Lithium-ion Batteries and Systems

TOSHIBA

TOSHIBA INTERNATIONAL CORPORATION

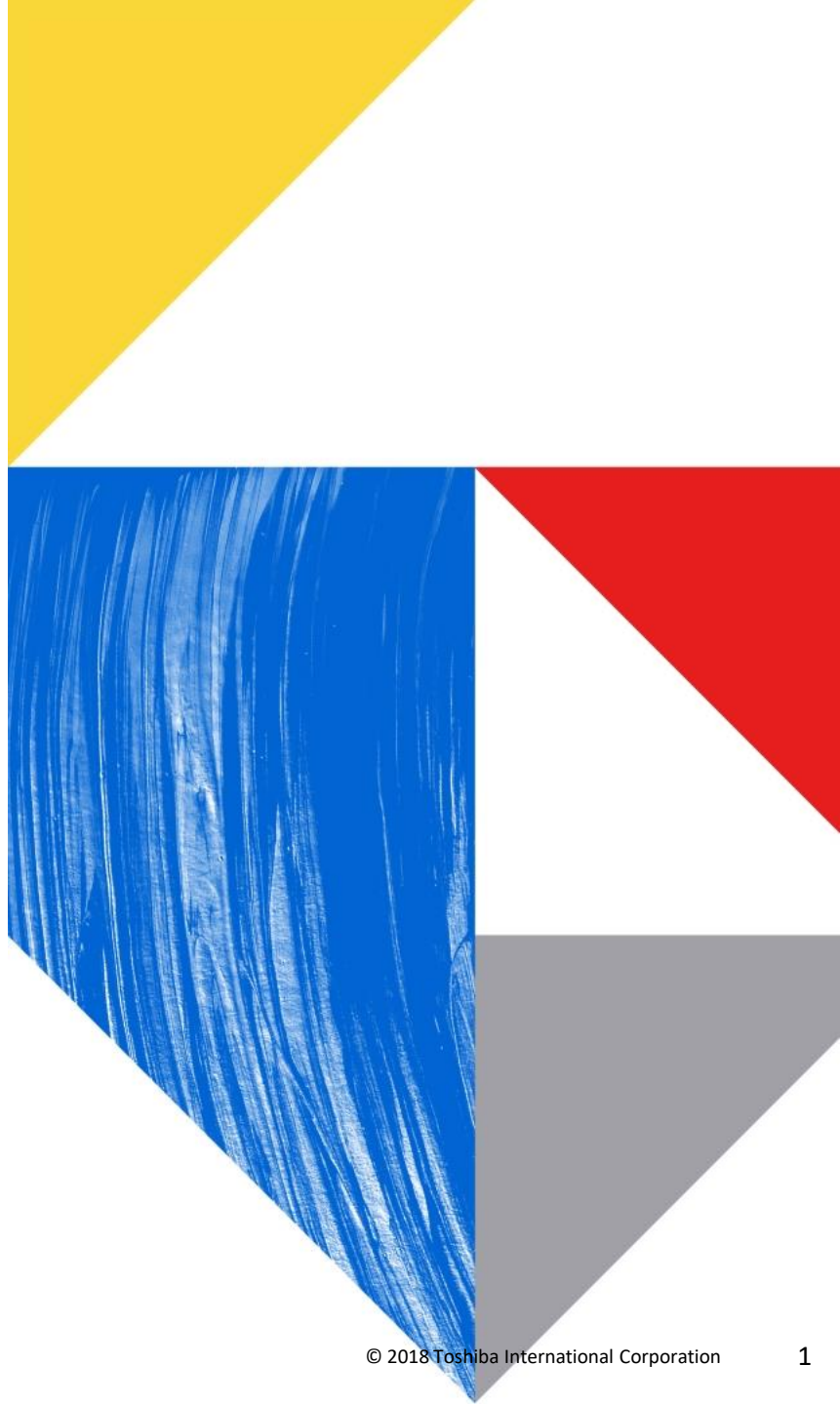
Power Electronics Division

Toshiba International Corporation

2019.06.13

01

Course Overview



Contents

Contents

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Battery Basics

What do they have in common?

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

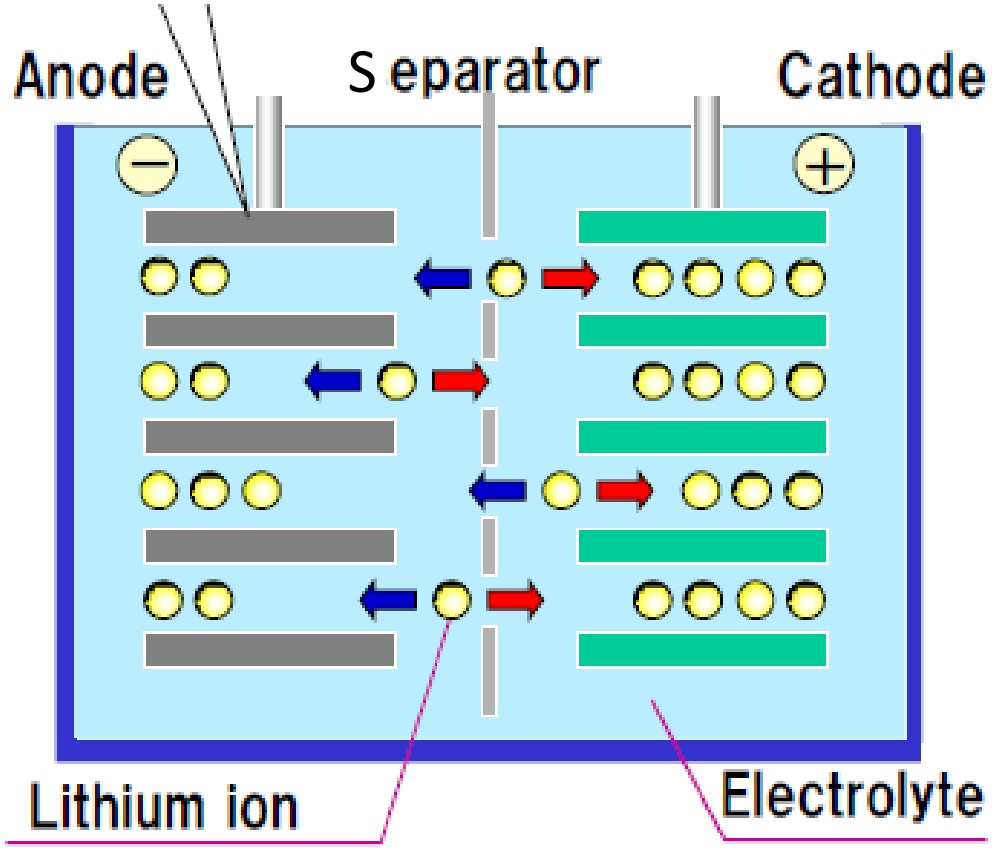
What is a lithium-ion battery?

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

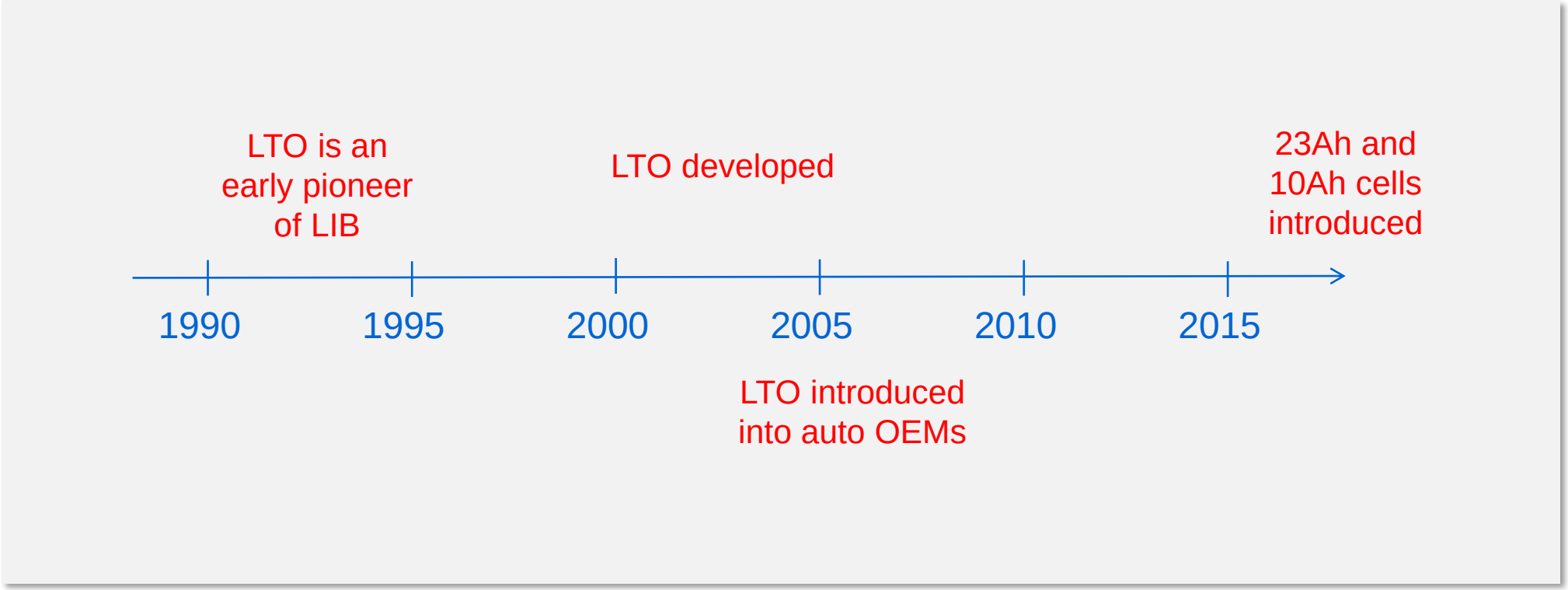
Common Lithium Chemistries

- 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

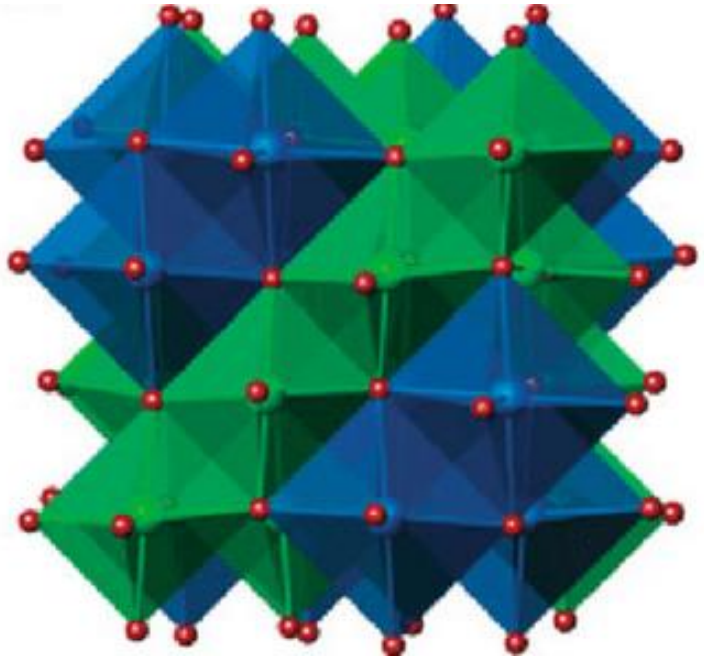
- LFP/LiFePO4 – Lithium Iron Phosphate
  - High specific energy: EV. Fast charging, long life (~5000 cycles)
- LMO/LMNO – Lithium Manganese Nickel Oxide
  - High specific power but can be adjusted for high specific energy or longevity: power tools, medical instruments, HEV. High charge, limited life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

History/Timeline



03

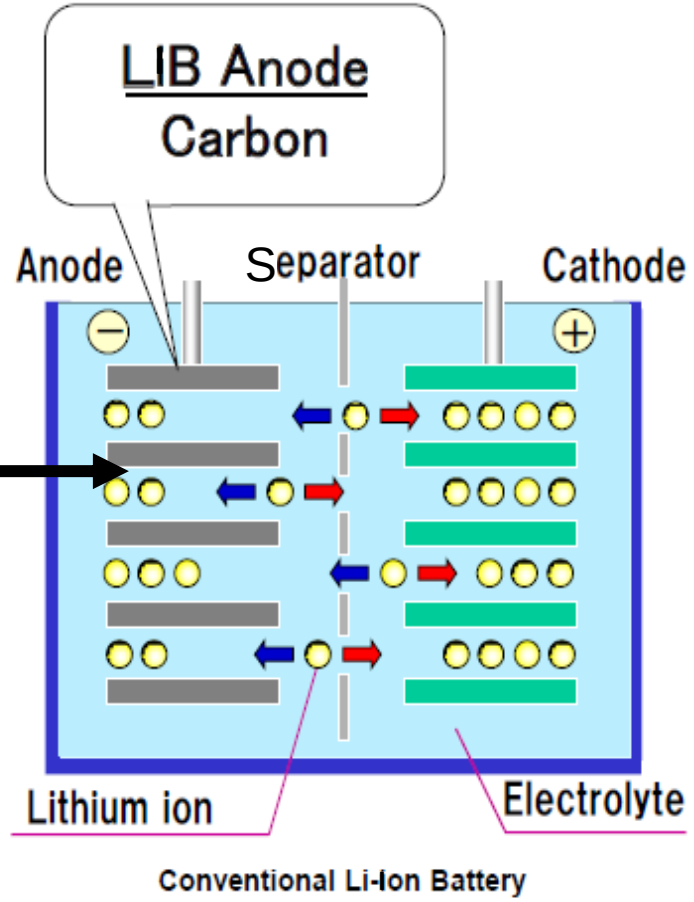
LTO Chemistry



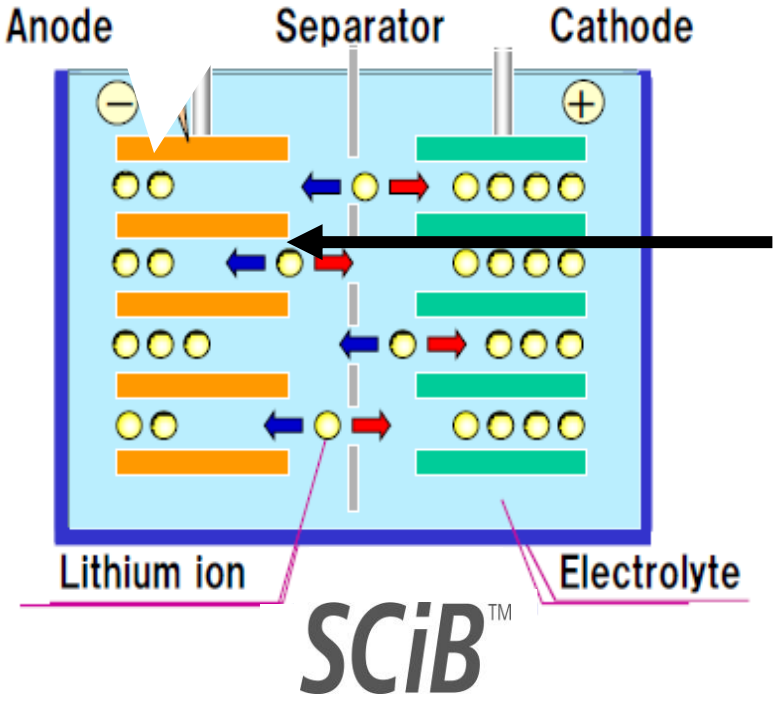
LTO Chemistry

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

Contains Carbon!



