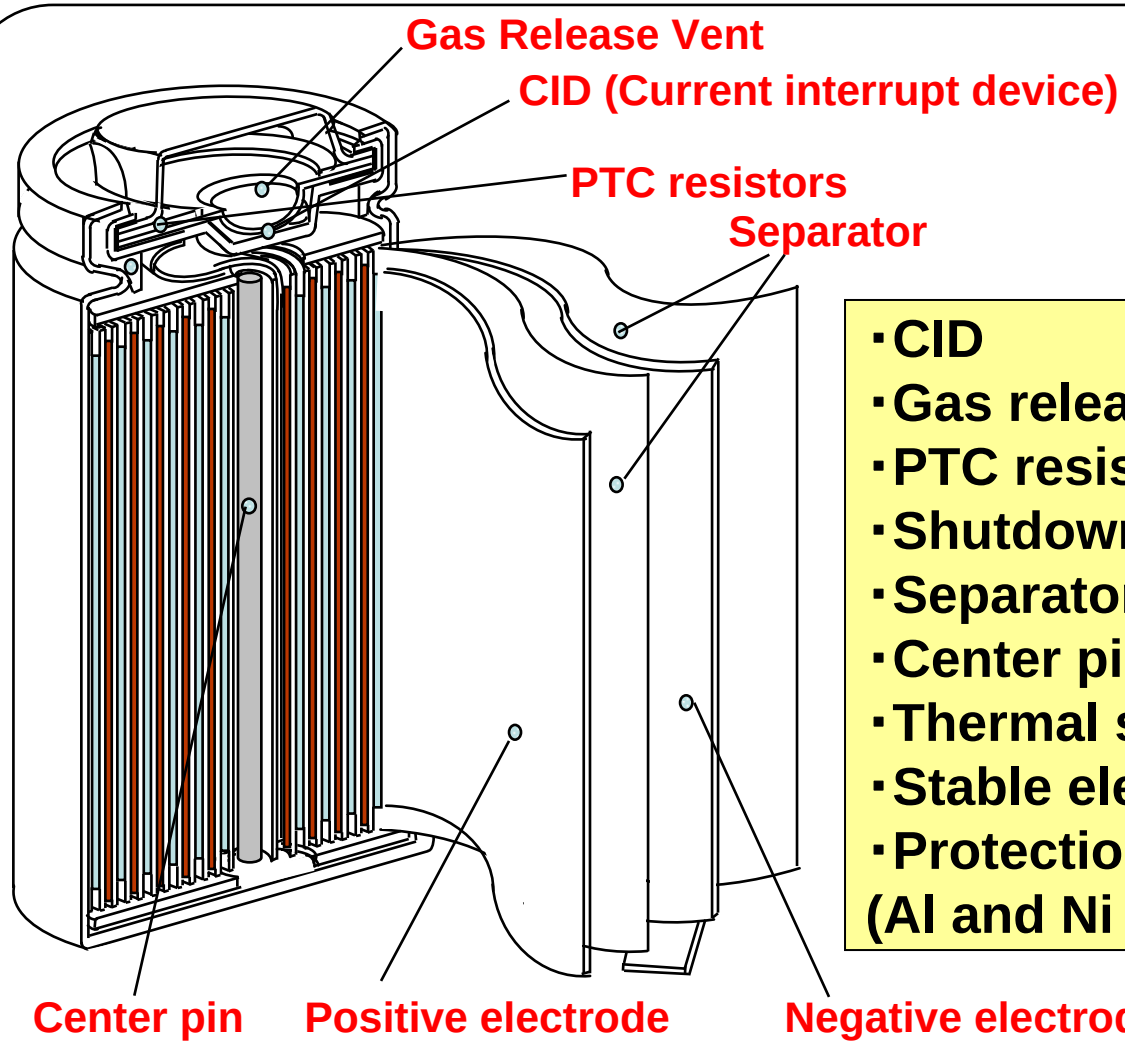
Stacking



Stacking +Winding



Safety design on Li-ion Cell



- CID
- Gas release vent
- PTC resistors (low power only)
- Shutdown separator
- Separator coating
- Center pin
- Thermal stable active material
- Stable electrolyte
- Protection tape on week point (Al and Ni tab)

