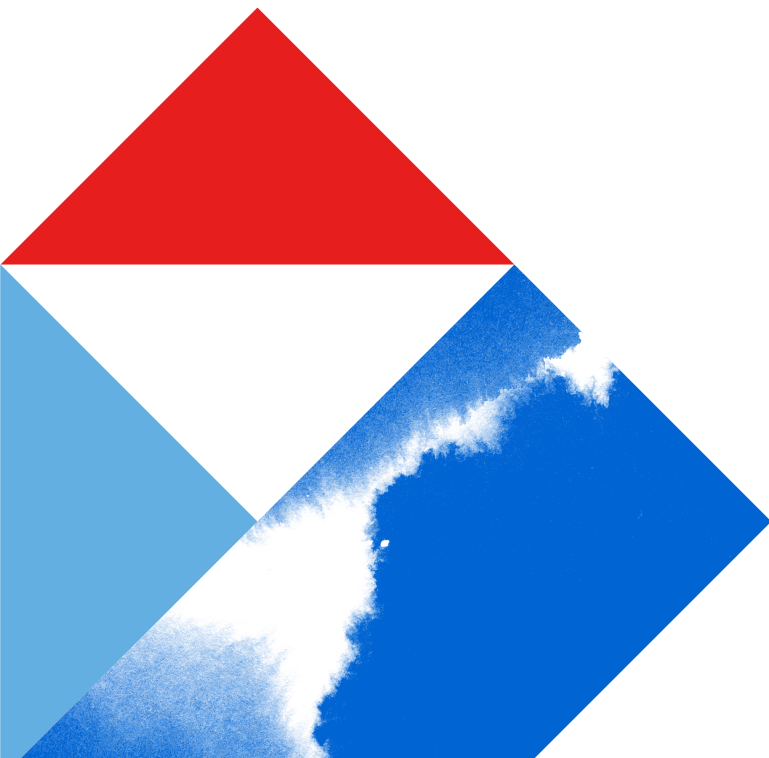


# TOSHIBA



LTO batteries minimise the total cost of ownership and make heavy-duty commercial vehicles more economical



Traction batteries for the electrification of heavy-duty commercial vehicles have to meet special requirements depending on the application area. Rapid charging of the traction battery in dump trucks, for example, prevents unnecessary downtimes and therefore maximises the yield of the mine. In addition, the battery in these vehicles needs to have a long service life. This eliminates battery replacement and minimises the total cost of ownership (TCO). For these and other applications, such as rail vehicles, ships, buses, trucks, cranes and systems for the stabilisation of the power grid, lithium titanium oxide batteries (LTO) offer clear advantages in both technical and economic terms.

Diesel engines have been the state-of-the-art up to now and are familiar to operators, which is why they are used in most industrial machines and heavy-duty commercial vehicles. However, the exhaust emissions from diesel engines are harmful to health and the environment. Depending on the field of application, special protection measures are required.

For example, when diesel-powered machines are used for mining, sufficient ventilation in the tunnels must be provided. Since this industry has one of the highest rates of increase in CO<sub>2</sub> emissions, this is becoming an increasing challenge. In addition, the heat generated by diesel vehicles can only be removed using suitable cooling systems. Ventilation and cooling measures, especially in the mining industry, require considerable volumes of investment, increasing operating costs.

Due to these circumstances, manufacturers of diesel-powered mining machinery and heavy-duty commercial vehicles are looking to switch to battery-electric drives as quickly as possible. LTO (lithium titanium oxide), out of the main lithium-ion battery chemistries including NMC (lithium nickel manganese cobalt oxide) and LFP (lithium iron phosphate), is best suited for heavy-duty commercial vehicles. Toshiba has many years of experience with this technology and in the use of SCiB battery cells based on LTO.

## Advantages of LTO battery chemistry

LTO cells use lithium titanium oxide as the anode material, unlike conventional battery technologies, which use graphite as anode material. This gives LTO several advantages (Fig. 1).

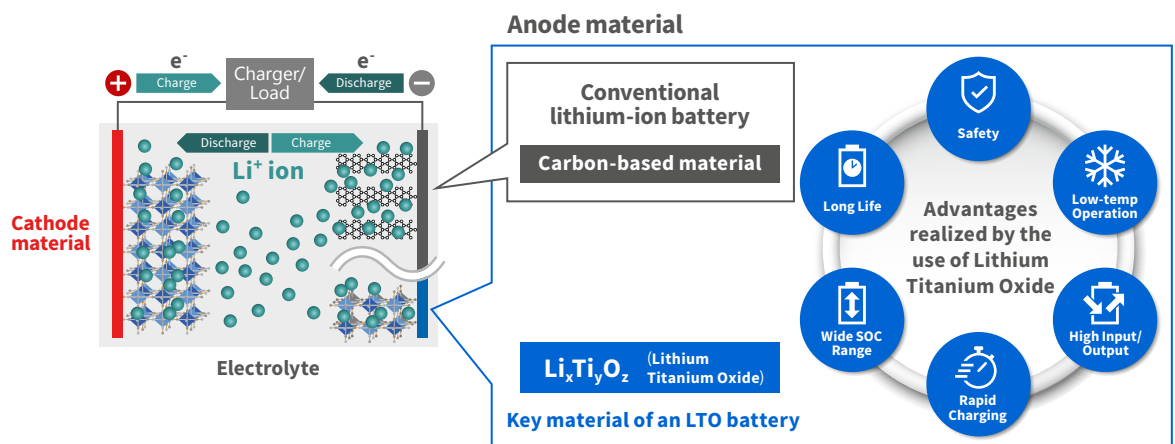


Fig. 1: The anode material used for LTO cells is lithium titanium oxide provides six advantages over cells using carbon based anodes.

