LITHIUM-ION BATTERY

What is a lithium-ion battery and how does

The lithium-ion (Li-ion) battery is the predominant commercial form of rechargeable battery, widely used in portable electronics and electrified transportation. The rechargeable battery was invented in 1859 with a lead-acid chemistry that is still used in car batteries that start internal combustion engines, while the research underpinning the Li-ion battery was published in the 1970s and the first commercial Li-ion cell was made available in 1991. In 2019, John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino **received the Nobel Prize in Chemistry** for their contributions to the development of the modern Li-ion battery.

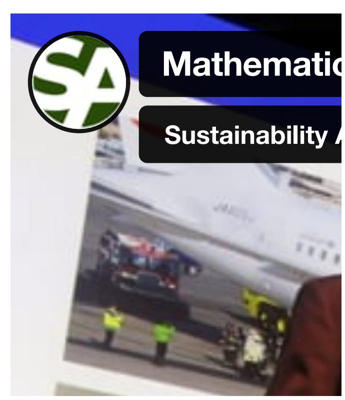
During a discharge cycle, lithium atoms in the anode are ionized and separated from their electrons. The lithium ions move from the anode and pass through the electrolyte until they reach the cathode, where they recombine with their electrons and electrically neutralize. The lithium ions are small enough to be able to move through a micro-permeable separator between the anode and cathode. In part because of lithium's small atomic weight and radius (third only to hydrogen and helium), Li-ion batteries are capable of having a very high voltage and charge storage per unit mass and unit volume.

Li-ion batteries can use a number of different materials as electrodes. The most common combination is that of lithium cobalt oxide (cathode) and graphite (anode), which is used in commercial portable electronic devices such as cellphones and laptops. Other common cathode materials include lithium manganese oxide (used in hybrid electric and electric automobiles) and lithium iron phosphate. Li-ion batteries typically use ether (a class of organic compounds) as an electrolyte.

Lithium ions are stored within graphite anodes through a mechanism known as **intercalation**, in which the ions are physically inserted between the 2D layers of graphene that make up bulk graphite. The size of the ions relative to the layered carbon lattice means that graphite anodes are not physically warped by charging or discharging, and the strength of the carbon-carbon bonds relative to the weak interactions between the Li ions and the electrical charge of the anode make the insertion reaction highly reversible.

Battery Applications

Mathematical



What are some advantages of Li-ion batteri

Compared to other high-quality rechargeable battery technologies (nickel-cadmium, nickel-metal-hydride, or lead-acid), Li-ion batteries have a number of advantages. They have one of the highest energy densities of any commercial battery technology, approaching 300 watt-hours per kilogram (Wh/kg) compared to roughly 75 Wh/kg for alternative technologies. In addition, Li-ion cells can deliver up to 3.6 volts, 1.5-3 times the voltage of alternatives, which makes them suitable for high-power applications like transportation. Li-ion batteries are comparatively low maintenance, and do not require scheduled cycling to maintain their battery life. Li-ion batteries have no memory effect, a detrimental process where repeated partial discharge/charge cycles can cause a battery to 'remember' a lower capacity. Li-ion batteries also have a low self-discharge rate of around 1.5-2% per month, and do not contain toxic lead or cadmium.

High energy densities and long lifespans have made Li-ion batteries the market leader in portable electronic devices and electrified transportation, including electric vehicles (EVs) like the Nissan Leaf and the Tesla Model S as well as the hybrid-electric Boeing 787. In terms of decarbonizing our economy's energy use, Li-ion technology has its greatest potential in EVs and electrified aviation.

What are some disadvantages of Li-ion batt

Despite their transformative effect on technology, Li-ion batteries still have a number c safety. Li-ion batteries have a tendency to overheat, and can be damaged at high voltag flammable, so damaged batteries can experience thermal runaway and combustion. Be

batteries, a number of shipping companies **refuse to perform bulk shipments of batt**
mechanisms to limit voltage and internal pressures, which can increase weight and lim
batteries are also subject to aging, meaning that they can lose capacity and frequently
cost, and safety make Li-ion batteries a poor fit for grid-scale energy storage. And desp
compared to other kinds of batteries, they are still around a hundred times less energy
Wh/kg by mass or 8760 Wh/L by volume.