Cell Design

Cylindrical type

Prismatic type

Laminated type

Small Format vs. Large Format Cell

Large Format cell

Development considering HEV / PEV use

- High pack reliability
- Low cell quality (poor uniformity)
- High cell price (>800USD/kWh)

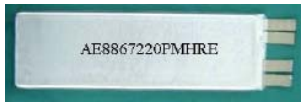
18650 type cell

Application of current technology

- High cell reliability
- Low cell price (<400USD/kWh)

For a 24V/10Ah battery pack

7S1P (7 cells)

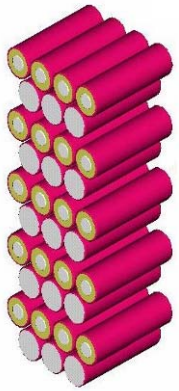


10Ah cell

7S2P (14 cells)

5Ah cell

7S5P (35 cells)



2Ah cell

Small Format vs. Large Format Cell

Cell

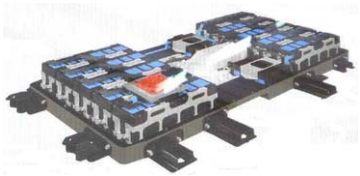
50 Ah

Module

4 Cells

Pack 360V, 16kWh

22 Modules (88 cells)



MITSUBISHI MOTORS

Speed: 80 mph (130 km/h)
Range: 100 mi (160 km)

2 Ah

621 Cells

11 Modules (6831 cells)

TESLA MOTORS

Speed: 125 mph (200 km/h)
Range: 236 mi (378 km)

CELLS

- Lithium ion cells
- Built IP around 18650 form factor
- Evaluate, not manufacture cells
- Leverage industry battery chemistry investments

