Argonne NATIONAL LABORATORY

EV BATTERIES AND RECYCLING

Increasing use of lithium-ion batteries for electric and hybrid vehicles creates new challenges and opportunities

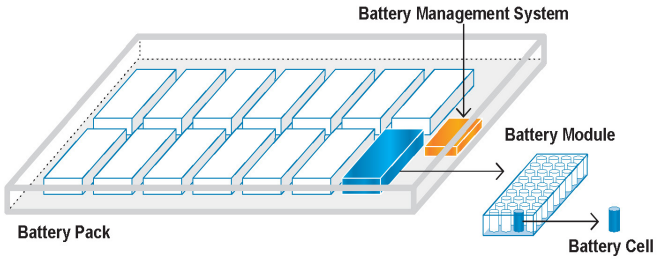
Demand for electric vehicles (EVs) is increasing. Electricity is cheaper and cleaner than conventional fuel, and EV maintenance costs are low. Also attractive are EVs' instant torque and quiet operation. In addition to advantages for individual drivers and for fleets, the multiple fuel sources used to generate the electricity that powers EVs create more energy resilience for the transportation sector, which supports national security.

With this uptick in EV demand comes questions about their batteries, how they are made, their safety, and what happens to them at the end of a vehicle's life.

BATTERY AND EV BASICS

Battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs) depend primarily on rechargeable high-energy lithium-ion (Li-ion) batteries. Li-ion batteries for vehicles are very reliable with long lifespans; most carry warranties of 8–10 years or 100,000 miles. Some HEVs still employ nickel metal hydride (NiMH) batteries, but those are phasing out.

The typical vehicle Li-ion battery is actually a *battery pack* consisting of multiple individual battery cells packaged into modules, which are then assembled into multi-module packs.



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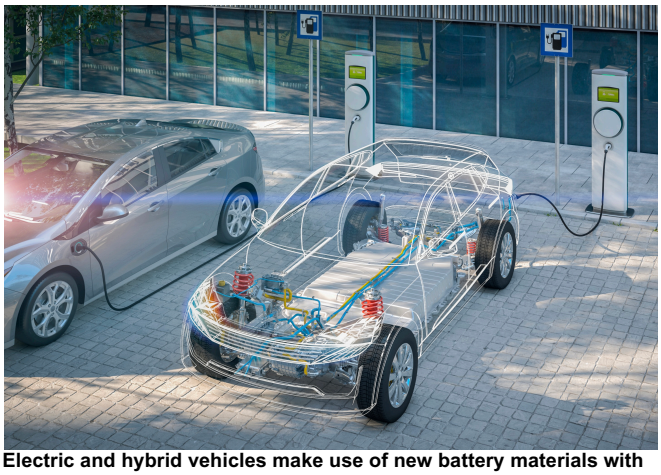

Electric and hybrid vehicles make use of new battery materials with life cycles that differ from those used in older vehicle technologies.

How safe are Li-ion batteries?

Today's vehicle Li-ion battery packs are quite safe when used, charged, and handled in accordance with the vehicle manufacturer's instructions. While there have been incidents involving Li-ion battery packs, they were typically associated with mishandling or damage to the battery pack or connected components, or exposure to combustible materials while in a damaged state.

It is important for consumers to understand and adhere to the vehicle manufacturer's guidelines concerning storage, maintenance, and charging of a BEV, PHEV, or HEV, as failure to do so can create or increase risks. Because Li-ion batteries can pose hazards in traffic collisions, first responders now receive training in how to handle BEVs, PHEVs, and HEVs in the event of such an incident.[1]

In the event of unusual or unexpected vehicle behavior, vehicle operators should reach out to the original equipment manufacturer (OEM) vehicle dealer for assistance, as they will have the most current servicing guidance.

[1] National Fire Protection Association. "Electric Vehicle Fires Are a Threat. Be Ready to Respond Safely." Available at https://www.nfpa.org/EV. Accessed September 30, 2022.

U.S. DEPARTMENT OF ENERGY
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HOW AND WHERE ARE LI-ION BATTERIES MADE?

Where do Li-ion battery materials originate?

