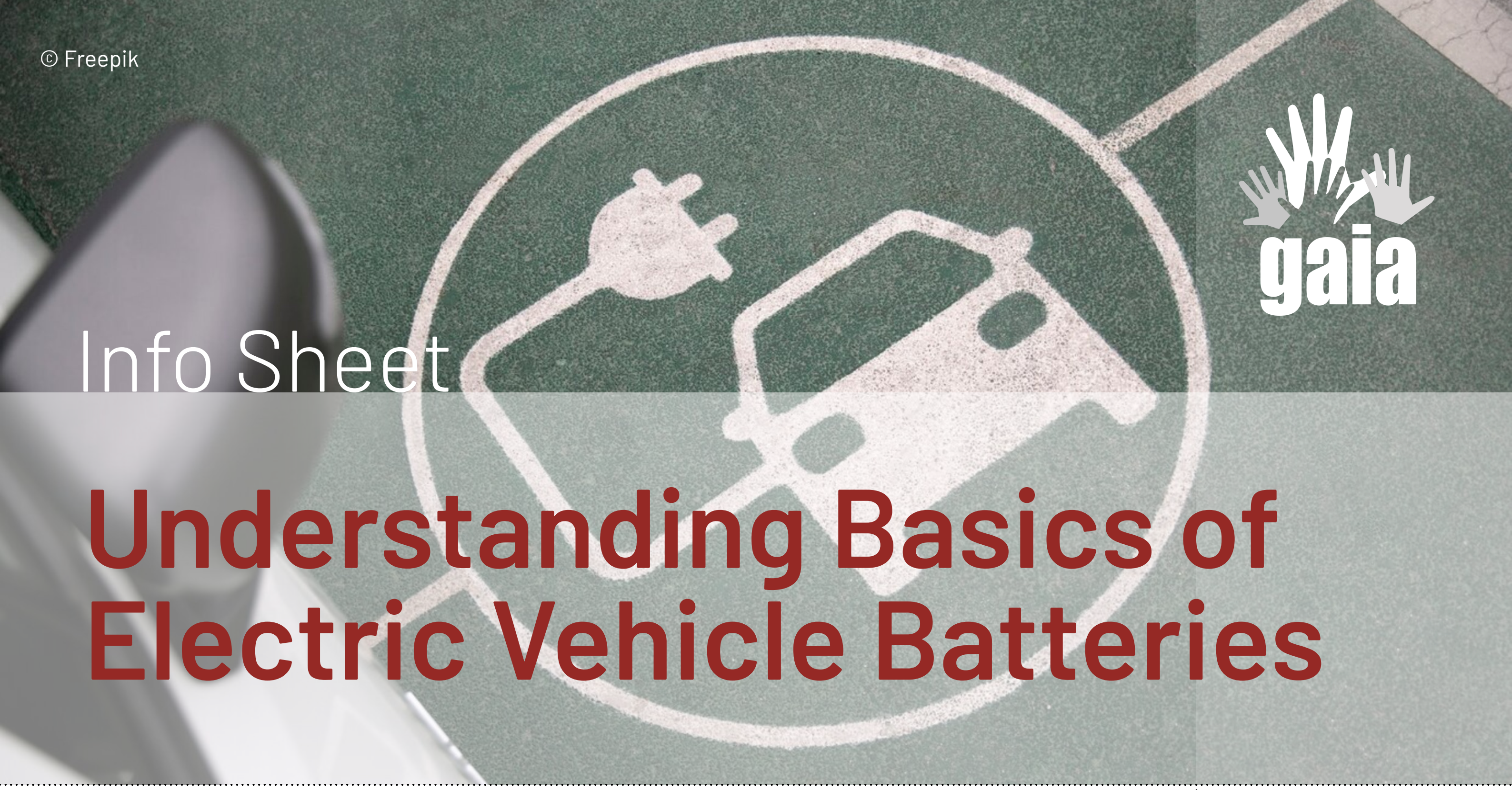

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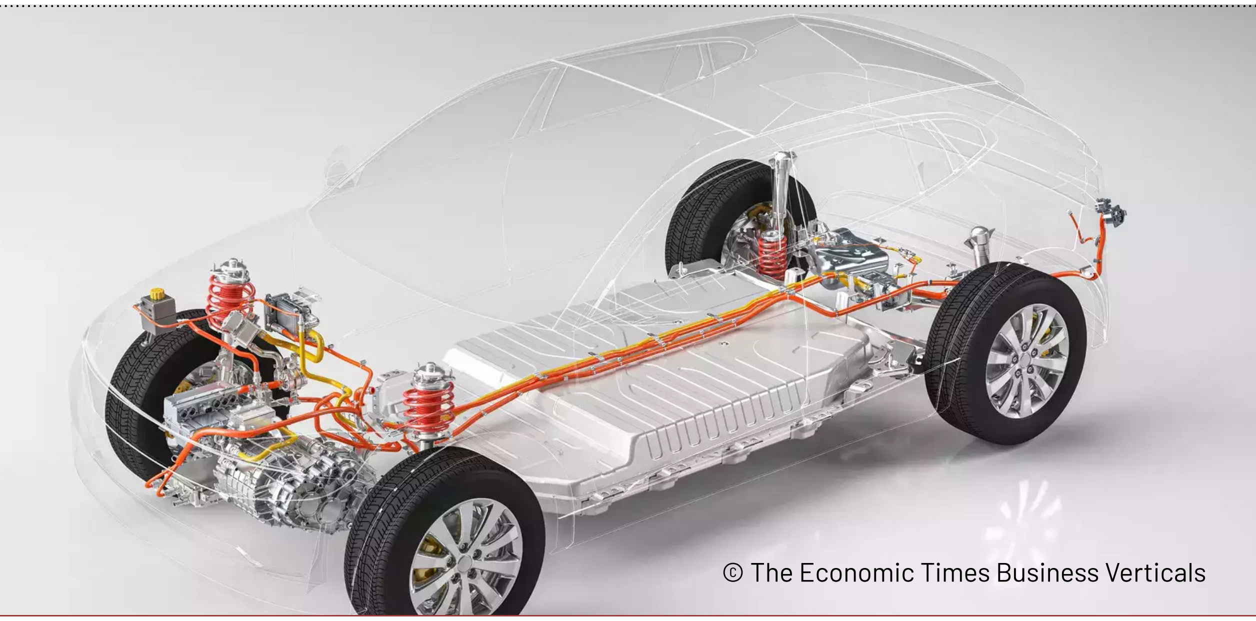
Info Sheet

Understanding Basics of Electric Vehicle Batteries

What are electric vehicle batteries?

The electric vehicle (EV) battery, also called a “traction battery”, is a rechargeable energy storage device that supplies power for electric mobility, from passenger vehicles to buses, two-wheelers, and even small-utility vehicles. Most EVs today rely on lithium-ion batteries (LIBs), preferred for their high power-to-weight ratio, impressive energy efficiency, and minimal self-discharge.[1]

1 U.S. Department of Energy. Alternative Fuels Data Center. https://afdc.energy.gov/vehicles/electric-batteries.



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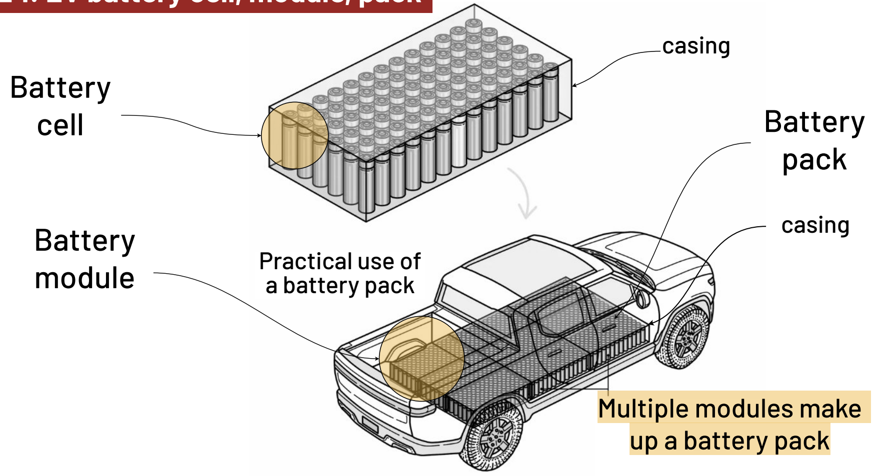
What are EV batteries made of?

While EV battery systems vary in weight and dimensions, a typical passenger EV battery weighs around 1,000lbs (~450kg) and is positioned under the vehicle's chassis for stability and optimal space utilization.

An EV battery is made of thousands of **lithium-ion cells.** The lithium-ion cells are the most fundamental element of the battery, responsible for producing the electric current needed to power the vehicle.

The most commonly used cells are a cylindrical shape resembling AA batteries used in consumer electronic devices, although very different in composition. Approximately 12 or more cells are grouped together, covered with polyethylene foam and enclosed in an aluminum-alloy or steel casing to form a **module**. Dozens of modules are encased plastic or metal to form a **battery pack**. The battery packs are then configured with a Battery Management System (BMS) and a temperature control device to complete the EV battery.

