

**Shmuel De-Leon
Energy Ltd**



Lithium Titanate Rechargeable Battery Market 2019

November 2019

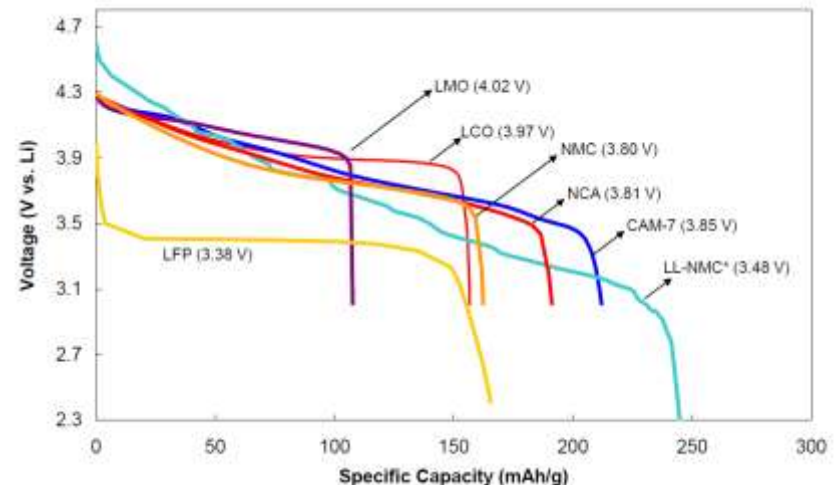
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Mass Production

R&D (Except Bollere for LI-Metal)

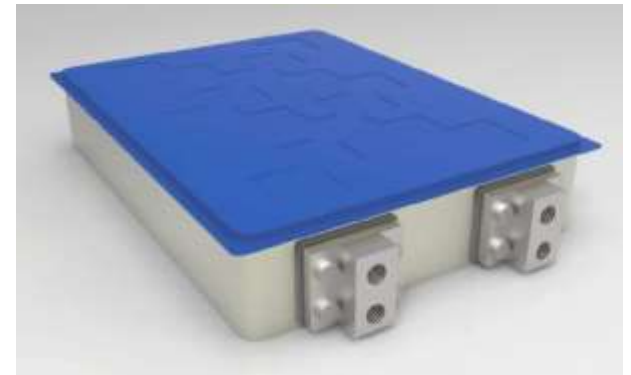
Technology	Anode	Cathode
Lithium Cobalt Oxide 3.6V	Graphite – Gr/Si	LCO
Lithium Manganese Oxide Spinel 3.8V	Graphite – Gr/Si	LMO
Lithium Nickel Manganese Cobalt 3.7-3.8V	Graphite – Gr/Si	NMC(111, 532, 622, 811)
Lithium Nickel Cobalt Aluminum 3.65V	Graphite – Gr/Si	NCA
Lithium Iron Phosphate 3.2V	Graphite	LFP
Lithium Titanite Oxide 2.3/2.4V	LTO	NMC, LMO, LFP
Lithium Nickel Manganese Oxide Spinel 3.8V	Graphite – Gr/Si	LNMO
Lithium Metal 3V	Lithium Metal	Different Options
Lithium Sulfur 2.4V	Lithium Metal	Sulfur

Lithium Rechargeable Systems



LTO Cells – Pro/Con

Advantages	Disadvantages
High <u>charge</u>/discharge rates (~10C possible)	Low cell voltage 1.9-2.4v
Very Long Cycle Life (Up to 60K)	Lower energy density than carbon anodes ~70-80 Wh/Kg, 130 Wh/l
Wide Operational Temp. Range -30 to 60 Deg C	Higher cost \$/kWh
Low self discharge ~2%/Month	Limited number of cell makers
Improved safety through higher resistance to thermal runaway	Limited world production capacity
Public domain technology	



