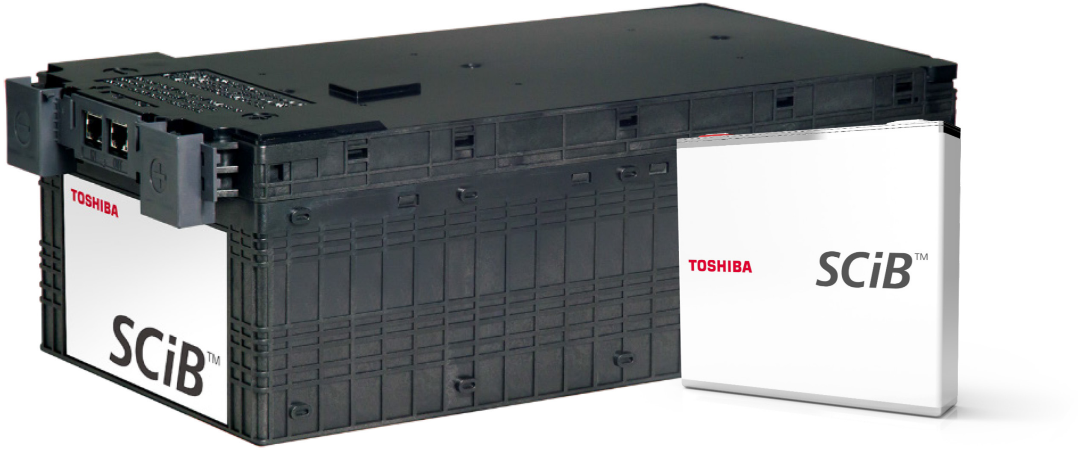
ACCREDITED IACET PROVIDER

Lithium-ion Batteries and Systems

Duration: 90 minutes
CEU Credits: 0.10



TOSHIBA
TOSHIBA INTERNATIONAL CORPORATION
Power Electronics Division
Toshiba International Corporation

2019.06.13

01

Course Overview

Instructor Introduction

Name: Jesus Penalver
Title: Technical Specialist
Background and experience

Course Overview

- Format: 7 Sections and Q&A and Assessment
- Certification: IACET
- Duration: 90 minutes
- Holistic Conceptual Development
- Miscellaneous: Safety, refreshments and restrooms

Contents

Contents

02

Battery Basics

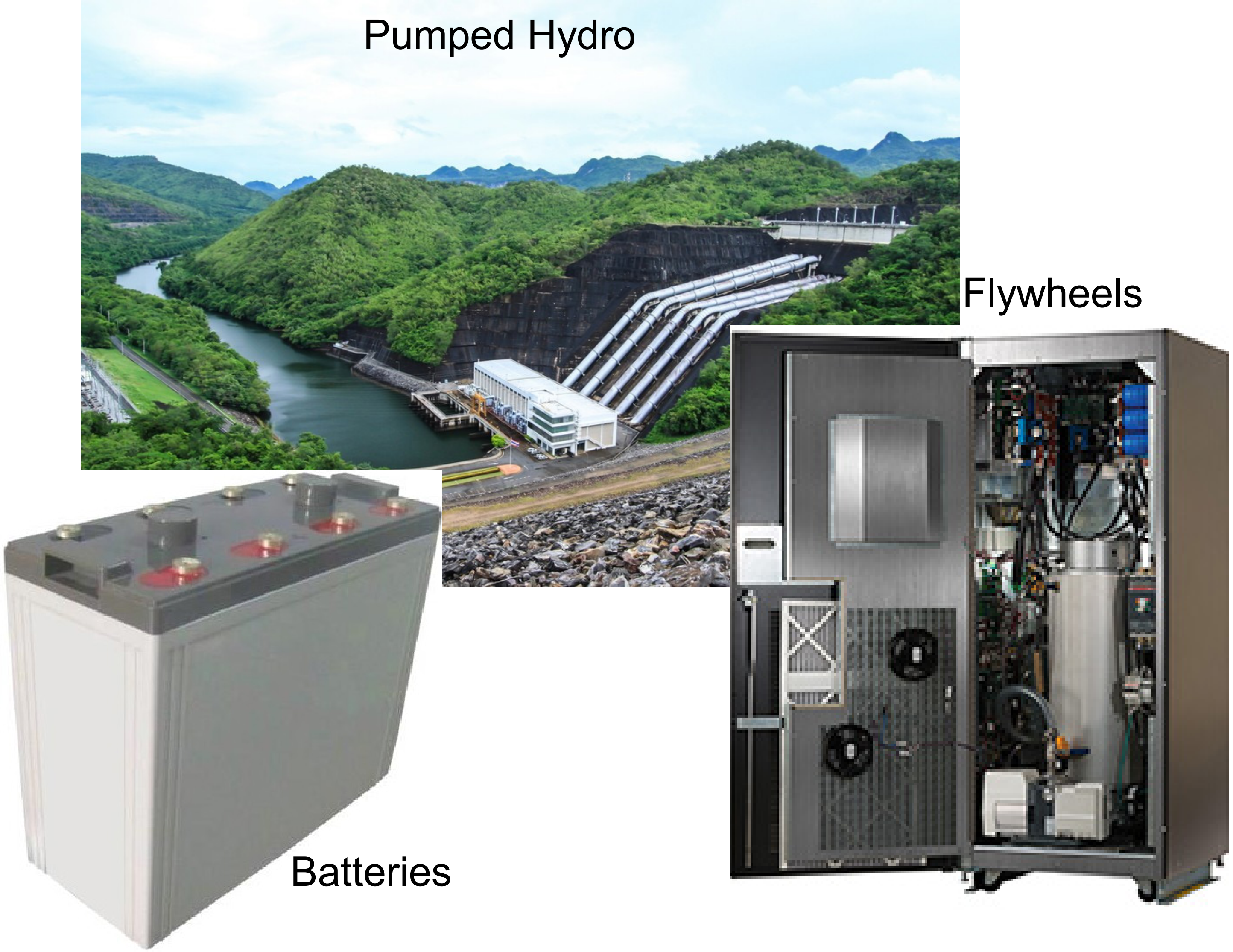
At the conclusion of this section, participants will be able to:

- List different energy storage mechanisms.
- Outline the layout and working of a standard lithium-ion battery.
- List different lithium-ion chemistries.
- List different standards affecting battery installations.

Learning Objectives

Battery Basics

Energy Storage Mechanisms



- **Flywheels – Kinetic Energy Storage**
- **Hydro – Potential Energy Storage**
- **Batteries – Specifically Electro-Chemical (Electrolytic) Energy Storage**

What is a battery?

- A chemical energy storage device.
- Has a positive end (cathode) and a negative end (anode).
- Both electrodes are suspended in electrolyte (transport medium).

What do they have in common?

- Aluminum
- Zinc
- Lithium
- Carbon
- Nickel
- Lead

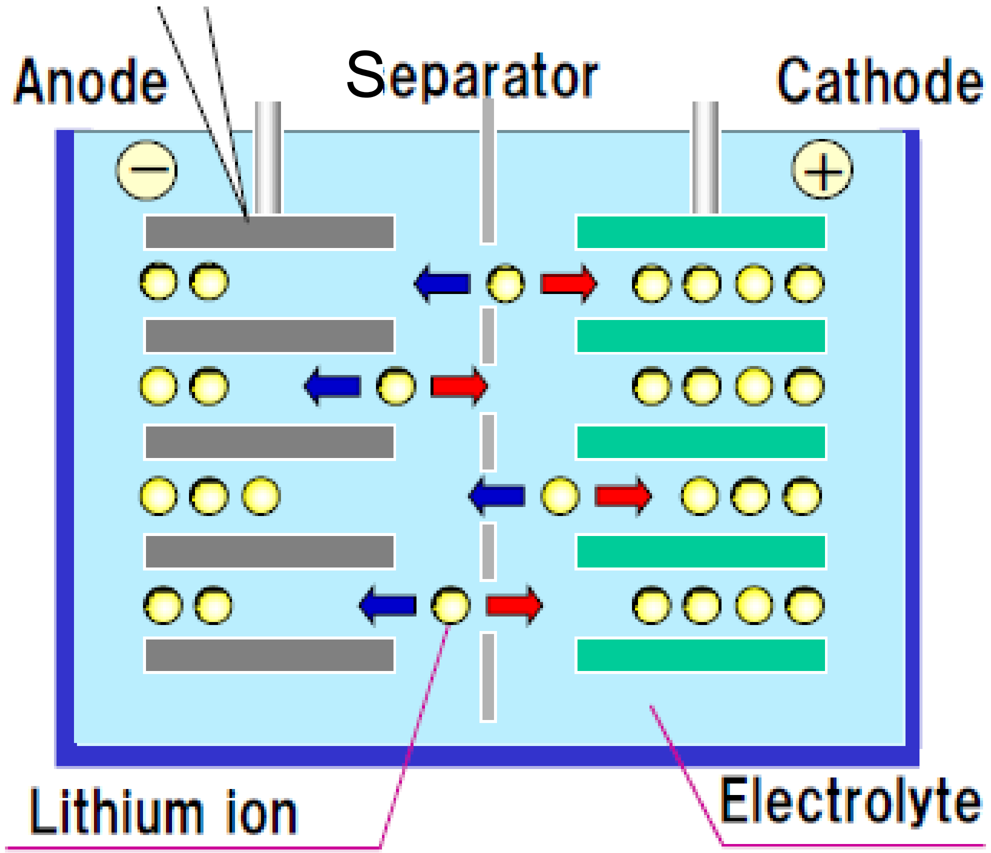
What is a lithium-ion battery?

As defined by UL:

A lithium-ion battery is an energy storage device in which lithium ions move through an electrolyte from the negative electrode (the "anode") to the positive electrode (the "cathode") during battery discharge, and from the positive electrode to the negative electrode during charging. The electrochemically active materials in lithium-ion batteries are typically a lithium metal oxide for the cathode, and a lithiated carbon for the anode. The electrolytes are typically a non-aqueous liquid, but can also be gel or polymer. A thin (on the order of microns) micro-porous film separator provides electrical isolation between the cathode and anode, while still allowing for ionic conductivity.

-"Safety Issues for Lithium Ion Batteries", Underwriters Laboratories, 2013

Lithium-ion Battery Basics



Conventional Li-ion Battery

Common Lithium Chemistries

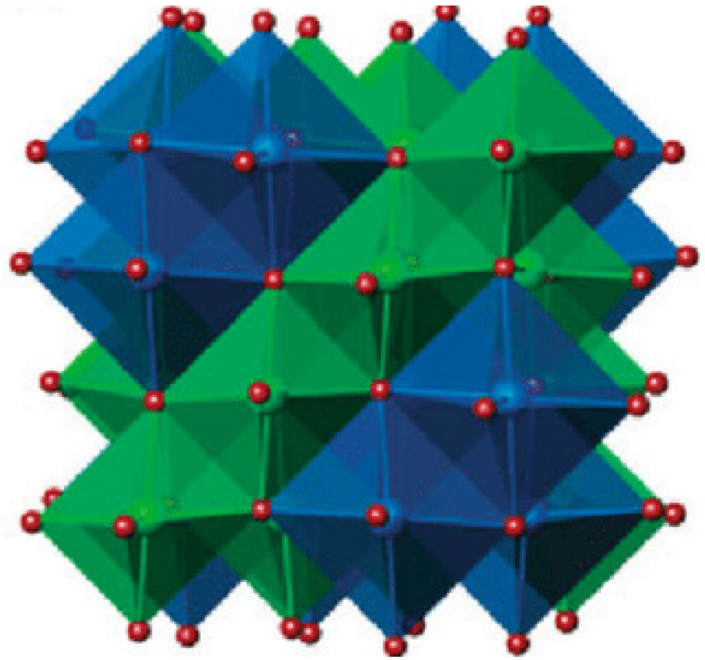
- LCO – Lithium Cobalt Oxide
  - High specific energy: mobile phones, laptops, etc. Slow charging, limited life (~1000cycles)
- NMC/NCM/MCN – (Lithium) Nickel Manganese Cobalt
  - Taylor for high energy or medium power: EV, power tools, e-bikes. Slow charging, good life (~4000 cycles).
- NCA – (Lithium) Nickel Cobalt Aluminum
  - High specific energy: Medical devices, industrial, fast charge possible, limited life (~1500 cycles)
- LiPol/LiPoly - Lithium Polymer
  - Low energy density, the electrolyte is porous-gel-like (v ‘liquid’): mobile phones, laptops, toys. Have great form factor (can have several shapes), expensive and limited life (~1000)

Common Lithium Chemistries

- LFP/LiFePO4 – Lithium Iron Phosphate
  - High specific energy: EV. Fast charging, long life (~5000 cycles)
- LMO/LMNO – Lithium Manganese Nickel Oxide
  - High specific power but can be adjusted for high specific energy or longevity: power tools, medical instruments, HEV. High charge, limited life (~1000).
- LTO – Lithium Titanate/Titanium Dioxide
  - High specific power, ESS-PV farms, grid stabilization, EV, heavy vehicles. Fast charge/discharge, very long life (20,000 cycles).

