

WHITE PAPER

SuperBattery energy storage enabling mining electrification

skeleton+



SUPERBATTERY ENERGY STORAGE ENABLING MINING ELECTRIFICATION

Mining is a significant contributor to greenhouse gas emissions globally: a report by McKinsey assigns 2-3% of global CO₂ emissions to the mining industry directly. Within mining, 40-50% of emissions are a result of diesel-powered machinery, mostly haul or dump trucks, making them one of the key areas for decarbonization by electrification. McKinsey highlights two alternatives for diesel fuel in mining: hydrogen and electricity.

While hydrogen is expected to play a large role in decarbonization globally in general, its downsides in mining come down to costs - hydrogen as a fuel is more expensive than diesel, leading to higher operating expenses.

Full electrification is challenging because of the high cost of battery energy storage. The harsh conditions and 24-hour operations in mines place high requirements for the robustness of lithium-ion batteries, and their lifetime at 2000-5000 cycles is not high to begin with. Lastly, about 6.5 hours per day are needed to recharge lithium-ion battery powered mobile machines, meaning more than 25% of the time the machines sit idle. This leads to high total cost of ownership and helps diesel remain as the lowest cost power source for mobile mining machines.

However, new energy storage alternatives are emerging, with the prime example being Skeleton Technologies' SuperBattery, which combines the characteristics of supercapacitors and batteries. The benefits of SuperBattery include:

- **Fast charging:** a mining haul truck can be charged in 90 seconds during unloading, resulting in no downtime.
- **50 000 lifecycles:** SuperBattery has ten times the lifetime of a lithium-ion battery.
- **Safety:** SuperBattery doesn't suffer from thermal runaways and there is no need for thermal propagation measures. SuperBatteries are safe, even when pierced, crushed, or overheated.
- **Sustainability:** SuperBatteries contain no cobalt, nickel, graphite, or copper, and are much easier to recycle than lithium-ion batteries.

Skeleton's SuperBattery will allow for electrification of diesel-powered mining haul trucks, enabling fast charging of the SuperBattery pack in 90 seconds and powering 20-30 minutes of operation. Recharging happens during unloading of the haul trucks, increasing efficiency in mining operations by eliminating downtime almost entirely.

What matters in the end with the choice of energy storage technology is the Total Cost of Ownership (TCO). SuperBattery is the only energy storage technology that allows for the electrified version to actually be cheaper, not just more environmentally friendly.

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What are SuperBatteries?

SuperBatteries are an energy storage technology developed by Skeleton to bridge the gap between high-power supercapacitors and high-energy Li-ion batteries. SuperBatteries offer the ideal combination of energy, power, and safety. The technology builds on Skeleton's industry-leading expertise in supercapacitor energy storage, combining the high power of supercapacitor technology with the high energy of lithium-ion battery technologies.

Li-ion Batteries

use a chemical reaction to store energy



 **Slow**

- + Limited power density (0.5 kW/kg)
- + **High energy density** (205 Wh/kg)
- + Limited cycle life (<6000)
- + Slow charge rate (1.5 C)
- + Safety concerns
- + Utilizes critical raw materials (Li, Graphite, Co)

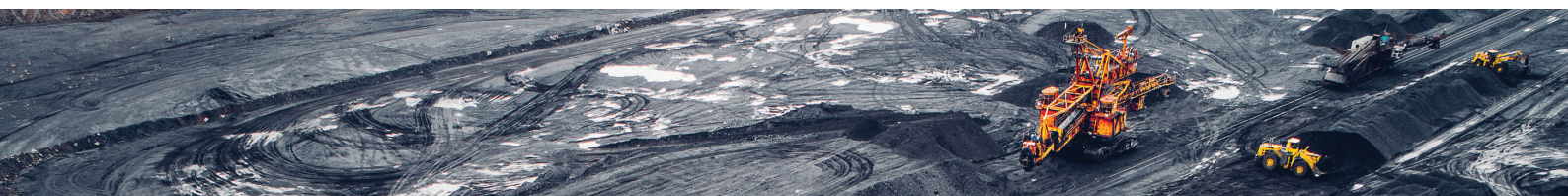
SuperBattery

Based on supercapacitor technology



 **Fast**

- + **High power density** (10 kW/kg)
- + Increased energy density (65 Wh/kg)
- + Long cycle life (50,000)
- + Fast charge (60s)
- + Extreme power (20 C continuous, 100 C peak)
- + High inherent safety
- + High recyclability and sustainability
- + No Graphite, no Co, <5% Li