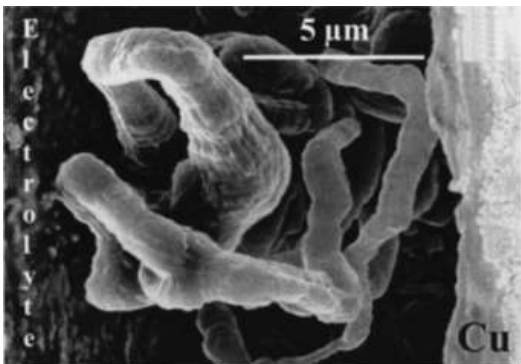
LTO Cell Internal Construction

Nano-Titanate Battery Construction



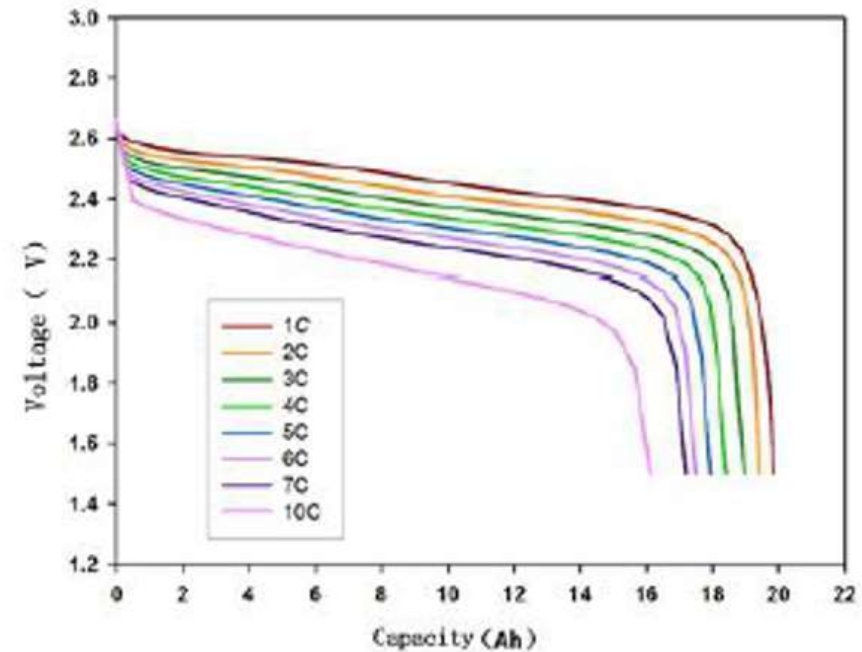
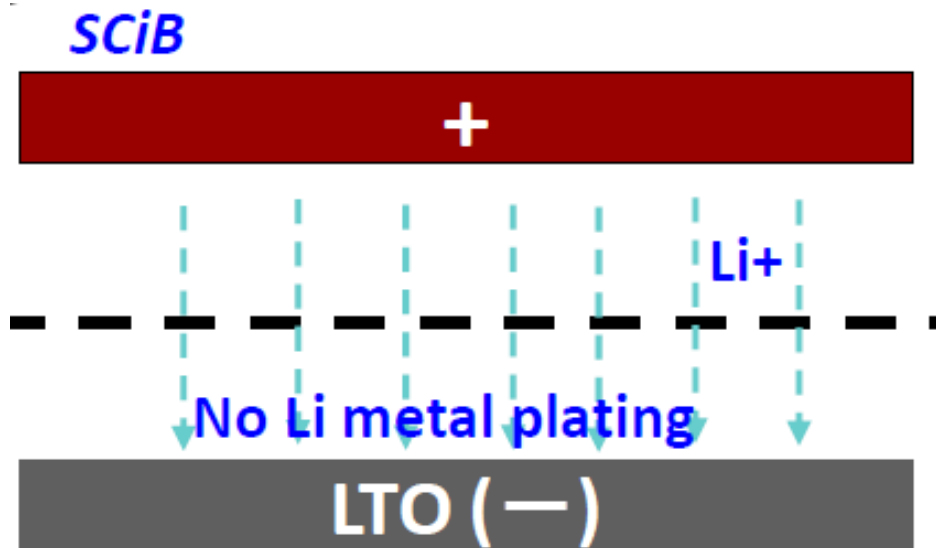
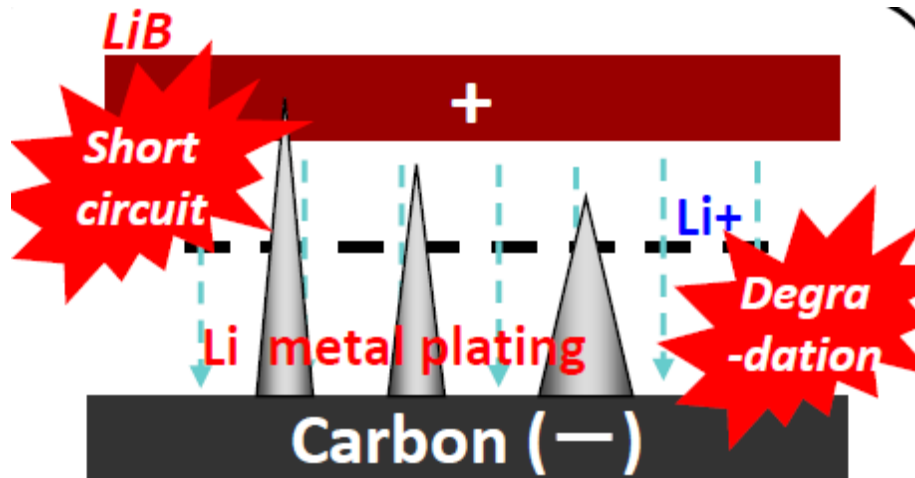
Why Graphite Anode Li-Ion Cells Cant be Charge Fast?