03

LTO Chemistry



LTO Chemistry

At the conclusion of this section, participants will be able to:

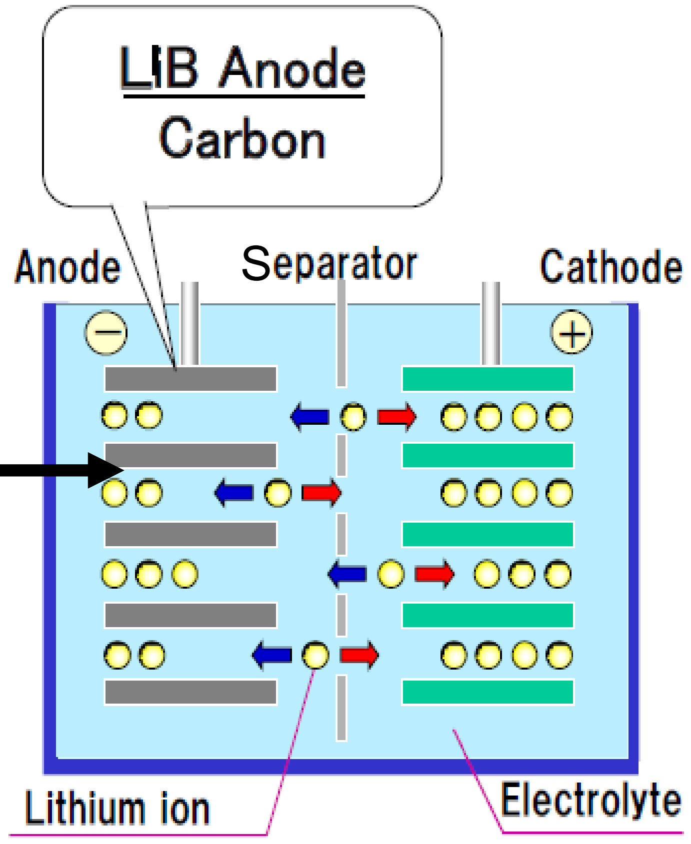
- Differentiate between other lithium-ion batteries and an LTO battery.
- Describe the ways lithium batteries catch on fire and how LTO batteries avoid/prevent those ways.
- Define C-rates, energy density, power density, battery SOC, EOL, and BOL.

Learning Objectives

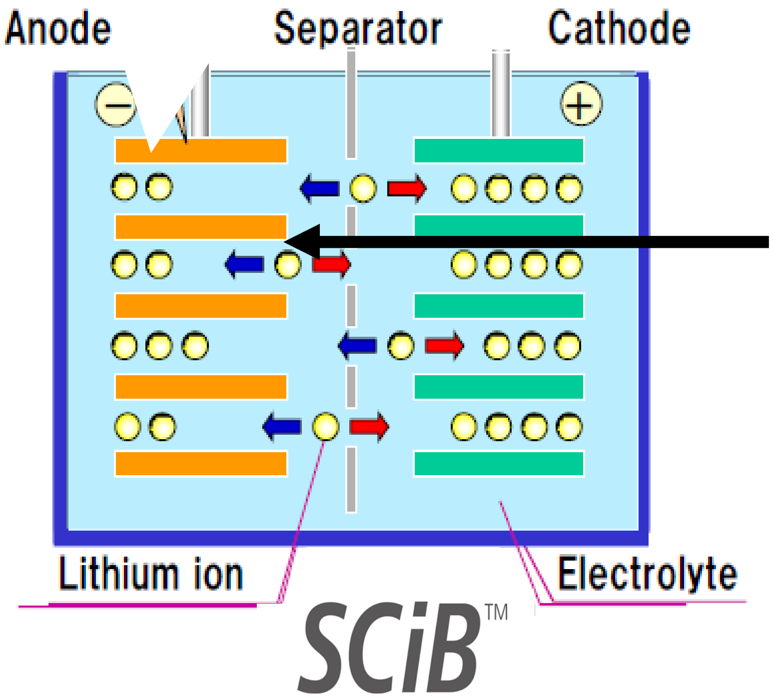
LTO Chemistry

SCiB™ is within the family of lithium-ion batteries (LIB);
However, SCiB™ exhibits greater benefits compared to the rest of LIBs

Contains Carbon!



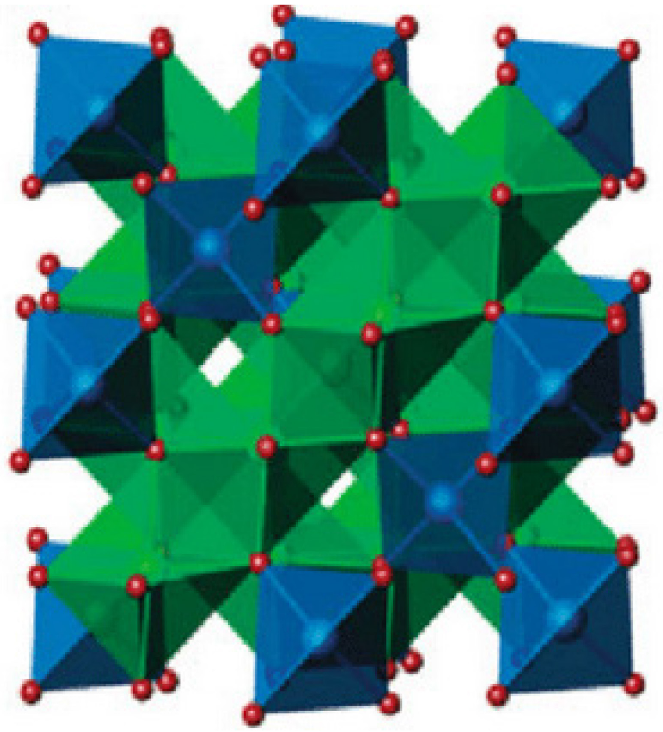
Conventional Li-Ion Battery



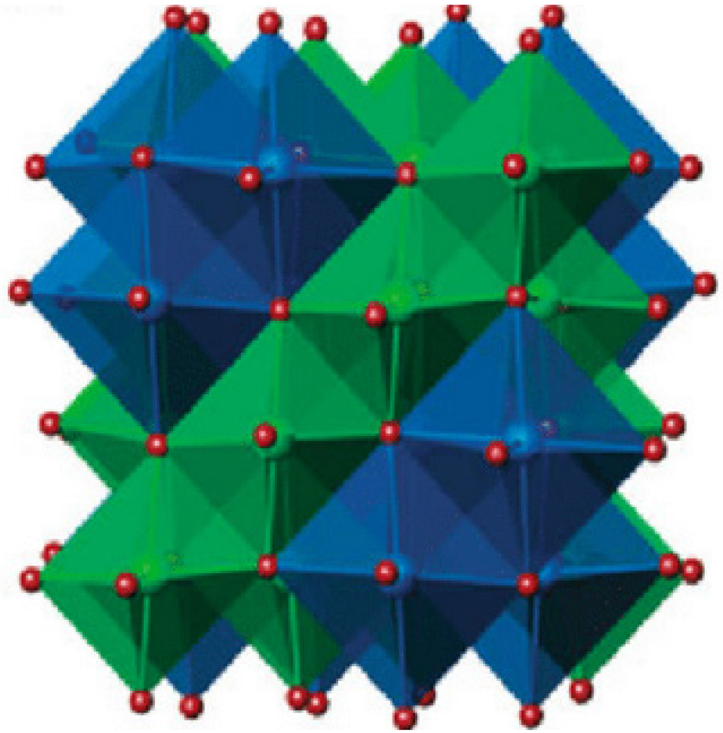
Carbon Free!

LTO Chemistry

LTO (Lithium Titanate) Structure



Non-lithiated LTO



Lithiated LTO

- **Octahedral lithiated structure**
- **Rigid lattice spinel – not layered nor olivine**
- **Special emergent properties owing to morphology**

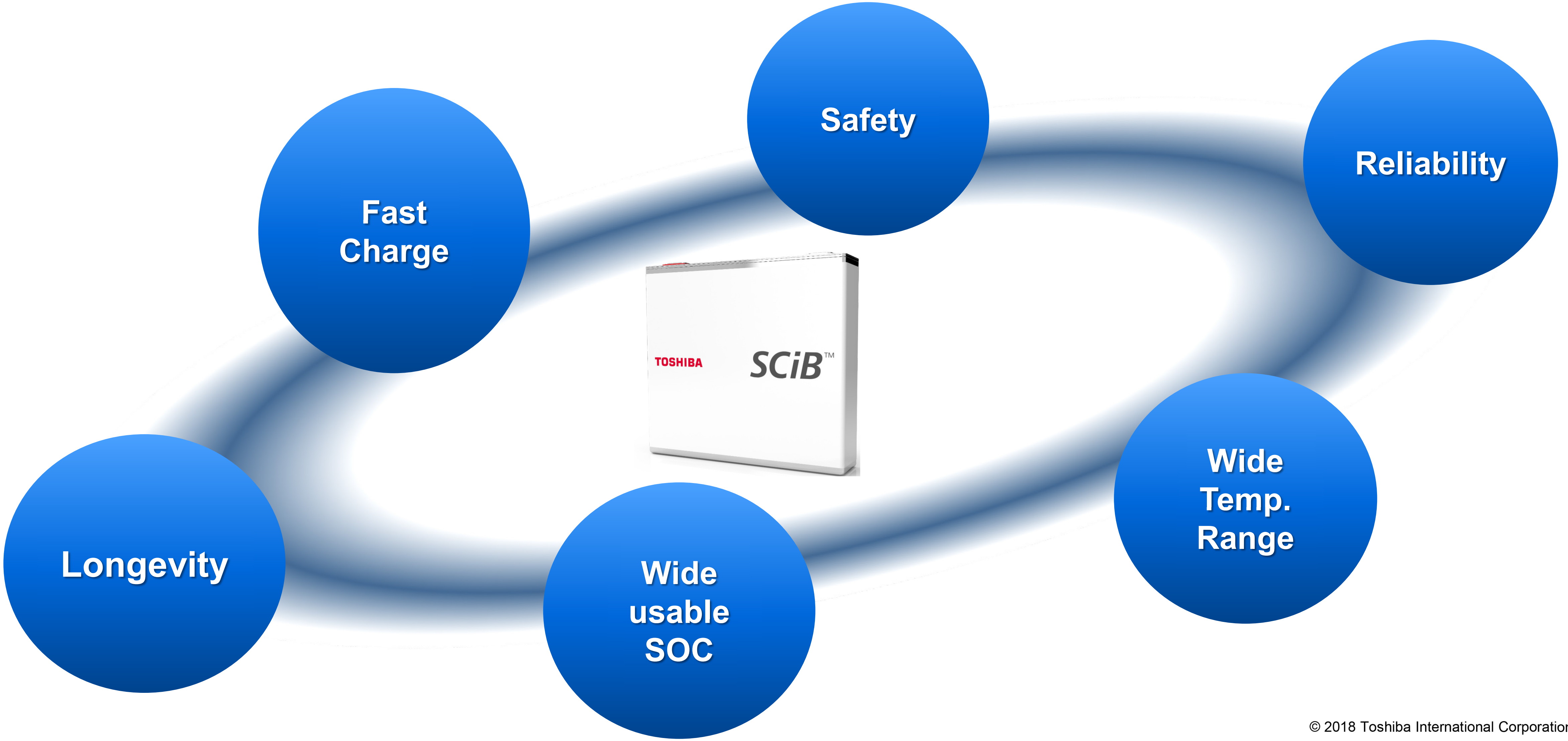
LTO Chemistry

Safety

- Growing concerns about lithium battery fires
- Several high profile incidents
- Causes a difficult to extinguish metal/ chemical fire
- Standards put in place by NFPA, UN, UL, IEEE, etc.