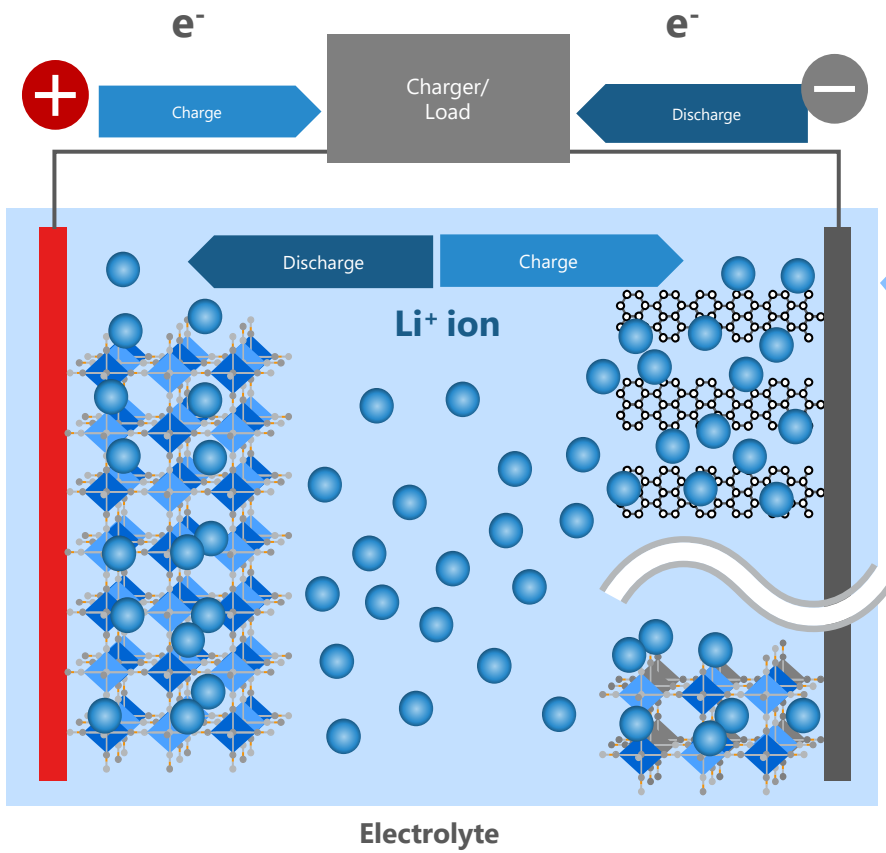
Conventional Li-Ion Battery



Carbon Free!

What is LTO?

SCiB™ is lithium-ion rechargeable battery that uses lithium titanium oxide (LTO) in its negative electrode.
Many advantages are realized by using LTO.



Negative Electrode

Conventional lithium-ion battery

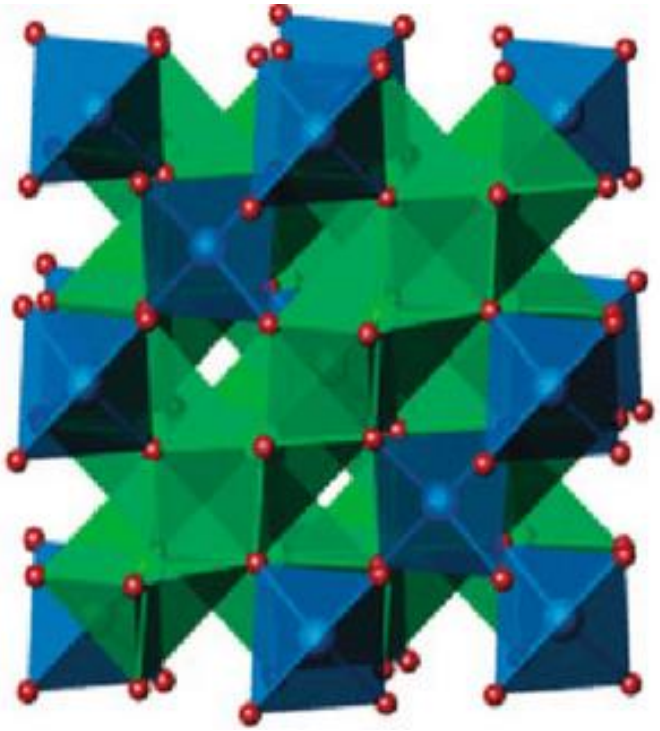
Carbon-based material

SCiB™

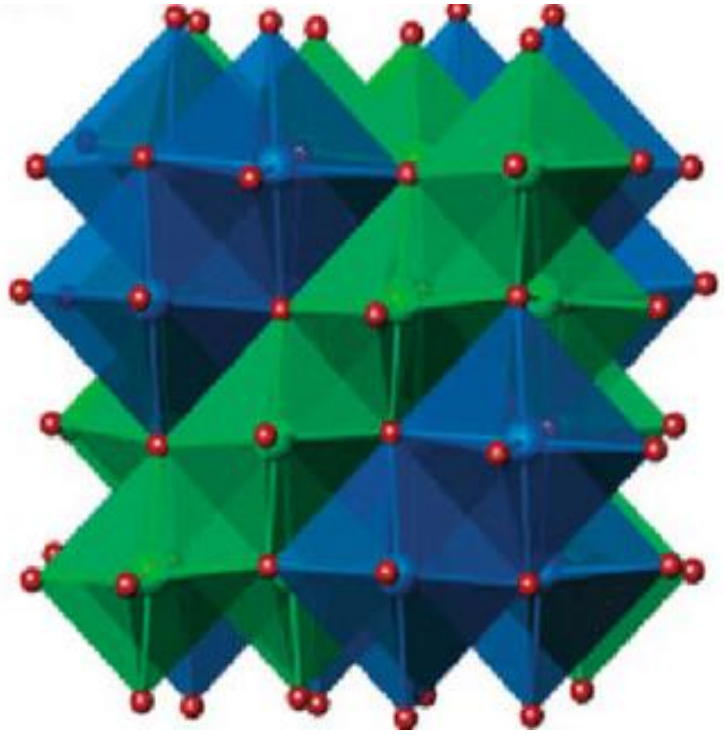
$Li_xTi_yO_z$ (Lithium Titanium Oxide)

Key material of SCiB™

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

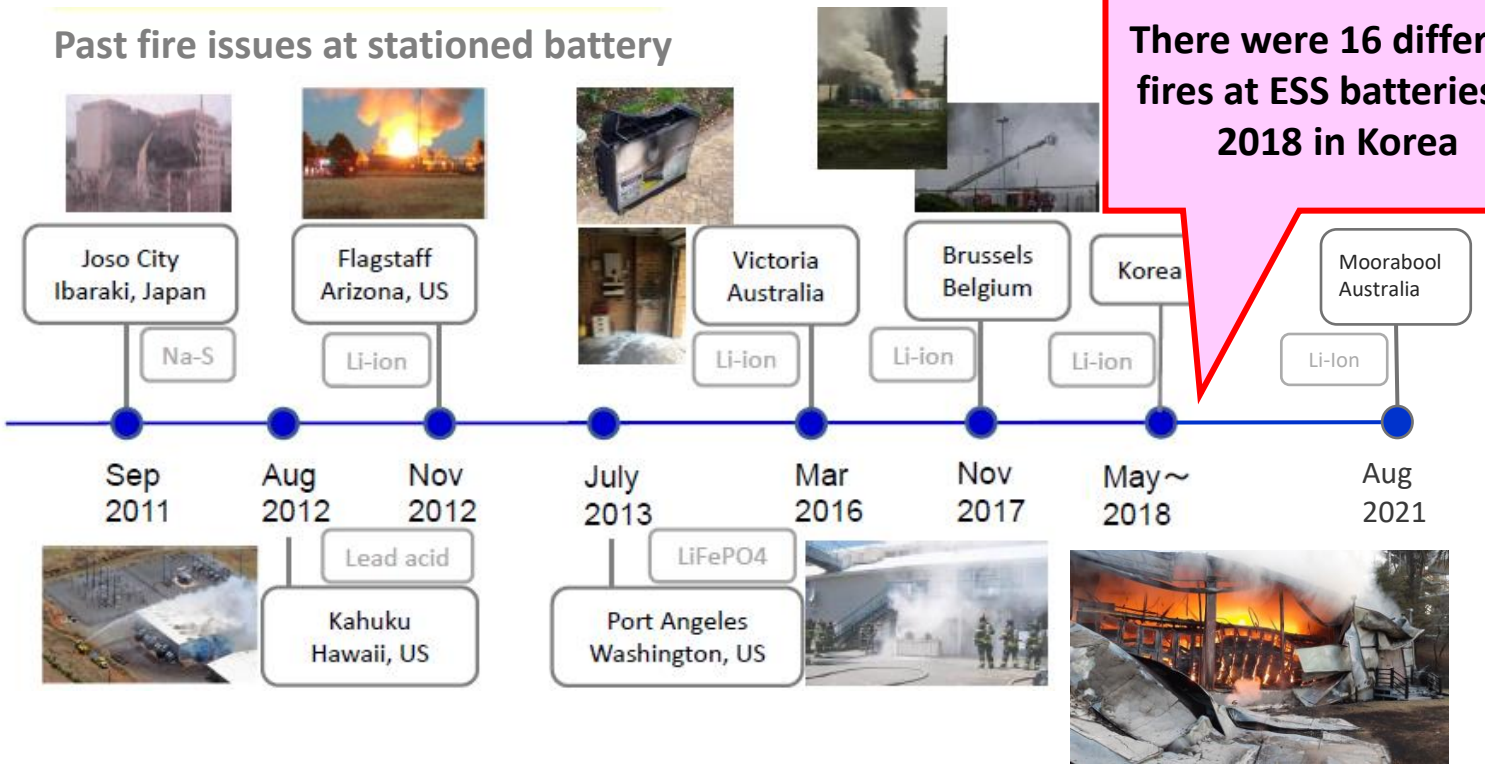
Safety

- 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.

Recent Instances of Battery Fires

Frequent fires raising concerns about safety of ESS

Past fire issues at stationed battery



There were 16 different fires at ESS batteries in 2018 in Korea

Root causes of safety issue in Li ion batteries

Overcharge | **Short circuit** | **Overheating**

- **Short circuit**
  - **Conductive Contaminant**
  - **Lithium Metal Plating**

What is SCiB™

SCiB™ or lithium titanium oxide or lithium titanate (LTO).