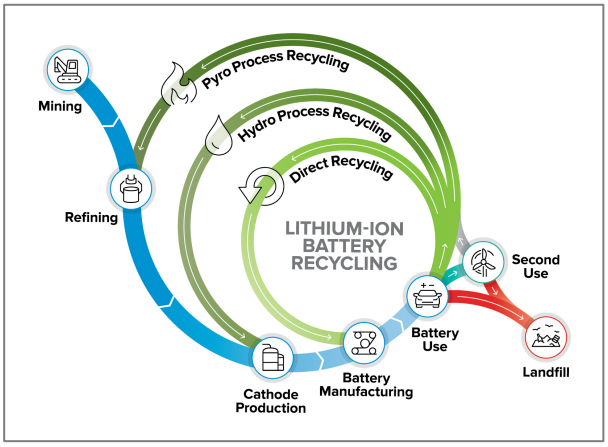
Many of the materials contained in a Li-ion battery (for example, cobalt, nickel, and lithium) come from outside the United States. Mining, processing, and shipping these materials comes with social, political, and environmental impacts. As became clear during the COVID pandemic, this makes the materials subject to supply chain disruptions and price volatility. Futhermore, much of the processing for these materials currently occurs outside North America, primarily in China.[2] As a result, many battery materials are shipped around the world before they arrive in the United States, contributing to their cost and carbon footprint.

Where are EV batteries manufactured?

According to Thomas™, as of 2022, the top 12 manufacturers of Li-ion batteries for vehicles are in China, Korea, and Japan.[3] As demand for EVs grows, vehicle manufacturers in the United States are working to develop more domestic Li-ion battery production capacity. Several U.S.-based Li-ion battery manufacturing plants are under construction or planned to come online in a few years.

In addition to manufacturing facilities, battery producers will also need skilled talent to build Li-ion batteries domestically, and manufacturers are working to develop training programs to prepare workers for building and servicing Li-ion batteries.

RECYCLING LI-ION BATTERIES AT END OF VEHICLE LIFE



The goal of Li-ion battery recycling is preventing materials from ending up in landfills following second use, as shown above in red.

What do owners of EVs need to do when they are disposing of their vehicles?

Fortunately, EV battery life is more than 10 years (and can be as long as 20 years), so most modern EV batteries are still in use, though many are nearing the end of their lives. EVs in good functioning condition can be sold or traded in for a new vehicle as can any other vehicle. Battery life is warranted by the OEMs, so any battery failing during the covered period (usually at least 8 years) will be replaced under warranty. More often than not, the battery outlasts the vehicle and can be certified by Underwriters Laboratory for resale.

Although it is not required by law, EVs that have been damaged or totaled should be handled by a qualified repair shop, dismantler, or scrapper, which can be located by consulting with an insurance company or OEM vehicle dealer. DOE has funded training programs on how to handle EVs that have been in accidents.[4]

Where do Li-ion batteries end up today after a vehicle's life ends, and can they be reused?

Recognizing the need to keep valuable Li-ion materials from entering the waste stream, researchers are investigating ways to take Li-ion battery packs from their end-of-life (EOL) and reuse them.

Many of those EOL battery packs will follow traditional EOL vehicle disposal patterns (e.g., resale in the aftermarket for parts or scrap) or be resold to the do-it-yourself market. Li-ion batteries for consumer devices are smaller than vehicle batteries, but those batteries have historically taken several paths at the end of their life, which may provide insights to EV battery end of life. Those paths include being delivered to retailers for recycling (U.S. recycling capacity is growing), kept by the original purchaser, resold in the original device through an online site, or, in the worst case, discarded as trash destined for a landfill. Batteries are unlikely to be discarded, however, because of the high value of the component materials.

Used EV batteries have plenty to offer once they have completed their vehicle work lives. Potential second-life applications for used vehicle Li-ion batteries include:

- Low-power EV uses, such as golf carts;
- Energy storage for EV charging;
- Replacement of lead-acid batteries;
- Backup power for telecommunication services;

[2] Olivetti, E.A., G. Ceder, G.G. Gaustad, and X. Fu, "Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals," *Joule 1*, 229–243, October 11, 2017.

[3] Thomas, "Top US and International Battery Suppliers and Manufacturers." Available at https://www.thomasnet.com/articles/top-suppliers/battery-manufacturers-suppliers/. Accessed August 9, 2022.

[4] National Fire Protection Agency Catalogs for Electrical Vehicle Safety Training https://catalog.nfpa.org/.

- Residential energy-storage services; and
- Utility energy-storage service.

After second-life use, most Li-ion batteries must be recycled. Today, China has the greatest Li-ion battery recycling capacity; North America currently has limited capacity, but large incentives are available (e.g., under the 2021 Bipartisan Infrastructure Law) to develop more recycling capability.

Which methods of recycling are used?

At the end of their 10-to-20–year lifespan, Li-ion vehicle batteries can be recycled by responsible recyclers, who know how to disassemble them safely and use the correct methods for recovering reusable materials. Today, three processes—pyrometallurgy, hydrometallurgy, and direct recycling, the newest process in its pilot stages—are used to recover Li-ion battery materials.