LTO Chemistry

Properties



Safety

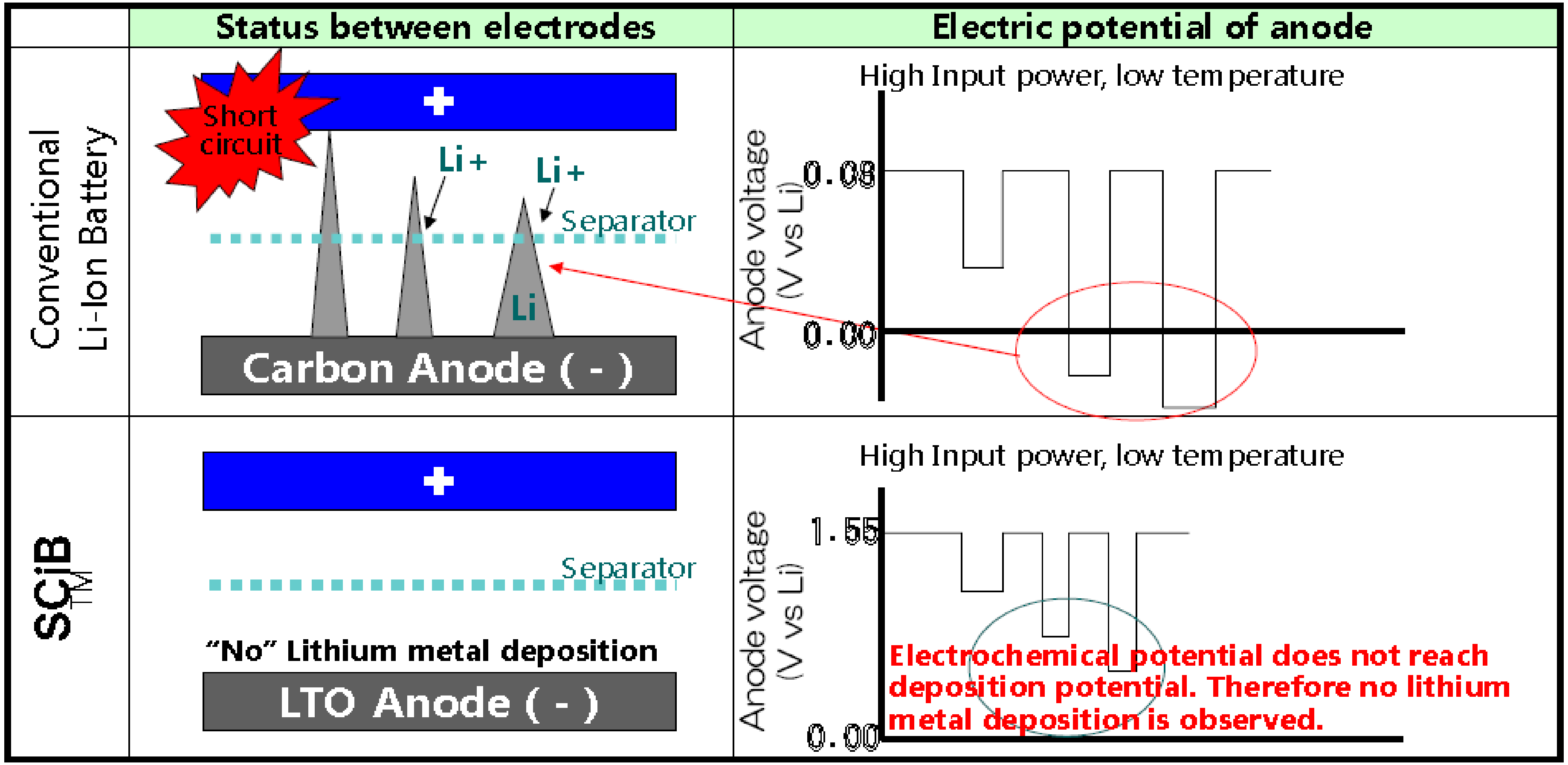
Causes of fires in lithium batteries

- **Internal Shorts**
  - Degradation
  - Contamination
- **External Shorts**

LTO Chemistry

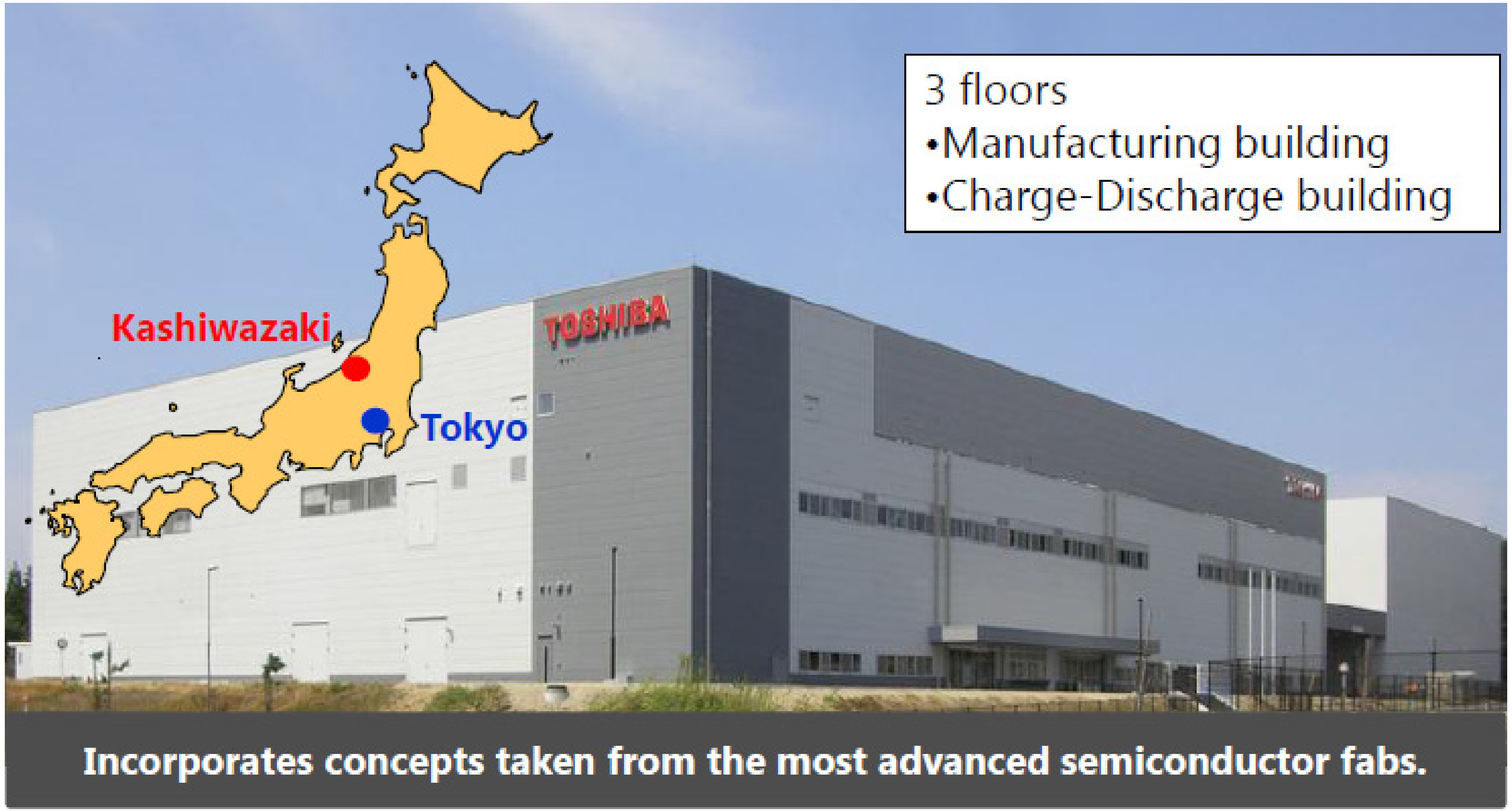
Safety

No Lithium metal deposition, even in cold conditions with high input power, and over a long cycle



LTO Chemistry

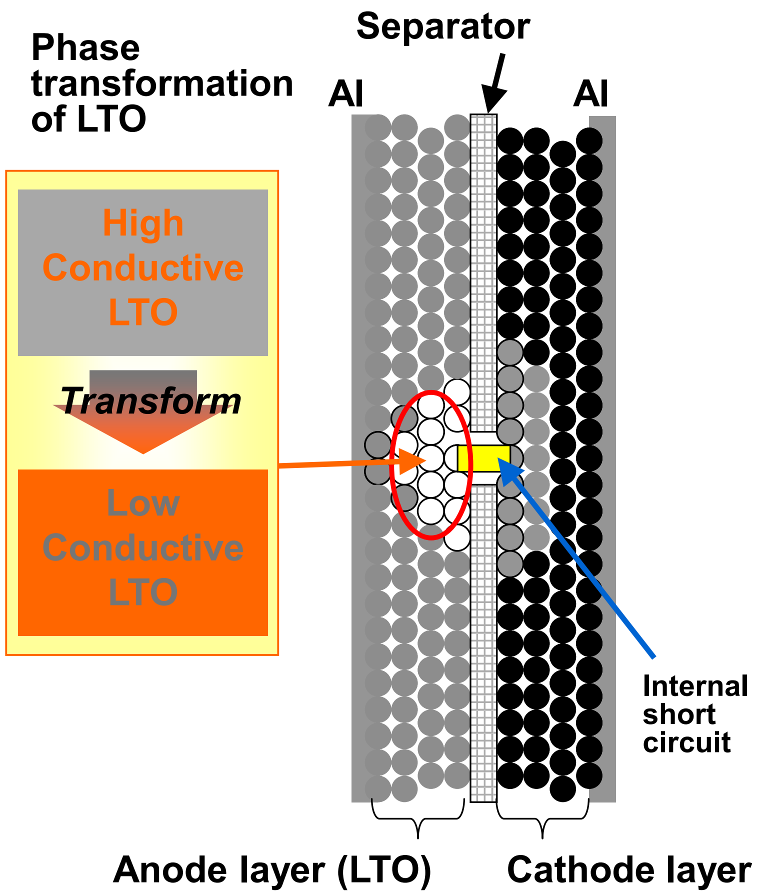
Safety

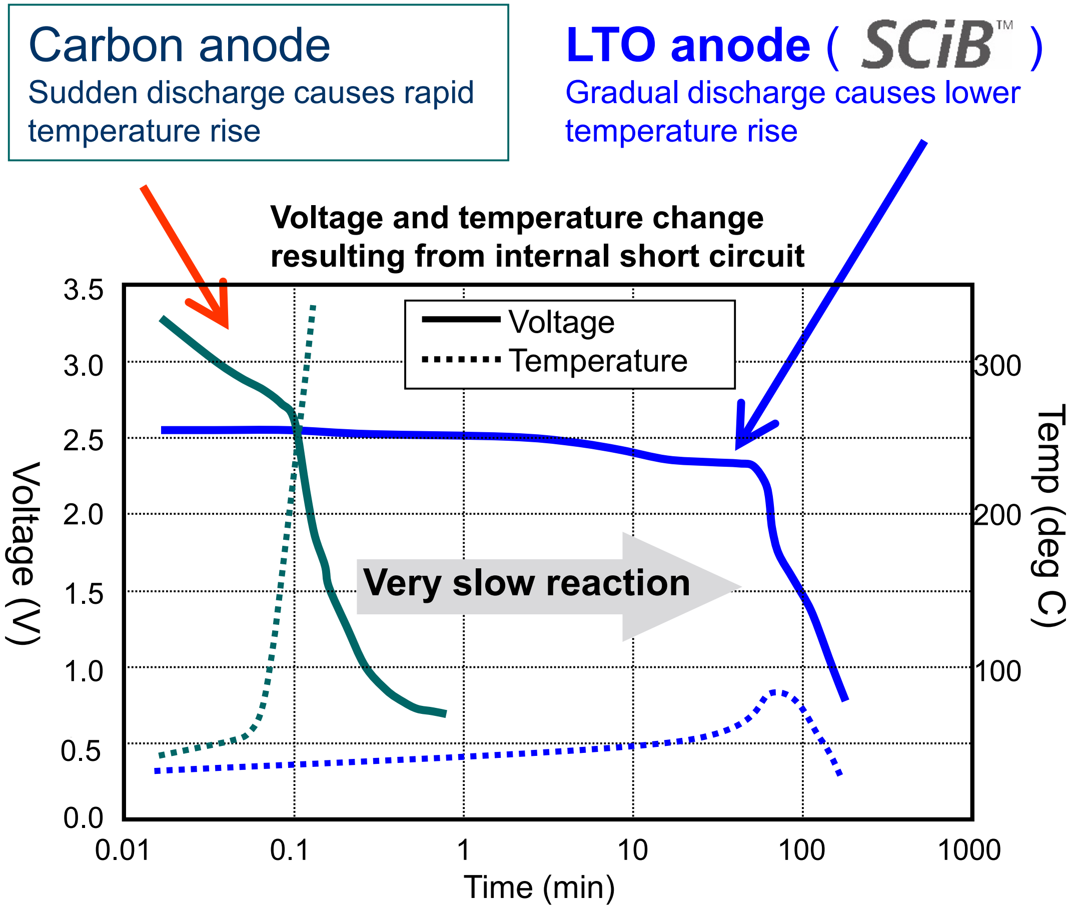


- Clean Room Manufacturing Environment
- Complete isolation between anode and cathode material