Safety:

Uses highly safe lithium titanium oxide (LTO)

Long life:

Over 20,000 cycles*

Low-temperature operation:

Can be used at temperatures as low as -30°C

Rapid charging:

Rechargeable in 6 minutes*

High input/output:

Chargeable at large current and provides large current output

Wide effective SOC range**:

Provides a large available capacity

* Measured with a particular single cell under specific conditions

** SOC: State of Charge

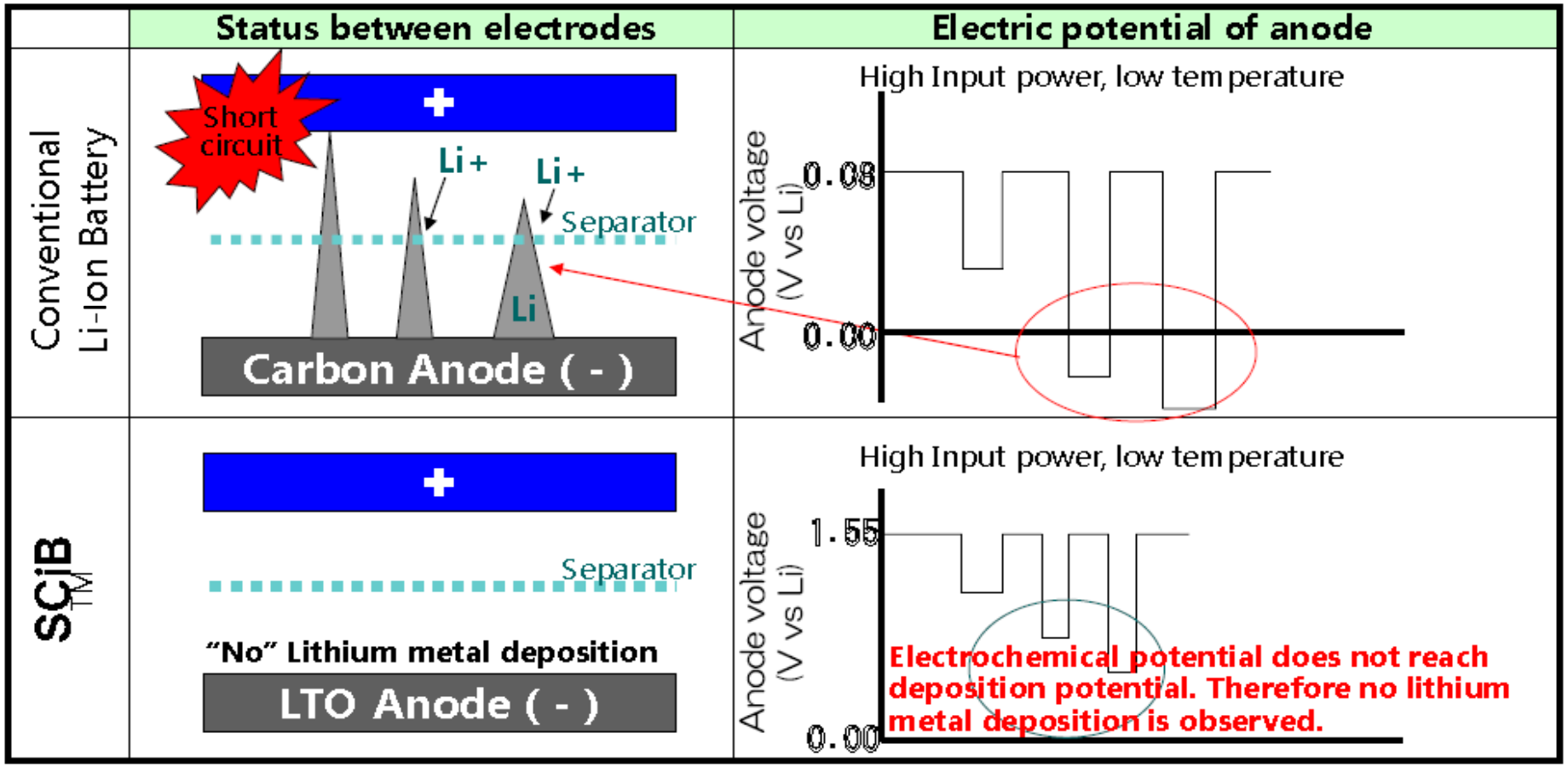
Causes of fires in lithium batteries

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

LTO Chemistry

Safety

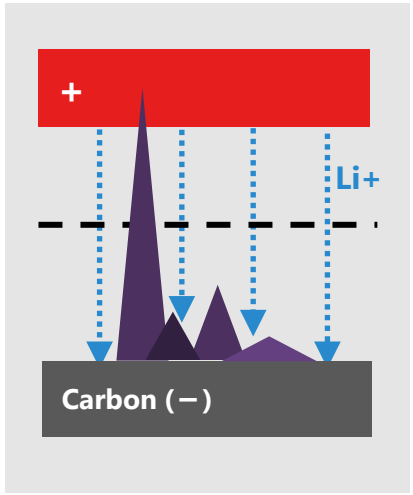
No Lithium metal deposition, even in cold conditions with high input power, and over a long cycle

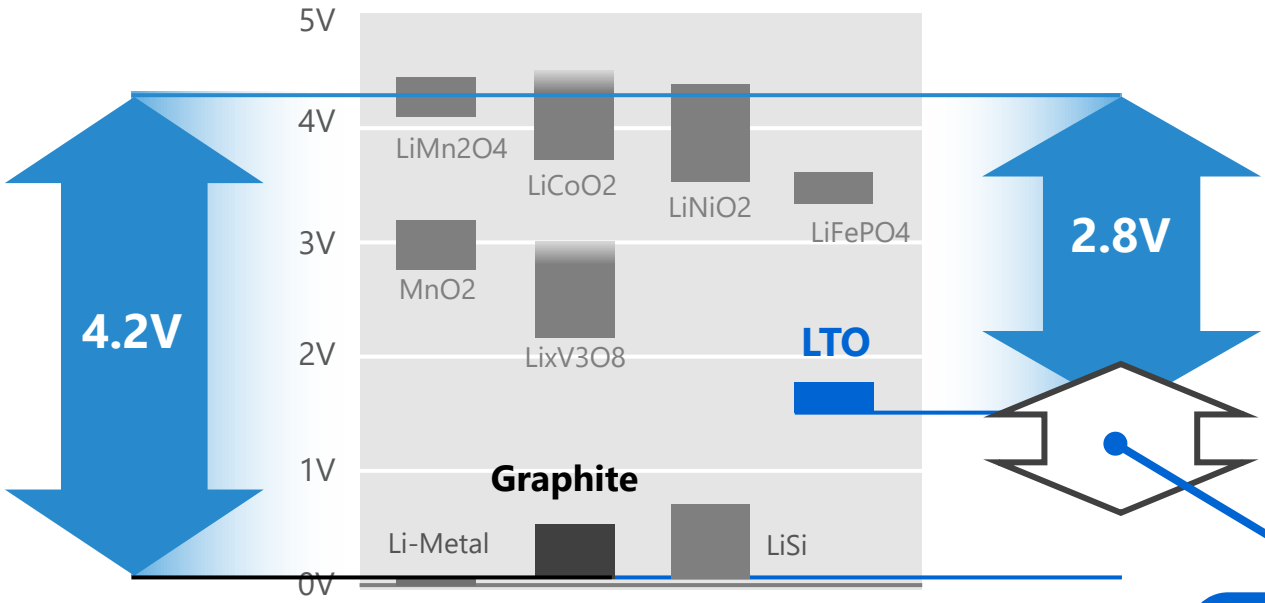


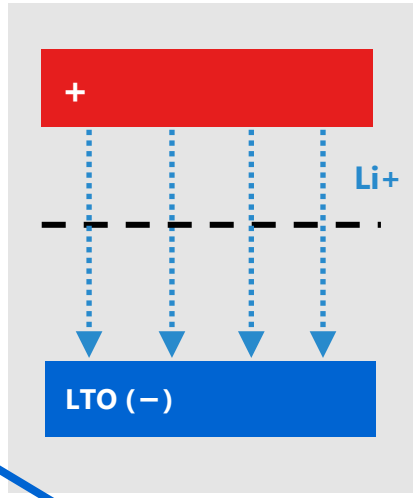
Advantages of LTO Negative Electrode (1)

Since the lithium metal does not deposit electrochemically, there is low risk of internal short circuit.

Carbon-based material | **LTO**







Chemical potential versus Li-Metal / V

Safety margin Against Li deposition

Product Quality

More than 30,000,000 cells have been delivered to automotive and industrial customers and no cell defects or failures have occurred in the field to date.

Production Site : Kashiwazaki Operations
- applied same design concept as Toshiba's state-of-art semiconductor plant
- ultra-dry environment to prevent moisture
- ultra-clean environment to prevent contamination

Cell Manufacturing Process Flow and Equipment

① Coating process

② Slitting & Press process

③ winding process

④ Assembling

⑤ Electrolyte Injection

Electrolyte

Laser welding

⑥ Inspection

Manufacturing devices

Coating

Slitting

Winding

Assembling

Assembling & Dimension check

Charge & Discharge inspection

Slurry preparation system

Roll press

Coil press

Vacuum drying

Cap unit assembling

Feeding of electrolyte

⑦ To Module Assembly Center

Quality Process Certifications

ISO/TS 16949: 2009

Lloyd's Register LRQA

CERTIFICATE OF APPROVAL

This is to certify that the Quality Management System of:

Toshiba Corporation
Kashiwazaki Operations
931-21, Oaza-Karuigawa, Kashiwazaki-shi,
Niigata-ken, 945-1396
Japan

has been approved by Lloyd's Register Quality Assurance
to the following Quality Management System Standard:

ISO/TS 16949:2009

The Quality Management System is applicable to:

Design, development and manufacture of
Lithium-ion rechargeable batteries.

This certificate is valid only in association with the certificate schedule bearing the same number on which the locations applicable to this approval are listed.

This certificate forms part of the approval identified by certificate number YKA 4004306

Approval
Certificate No: YKA 4004306/TS-A

Certification Date: 21 March 2015
Certificate Expiry: 20 March 2018

Issued by: Lloyd's Register Quality Assurance Limited

IATF Certificate No: 0205940

Queen's Tower A, 10th Floor, 2-3-1, Minatomirai, Nishi-ku, Yokohama 220-6010, Japan
For and on behalf of Hramford, Middlemarch Office Village, Siskin Drive, Coventry, CV3 4FJ, United Kingdom

ISO 9001:2008

Lloyd's Register LRQA

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ISO 9001:2008, JIS Q 9001:2008

The Quality Management System is applicable to:

Design, development and manufacture of
Lithium-ion rechargeable batteries and pack-batteries.

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Approval
Certificate No: YKA 4004306

Original Approval: 22 March 2009
Current Certificate: 22 March 2015
Certificate Expiry: 21 March 2018

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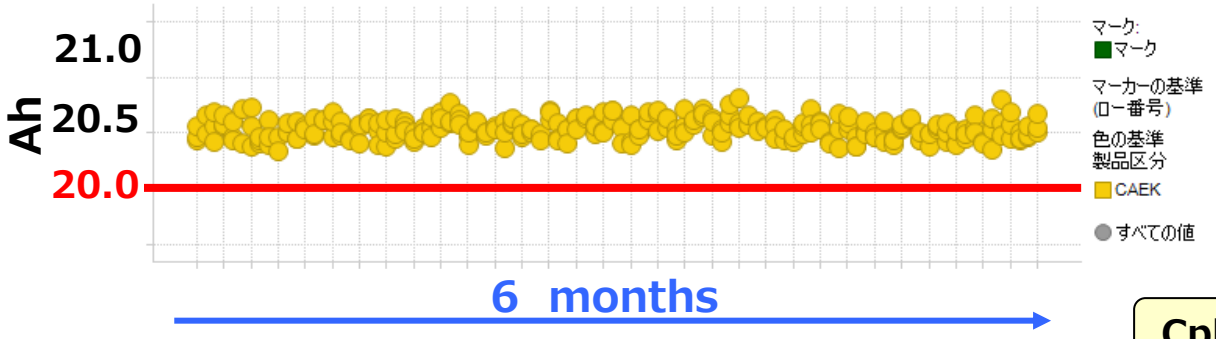
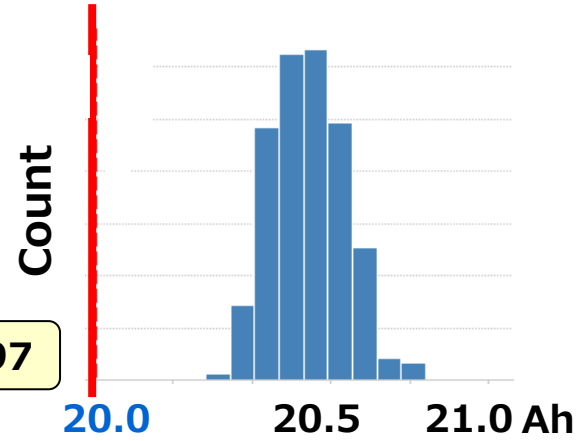
Production Quality Performance

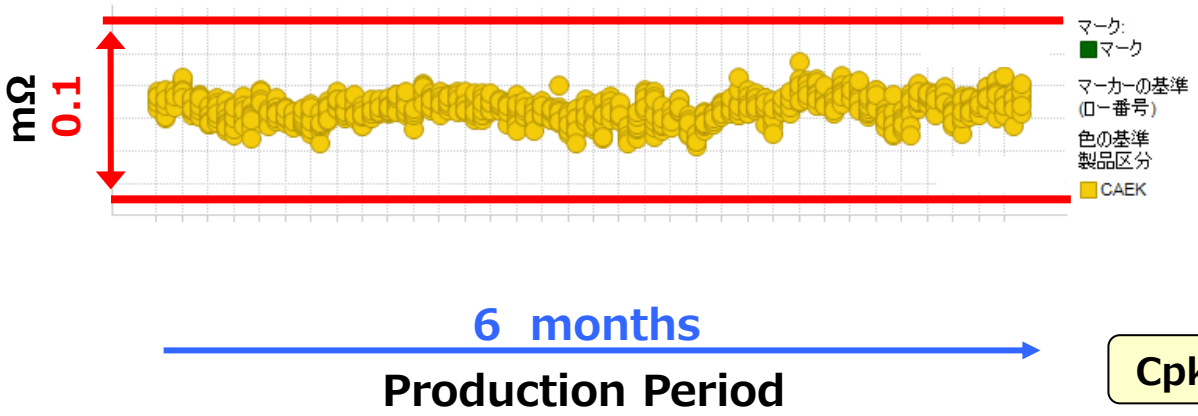
Cell capacity (Ah)