FIGURE 1: EV battery cell, module, pack



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By weight, the majority of a medium-sized EV battery pack is the battery pack and module casing, electrolyte, binder and separator; these components are made of copper, aluminum, steel, and polymers. Aluminum for the casing makes up about 20 to 30% of the total battery cell mass.[2] The remaining weight, about 185 kg, is the cathode active materials and the anode, made up of metals and minerals including graphite (115 lbs or 52kg), aluminum (77 lbs or 35 kg), nickel (64 lbs or 29 kg), copper (44 lbs or 20 kg), steel (44 lbs or 20 kg), manganese (22 lbs or 10 kg), cobalt (18 lbs or 8 kg), lithium (13 lbs or 6 kg), iron (11 lbs or 5 kg).[3]

2 Transport & Environment, 2021. From dirty oil to clean batteries. See also Bhutada, Govind. 2022. "The Key Minerals in an EV Battery." Elements, May 2, 2022. https://elements.visualcapitalist.com/the-key-minerals-in-an-ev-battery.

3 ibid.

The components of a lithium-ion battery cell

Each lithium-ion cell is made up of four major components: **cathode** (positive electrode with high-value minerals), **electrolyte** (made of lithium salt), **separator** (a polymer-based membrane), and **anode** (negative electrode, usually mostly graphite). An LIB generates electricity through chemical reactions of lithium, which is inserted into the cathode.

In addition, each electrode has an integral polymeric glue (1-8%) – known as a '**binder**', and this is typically used to coat the electrodes (cathode, anode) and the separator.[4] This glue is a fluorinated polymer such as polyvinylidene fluoride (PVDF) or polytetrafluoroethylene (PTFE), which are manufactured with Per- and Polyfluorinated Substances (PFAS), commonly referred to as "forever chemicals".[5]

The **separator** is a thin sheet of material that is often composed of a single- or multilayer plastic (polypropylene) or ceramic based material.[6] It functions as a physical barrier keeping the cathode and anode apart to prevent a short circuit.[7]

Electrolyte is a mixture of chemicals in a solvent, which serves as the medium that enables the movement of lithium ions between the cathode and anode. It commonly includes lithium hexafluorophosphate (LiPF6) and other additives required to improve SEI formation, give flame retardance, improve conductivity, and reduce gas build-up.

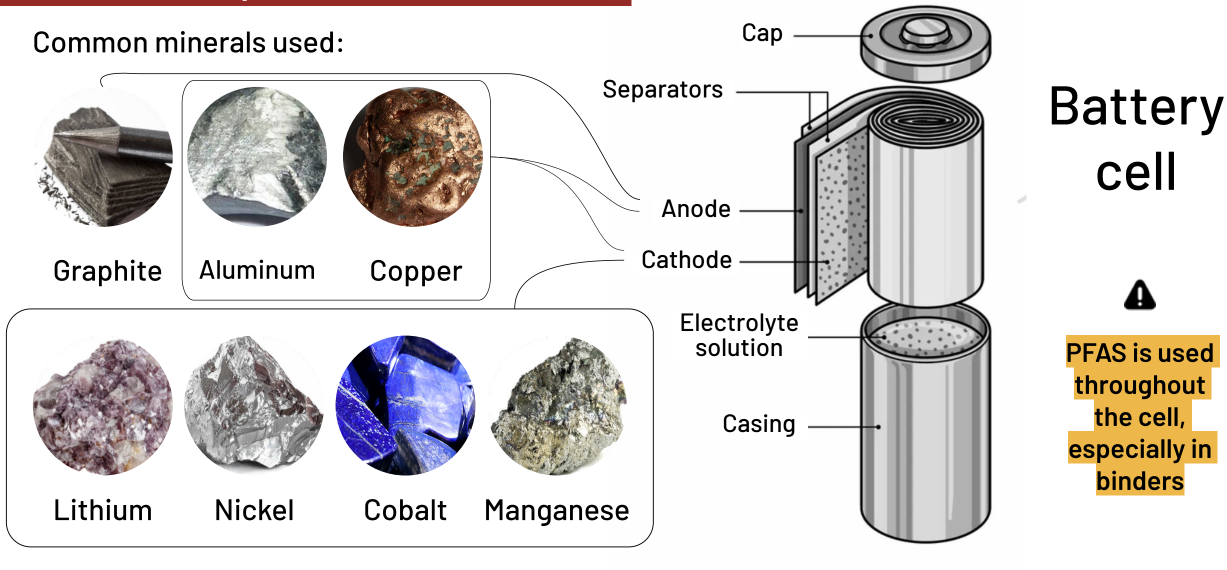
4 Performance Coating Teams. 2020. "The Role of Binders in Lithium Battery Electrode Coatings," Lubrizol, April 6, 2020. https://www.lubrizol.com/Coatings/Blog/2020/04/Binders-in-Lithium-Battery-Electrodes.