CEI Research Highlights

A major focus of CEI energy storage research is the development of novel materials to
researchers develop substitutes for the components of a conventional Li-ion battery, s
graphite. Others work to improve upon well-developed battery components by building
can improve the speed and efficiency of charge cycles, with physical features that are s
researchers are also exploring alternative chemistries to Li-ion that might be suitable f

For example, chemical engineering (ChemE) professor **Vincent Holmberg** and **his rese**
alloying materials for Li-ion batteries. Materials like silicon, germanium, and antimony
results in greater capacities than graphite anodes that rely on intercalating Li ions betw
materials experience greater changes in physical volume that can deform the electrode
But by introducing a nanostructure into the alloying material, the Holmberg group can
from the charge and discharge reactions. The physical morphologies of the electrodes
transfer charge, as can any chemical interactions between the lithium ions and the sur

Developing a deeper understanding of reversible "conversion" charge-discharge reactio
chemistries with higher theoretical energy densities, such as lithium-sulfur. With sulfur
weight, Li-S batteries could be cheaper and lighter than Li-ion batteries with graphite a
simultaneously with long cycle life remains a grand challenge for energy storage scient
often fail due to the formation of "dendrites" of lithium metal growing on the anodes li

Materials science & engineering professor **Jun Liu** investigates the degradation mechar
cobalt (NMC) cathodes in pouch cells, and has presented fundamental linkages among
structural evolution of solid–electrolyte interphase layers. Meanwhile, CEI director and
group are working on computational models of Li-S systems that can be corroborated
of the Battery500 Consortium — led by the Pacific Northwest National Laboratory (PN

committee — which aims to develop next-generation EV batteries with energy densitie: double the industry standard.

With technological progress in mobile electronics driving demand for denser batteries, dimensional (3D) electrode architectures and additive manufacturing methods to rapid improved performance. Research led by mechanical engineering (ME) professor **Corie (** focuses on how 3D electrode architectures can improve many aspects of battery perfor art prototyping and testing capabilities at the **Washington Clean Energy Testbeds**, ME professor **J. Devin MacKenzie's** group and the Holmberg group are collaborating to str electrodes. Special inkjet printers allow these engineers to build 3D electrode architect one of the only open-access, high-throughput roll-to-roll electronics printers in the wor scales. The Testbeds, at which MacKenzie is technical director, also house top-of-the-lir equipment to validate new electrode designs.

CEI researchers are also creating physical, mathematical and computational models to These models can help optimize battery performance and charge/discharge cycles and Schwartz group is advancing diagnostics for Li-ion batteries to obtain data on day-to-da alternative to a physical "autopsy" at the end of the device's use. Along with physics-ba diagnostic tools can detect signs of degradation in real time, allowing users to modify t Furthermore, researchers in the Schwartz group use these models to project second liv EV performance standards, **such as in solar-powered microgrids.**

With the **UW "Hyak" supercomputer**, researchers can simulate molecules and their kir understand electrochemistry from a perspective that is not afforded to experimental te

CEI researchers also use direct imaging techniques like x-ray spectroscopy to understar **Jerry Seidler's lab** has developed a method to perform X-ray absorption near edge stru benchtop. The technique provides relatively detailed measurements of certain charact having to open it and thus disrupt the system. Previously, XANES could only be accomp from instruments such as a synchrotron. These are extremely large and expensive facil available to the public via federal labs with months-long waiting lists.. But as optoelectr lab spun out a company to prototype a $25,000 benchtop instrument that can mimic th **EasyXAFS** already enables scientists to obtain XANES measurements in hours, which ca batteries and other energy-related materials and devices.

Meanwhile, **chemistry professor Cody Schlenker and his group** investigate the funda
storage systems with the goal of gaining a deeper understanding of electrochemical pr
with spectroscopy, the lab can identify changes in vibrational frequencies and in the dy
specific chemical phenomena at key interfaces between electrodes, separator membra

Explore More

- **Website on batteries and battery reuse** created by Clean Energy Bridge to Resear