1. Lithium Graphite Anode accepts the lithium ions at a slow rate although the Cathode can transfer them at a faster rate.
2. During ultra fast charging the cell faces **deposition** of lithium metal in the form of dendrites or as a high surface area film over the Anode.
3. That Leads to very fast capacity degradation and increase of internal impedance.
4. That Leads to safety problems like internal short circuit and explosion when the dendrites reach the cathode.



Fast discharge is easy like going down stairs.
Fast charge is difficult like climbing stairs.

LTO Cells Fast Charging



Charging LTO/LMO Cell
at Different C-Rates

LTO Battery Optional Cathodes

Cathode	LFP	LMO	LNO	NMC
Nominal Voltage	1.8-1.9V	2.4V	2.2V	2.2V
Voltage Range	2.8-1.5V	2.7-1.5V	2.7-0V	2.75-1.5V
Max Charge rate	5C	10C	10C	5C
Temp. Range	-15 to 60 C	-30 to 55 C	-10 to 40 C	-30 to 55 C
Cycle life	<= 30K	<= 60K	<= 10K	<= 10K
Energy Density	60-70 Wh/kg 130-140 Wh/l	60-75 Wh/kg 140-170 Wh/l	75-90 Wh/kg 180-200 Wh/l	75-90 Wh/kg 180-200 Wh/l



**ENAX Japan, LTO/LNO
Cells**

*** Can be discharge to 0V**



Xalt LTO-LMO Cell - 62K Cycles to 80% DOD @ 1C Charge-Discharge

XALT® 60Ah High Power Lithium-Ion LTO Cell



The XALT® Energy Advantage

- Outstanding fast charge capability
- Extremely high power-to-energy ratio
- Unparalleled long cycle life
- Wide operating temperature range
- Low, stable impedance and heat generation provide improved safety

Xalt Energy developed the highest Cycle Life LTO cells but stop to produce cells from 1/2018

Features

Long Life/Low Cost-per-Cycle/

Exceptional Quality

- High power Lithium Titanate Oxide (LTO) chemistry
- Wide operating temperature range
- Long cycle and calendar life
- Continuous fast-charge capability in excess of 6C
- Prismatic (flat plate) design
- Large capacity single element cell design
- Highly automated manufacturing

Advantages

Ideal for High Power applications requiring frequent fast charging and high cycle life

- Commercial transportation with on-route charging
- Grid & stationary storage
- ISO & sub-ISO marine
- Industrial equipment
- Harsh, remote environments