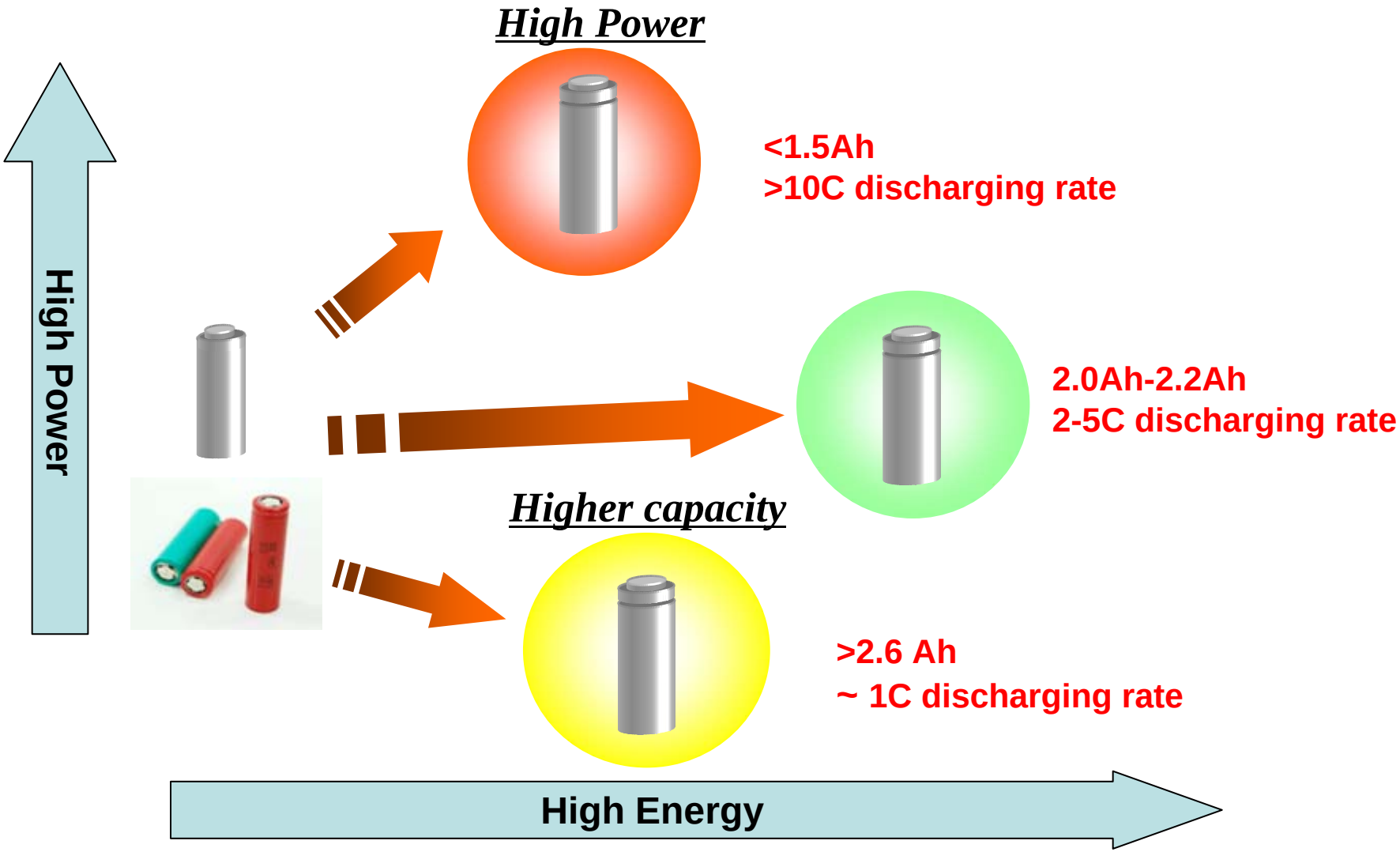
SHEET

- Sheet: 621 Cells
- Modular, scalable design
- IP in charge balancing and cooling
- Battery longevity (cycle & calendar life)

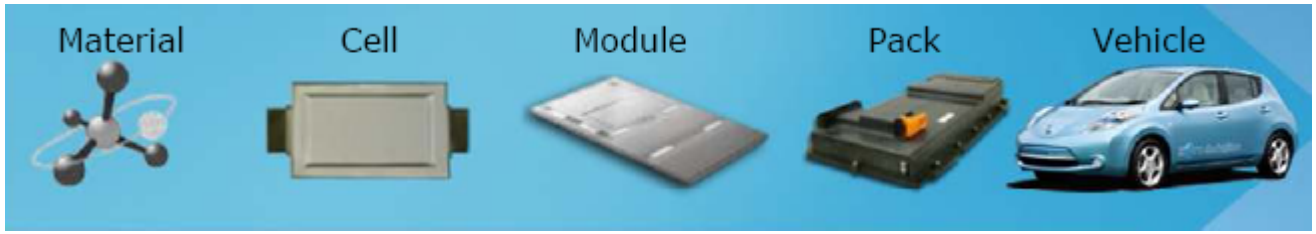
BATTERY