Resistance to Short Propagation

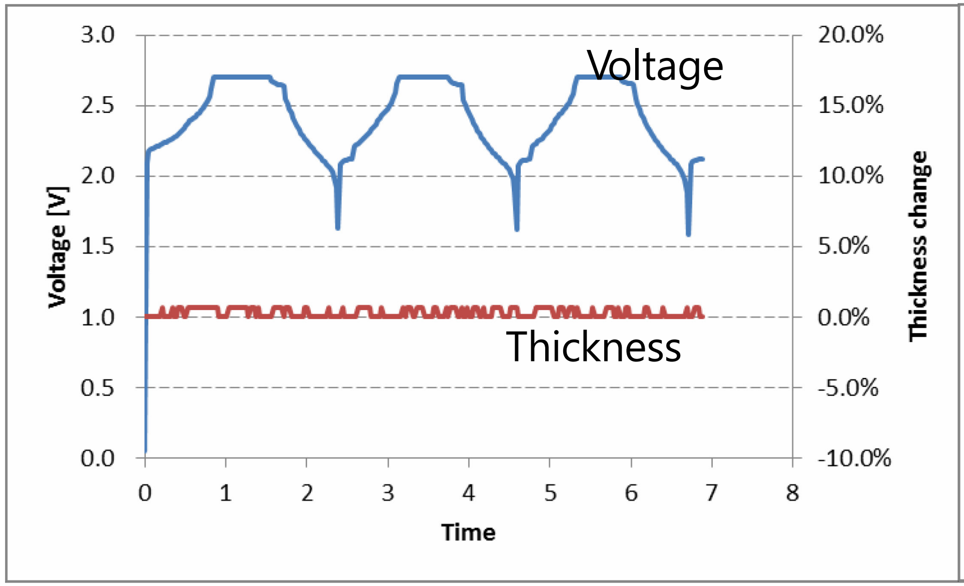
In the event of internal short, LTO phase transformation prevents large current flow, causing self-isolation and preventing propagation.



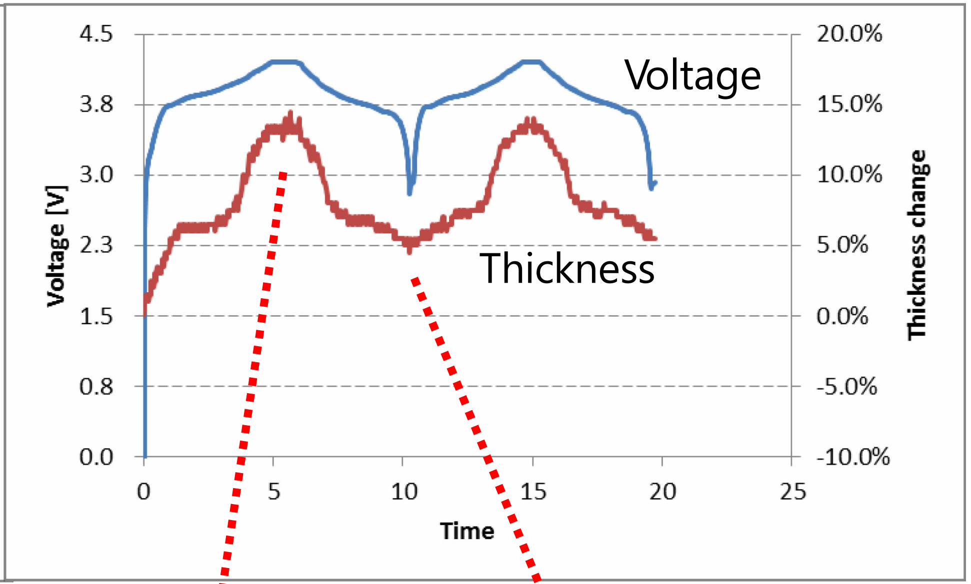


Thickness Stability Enables Long Cycle Life

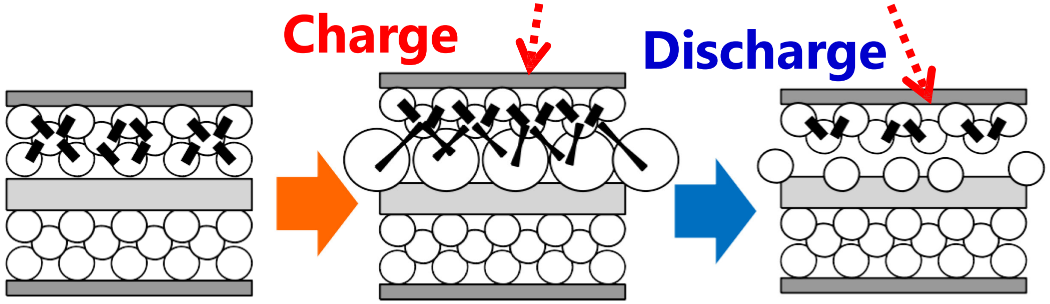
LTO anode



Carbon Anode



Degradation by expansion/contraction



SCiB™ is stable after repeated charge/discharge

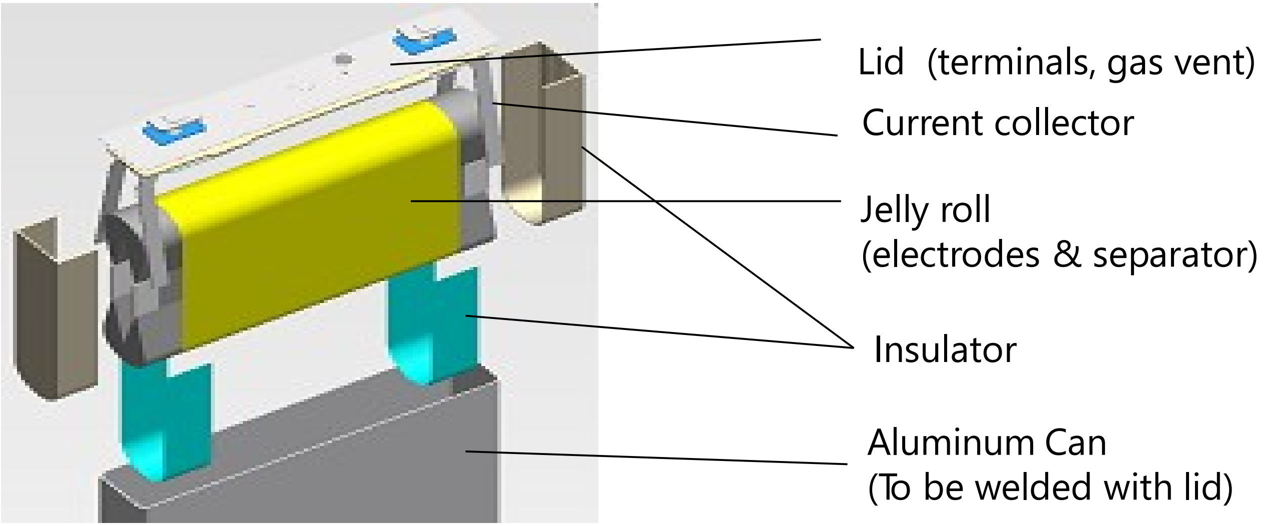
Material & Structure of SCiBTM

**SCiB™ is within the family of lithium-ion batteries (LIB),
But SCiB™ offers excellent performance compared to other LIBs**

Material

	Anode	Voltage
SCiB(20Ah)	**LTO**	**2.3V**
Competitor A	Carbon	3.6V
Competitor B	Carbon	3.3V
Competitor C	Carbon	3.7V

Structure



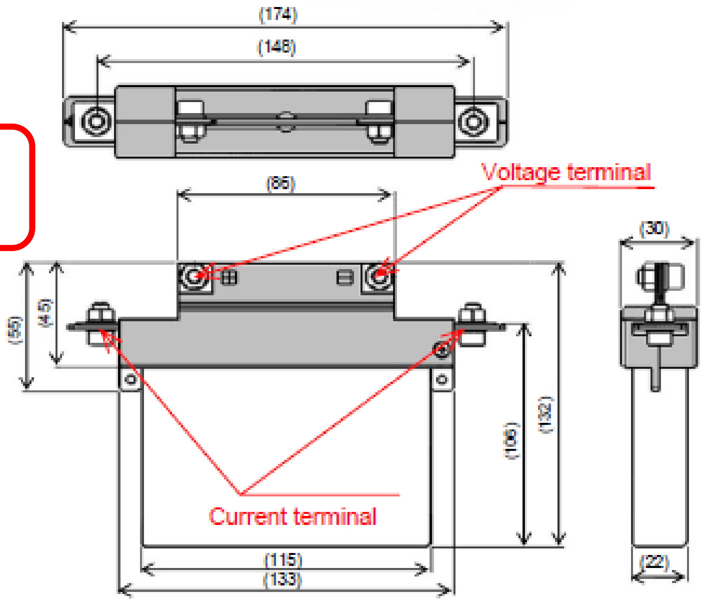
Low Internal Resistance

Very low internal resistance in SCiB™ enables it high rate performance.

- **Application : EV, PHEV, Stationary, Industrial Use, etc..**

Nominal Capacity	20 Ah
Nominal Voltage	2.3 V
Voltage Range	1.5～2.7V
Maximum Current	100A (Constant) / 200A (Within 10 seconds)
Internal Resistance	1.0mΩ (approx.) (DC10sec, SOC50%, 25℃)
Specific Energy	89Wh/kg
Energy Density	176Wh/L
Dimensions	W116 ×H106 ×22 mm
Weight	515g ± 15g

Specification, technical data and performance data in this material are tentative. Those are Subject to change without prior notice.



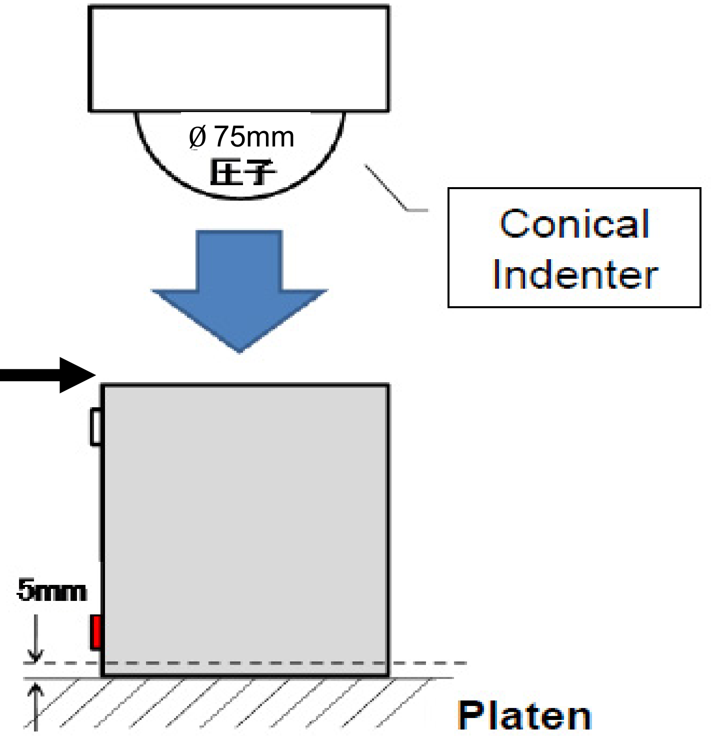
LTO Chemistry

Safety

No fire and no explosion occurs even when fully crushed

Press to Side-Face

Lateral Surface



Test condition Temp : Room Temp.
SOC : 100%

Safety

No Carbon = No Fire

LTO Chemistry

Cell/Battery Related Definitions

C-rates: Inverse proportion of nominal capacity of a battery with regards to charge time.

Power Density: Total usable power stored in a given volume.

Energy Density: Total usable energy (power over time) stored in a given volume.

SOC: State of charge or the percentage of power stored in a battery as it relates to the nominal capacity.

