Sulfur-based batteries could offer electric vehicles a greener, longer-range option

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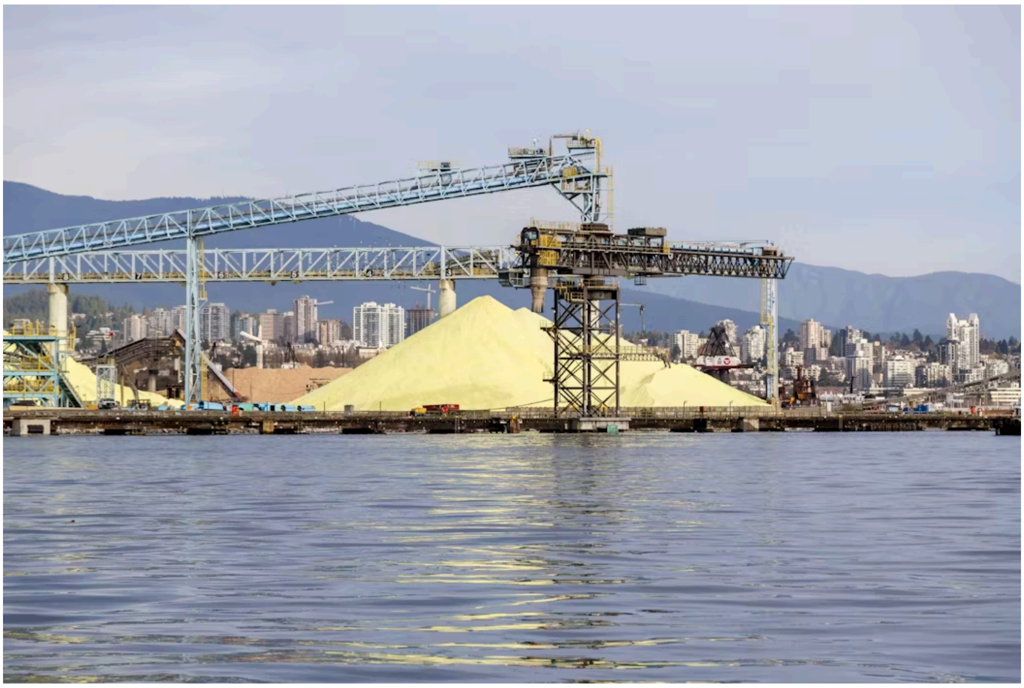

Sulfur is abundant and inexpensive, making it an attractive ingredient for making batteries.
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Picture an electric car that could go 600, 700 or even 1,000 miles on a single charge. That's much farther than the longest-range electric vehicles on the U.S. market, according to Car and Driver magazine – and twice as far the official rating for the long-range, rear-wheel-drive Tesla Model 3, which has a maximum rated range of 363 miles.

Current EVs use lithium-ion batteries, which are also found in smartphones, laptops and even large-scale energy storage systems connected to the power grid. A standard for decades, these batteries have been tweaked and improved by generations of scientists and are now close to their physical limits. Even with the best materials and most optimized designs, there is only so much energy that can be packed into a lithium-ion battery.

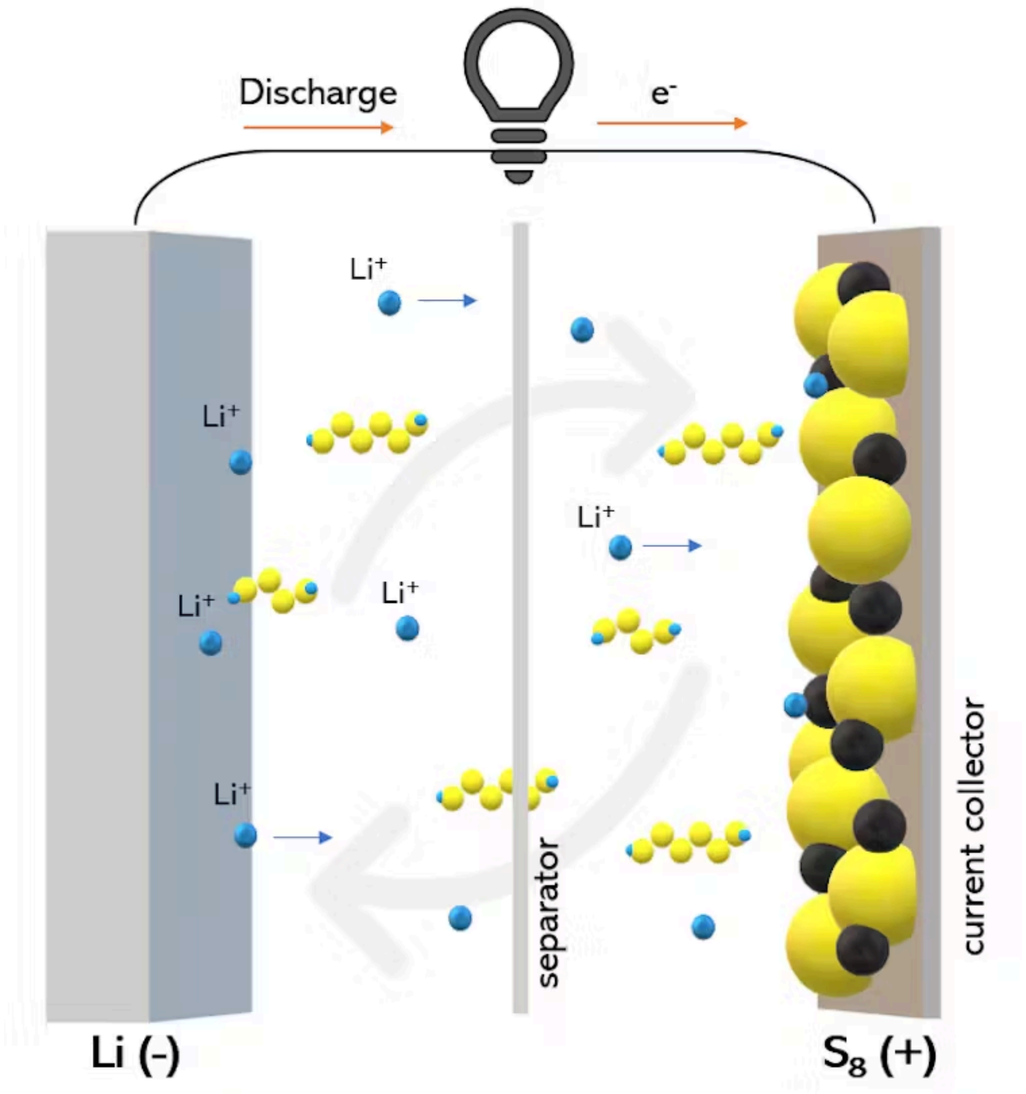
I'm a materials engineer who studies these batteries and seeks alternatives with better performance, improved environmental sustainability and lower cost. One promising design uses sulfur, which could boost battery capacity significantly, though some key roadblocks remain before it can be widely used.