Performance Characteristics

Performance Characteristics	Typical
Capacity (Rated @ C/3)	60 Ah
Voltage (Nominal)	2.25V
Discharge Energy (C/3)	132 Wh
Weight	1745g
Specific Energy	≥ 76 Wh/kg
Energy Density*	≥ 170 Wh/L
DC Resistance (10 s @ 50% SOC)	0.4 mΩ
Peak Power* (10 s @ 50% SOC)	2,500W
Specific Power*	> 1400 W/kg
Power Density**	3200 W/L

*Volume includes core cell dimensions excluding tabs

**Defined by Freedom Car PA @ 50% SOC

Cycle Life

Cycle Life	Typical
100% DOD Cycles @ 1C charge-discharge	>40,000 cycles*
80% DOD Cycles @ 1C charge-discharge	>62,000 cycles*
60% DOD Cycles @ 1C charge-discharge	>110,000 cycles*

*Cycle life to 80% of rated capacity

Operational Range

Operational Range	Typical
Upper Voltage Limit	2.9V
Lower Voltage Limit	1.5V
Charge Temperature Range	-30°C to +60°C
Discharge Temperature Range	-30°C to +60°C

Cell Dimensions

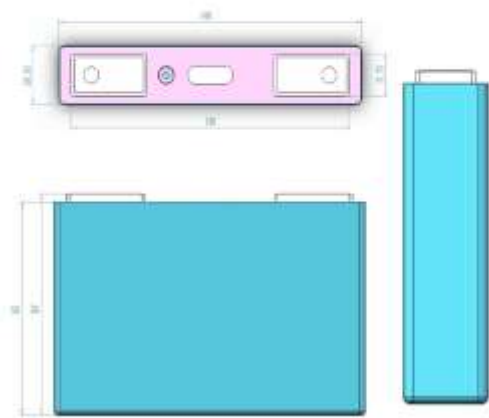
Cell Dimensions	LxWxT
Millimeters	263x266x12.8



LTO Cell Makers Per Country

Country	Number of Cell Makers
China	11
USA	1
Japan	2
Germany	2
Taiwan	1

* There are some minor manufacturers not covered by this research

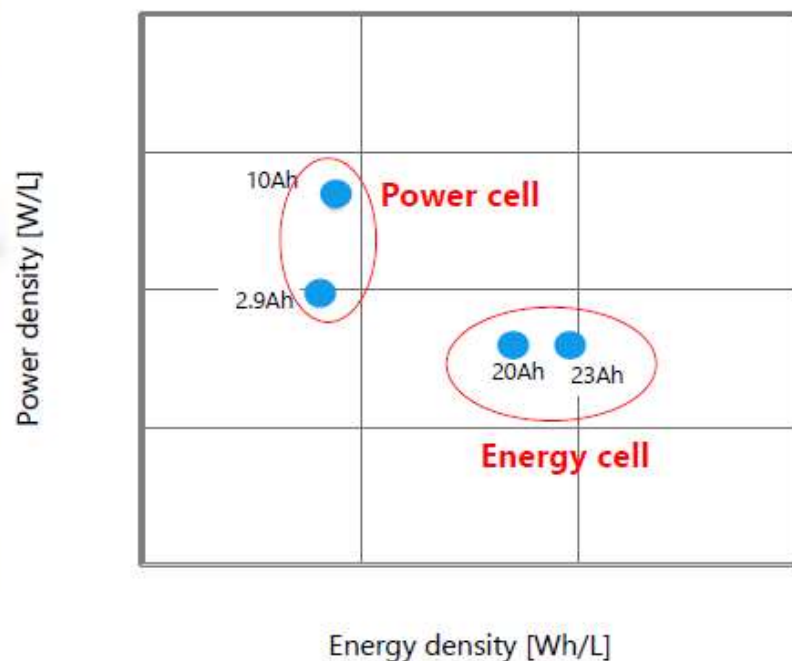


Automotive hard
case prismatic
LTO cell made by
Lishen China

Toshiba is the Leading LTO Cells Maker

SCiB™ Cell Lineup

	20Ah cell	23Ah cell	2.9Ah cell	10Ah cell
Photo				
Category	High Energy	High Energy	High Power	High Power
Dimension	116 x 106 x 22 mm	116 x 106 x 22mm	63 x 97 x 14 mm	116 x 106 x 22mm
Weight	515 g	550g	150 g	510g
Nominal Capacity	20 Ah	23 Ah	2.9 Ah	10Ah
Voltage	2.3 V	2.3 V	2.4 V	2.4V