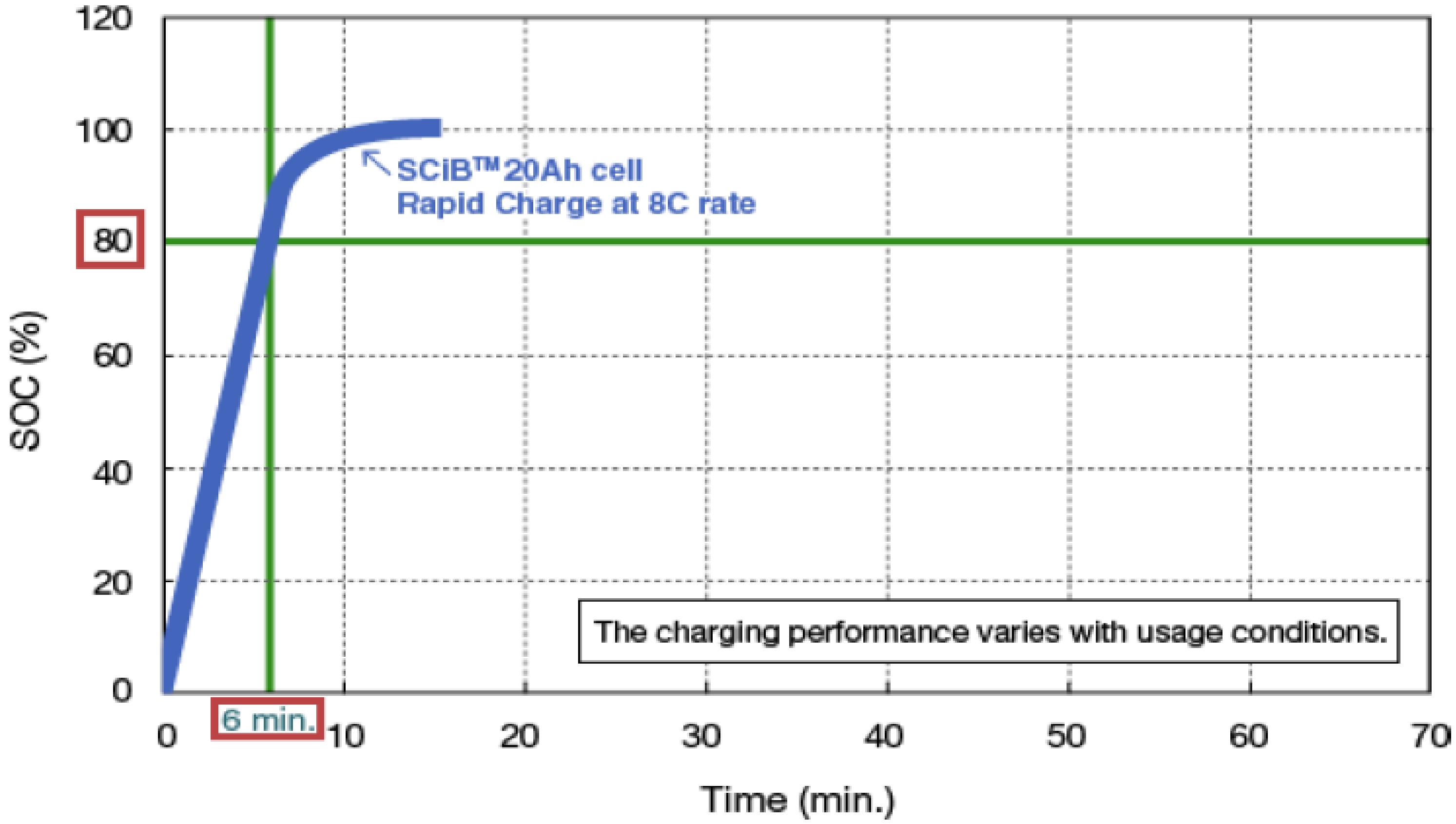
BOL: Beginning of life.

EOL: End of life.

LTO Chemistry

Fast Charge

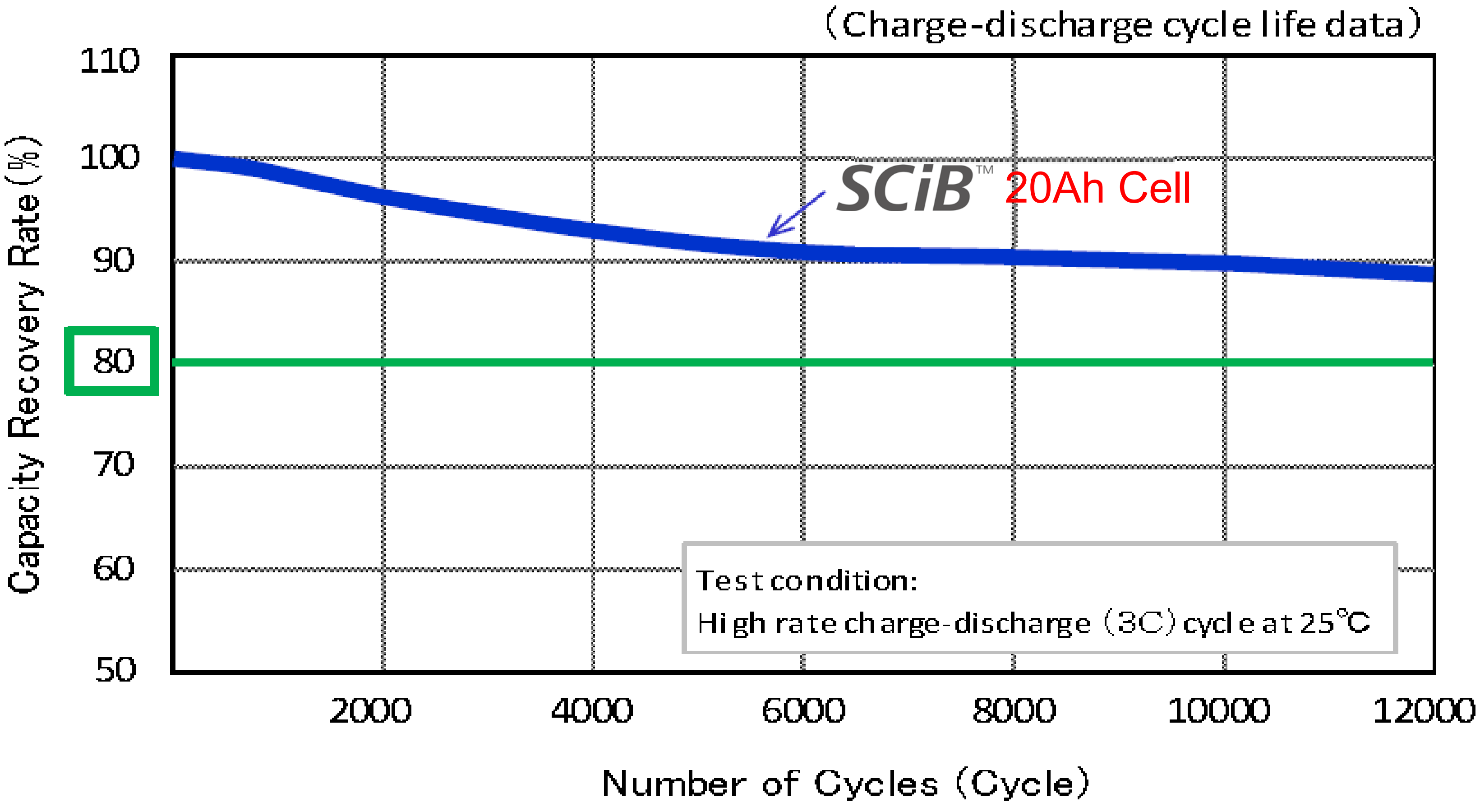
LTO has a very short dis/charge time.
-Only 6 minutes to up to 80% of capacity.



LTO Chemistry

Wide Usable SOC

Realizes very high number of charge/discharge cycles

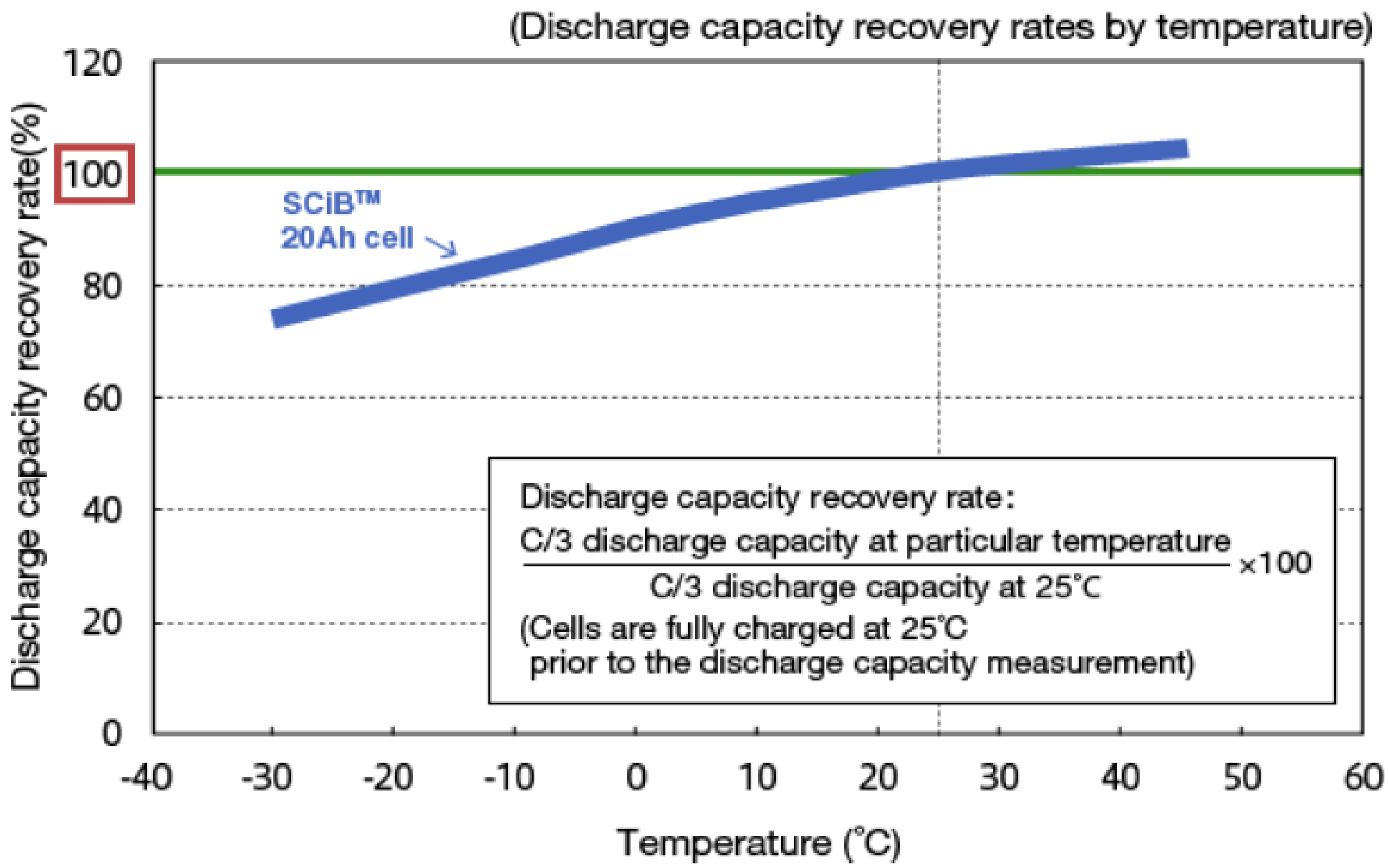


***EOL = 80% BOL = 17k cycles**

LTO Chemistry

Wide Operating Temperature

Usable in ambient temperature of minus 30°C.