Lithium-sulfur vs. Lithium-ion

Any battery has three basic components: a positively charged region, called the cathode; a negatively charged region, called the anode; and a substance called the electrolyte in between, through which charged atoms, also known as ions, move between the cathode and anode.

In a lithium-ion battery, the cathode is made of a metal oxide, typically containing metals such as nickel, manganese and cobalt, bonded with oxygen. The materials are layered, with lithium ions physically between the layers. During charging, lithium ions detach from the layered cathode material and travel through the electrolyte to the anode.

The anode is usually graphite, which is also layered, with room for the lithium ions to fit between them. During discharge, the lithium ions leave the graphite layers, travel back through the electrolyte and reinsert into the layered cathode structure, recombining with the metal oxide to release electricity that powers cars and smartphones.



Lithium-sulfur batteries like this one have different chemistry than more commonly known lithium-ion batteries.

Egibe via Wikimedia Commons, CC BY-SA

In a lithium-sulfur battery, the lithium ions still move back and forth, but the chemistry is different. Its cathode is made of sulfur embedded in a carbon matrix that conducts electricity, and the anode is made primarily of lithium itself, rather than graphite layers with lithium in between.

During discharging, the lithium ions travel from the anode, through the electrolyte to the cathode, where – rather than sliding in between the cathode layers – they chemically convert sulfur in sequential steps to a series of compounds called lithium sulfides. During charging, the lithium ions separate from the sulfide compounds, leave the cathode behind and travel back to the anode.

The charging and discharging process for lithium-sulfur batteries is a chemical conversion reaction that involves more electrons than the same process in lithium-ion batteries. That means a lithium-sulfur battery can theoretically store much more energy than a lithium-ion battery of the same size.

Sulfur is inexpensive and abundantly available worldwide, meaning battery manufacturers do not need to rely on scarce metals such as nickel and cobalt, which are unevenly distributed on Earth and often sourced from regions such as the Democratic Republic of Congo, which has limited worker safety regulations and fair labor practices.

Those advantages could deliver batteries with far more capacity and that are cheaper and more sustainable to produce.

Why aren't lithium-sulfur batteries widely used yet?

The biggest obstacle to mass production and use of sulfur-based batteries is durability. A good lithium-ion battery, like those in an electric vehicle, can go through thousands of cycles of discharging and recharging before its capacity starts to fade. That amounts to thousands of car rides.

But lithium-sulfur batteries tend to lose capacity much more quickly, sometimes after fewer than 100 cycles. That's not very many trips at all.

The reason lies in the chemistry. During the chemical reactions that store and release energy in a lithium-sulfur battery, some of the lithium sulfide compounds dissolve into the liquid electrolyte of the battery.

When that happens, those amounts of both sulfur and lithium are removed from being used in any remaining reactions. This effect, known as "shuttling," means that with each round of discharging and recharging, there are fewer elements available to release and store energy.

In the past couple of decades, research has produced improved designs. Earlier versions of these batteries lost much of their capacity within a few dozen discharge–recharge cycles, and even the best laboratory prototypes struggled to survive beyond a few hundred.

New prototypes retain more than 80% of their initial capacity even after thousands of cycles. This improvement comes from redesigning the key parts of the battery and adjusting the chemicals involved: Special electrolytes help prevent the lithium sulfides from dissolving and shuttling.

The electrodes have also been improved, using materials such as porous carbon that can physically trap the intermediate lithium sulfides, stopping them from wandering away from the cathode. This helps the discharge and recharge reactions happen without so many losses, making the reactions more efficient so the battery lasts longer.

The road ahead

Lithium-sulfur batteries are no longer fragile laboratory curiosities, but there are significant challenges before they can become serious contenders for real-world energy storage.

In terms of safety, lithium-sulfur batteries have a less volatile cathode than lithium-ion batteries, but research is continuing into other aspects of safety.

Another problem is that the more energy a lithium-sulfur battery stores, the fewer cycles of charging it can handle. That's because the chemical reactions involved are more intense with increased energy.

This trade-off may not be a major obstacle for using these batteries in drones or grid-level energy storage, where ultrahigh energy densities are less critical. But for electric vehicles, which demand both high energy capacity and long cycle life, scientists and battery researchers still need to sort out a workable balance. That means the foundation for the next generation of lithium-sulfur batteries is likely still a few years down the road.

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