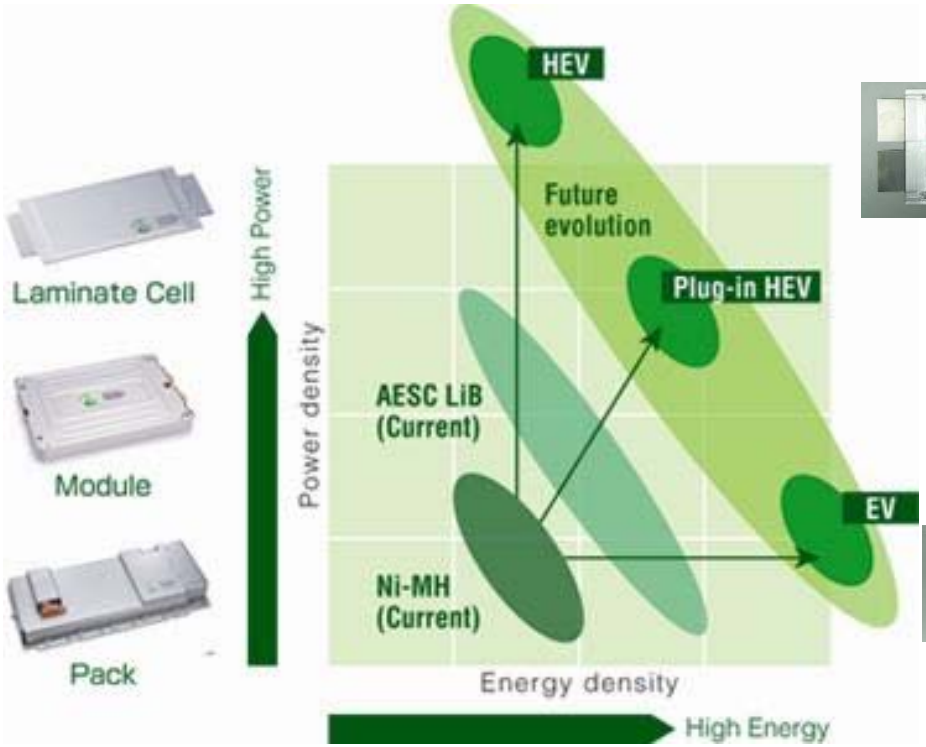
- Battery Pack: 6,831 cells
- 53 kWh
- Battery system safety
- Battery system durability
- Up to 150,000 mile life
- Scalable, automated assembly
- Worldwide approval for transport and use