04

Chemistry Comparison

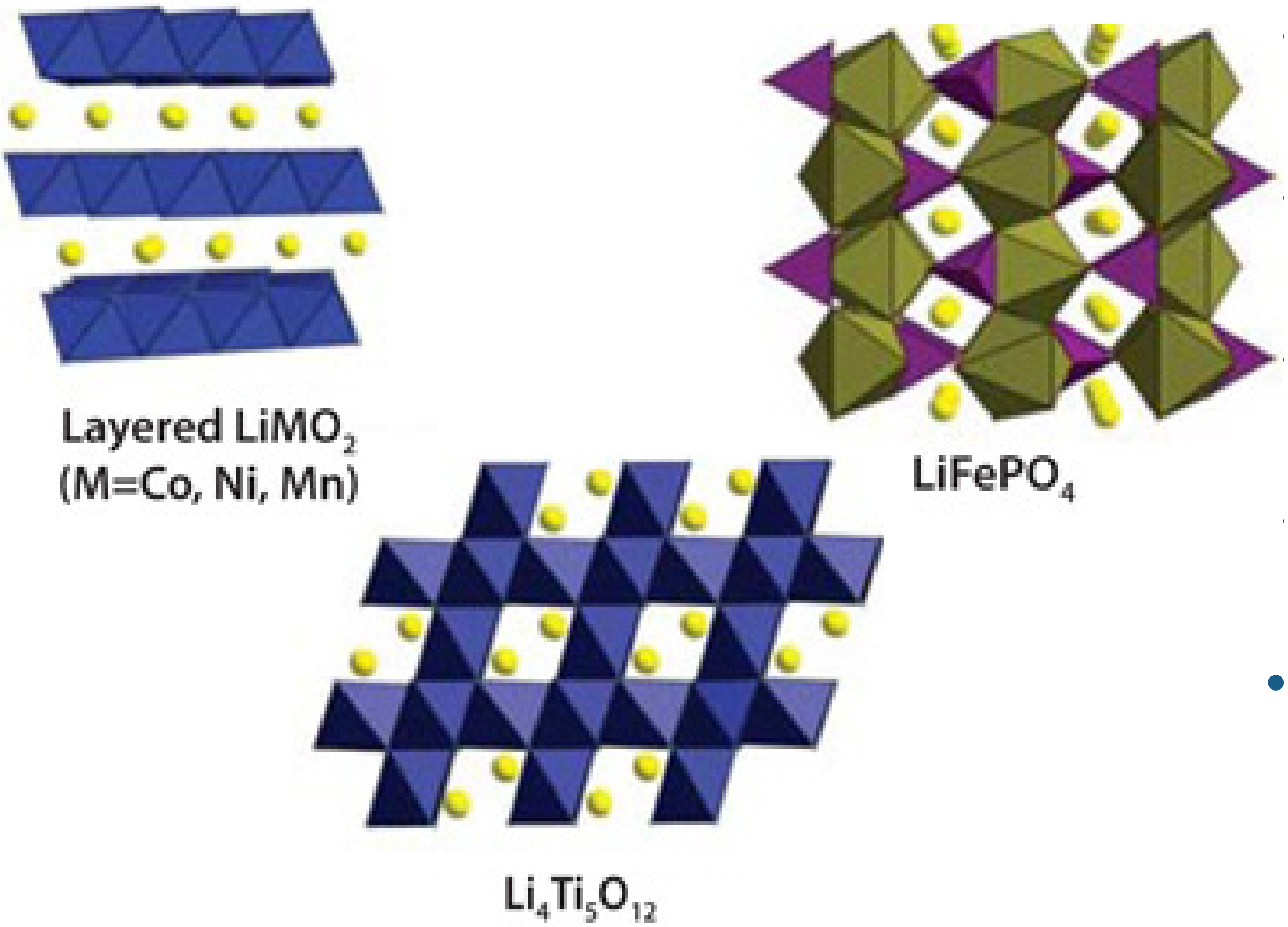
At the conclusion of this section, participants will be able to:

- List the common lithium-ion chemistries found in the market and evaluate the benefits of each.
- Justify the pros and cons of LTO batteries compared to other lithium-ion chemistries.

Learning Objectives

Chemistry Comparison

Li-ion Chemistry Comparison

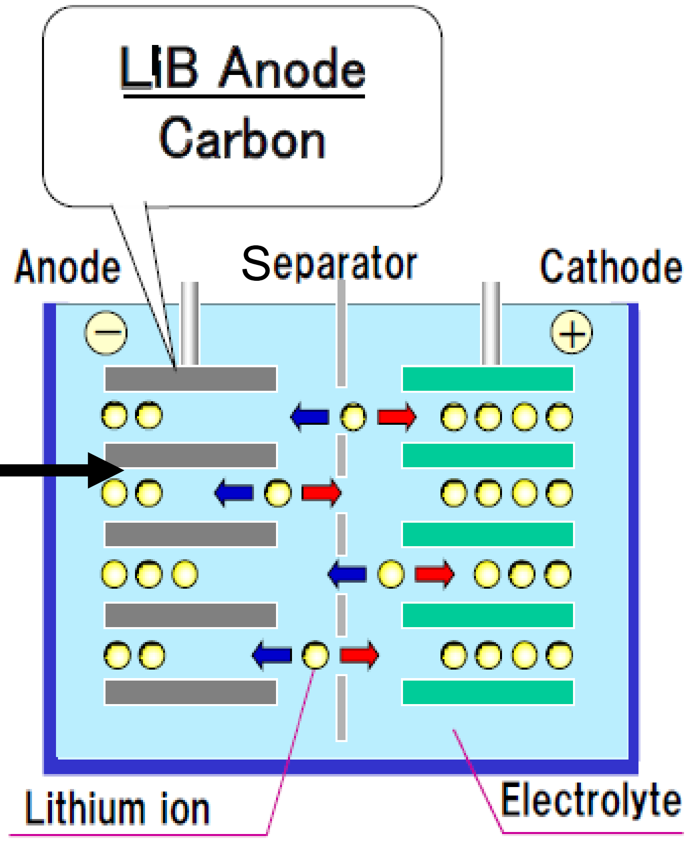


- LCO/LiCo – Lithium Cobalt
- NMC/NiMnCo – Nickel Manganese Cobalt
- LMO/LiMnO – Lithium Manganese Oxide
- LFP/LiFePO4 – Iron Phosphate
- LFS/LiFeSiO4 – Iron Silicate

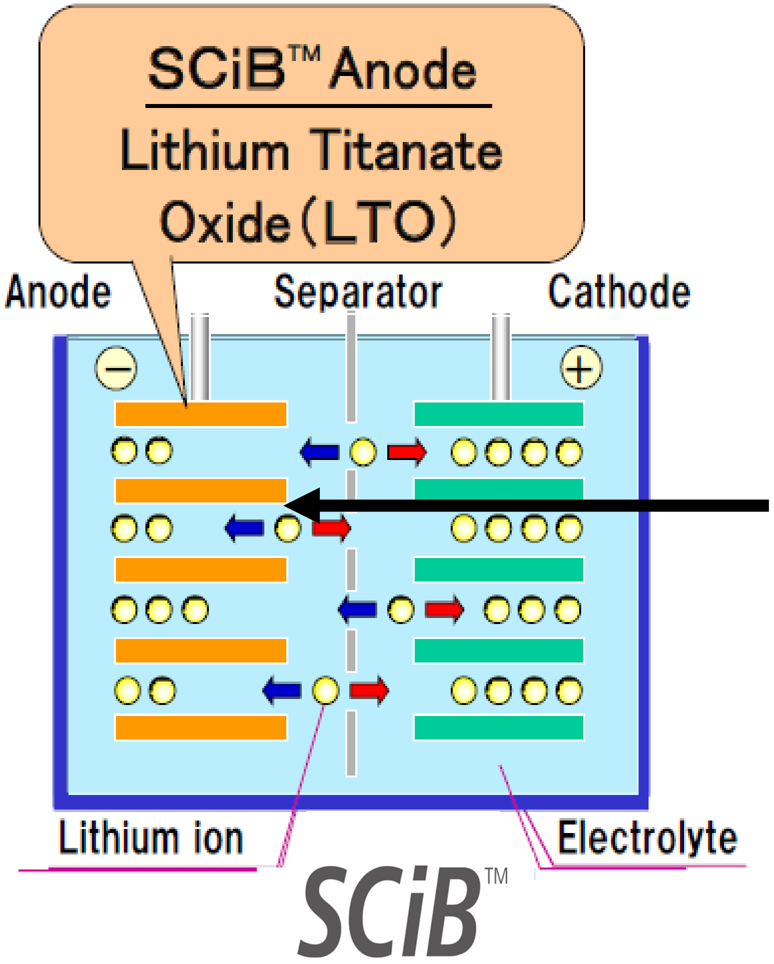
Chemistry Comparison

SCiB™ is within the family of lithium-ion batteries (LIB), but SCiB™ offers excellent performance compared to other LIBs

Contains Carbon!



Conventional Li-ion Battery



Carbon Free!

What is Thermal Runaway?

As defined by NFPA 855 (2020), 3.3.20:

Thermal Runaway. The condition when an electro-chemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion.

What is the main cause of Thermal Runaway?

What is the main trigger that causes electro-chemical batteries to go into Thermal Runaway?

High input V on the terminals compare to its changing internal chemistry. With time and cycles, internal chemistry changes and therefore, the “nominal” 100% SOC (float), charging voltage now becomes high voltage.

Chemistry Comparison

Cell Level Li-ion Chemistry Comparison

Manufacturer	Panasonic	Samsung	Toshiba
Chemistry	NMC	LiFePO4	SCiB LTO
Voltage	3.6V	3.3V	2.3V
Specific Energy	150Wh/kg	110Wh/kg	90Wh/kg
Charge Rate	0.7-1C	1C	8C
Discharge Rate	3C	3C	8C
Usable SOC	70%	80%	100%
Cycle Life	2000 - 4000	4000 - 5000	17000
Induced Thermal Runaway w/safety removed & constant high V	210° C	270° C	NA

Pertinent Safety Standards and Code Regulations

- UL 1642 – Cell level certification
- UL 1973 – Module and system level certification
- UL 9540 – System level certification
- NFPA 855 – Fire protection code
- UN DOT 38.3 – Lithium battery transportation standard

Chemistry Comparison

Pertinent Safety Standards and Code Regulations

Test Criteria/Standard	UL 1642	UL 1973
External short circuit	•	•
Abnormal charge/Overcharge	•	•
Forced discharge/Overdischarge	•	•
Crush	•	•
Impact (cell)	•	
Shock	•	•
Vibration	•	•
Heating (cell)	•	
Temperature cycling	•	•
Low pressure (altitude) (cell)	•	
Projectile/External fire	•	•
Drop		•
Continuous low rate charging		
Molded casing heating test		•
Insulation or isolation resistance		
Internal short circuit test or propagation test		•

UL 9540:

- Fluid equipment
- Hazardous spill containment
- Combustible concentrations
- Fire detection and suppression

NFPA 855 (as per Version 2020):

- Requires compliance with UL 9540A and 1778
- Maximum string capacity of 50kWh and maximum ESS capacity of 600kWh (group separation of 3 ft for 250kWh sizes, not-dedicated use building)
- Only applies to ESS larger than 20kWh

05

LTO Cells

LTO Cells

At the conclusion of this section, participants will be able to:

- Describe the problems innate to li-ion cells, and how LTO overcomes them.
- Describe how the LTO cell is constructed.