5 Lohmann, Rainer, Ian T. Cousins, Jamie C. DeWitt, Juliane Glüge, Gretta Goldenman, Dorte Herzke, Andrew B. Lindstrom, et al. 2020. "Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS?" Environmental Science & Technology 54 (20): 12820-28. https://doi.org/10.1021/acs.est.0c03244.

6 Warner, John T.. The Handbook of Lithium-Ion Battery Pack Design : Chemistry, Components, Types and Terminology. San Diego: Elsevier Science & Technology, 2015. Accessed May 6, 2024. ProQuest Ebook Central., 32.

7 Samsung SDI. n.d. "The Four Components of a Li-ion Battery." Accessed May 6, 2024. https://www.samsungsdi.com/column/technology/detail/55272.html.

FIGURE 2: Main components of a lithium-ion cell



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EV battery construction: cells, modules, and packs

Battery components are folded or wrapped around multiple times into different types of battery cells (see Figure 3), known colloquially as 'pouch' (soft encasement), 'cylinder' (aka. 'jelly roll' or 'Swiss roll') and 'prismatic' (rectangular folds).[8]

While cell-module-pack construction seems most prevalent, innovation continues. Vehicle manufacturers often use fewer modules to make the battery lighter and place the cells directly into packs (cell-to-pack) to avoid additional material use. Some manufacturers have taken this approach further to put cells directly into the vehicle body (cell-to-chassis) with an aim to increase integration and reduce overall weight. However, such cell-to-pack or cell-to-chassis design makes it harder to dismantle and take apart the battery from the vehicle, which might not be suitable for future regulations and targets for recovery of critical materials.[9]

The scale and configuration of these cells in battery packs vary according to different vehicles' unique requirements and capacities. The configuration in buses and two-wheelers will differ. As for the number of battery cells used in a vehicle, Tesla Model S and X use battery packs that contain about 7,104 battery cells,[10] and Rivian's RT1 contains 7,777 cells.[11]

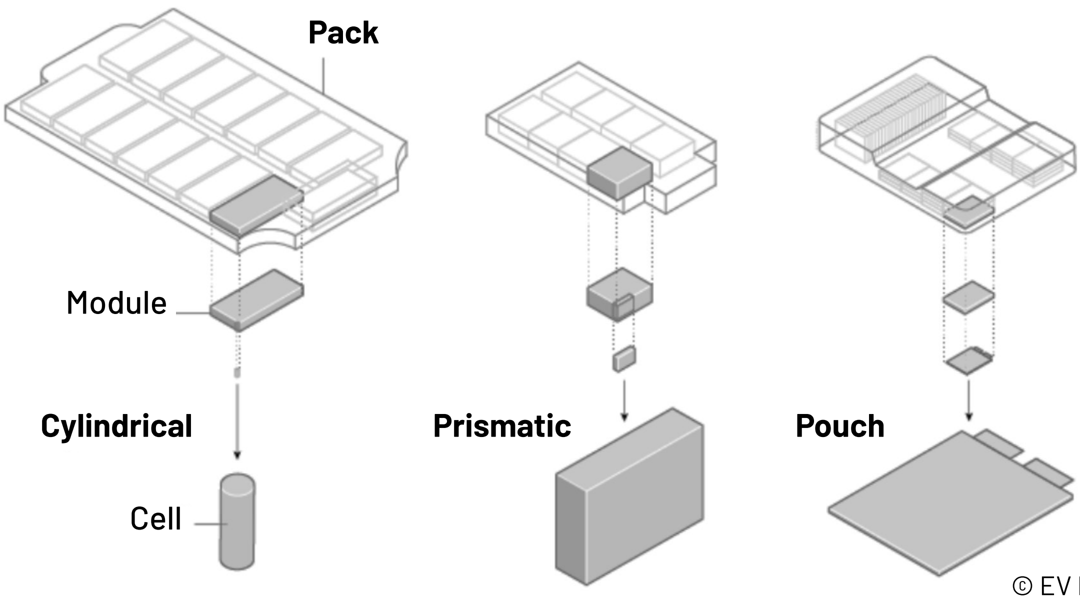
8 Figure 2 of: Harper, Gavin, Roberto Sommerville, Emma Kendrick, Laura Driscoll, Peter Slater, Rustam Stolkin, Allan Walton, et al. 2019. "Recycling Lithium-Ion Batteries from Electric Vehicles." Nature 575 (7781): 75–86. https://doi.org/10.1038/s41586-019-1682-5.