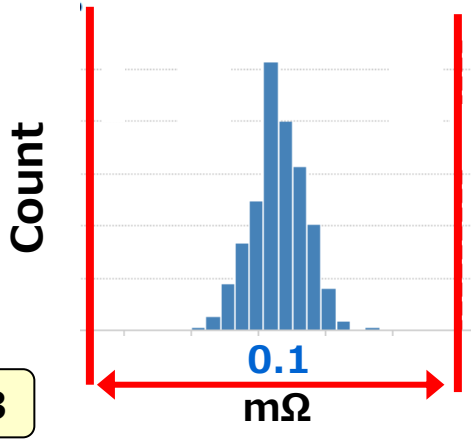




Cpk 1.97

AC-Impedance (1kHz)





Cpk 2.33

Cpk of 2.0 = 6.0 Sigma = 0.002 PPM out of tolerance (2 parts per billion)

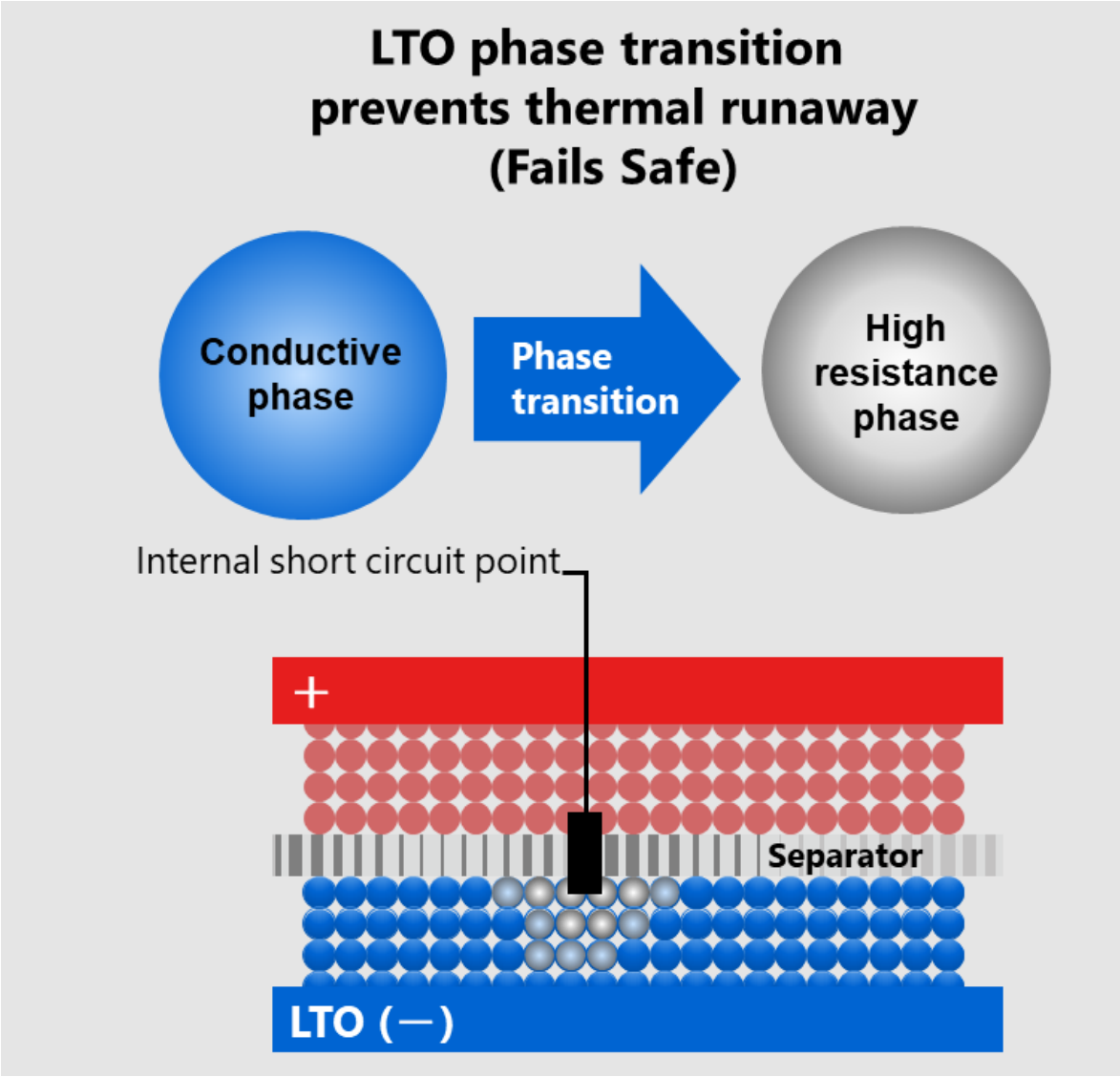
Common Terms used in the lithium battery market

Internal Resistance (IR or DCIR) – The difference in energy supplied versus energy received during charge/discharge which is lost as heat.

- SCiB offers 2-4 times less IR over competitive lithium ion batteries.
- Less self-heating enables SCiB to:
  - Be used in higher ambient conditions
  - Supply higher charge/discharge rates
  - Yield longer life (calendar & cycle)

Advantages of LTO Negative Electrode (3)

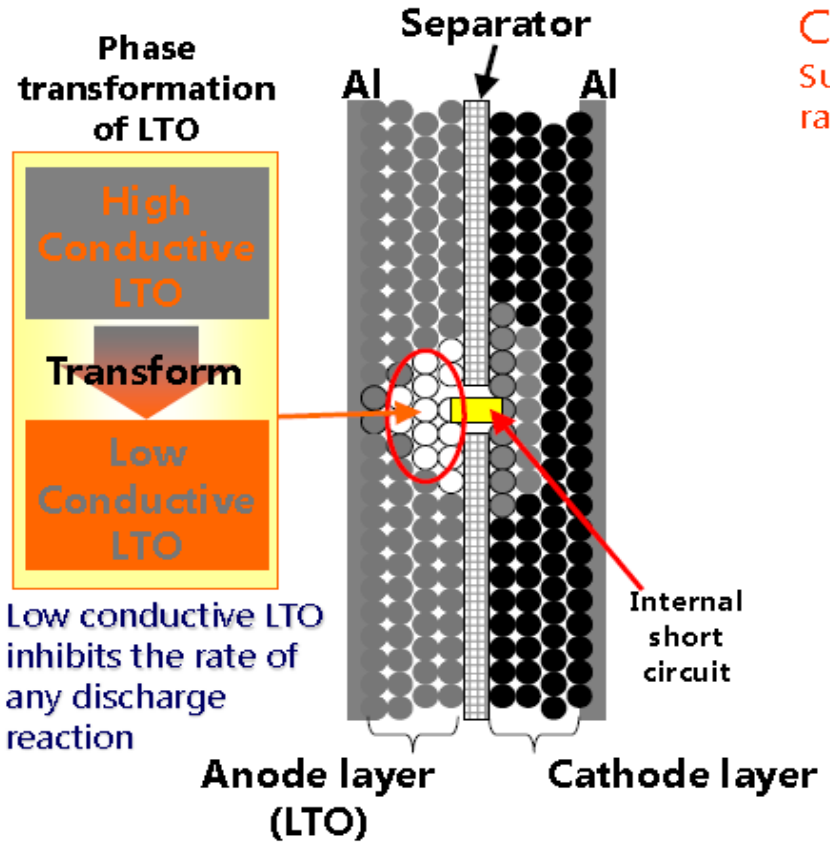
Original self healing mechanism against internal short circuit

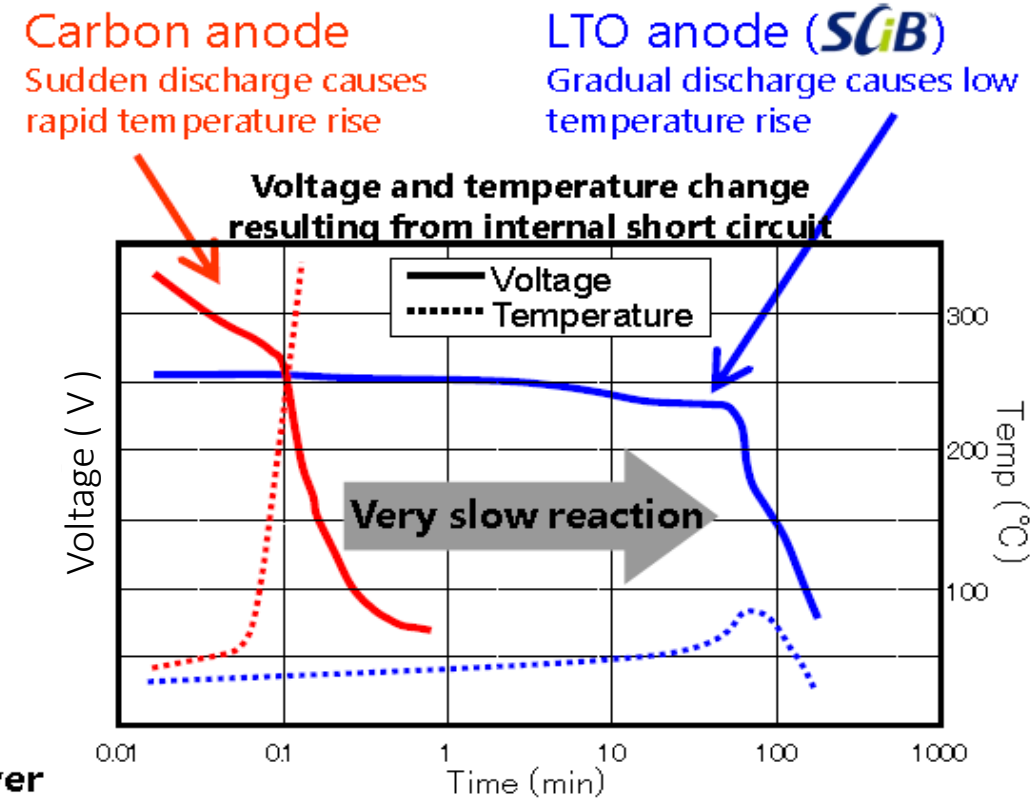


LTO Chemistry

Safety

Phase transformation in the LTO anode provides protection against internal short circuiting.



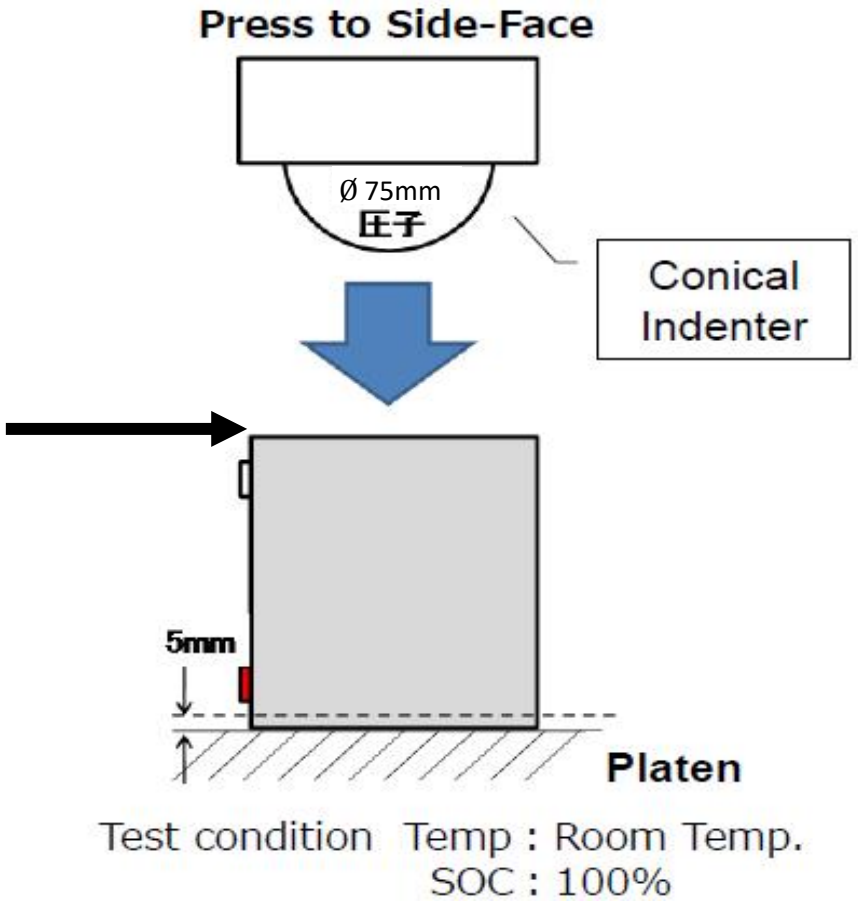


LTO Chemistry

Safety

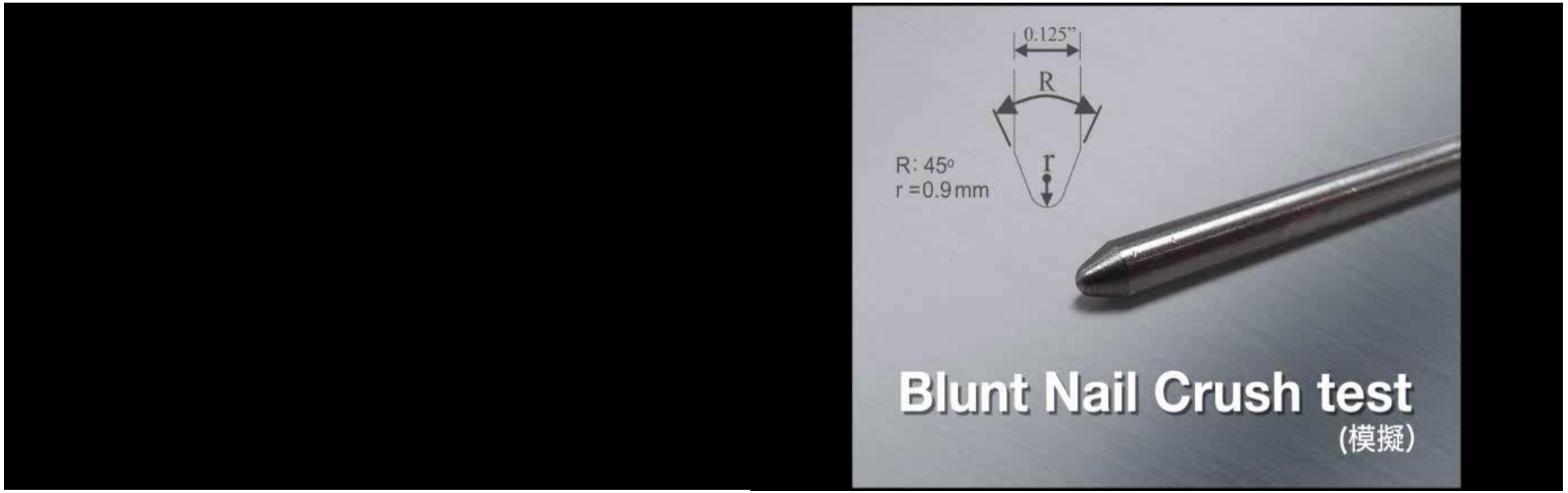
No fire and no explosion occurs even when fully crushed

Lateral Surface



Safety

No Carbon = No Fire



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.

