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News & Highlights

Development of Lithium-Ion Batteries Wins Nobel Prize

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We now live in a rechargeable world built on lithium (Li)-ion batteries (LIBs). In October 2019, three scientists/engineers who played pivotal roles in the development of LIB were each honoured with a one-third share of the Nobel Prize in Chemistry (Fig. 1) [1].

The LIB story began in the 1970s with M. Stanley Whittingham, now at Binghamton University, State University of New York, who discovered a hugely energy-rich material—titanium disulfide—that he used to create a novel cathode in a lithium battery. The battery, in which positively charged lithium ions moved back and forth between the electrodes during its charge/discharge cycle, had a potential of over two volts, but its anode contained highly reactive metallic lithium and therefore had a tendency to explode.

The next chapter features John B. Goodenough, now with the University of Texas at Austin, who at age 97 is the oldest recipient of a Nobel Prize in history. He predicted that a metal oxide would provide greater potential than a metal sulfide, and in 1980 showed that a lithium battery with a cobalt oxide cathode could hit four volts.

The story was completed by Akira Yoshino, now at Meijo University in Nagoya, Japan. In 1985, he removed reactive lithium from the anode and used petroleum coke instead, creating a safer, commercially-viable LIB.

Now ubiquitous, LIBs powered the boom in portable devices, most notably cell phones and laptops, and made possible the ongoing revolution in electric vehicles (EVs).

But the story goes on. A relentless drive for improved performance is powering research on novel Li chemistries and battery configurations. Today's LIB technology has matured for four decades, and it is getting increasingly difficult to squeeze out more performance. Changes in battery technology are also being driven by environmental and ethical impacts of battery production, which have come into sharper focus. Research on competing solid-state battery technologies is active as well.

At the start of 2020, Dr. Mahdokht Shaibani, a research fellow in the Department of Mechanical and Aerospace Engineering at Monash University in Victoria, Australia, and colleagues made headlines with a breakthrough in lithium–sulfur batteries [2]. A sulfur-based cathode can store considerably more energy than those used in conventional LIBs, but it undergoes a large volume change (about 78%) during use as it takes in and releases lithium. This causes sulfur electrodes to disintegrate with use, rapidly losing capacity.

Fig. 1. Researchers, now Nobel laureates, winners of the 2019 Nobel Prize in Chemistry for their work that led to the LIB that ubiquitously power our rechargeable world (right to left): Professor John B. Goodenough (the University of Texas at Austin, USA), Professor M. Stanley Whittingham (Binghamton University, State University of New York, USA), and Professor Akira Yoshino (Asahi Kasei Corporation, Tokyo, and Meijo University, Nagoya, Japan). Credit: Nobel Media/A. Mahmoud, with permission .

To deal with this problem, Shaibani and colleagues developed an electrode architecture that is expansion tolerant. Whereas sulfur cathodes are typically made by binding together a slurry of sulfur particles with a dense polymer network, the team's manufacturing technique used smaller proportions of those same binders, connecting the sulfur particles with polymer "bridges," and leaving relatively large voids to accommodate the aggressive expansion and contraction. Their fabrication method resulted in "unprecedentedly high areal capacity," high stability for more than 200 charging cycles, and over 99% efficiency in charging/discharging [2].

"In theory, the lithium–sulfur system offers up to a five-fold increased specific energy compared with lithium-ion and at a significantly reduced cost," said Shaibani. "But from a practical point of view, considering the current advancements of our research group and others, around a two-fold increase at battery pack level is expected when introduced to the market, hopefully in the next two to four years."

Such a doubling of the capacity of rechargeable batteries would boost power-hungry smartphones. And while the top-end EV, the Tesla Model S, claims a range of 373 mi (600 km) [3], most EVs offer significantly less than that [4]. The increased capacity of a lithium–sulfur battery could go a long way to decrease the "range anxiety" associated with today's EVs.

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Lithium–sulfur batteries may also be preferable from an environmental perspective. A sulfur cathode is made with abundant sulfur, carbon, and the binder—no heavy metals are required. "The path towards greener, more sustainable, and more ethical batteries lies at the heart of our research philosophy, designing electrodes that have comparable or superior performances to today's electrodes but are inherently greener and have global material abundance," said Shaibani.

A similarly environment-friendly battery is apparently being developed by IBM. In December 2019, Young-Hye Na, manager of Materials Innovations for Next-Gen Batteries at the IBM Almaden Research Center in San Jose, California, announced the discovery of a chemistry for a new battery that replaces heavy metals or other substances with sourcing concerns with materials that can "be extracted from seawater" [5]. IBM also claimed its battery had greater power density than LIBs can achieve and used a low flammability electrolyte. No supporting evidence or details of the materials has yet been released, however.

Such innovations are welcome for several pressing reasons, one of them ethical. A typical cathode in a modern LIB contains oxides of nickel, manganese, and cobalt. Cobalt is particularly problematic. About half of the world's supply is mined in the Democratic Republic of the Congo, often by people—including children—working in perilous conditions, leading to some to call cobalt the "blood diamond of batteries" [6].

But even without this downside to cobalt, a supply issue looms. The EV market is booming, with sales of over two million in 2018 projected to rise to more than 28 million in 2030 [7]. If so, the global demand for cobalt could outstrip supply by as early as 2025 [8]. This situation has been described as "a serious and potentially unsolvable constraint on the growth of the Li-ion industry," by Sam Jaffe, managing director of Cairn Energy Research Advisors in Boulder, Colorado [9].

Another unfortunate aspect of LIBs is that the liquid electrolyte inside, through which the lithium ions travel, is typically unstable [10]. In 2016, for example, Samsung's Galaxy Note 7 mobile device was famously recalled twice, then discontinued, after the batteries in many of the devices overheated and exploded [11]. Stability in batteries is particularly important in an EV packed with them. A potential solution to this problem is solid-state batteries, which in theory could achieve greater energy density [12]. In addition, such batteries could be safely used at a range of temperatures at which the fluid in conventional batteries would freeze or boil. A key challenge—among many others—is to develop solid materials that can conduct ions as quickly as the fluid electrolytes used in standard batteries. Car makers including Ford and BMW are investing in solid-state battery technology, and Toyota is rumoured to be set to reveal a prototype electric vehicle boasting a solid-state battery at the 32nd Summer Olympics in Tokyo—though no production car will follow for at least five years [13]. In any case, it is unlikely that solid-state batteries will be competing with the dominance of LIBs soon [14].

In the meantime, efforts to improve on LIBs or portable batteries in general cannot overshadow the stunning progress existing LIBs have delivered. As the Royal Swedish Academy of Sciences noted when announcing the 2019 Nobel Prize in Chemistry, LIBs "have laid the foundation of a wireless, fossil fuel-free society, and are of the greatest benefit to humankind" [15].

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