Particularly impressive is the very long lifespan of LTO batteries, in terms of both shelf life and cycle stability. The extremely high cycle stability, which ultimately also reduces the TCO, is enabled by the characteristics of LTO as a zero-strain technology (ZS). ZS means that LTO cells hardly expand during charging and discharging, so there are no mechanical stresses involved which, for example, foster the formation of hairline cracks in the anode, thereby reducing cycle stability or accelerating ageing.

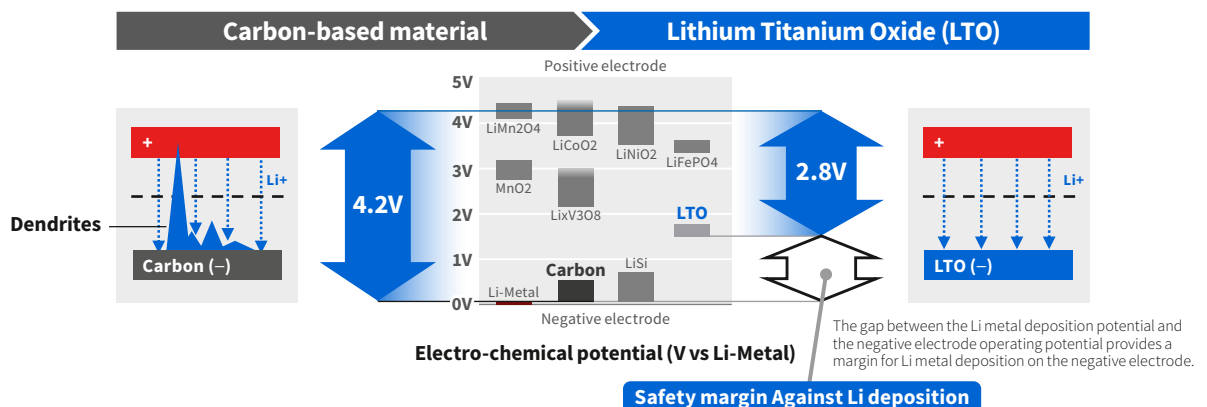
Conventional batteries can normally be charged at a maximum of 1 C. LTO cells, on the other hand, allow charging at 50 C with suitable cooling (high input/output). In practice this means that LTO batteries can be charged very quickly and with maximum performance (rapid charging) – at 20 C, for example, in just three minutes from 0% to 80% State of Charge (SoC).

Another outstanding feature of LTO cells is that they are particularly safe. In the event of LTO cells becoming deformed, for example in an accident, resulting in an internal short-circuit, the lithium titanium oxide discharges at the internal short-circuit point and there is a phase change from the conductive to the high-resistance phase. As a result, the affected cell only discharges slowly and in a controlled manner, meaning that far less heat is generated. The risk of thermal runaway with a danger of fire and explosion is thus much lower than is the case with conventional battery cells.

In addition, LTO cells offer advantages in terms of their behaviour at low temperatures. Whereas batteries with graphite-based anodes should not be charged at temperatures below 0 degrees Celsius – this would accelerate the ageing process and could lead to an internal short-circuit – LTO cells can be charged and discharged at temperatures as low as -30 degrees Celsius.

LTO cells also score points with their wide SoC range. This means that up to 100% of the nominal capacity can be used with LTO cells.

The electrochemical potential of graphite and lithium metal is very similar. There is therefore a risk when charging at a high C-rate or charging at low temperatures of lithium-ions being deposited on the carbon-based anode and needle-like structures (dendrites) forming between the anode and cathode, which may lead to an internal short-circuit. Since there is a much greater difference in chemical potential between lithium metal and LTO, this risk is effectively minimised in the case of LTO cells (Fig. 2).

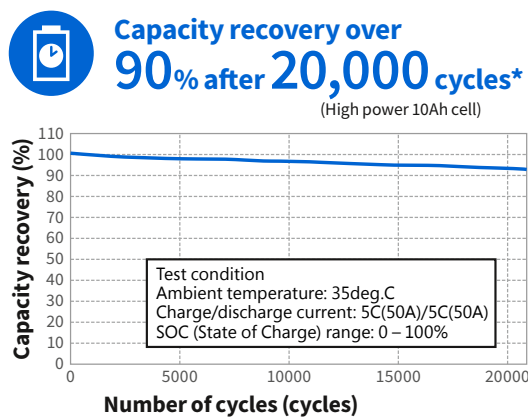


**Fig. 2:** The safety cushion in terms of the chemical potential between lithium metal and LTO means that no lithium ions are deposited on the anode, which significantly reduces the risk of internal short-circuits due to dendrites in LTO cells.