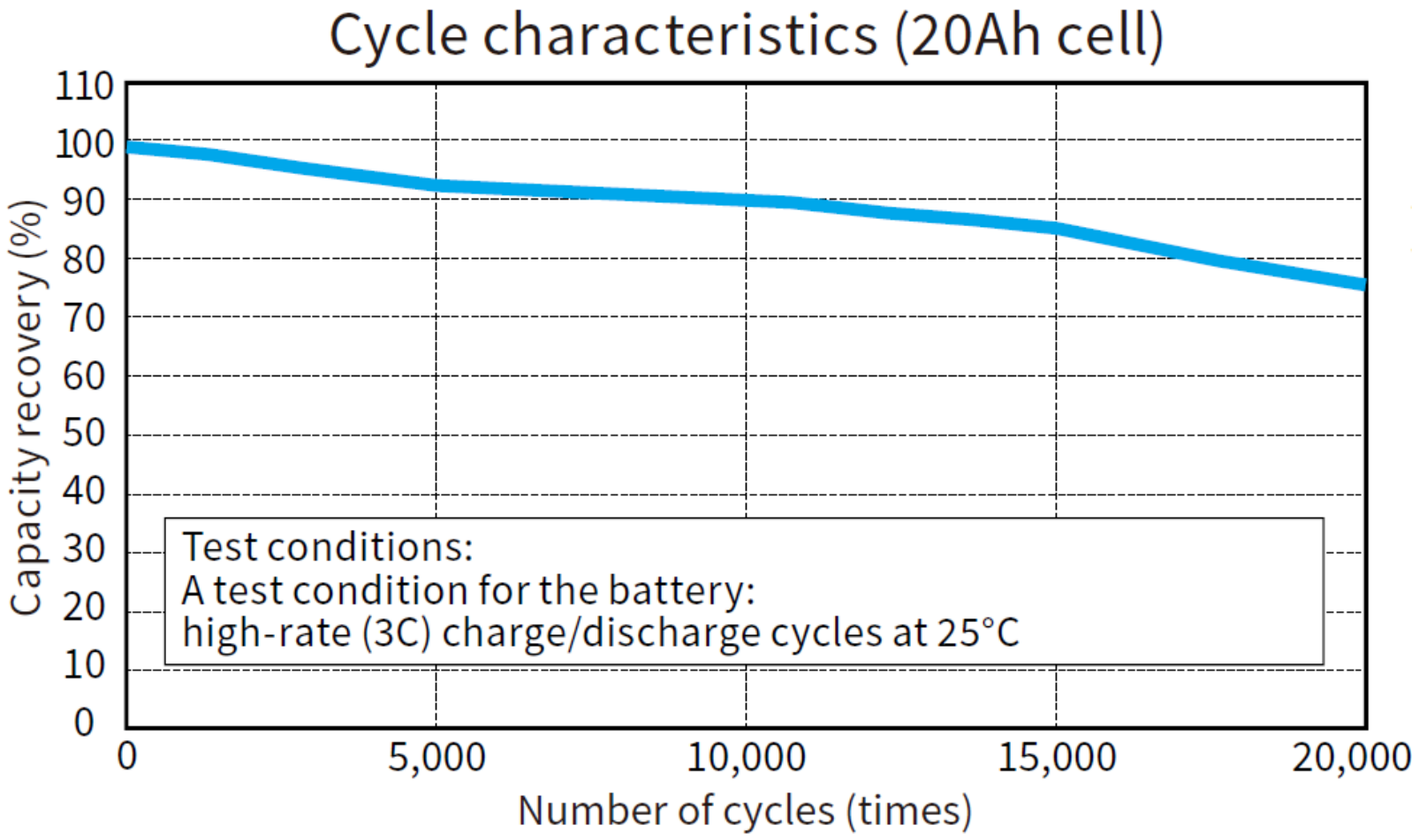
SOC: State of charge or the percentage of power stored in a battery as it relates to the nominal capacity.

BOL: Beginning of life.

EOL: End of life.

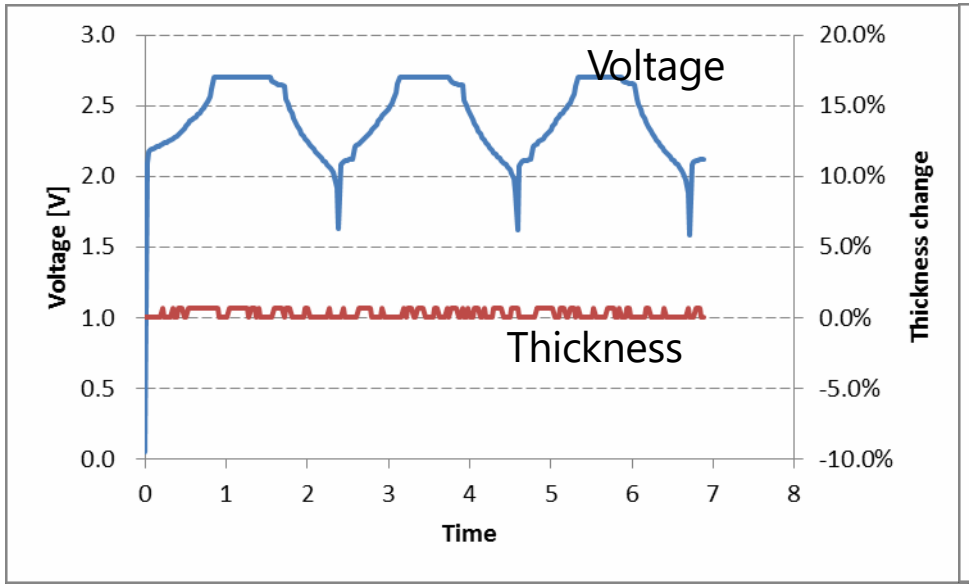
Cycle Life Performance

More than 70% capacity remains even after 20,000 charge/discharge cycles.

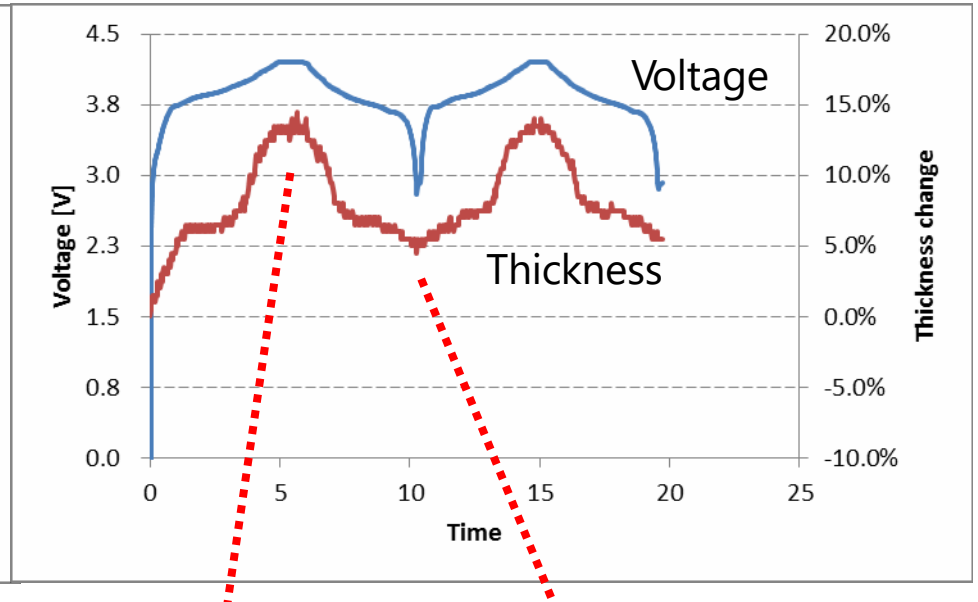


Thickness Stability Enables Long Cycle Life

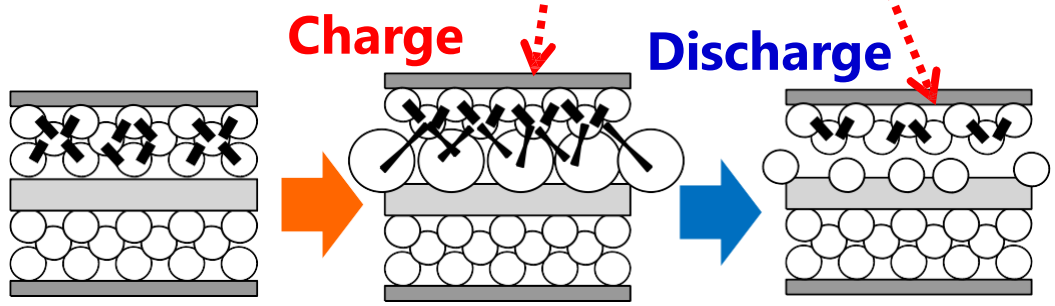
LTO anode



Carbon Anode



Degradation by expansion/contraction

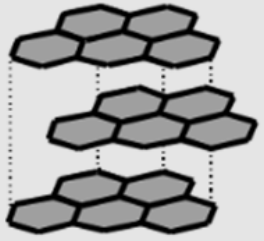
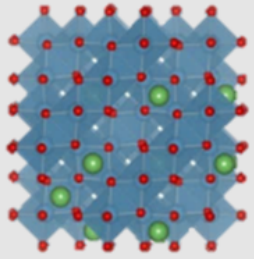


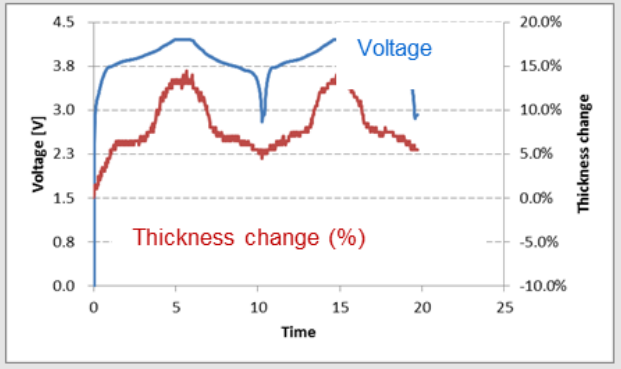
SCiB™ is stable after repeated charge/discharge

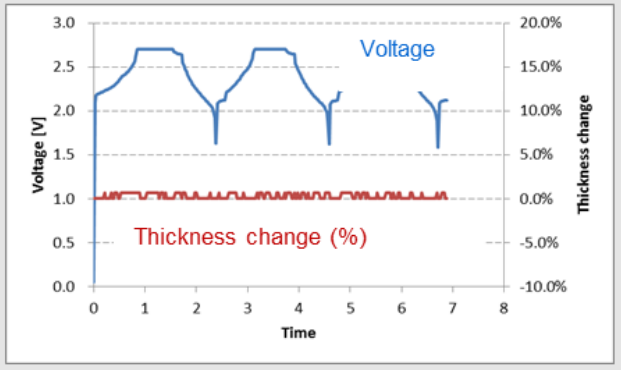
Advantages of LTO Negative Electrode (2)