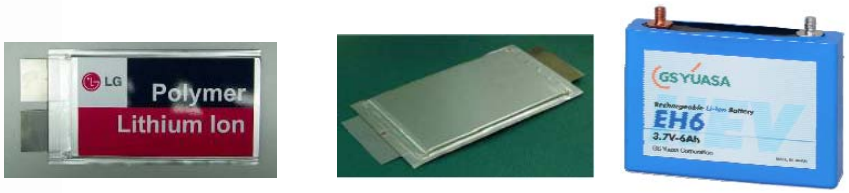
18650 Cell Developments



EV Cell Developments







6-10 Ah, >3000W/kg

30-50 Ah, <1000W/kg

Battery Management System

Cell selection
- cell chemistry
- cell design
- cell characterization
- cell sorting & grouping

Cell balance

Protection
- cell condition monitoring (T,V,C)
- cell control of operation conditions
- circuit design
- mechanical design (vibration, impact…)

Safety
Reliability
Efficiency
Intelligent

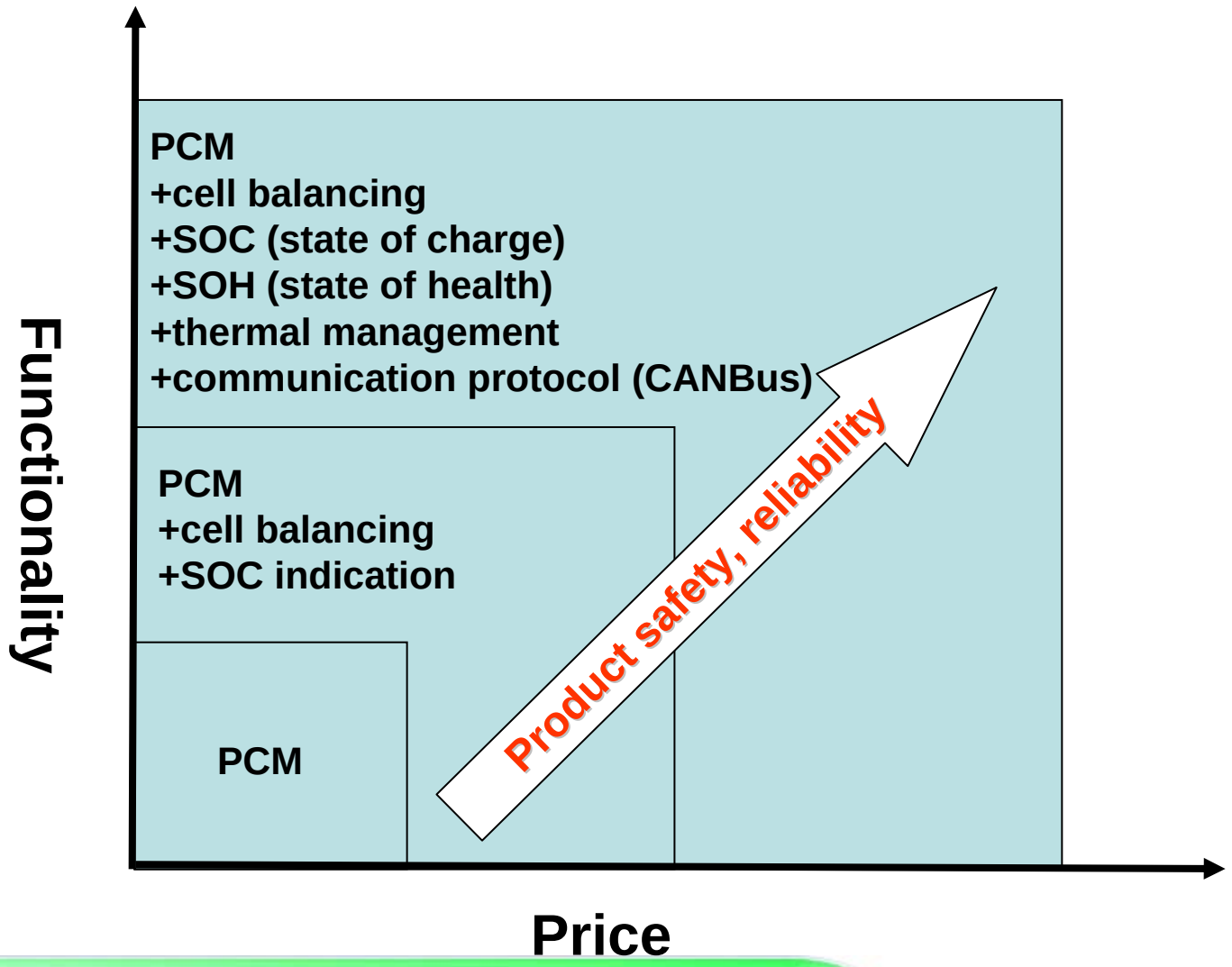
Diagnosis
- monitoring & alarm
- recording