Of these methods, direct recycling, once commercialized, will be preferred due to its lower environmental impact and cost. Evaluation using Argonne National Laboratory's award-winning GREET and EverBatt models shows that direct recycling would result in fewer environmental impacts and greater material recovery than would pyrometallurgical or hydrometallurgical processes. Direct recycling has the potential to decrease:

- Costs by 40%
- Energy use by 82%
- Greenhouse gases by 68%
- Water use by 77%
- Sulfur oxide emissions by 91%

BUILDING A ROBUST U.S. BATTERY RECYCLING INFRASTRUCTURE IS A PRIORITY

According to a White House report, "*Increased recycling can decrease the need for new raw material extraction and production. Different recycling processes reintroduce that material at different stages of the supply chain. A more robust domestic recycling industry will be most effective at securing material supply chains if paired with growth at various stages of manufacturing. Without a footprint in the earlier stages of manufacturing (including materials processing, as well as electrode, cell, and pack manufacturing), intermediate recycled products will be exported to markets/countries that have these capabilities.*"[5]

What Is the U.S. Department of Energy's Role?

In 2019, the U.S. Department of Energy (DOE) established the ReCell Center, based at Argonne National Laboratory, to make recycling economical, to help enable the United States to compete in the global recycling industry, and reduce reliance on foreign sources of battery materials. ReCell is a collaboration between Argonne, the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and several universities, including Worcester Polytechnic Institute, the University of California at San Diego, Michigan Technological University, and Tennessee State University. Collaborators from across the battery supply chain, including battery manufacturers, automotive OEMs, recycling centers, battery lifecycle management services, and material suppliers also work with the ReCell Center.

In addition, DOE offers new funding opportunities every year to address development of technologies needed to expand the availability of U.S.-based Li-ion battery recycling.

This comprehensive set of solutions requires concerted action, guided by an aggressive goal: to develop and domestically manufacture energy storage technologies that can meet all U.S. market demands by 2030.

The 2021 Bipartisan Infrastructure Law and the 2022 Inflation Reduction Act

The 2021 Bipartisan Infrastructure Law delivers substantial funding for new DOE programs to move the U.S. economy toward a clean energy, lower carbon emissions future by advancing the nation's energy infrastructure, supporting research and development in battery manufacturing and recycling, as well as significant funds to encourage domestic production of batteries and battery materials.

Between 2022 and 2027, the Bipartisan Infrastructure Law will stand up 60 new DOE programs, including 16 demonstration and 32 deployment programs. The law also expands funding for 12 existing Research, Development, Demonstration, and Deployment (RDD&D) programs.

Additionally, the Inflation Reduction Act (IRA) of 2022 has mandated significant tax benefits to battery producers for domestic production and materials extraction, as well as to consumers for purchasing vehicles with domestically produced batteries.

DOE looks forward to being a partner for states, communities, and industry as the U.S. economy moves toward a clean energy, lower emissions future by strengthening the nation's outdated energy infrastructure.

[5] The White House, "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth," 100-Day Reviews under Executive Order 14017 (June 2021). Available at https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf?utm_source=sfmc%E2%80%8B&utm_medium=email%E2%80%8B&utm_campaign=20210610_Global_Manufacturing_Economic_Update_June_Members.

Resources

- **Electric Vehicles**
  U.S. Department of Energy Alternative Fuels Data Center
  https://afdc.energy.gov/vehicles/electric.html
- **ReCell Center**
  https://recellcenter.org/
- **Federal and State Laws and Incentives**
  U.S. Department of Energy, Alternative Fuels Data Center
  https://afdc.energy.gov/laws
- **Bipartisan Infrastructure Law Programs**
  U.S. Department of Energy
  https://www.energy.gov/bil/bipartisan-infrastructure-law-programs
- **Lithium-Ion Recycling Prize**
  U.S. Department of Energy
  https://www.energy.gov/bil/lithium-ion-recycling-prize
- **Energy Storage Grand Challenge**
  U.S. Department of Energy
  https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge
- **EverBatt**, Argonne's closed-loop battery recycling model
  https://www.anl.gov/amd/everbatt
- **GREET**, Argonne's life-cycle analysis model
  https://greet.es.anl.gov/
- **Electric Vehicle Community Preparedness Online Trainings**
  National Fire Protection Association
  https://catalog.nfpa.org/Alternative-Fuel-Vehicles-Safety-Training-C4105.aspx

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