Long life realized by little volume change during charge/discharge

Swelling during charge/discharge affects battery life

Carbon-based material	LTO
	
5～15%	Nearly 0

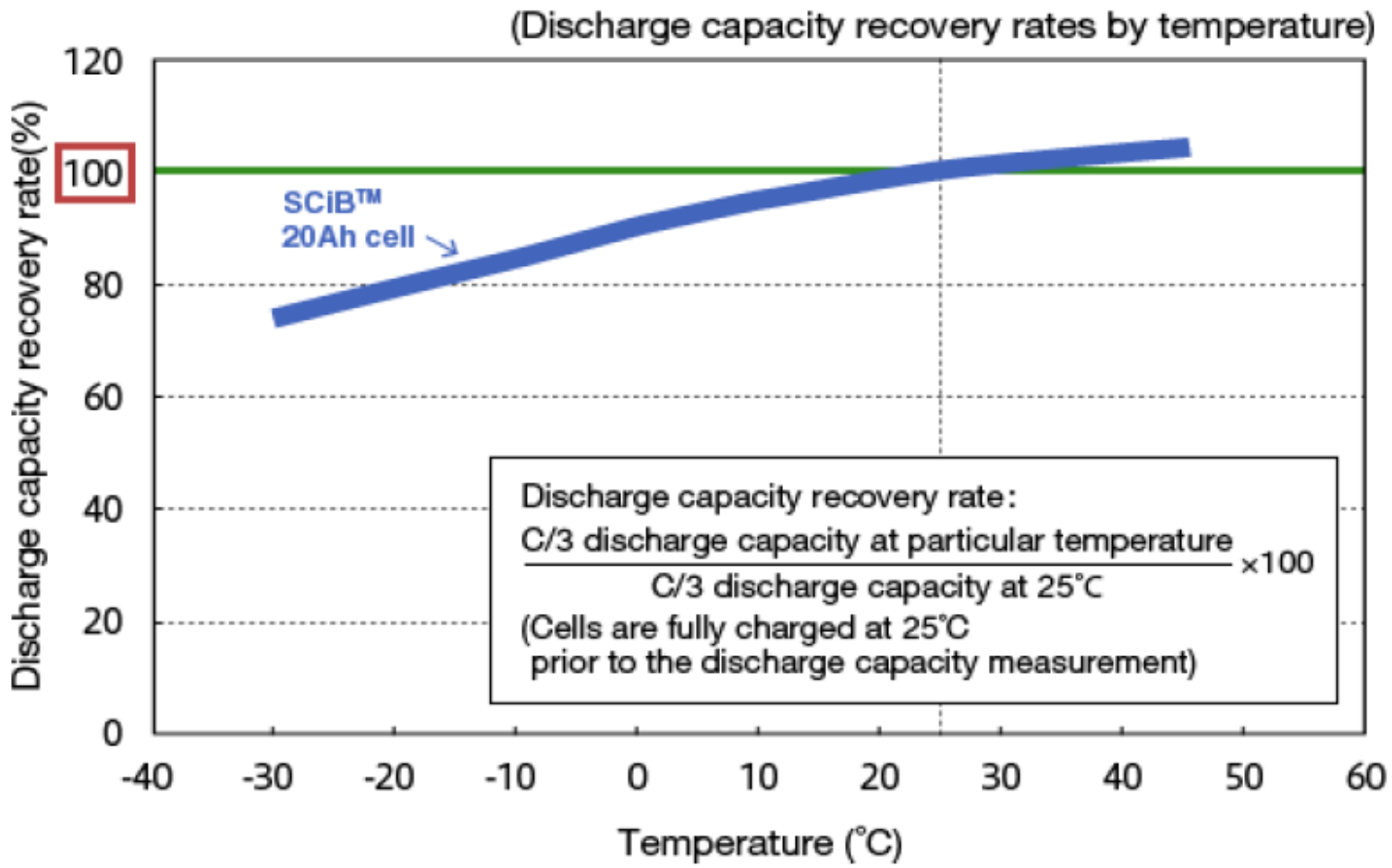




LTO Chemistry

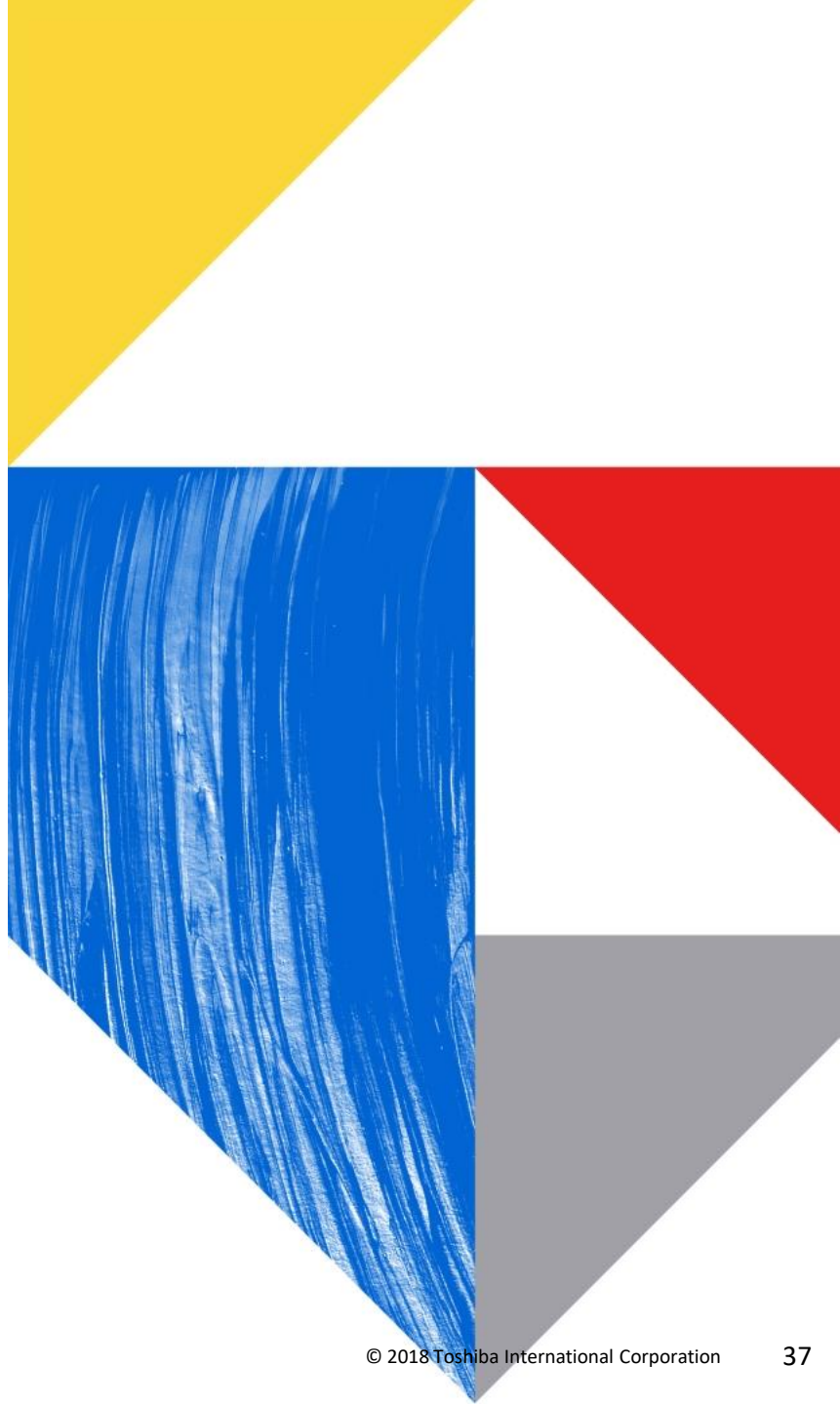
Wide Operating Temperature

Usable in ambient temperature of minus 30°C.



04

Chemistry Comparison



Chemistry Comparison

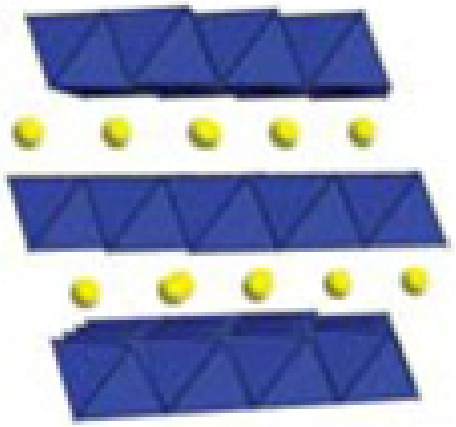
At the conclusion of this section, participants will be able to:

- 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.

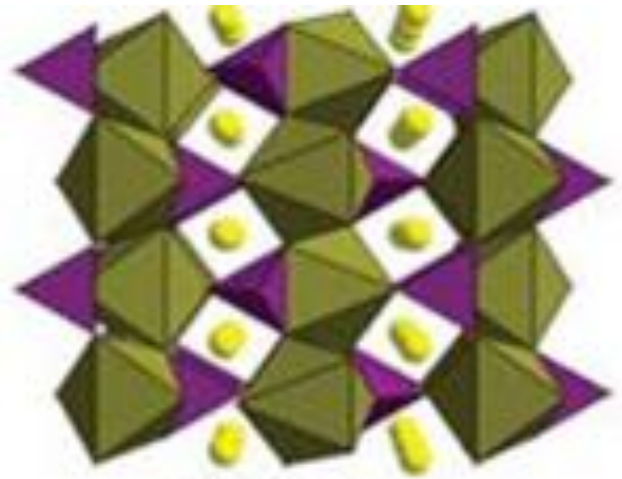
Learning Objectives

Chemistry Comparison

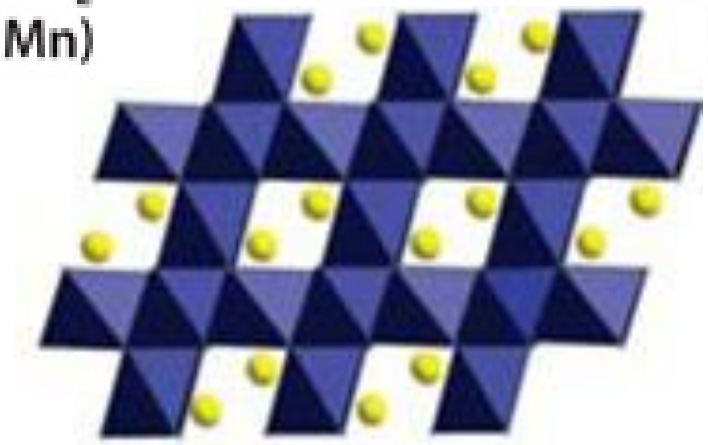
Li-ion Chemistry Comparison



Layered $LiMO_2$
(M=Co, Ni, Mn)



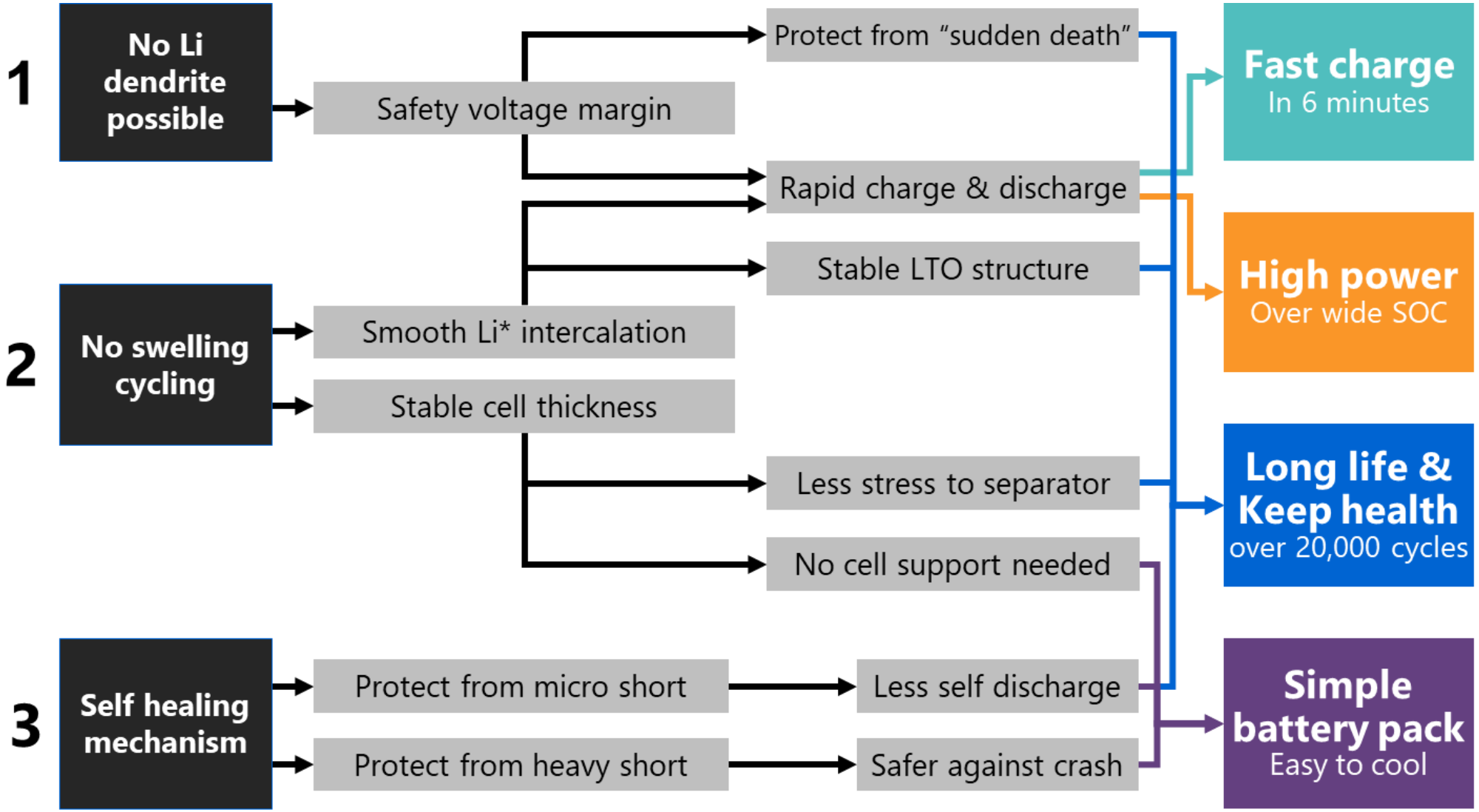
$LiFePO_4$



$Li_4Ti_5O_{12}$

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

Why LTO Anode? : Benefit to Application & End User



Three characteristics of LTO give SCiB™ with valuable properties

Chemistry Comparison

Cell Level Li-ion Chemistry Comparison

Manufacturer	Vendor 1	Vendor 2	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 Results (Cell)	Fire	Fire	Venting, No fire.

Common Terms used in the lithium battery market

C-Rate – A battery's charge/discharge capability as a factor of its energy (Amps or Watts).