Status Indication
- SOC & SCH estimations

Charger
- precise current and voltage control
- multi-mode charging control

Communication protocol
- Data and energy control interface

BMS Functionality vs. Price

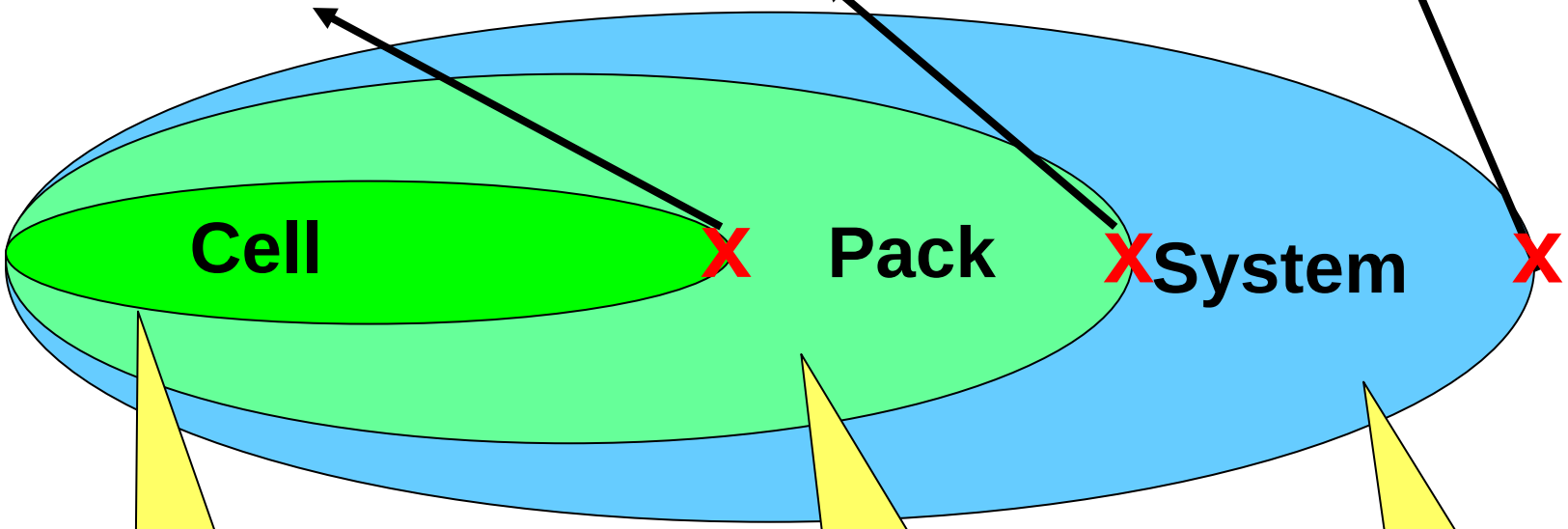


Outlook of EV battery Safety Design

Prevent thermal runway
-material decomposition
-internal short circuit

Prevent thermal runway
-cell heating propagation
-internal short circuit

Prevent thermal runway
-charging at high V & T
-abnormal use



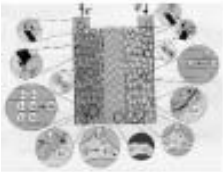
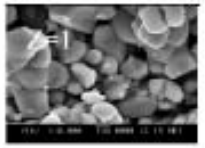
- Basic Design
- Manufacturing

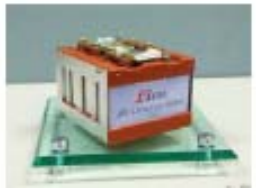
- Mechanical Design
- Electronic Protection
- Mechanical Protection

- Communication
- Software interface
- Power control

"Cell", "Pack" and "System" level approach can prevent the thermal runaway accident.

How to Improve Battery Safety?



Material **Cell** **Module/Pack**

Chemistries

Cathode:

$LiMn_2O_4$, $LiFePO_4$, Blending

Anode:

Si, Sn-based, $Li_4Ti_5O_{12}$

New electrolyte:

Non-flammable, Ionic liquid, Polymer/Gel type

Separator:

Ceramic separator

Additives

Redox shuttle,

SEI modification

Mechanicals

Electrode winding/stacking

CID

PTC

Safety vent

Central pin

Electronics

Battery management system :

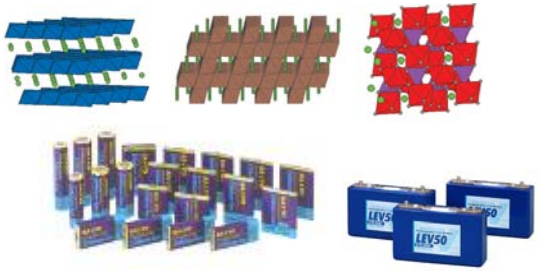
Cell monitoring (T, V, A)

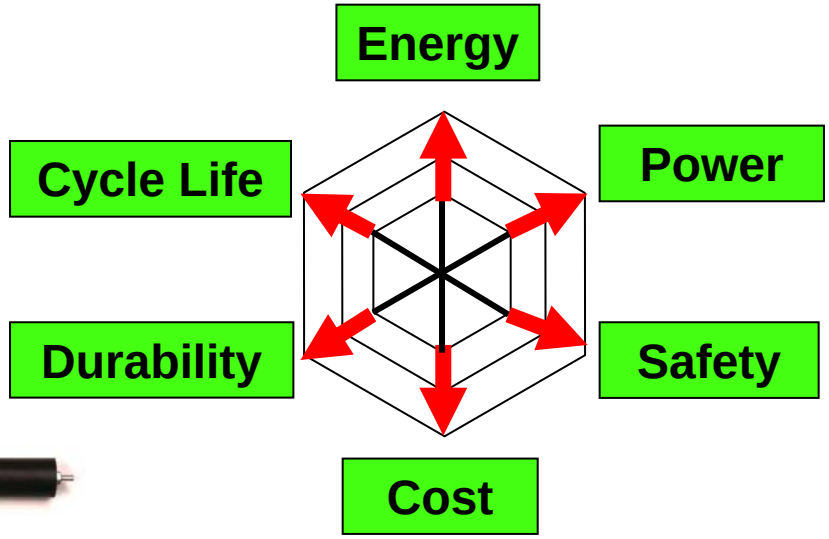
Module/pack protection

Conclusions

- To understood Key factors for cell/battery safety
- Energy density increase by safety control (Ni-based cathode)
- Proper design for proper use

Right material





Right cell/pack design

Right application

Thank you for kind attention!!