Learning Objectives

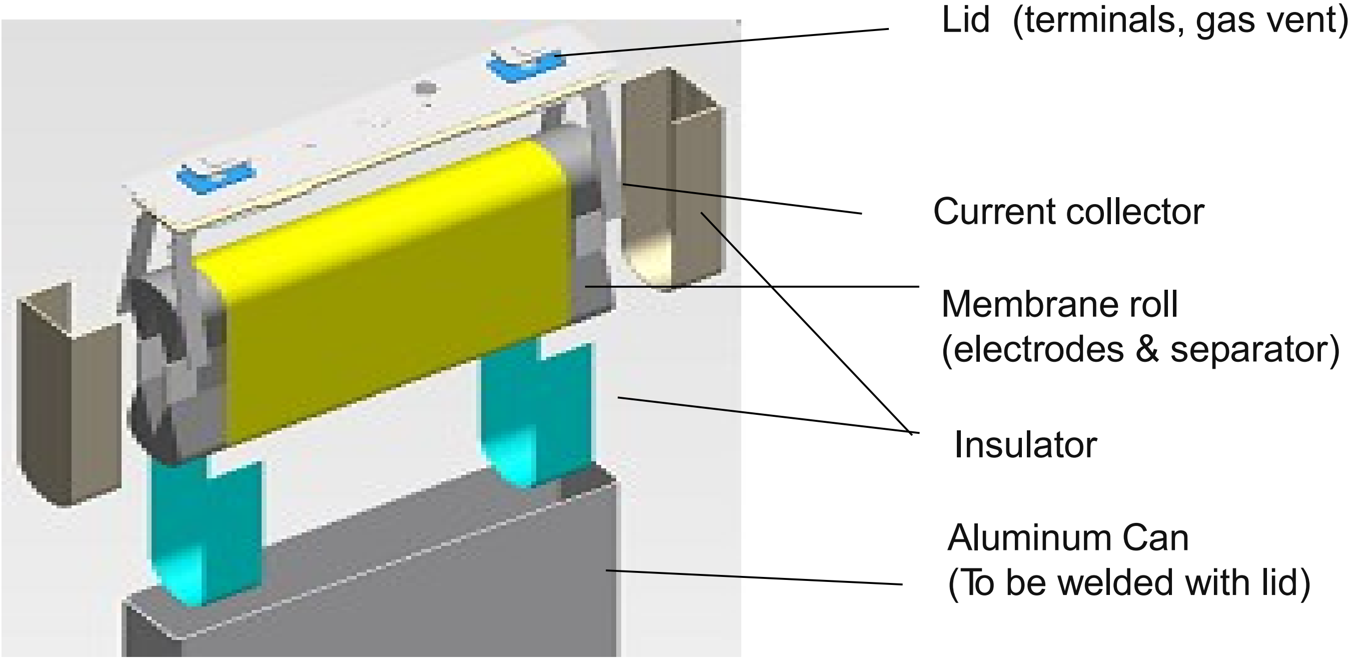
LTO Cells

Cell Design Considerations

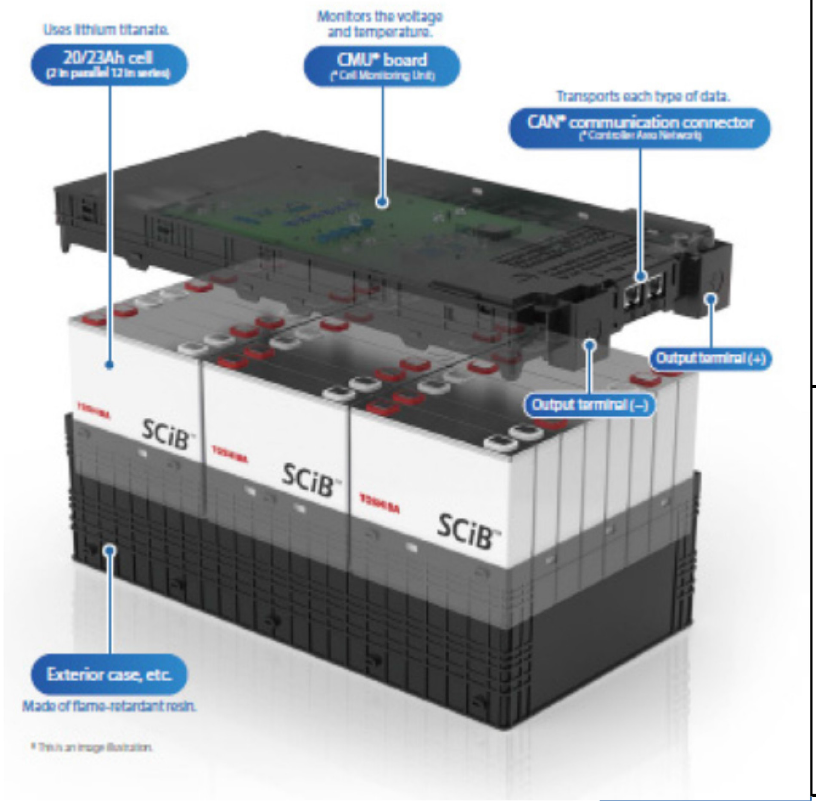
- Outgassing: The problem of cells swelling up over time or because of improper cycling.
- Terminal limitation: The terminal contacts limiting the flow of power and latency.
- Loose contacts: The connection between the terminals getting disturbed over time causing dropping of the load or sparks.
- Weight: The physical mass causing a limitation in terms of where the cells can be used.

LTO Cells

LTO is within the family of lithium-ion batteries (LIB),
But LTO offers excellent performance compared to other LIBs

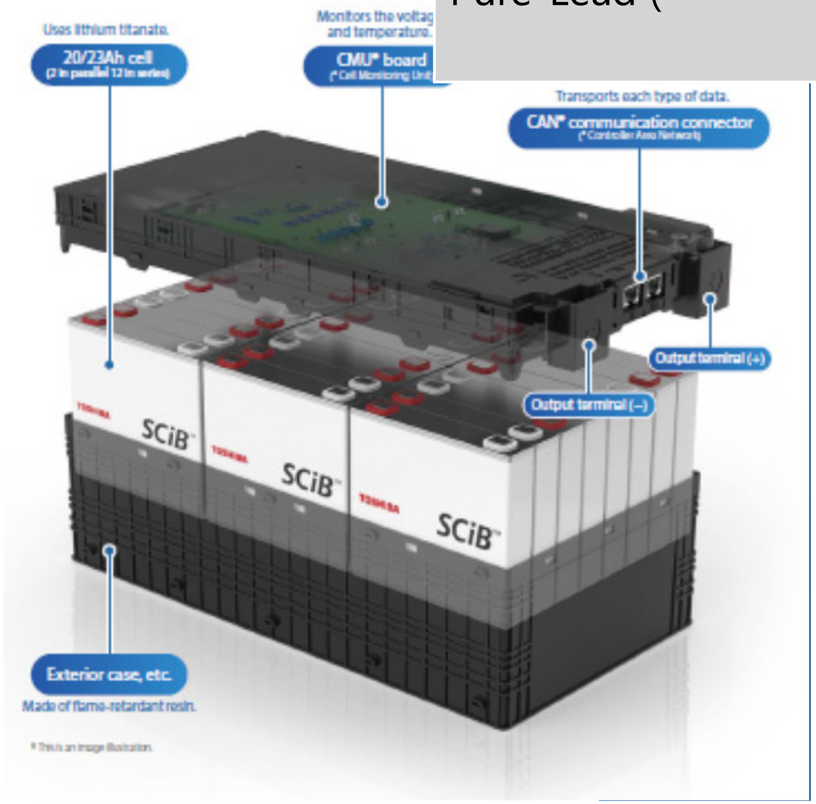


SCiB Modules – 2P12S

Product	Type	Cell Configuration	Specification	Application
		Type 3 - 20 (20Ah cell)	- Voltage: 18.0V - 32.4V - Nominal capacity: 40Ah - Nominal energy: 1104 Wh - Dimension: 359(W)x187(D)x123(H) - Mass: approx 14kg - Functions: cell voltage/temp monitoring, cell balancing, CAN communication	Stationary ESS
		Type 3 - 23 (23Ah cell)	- Voltage: 18.0V - 32.4V - Nominal capacity: 46 Ah - Nominal energy: 1242 Wh - Dimension: 359(W)x187(D)x123(H) - Mass: approx 14.6kg - Functions: cell voltage/temp monitoring, cell balancing, CAN communication	

SCiB Modules – 2P12S

	Weight	Dims
SCiB(20Ah)	30.86 Lbs	14.2”x7.4”x4.8
Pure-Lead (	151 Lbs	24”x12.74”x4.97”

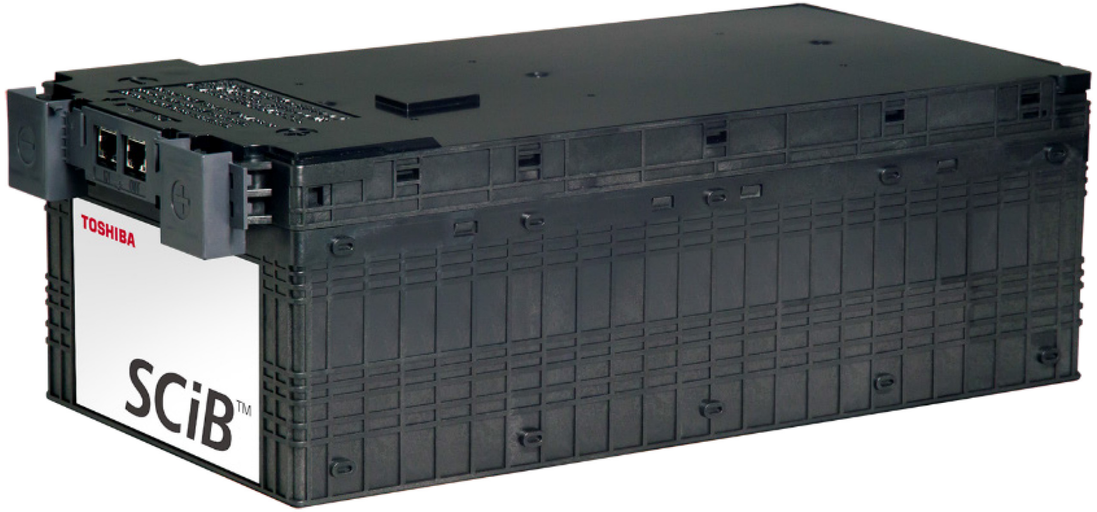


~200Ah

~170AH

06

LTO Modules and Systems

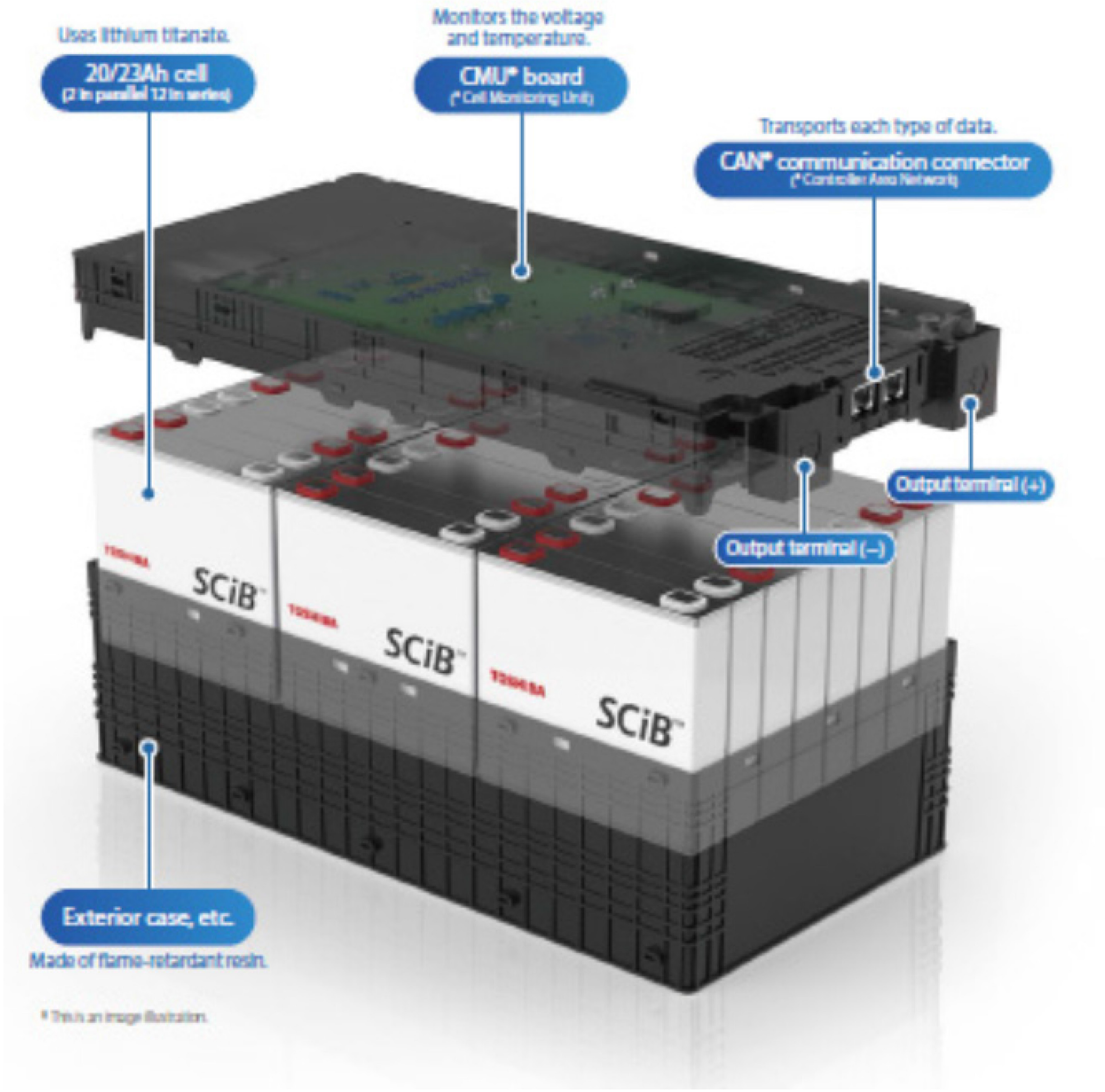


At the conclusion of this section, participants will be able to:

- Describe how a LTO module is constructed.
- Define CANbus 2.0, BMS, CMU, and BMU.
- Explain the multi-layered communication protocol and how this affects system safety and expandability.