Automotive LTO Stop-Start 12V & 48V Battery Packs



Mild Hybrid, JCI, 48V LTO
Battery made by Toshiba
cells



Stop-Start, JCI, 12V LTO
Battery made by Toshiba
cells

Milde Hybrid systems feature a larger motor that can regenerate energy and use to send some additional power to the drivetrain

Automotive LTO Batteries for Opportunity Buses



- Mainly for fast charging buses (Opportunity charging) or Trolley buses
- Typical battery size – 624V, 60-120kWh
- High discharge power as small battery pack need to drive heavy bus
- Can be charge up to 10C at the bus stops
- Long service and cycle life which allow 15 years of bus operation
- Operate well in low and high temperatures (-30 – 60 C)
- Small scale use in China and pilot projects worldwide

Automotive LTO Batteries for Traction Locomotive



- Mainly for regenerating energy while the train stop/start at the train station
- Typical battery size – 576V, 60Wh
- High discharge/charge power for short time (30-45 sec)
- Long service and cycle life which allow 20 years operation

Grid Storage LTO Battery Packs

■ 储能电池系统

Energy storage battery system



UPS电源
UPS power supply



通信后备电源
Communication backup
power supply



微网储能电源
Micro grid energy storage system



光伏储能电源
Photo-voltaic energy
storage system

48V, 2.5kWh Industrial Battery pack for ESS, Micro-Grid, UPS, Cellular Towers (BTS)- Mainly used indoor

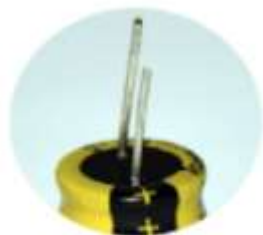
LTO Batteries for Space Application – Satellites



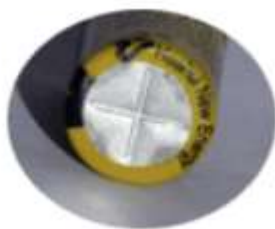
Figure 2 Soft prototype LTO cell with 0V storage capability

- LTO can be used for high pulse cycling for LEO satellite applications
- LTO has an excellent cold temperature performance that can eliminate the need for thermal management
- Soft LTO cells can be stored at 0V and recovered -

Miniature LTO Cells for Electronic Cigarettes



The positive and negative pole leads to the same direction. And the sealing temperature explosion-proof at the top of lithium titanate battery can be automatically carbonized when over-heat and short-circuit.



The cross-proof line at the bottom of lithium titanate battery can release gas when over-swelling or over-pressure. This fundamentally eliminated the danger of explosion, fire.

[Lithium Titanate Battery LTO1015 40mAh 2.4V](#)

LTO 1015 40mAh 2.4V



Dimensions(D*L): 10*15 (mm)

Application: Mini electronic cigarettes

Implantable Medical LTO Cells from Medtronic USA



Medtronic announced at Florida international battery seminar conference 3/2018 the beginning use of LTO rechargeable implantable battery

LTO Battery Pack Market Forecast & Trends 2019-2025

- **Battery electrochemistry with a high growing rate for the ESS and xEV markets.**
- **Limited number of cell makers (17) and cell models.**
- **Toshiba leading the market with an automatic mass production lines.**
- **Improved energy and power density can be expected in the near future**
- **High cost for a new technology but expected to decrease as production capacity will grow in the coming years.**



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Information for presentation obtained by:

- 1. Public web sources.**
- 2. Shmuel De-Leon Battery/Energy Sources DataBase ® (Includes 29000 cell PDF data sheets) <http://www.sdle.co.il/Default.asp?sType=0&PageId=45580>**