- Examples:
  - 1C on a 10Ah battery is 10A
  - 2C on a 10Ah battery is 20A
  - ½C on a 10Ah battery is 5A
- SCiB C-Rate is 3-4 times higher than most competitors giving it superior discharge capabilities.
- A higher C-Rate battery can offer the same power with less energy. **Do More With Less!**
  - Less energy equals:
    - Less cost
    - Smaller size
    - Lighter weight

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.

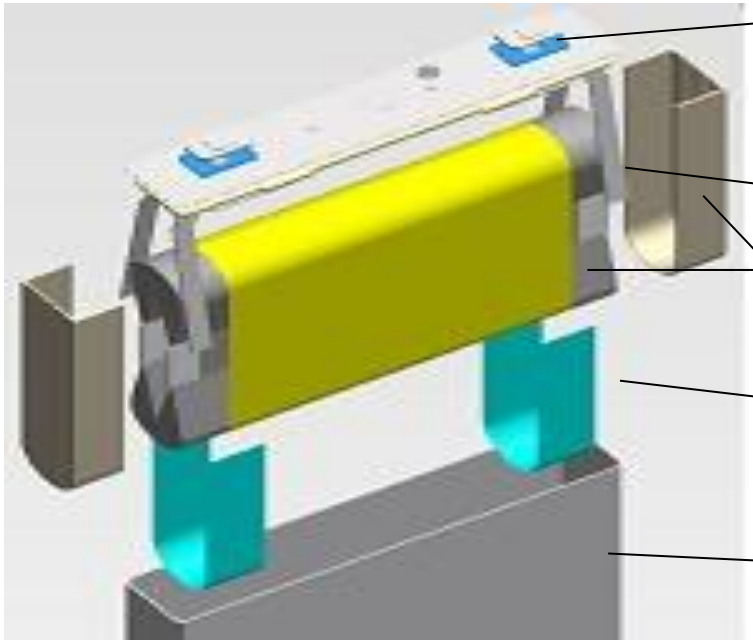
Learning Objectives

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.

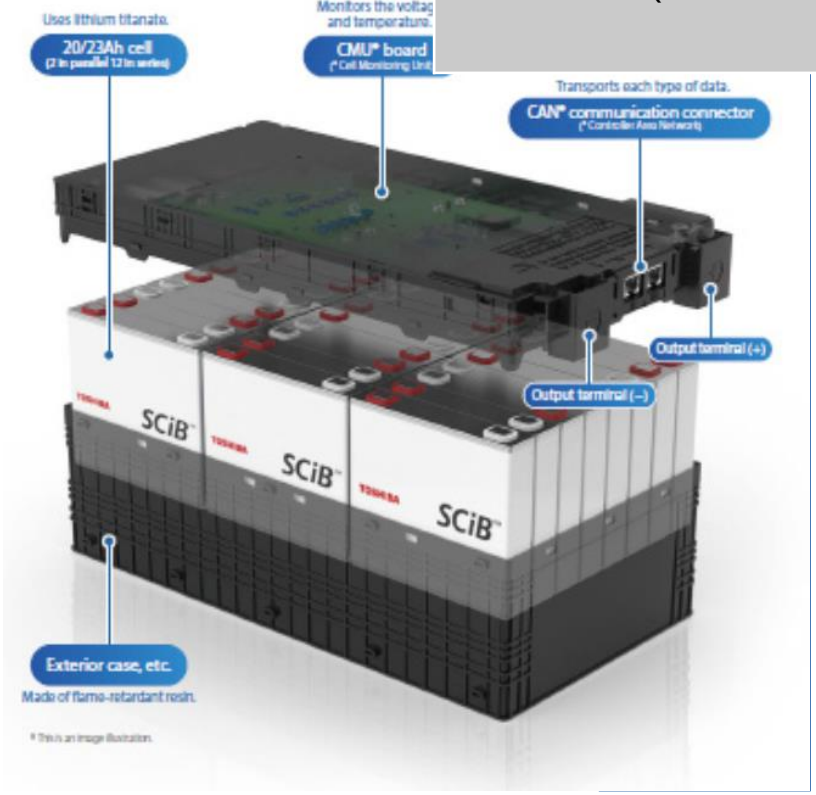
LTO Cells

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



SCiB Modules – 2P12S

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

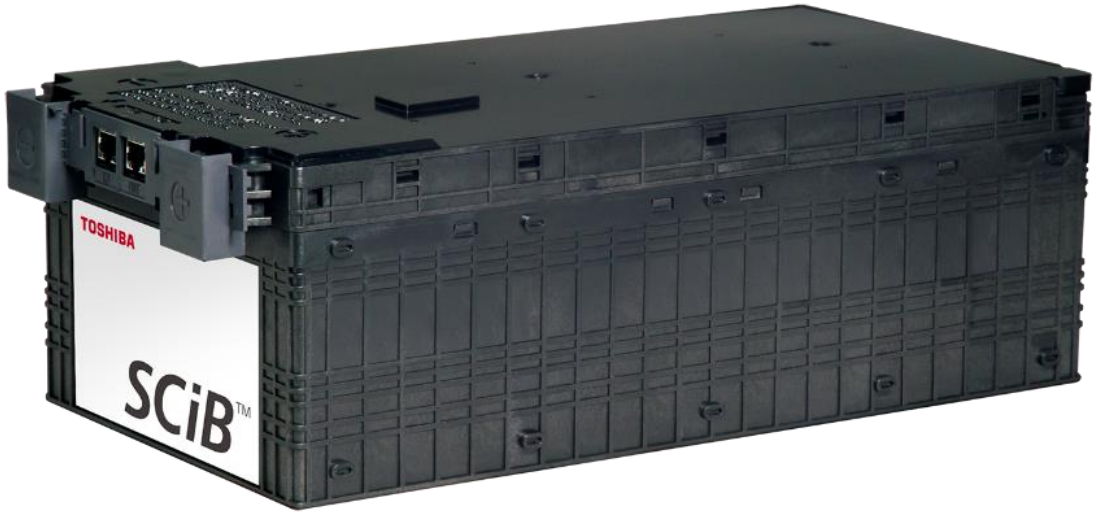


~200Ah

~170AH

06

LTO Modules and Systems

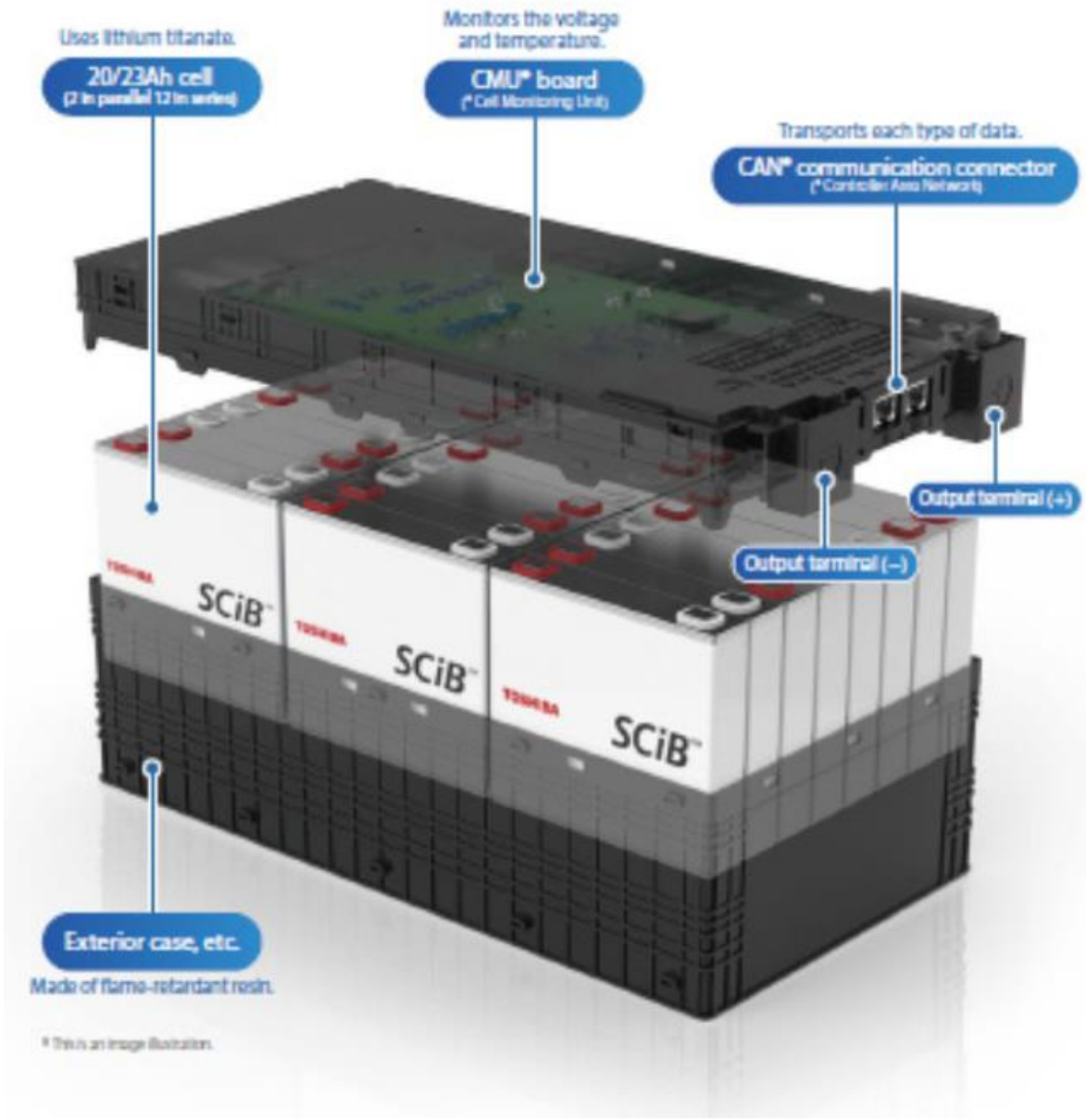


At the conclusion of this section, participants will be able to:

- 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

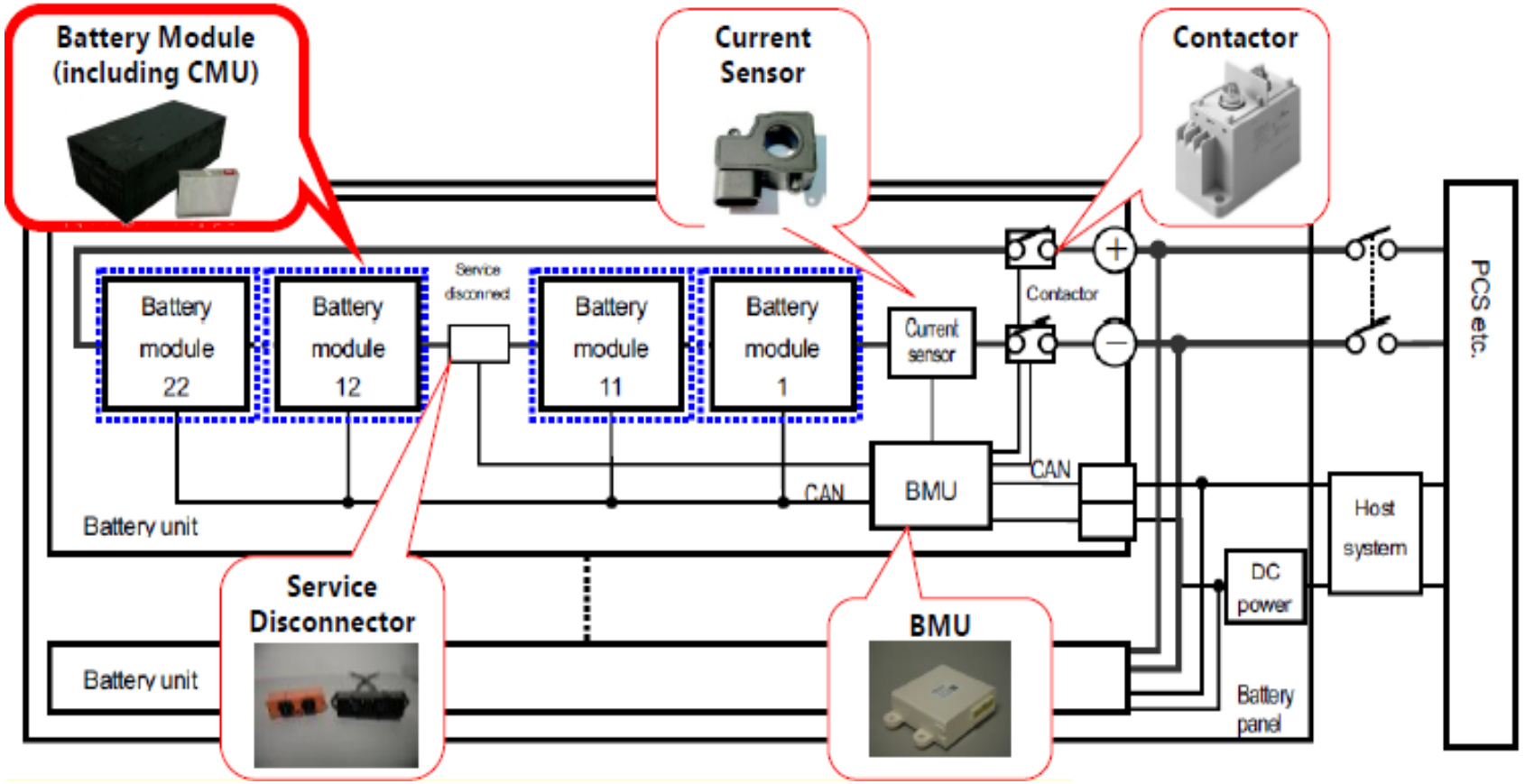
LTO Modules and Systems



Type 3 - 23 (23Ah cell)	- Voltage: 18.0V - 32.4V - Nominal capacity: 40Ah - Nominal energy: 1242 Wh - Dimension: 359(W)x187(D)x123(H) - Mass: approx 14.6kg - Functions: cell voltage/temp monitoring, cell balancing, CAN communication

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

SCiB Modules – Systems

For industrial devices and stationary systems
Type3-20 / Type3-23

For Automotive Type1-23

1 BMU
(Battery Management Unit)

BMU monitors the cell voltage and temperature of each battery module, and protects the battery if an abnormality is detected. Additionally, this measures the charge/discharge current, and calculates the SOC value. Furthermore, this notifies the upper controller of the battery information, measurement/calculation information, etc. via Ethernet or CAN communication.