## Reduction in TCO

Despite the many technical advantages of LTO technology, it is often just the initial costs, or in other words the costs per kWh, that are taken into consideration, resulting in the selection of NMC and LFP. However, the economic benefit of LTO batteries minimising the TCO is often overlooked.

For heavy-duty commercial vehicles, which have to run for an extremely long period of 10 to 25 years, LTO technology makes sense due to its high cycle stability alone. Toshiba's LTO cells typically deliver cycle stability of 20,000 cycles. Depending on the load profile and cell type, however, this value can be significantly higher (Fig. 3). By comparison, typical values for NMC and LFP range from about 3,000 to 5,000 cycles.



**Fig. 3:** The high cycle stability, leading to the long life of the cells, is a major advantage of LTO technology. LTO cells offer cycle stability of 20,000 cycles and even more depending on the load profile.  
(\*Cycle characteristics/performance depends on cell type and usage conditions)

To convey the advantages of LTO battery technology and its impact on the TCO, Toshiba carried out two case studies for heavy-duty commercial vehicles with its LTO batteries (brand name: SCiB™).

## Fast charging at 155 kW between cycles

The first case study featured a Normet heavy-duty commercial vehicle from the M-range (Fig. 4). The traction battery used is a 90 kWh battery with 23Ah high-energy LTO cells. With a depth of discharge (DoD) of up to 89% with seven cycles per day, a quite demanding load profile is simulated here. In this case, fast charging occurs at 155 kW between cycles. The resultant value with the 90 kWh battery used is approx. 1.7 C. In comparison, NMC and LFP cells can typically be charged at a maximum of 1 C, i.e. with a maximum of 90 kW.



**Fig. 4:** The traction batteries used in the heavy-duty commercial vehicles from the M-range from Normet are 90 kWh batteries with 23Ah High Energy LTO cells from Toshiba.

Despite the demanding load profile, the battery's service life simulation showed that it still has a capacity of 82% after 15 years. This equates to 28,000 full cycles, which is a higher value than normally stated by Toshiba. In practice this means that the battery does not need replacing within the vehicle's service life of 15 years. With LFP solutions, on the other hand, the battery needs replacing between one and eight times over the course of the vehicle's service life, depending on the cell type.

With LTO, therefore, the TCO can be reduced by a factor of up to 4.5 compared to LFP. Moreover, two to fourteen times less waste (in tons) is generated over the 15 years of operation, which conserves resources and protects the environment. This makes LTO not only more economical, it makes sense in terms of sustainability too.

## The traction battery in the dump truck lasts 20 years

In the second case study, Toshiba simulated the traction battery of a dump truck (Fig. 5). Dump trucks are still operated with diesel engines, and these generally have to be replaced every seven years due to the high demands placed on them. Furthermore, mine operators have a set CO<sub>2</sub> budget, which is currently more or less completely used up. This challenges the goal of increasing the mine's production output. To reduce the CO<sub>2</sub> footprint and further increase production, mine operators are aiming to replace diesel engines with clean electric motors.



**Fig. 5:** An electric traction battery with LTO cells achieves a service life of 20 years in the dump truck simulation, lasting far longer than a diesel engine.

In this case a 920 kWh battery with 20Ah High Power LTO cells was considered and simulated. The battery has a DoD of just 49% per cycle in comparison to 89% in the first case study, resulting in a far longer service life.

In the example, adequate cooling (water temperature of 20 degrees Celsius) and a work cycle basis of 38 cycles per day with 30 minutes per cycle were assumed. This high work cycle basis means that the battery can only be charged when the vehicle is stationary during loading.

Since it only takes three minutes to load the vehicle, the entire energy consumed in 30 minutes must be recharged during this time. This leads to a very high charging rate of 8.3 MW between the cycles and results in a C-rate of over 8. The result of this service life simulation is that the capacity after 20 years is still at least 83%. This equates to 138,000 equivalent full cycles, which significantly exceeds the official figure provided by Toshiba of 20,000 full cycles.

This means, that the battery does not need to be replaced in 20 years. With LFP, on the other hand, the operator might need to replace the battery once a year in the worst-case scenario. In summary, LTO batteries can reduce the TCO to as little as one-sixteenth compared to LFP technology.

In this example, LTO also demonstrates its sustainability credentials, generating up to 64 times less waste compared to LFP technology, which leads to reduced resource consumption.

### The right SCiB cell for every application

The range of SCiB products offered by Toshiba covers three cell types: High Power, Combination and High Energy.

The High Power cells with 2.9 Ah or 10 Ah and 2.4 V rated voltage are suitable for applications in which particularly rapid charging and discharging with high currents is the priority.

The Combination cells with 20 Ah and 2.3 V rated voltage cover applications with high energy requirements which have to operate continuously and whose battery must be able to be charged and discharged with high currents.

The High Energy cells offer a high capacity of 23 Ah or 26 Ah with 2.3 V rated voltage and are suitable for such applications as bus, rail or marine.



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