	GEN1 Supercapacitors	GEN2 Supercapacitors	SuperBattery	LFP battery	LTO battery
Cost per [€/kWh]	100%	58%	8%	2%*	9%
Cost per 1s power [1MW]	13%	9%	13%	100%	40%
Cost per 10s power [1MW]	35%	24%	24%	100%	40%
Cost per 2 min power [1MW]	100%	58%	10%	52%	17%
Energy throughput per 1000€ - [MWh]	58%	100%	38%	16%	7%
Cycle life [cycles]	1,000,000	1,000,000	50,000	6,000	10,000
Calendar lifetime	15 years	15 years	15 years	6-8 years	6-8 years

*IHS Markit H2 2019 report

Footprint comparison,
number of modules
required

1MW / 1s



1MW / 2min



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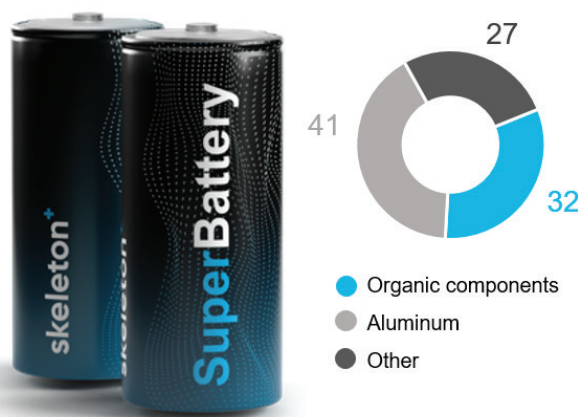
While supercapacitors are ideal for high-power applications for up to 60 seconds, SuperBatteries have enough energy for 15-30 minutes of application time, depending on energy and power requirements. SuperBatteries fill a gap in the energy storage market, which has previously been filled by significantly oversizing battery packs in order to meet power requirements.



Safety and sustainability

Safety is one of the key considerations in mining operations, especially in underground activities. Lithium-ion batteries have well-known risks with thermal runaways and diesel fumes create both an immediate hazard, especially underground, and long-term health issues from fumes and carbon emissions.

SuperBatteries do not suffer from thermal runaways and there is no need for thermal propagation measures. They are safe, even when pierced, crushed, or overheated, as confirmed by safety testing (information available on skeletontech.com).



SuperBatteries have advantages over Li-ion batteries in both materials and the cell design itself:

- A narrow range of required materials: no cobalt, no nickel, no copper, <5% lithium
- Safer to handle than Li-ion batteries (no lithiated graphite)
- Minimal number of components reduces manufacturing complexity and increases reliability
- No risks of fires or explosions upon disassembly or accidents
- Aqueous coating for both Anode and Cathode
- Aqueous processing for recycling possible



SuperBatteries enable electrification and decarbonization of mining

Full electric haul trucks

Diesel-powered haul trucks are one of the biggest emitters of CO₂ in mining, which make them an enticing target for electrification. The massive size and weight of these machines, especially when fully loaded, leads to high fuel consumption: one CAT 797B dump truck can carry 400 tonnes of ore and consumes about 114 liters per hour.