Learning Objectives

LTO Modules and Systems



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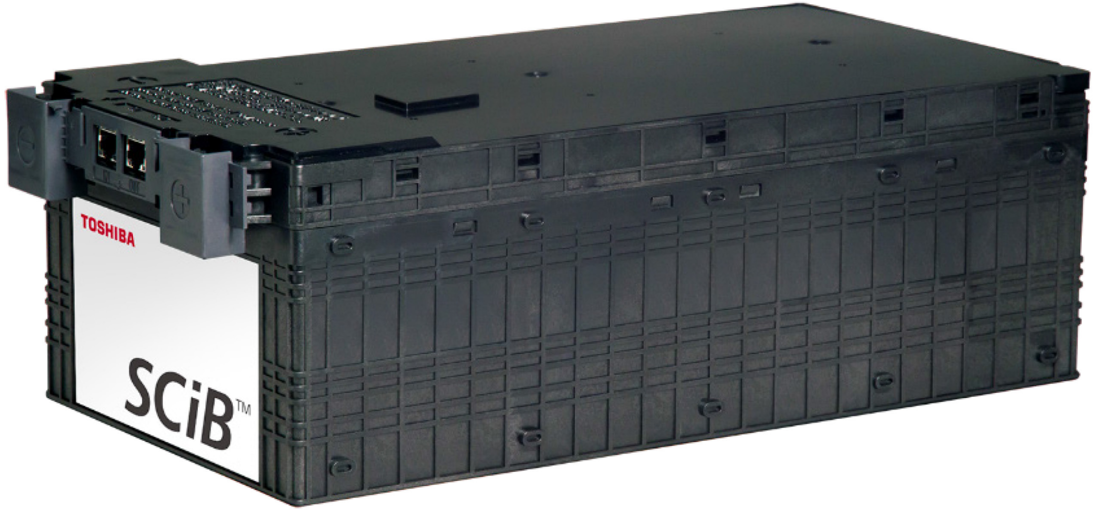
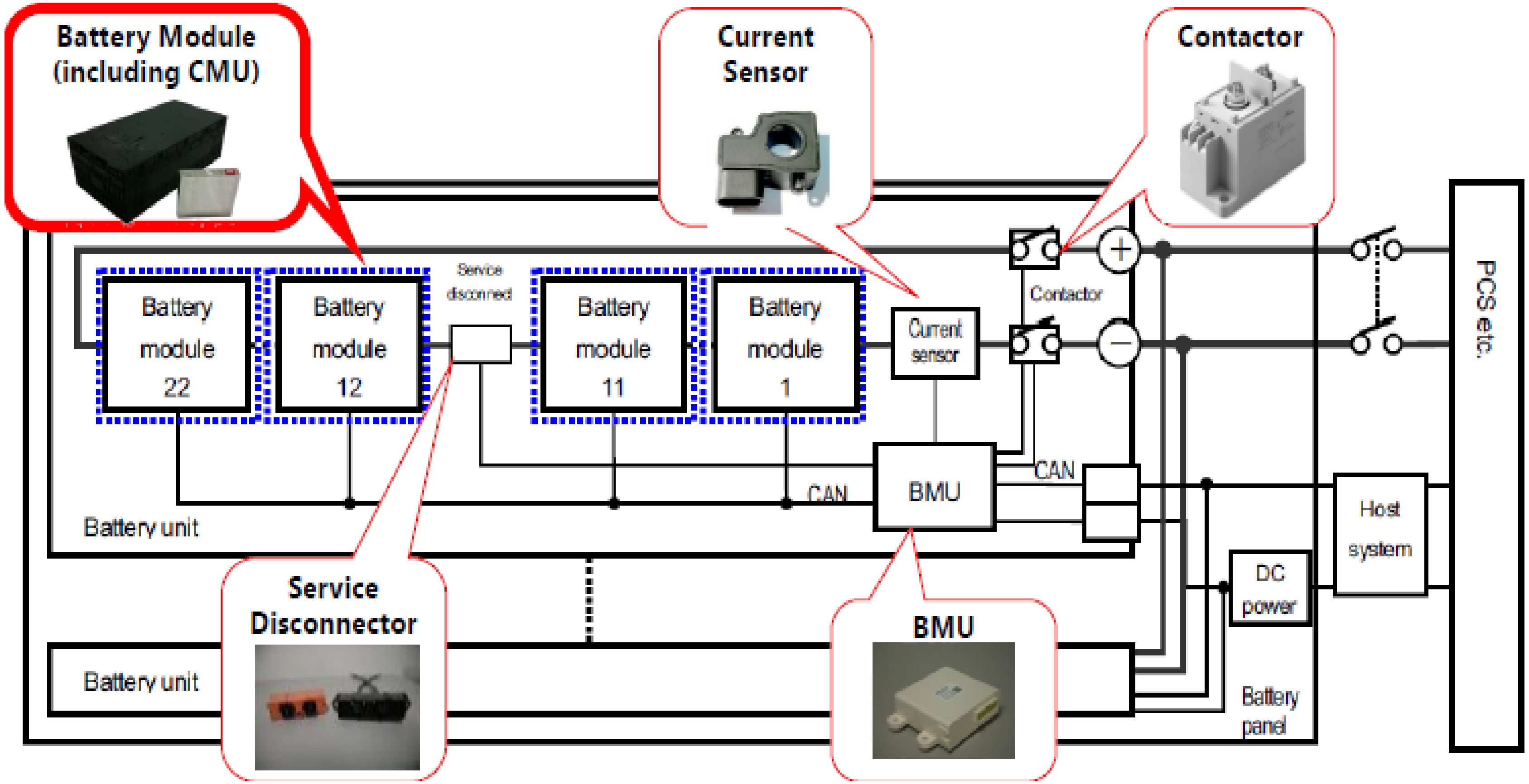


LTO Modules and Systems

Battery Module, BMU, Contactor, and Service Disconnector are available to build up battery system by customers.



- 3 Tiered Battery Management System
- Multiple Fail-safes
- Expandable, Multi-level Architecture
- CANbus 2.0

07

Applications

At the conclusion of this section, participants will be able to:

- List two main areas where batteries are used.
- Explain how batteries are applied in different fields and industries.

Learning Objectives

Applications

Passenger Vehicle

minicab-MiEV(10.5)

Wagon R

Swift

i-MiEV(M)

Fit EV

Spacia

Heavy Equipment

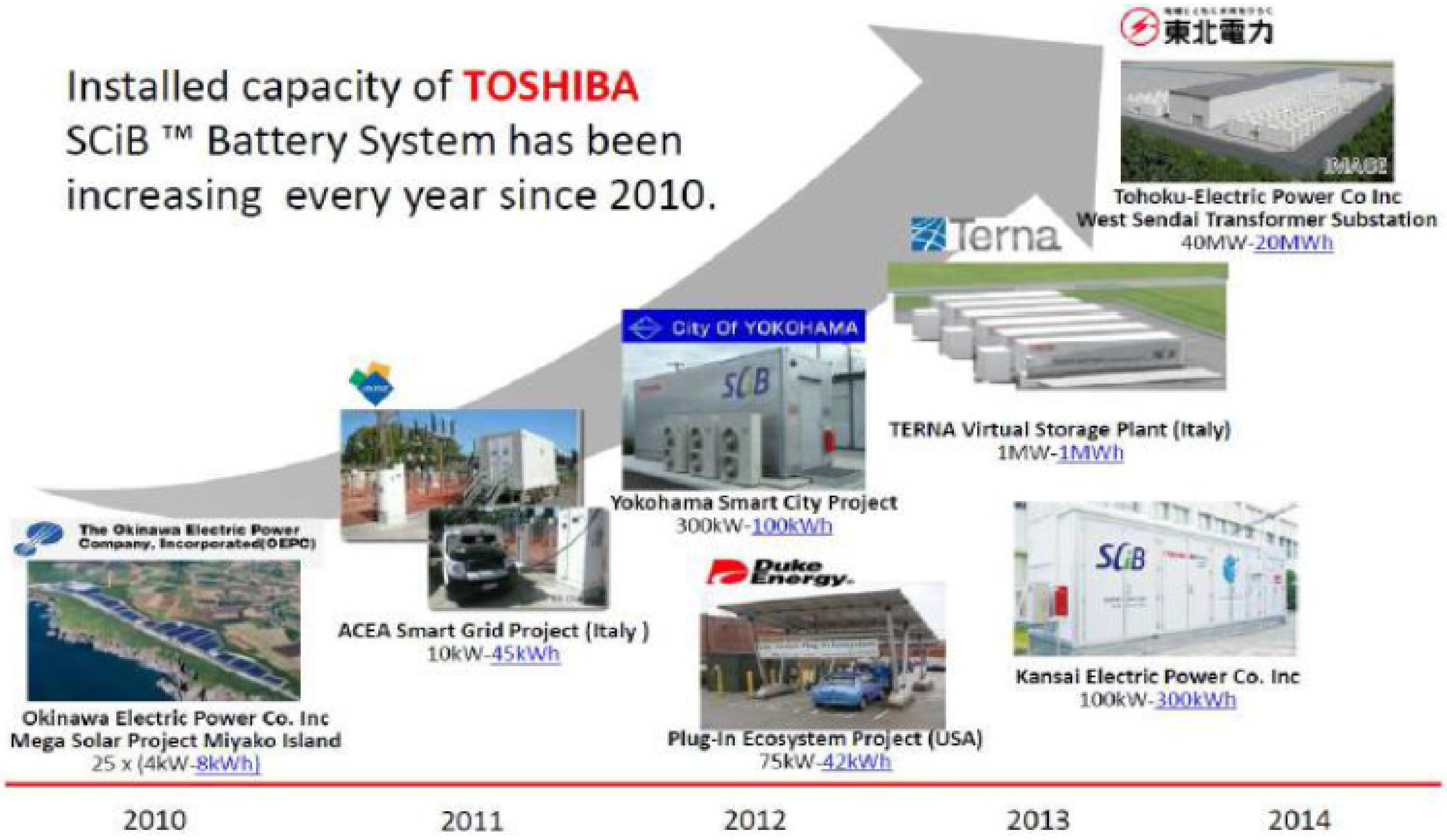
Transit Bus

EV

HEV

Commercial Vehicles

Applications



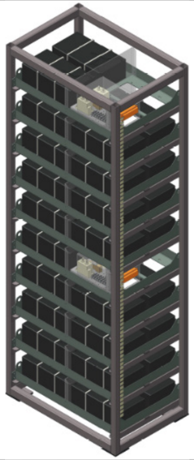
Applications

SCiB Product Systems

Energy Management Systems

DC Power Systems

UPS Energy Storage System



Energy Storage Racks and Containers

Applications

Each cabinet has:

- 36 SCiB modules is 44.7kWh
- Support 250kVA load for 2 minutes
- 12 year full warranty
- Built-in redundancy
- Can be matched to any UPS

UPS Applications

The problems typical for the UPS market. Most are seeking to…

- Make the most of physical space and power capacity.
- Avoid unexpected shutdowns and expecting high power factor and good power quality.
- Manage assets and their connections across deployment, possibly remotely.
- Manage energy usage & costs.
- Reducing operating expenses.

UPS Applications

Longer Life

- VRLA = 500 cycles; Li-ion Batteries = 5,000 cycles; SCiB = 17,000 cycles
- Design life of 15-20 years, warranty 12 years

Zero Maintenance Cost

- Preventative maintenance included every 3 years to check non-battery components: PCBs, contactors, fuses, etc.

Temperature Range

- SCiB UPS battery operating range is higher than VRLA or other lithium batteries
- Lead acid life is cut in half for every 10°C increase
- The exponential savings in cooling!

Trending price to be 2.3 times more than VRLA but less expensive than a flywheel

08

09

Assessment and Evaluations

Quiz time!!!

- Define:
  - SOC
  - BMU
  - Energy Density
  - BOL
  - C-rates
- Explain how the multi-level architecture helps make the system safer.
- What is LTO and how is it different from other li-ion chemistries?
- Explain how li-ion battery fires are caused and why LTO is a safer chemistry.

Quiz time!!!

- Define:
  - Lithium-ion battery
  - Lithiation
- Explain how a lithium-ion battery works.
- Which are some of the standards affecting lithium-ion battery installations?