2 Contactor
(MC)

The contactors are installed respectively to the positive terminal and negative terminal of the main circuit to shut down the main circuit in response to instructions from BMU if an abnormality occurs in the battery.
* The drive signal cable comes with the H type.

3 Current leak sensor
(Earth-leakage sensor ; ELS)

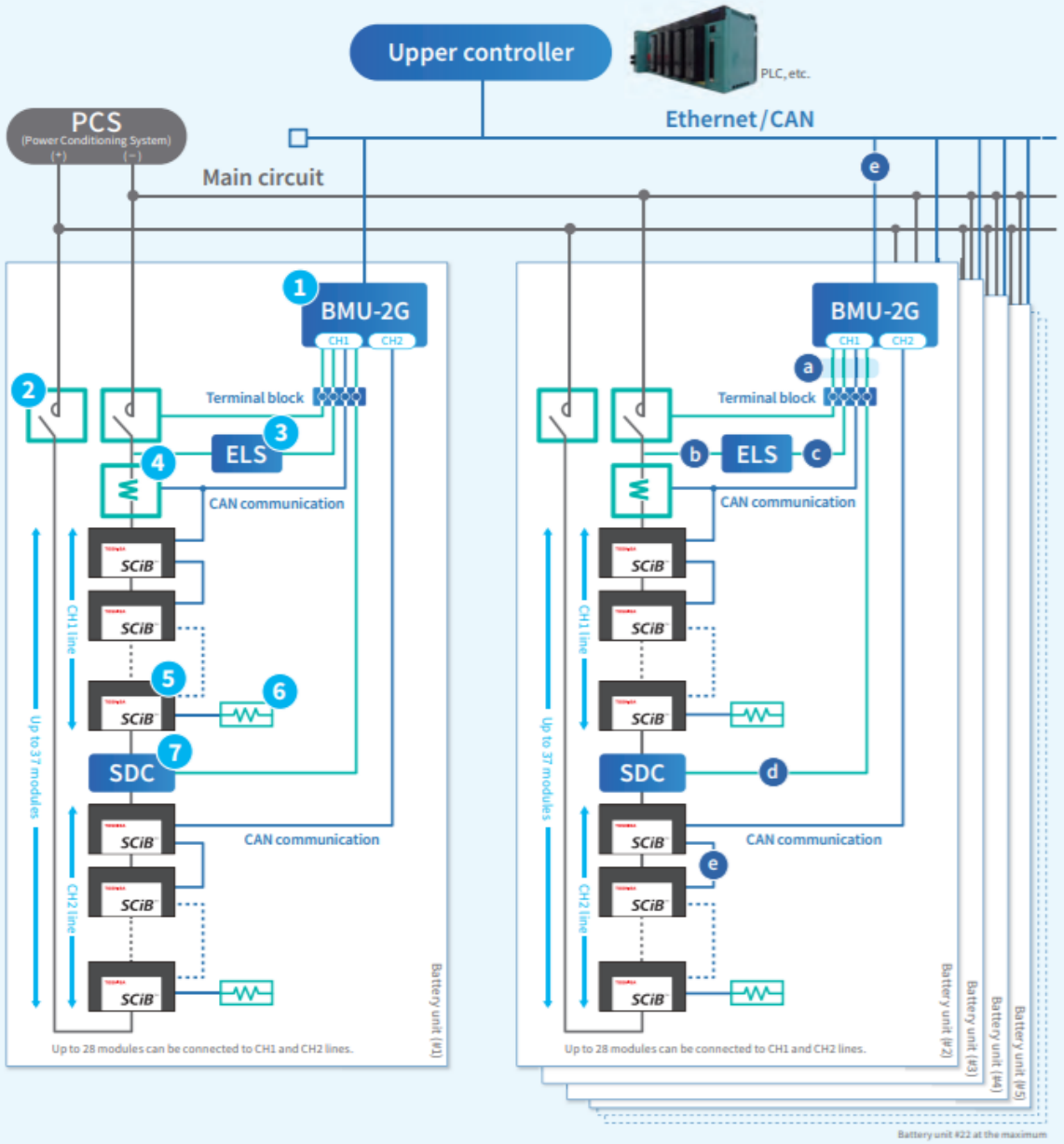
The current leak sensor detects leakage in response to instructions on the fault diagnostic signal from the upper controller after the main circuit is shut down.

4 Current sensor
(Hall Current Transformer : HCT)

The current sensor measures the charging/discharging current. The measured data is sent to BMU via CAN communication. (only for BMU-2G)
* The CAN communication connector is to be prepared by customers.

5 Battery module (MDL)

The battery module consists of 24 cells (2 in parallel and 12 in series), and incorporates the cell monitoring unit (CMU) that monitors the voltage and temperature of these cells.



6 Termination plug (TP)

The termination plug is the termination resistor for CAN communication.

7 Service disconnect
(SDC)

The service disconnect is used to disconnect the main circuit when installing / removing the battery module or during the maintenance work. The built-in fast acting fuse to protect the battery in the case of external short circuit.

* SDC-1500 does not have a built-in protection fuse. Use a commercially-available fuse additionally.
The example of fuse use
• HINODE ELECTRIC (750GH-200UL)
• Mersen (HP10NH2GPV200B)

Cable types

a BMU connection cable

Use the BMU connection cable to connect between BMU and other components, upper device, maintenance device, and 12VDC power source.

b Current leak sensor main circuit cable

Use this cable to connect to the connector used for the current leak sensor main circuit connection.

c Current leak sensor connection cable

Use this cable to connect to the current leak sensor control signal connector.

d SDC-750 fitting detection cable

Use this cable to connect to the fitting detection connector of the service disconnect.
* The cable for SDC-1500 is to be prepared by customers.

e Connection cable for Ethernet/CAN communication
This cable is to be prepared by customers.

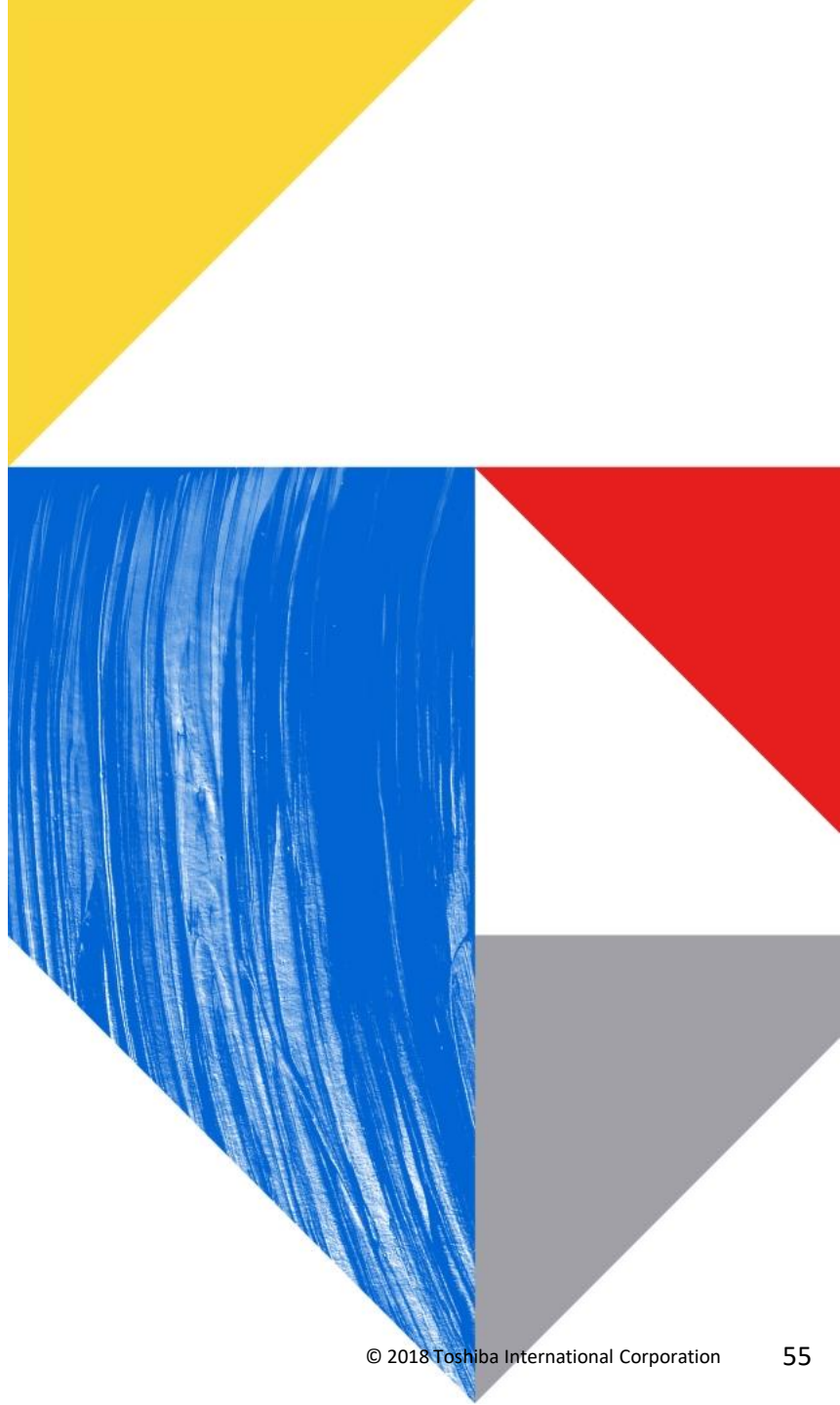
Use this cable for the CAN-communication connection between BMU-2G and the upper communication (Ethernet), module, BMU, or current sensor (C type).
Recommended cable (STP straight cable, category 5e or higher)
Note: The CAN communication cable extension length cannot exceed 40 m.

Component		Connector	Remarks
BMU-2G	Main on the CH1 side	Dedicated	Mixed with other control cables
	Sub on the CH2 side		
HCT	Current sensor (C type)		Common to IN/OUT
MDL	Battery module	RJ45	IN/OUT independent

*Cable end is to be appropriately processed by customers.

07

Applications



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

Automotive

3 major Japanese OEMs adopted SCiB™ for EV and Start-Stop applications.
Several other automotive programs are progressing towards production launch.

SUZUKI

Suzuki
Wagon R

2.9Ah (High Power) Cell

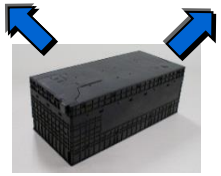
Drive@earth

MITSUBISHI MOTORS

Mitsubishi
i-MiEV

MINICAB-
MiEV

MINICAB-
MiEV Truck



20Ah ×2P12S module

HONDA

Honda
Fit EV

20Ah Cell

Wagon R

FZ S-ene CHARGE

Spacia

X S-ene CHARGE

Alto

X ene-CHARGE

Swift

X S-D J E ene-CHARGE

Solio

HYBRID MZ HYBRID

Compact size
(Underneath asst.seat)
※Photo. from Suzuki

SCiB™ is used in
more than 3 million vehicles
on the road.

Applications

Passenger Vehicle

minicab-MiEV(10.5)

SUZUKI ene-CHARGE HONDA MITSUBISHI MOTORS

Wagon R

Swift

i-MiEV(M)

Fit EV

Spacia

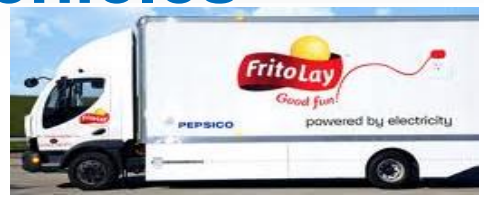
Heavy Equipment

Transit Bus

EV

HEV

Commercial Vehicles



Applications

SCiB Product Systems

Energy Management Systems

DC Power Systems

UPS Energy Storage System

Energy Storage Racks and Containers

G9000 SCiB ESS Overview

LTO Application Benefits - UPS

- **Safe** – Very low risk of generating fire even if mechanically abused.
- **High Discharge Power** – A smaller energy battery can provide the same power.
- **High Charge Power** – Batteries can be charged quickly to minimize downtime.
- **Efficient** – Low self-generated heat allows for use in higher ambient conditions.
- **High Temperature** – Superior aging effects compared other chemistries at elevated temperatures.
- **Long Life** – Over 5 times the cycle life and much less calendar aging than other chemistries.
- **Predictive** – SCiB's voltage profile provides for accurate SOC and SOH forecasting.
- **High Quality** – Toshiba's manufacturing yields very closely matched allowing for longer life and more uniform aging.
- **Class Leading** – Toshiba's proven solutions are assembled in the USA.
- **12 Year Warranty!**
- **Do more with less!** – SCiB's numerous capabilities allow for a smaller battery to provide the same productivity, with longer life, and with less downtime offering the best cost of ownership.

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.