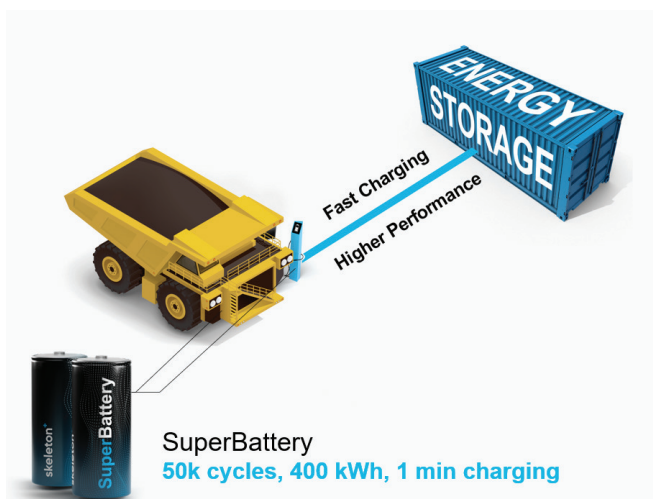
The cost of diesel fuel consumed on some mining sites adds up to more than 50% of the mine's total cost of energy, meaning any decrease in operating costs can have a meaningful impact on the bottom line.

Lithium-ion batteries are a potential solution for haul truck electrification, but they have several downsides:

- Stationary charging means significant downtime, because lithium-ion batteries do not support fast charging, or their lifetime is shortened if the charging speed used is too high.
- Li-ion batteries are a safety concern for mines, especially in underground operations.
- The relatively short lifetime of lithium-ion batteries also means they need to be replaced often, increasing total cost of ownership. Lifetime is further reduced when current is increased to decrease charging time.



Electrifying one haul truck is the equivalent of eliminating the CO₂ emissions of 11,000 passenger cars yearly.

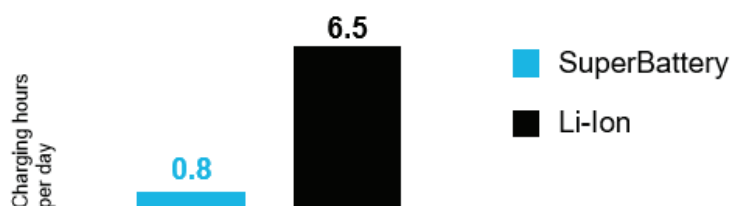


SuperBatteries can charge at C-rates of up to 60 C and offer 50,000 lifecycles. 400 kWh SuperBattery packs are charged in 60 seconds during unloading, enabling almost total elimination of downtime, increase in efficiency even compared to diesel-powered haul trucks, and lowered peak demand on the grid.

SuperBattery enables fast charging

A Li-ion-powered electric haul truck requires 6.5 hours of charging time daily, meaning more than 25% of daily working hours for a haul truck are spent charging.

SuperBattery-powered haul trucks, on the other hand, can be charged while the truck is being unloaded, eliminating the vast majority of downtime and increasing efficiency significantly. SuperBatteries can be charged in 60 seconds and are able to power the haul truck for 20-30 minutes until the next recharge.



Trolley assist

Some mines use a trolley assist system, where haul trucks use an overhead contact line for electrical energy as power source. The benefits include lower fuel costs and CO2 emissions, because the trucks are not fully reliant on diesel engines, but the overhead contact lines also limit freedom of movement and have an impact on logistics and route planning for mines.

SuperBatteries offer an alternative, providing short-term propulsion and eliminating several challenges that catenary networks create:

- Entire energy for propulsion must be supplied from the catenary network
- Several vehicles are connected to the network and operate simultaneously
- High load on the existing contact network
- Voltage sag on the contact network during peak power load
- High energy waste during braking
- Intermittent contact with catenary can cause voltage drop on the drives, causing vehicle propulsion system to trip

SuperBatteries can be used to capture breaking energy and use it to accelerate, reduce the load and energy consumption from the network, and to provide short-range catenary-free propulsion.

Next steps in decarbonizing mining

SuperBatteries can help electrify a number of other types of mining machines, such as loaders, trucks, and drills, and others, as well as stationary machinery and solutions in mines. The combination of power, energy, and lifetime, not to mention the advantages safety and sustainability, make SuperBatteries an excellent choice for mining electrification and decarbonization. However, what makes SuperBatteries the key enabler in mining is the fact that, along with all the other positives, they are simply the only energy storage technology that allows cost reduction in the operating costs in mining.