9 Edmondson, James. 2023. What the New EU Battery Regulation Means for Cell-To-Pack/Body. IDTechEx. https://www.idtechex.com/en/research-article/what-the-new-eu-battery-regulation-means-for-cell-to-pack-body/29638.

10 "Getting Better in Creating Problems, What about Creating Solutions?" n.d. IEEE Future Directions. Accessed May 6, 2024. https://cmte.ieee.org/futuredirections/2020/12/10/getting-better-in-creating-problems-what-about-creating-solutions.

11 Gilboy, James. 2021. "2022 Rivian R1T First Drive Review: The Electric Pickup Revolution Is Real, and It's Here." The Drive. September 28, 2021. https://www.thedrive.com/new-cars/42512/2022-rivian-r1t-first-drive-review-the-electric-pickup-revolution-is-real-and-its-here.

FIGURE 3: Types of EV battery cells



Understanding battery chemistries

There are many types of LIB chemistries, which are generally classified by the active materials used in the cathode.[12] While the anode is commonly composed of graphite, the cathode contains some combination of minerals including lithium. LIBs require the critical minerals lithium, cobalt and nickel. Battery chemistries requiring lithium, nickel and cobalt include **Nickel-Manganese-Cobalt (NMC) batteries** and **Nickel-Cobalt-Aluminium Oxide (NCA) batteries.**

An alternative battery chemistry that in 2022 reached 30 percent of EV battery market share is **Lithium-Iron-Phosphate (LFP) batteries**.[13] These still require the critical mineral lithium, but no cobalt or nickel, reducing their reliance on critical minerals. While LFP batteries have a shorter range than LIBs, they do not degrade as fast in the long-term. Another emerging viable alternative battery chemistry is **Sodium-Ion (Na-ion) batteries**, which require no critical minerals: no lithium, cobalt or nickel.[14] This battery chemistry is estimated to cost less to produce, but also comes with lower energy density than even the least energy-dense LIBs.[15]

Solid-state batteries (SSBs) have also been emerging with much hype as they have a higher capacity and energy density and are quick-charging. However, they require 35 percent more lithium compared to lithium-ion chemistries. Moreover, while SSBs perform better than LIBs, they have a fault whereby they branch out (known as dendritic structures) into the liquid electrolyte during charging which makes the battery unsafe.[16]

12 The capture of metals from what is termed the 'cathode active material' (CAM) provides the economic incentive for LIB recycling.

13 International Energy Agency. n.d. "Electric Vehicles." Accessed May 6, 2023. https://www.iea.org/energy-system/transport/electric-vehicles.

14 JAC Motors. 2023. "JAC Motors unveils world's first sodium-ion battery vehicle." Last Modified March 6, 2023. https://jacmotors.co.za/jac-motors-unveils-worlds-first-sodium-ion-battery-vehicle/.

15 (International Energy Agency, 2023).

16 Varzi, A., Raccichini, R., Passerini, S., Scrosati, B. 2016. Challenges and prospects of the role of solid electrolytes in the revitalisation of lithium metal batteries. Journal of Material Chemistry A, 4, 17251.

FIGURE 4: History of EV battery evolution

Fire risks of lithium-ion batteries

Lithium-ion cells carry a very high risk of fire due to thermal runaway. This occurs when heat builds up in the battery faster than it can be dissipated, causing the battery to off-gas or even explode. Worse still, a lithium-ion battery stored near or next to another battery or batteries can set off a chain reaction, making an already tough fire to fight even worse. When they reach thermal runaway, lithium-ion battery fires can burn for hours or even days, and it may take up to 40,000 gallons (152 metric tons) of water to extinguish.[17] Lithium-ion batteries cause dozens of fires in recycling centers every year.

17 Valentic, Stefanie. n.d. "Reducing Lithium-Ion Battery Fires in Waste Facilities." Accessed May 6, 2024. https://www.waste360.com/waste-recycling/reducing-lithium-ion-battery-fires-in-waste-facilities-part-one.

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What happens when an EV battery has reached its end-of-life in a vehicle?

EV batteries are typically retired when their capacity drops to 70 to 80 percent of their original state or experience hardware failure, after operating in a vehicle for approximately 10 to 20 years.[18]

While automakers consider battery health under 70 percent capacity not up to standards for powering a vehicle (and eligible for return under warranty), the remaining capacity can be repurposed and used for an additional 5 to 13 years in second-life applications such as microgrids, grid storage-backup, and car charging, portable power generators, e-bikes, etc.[19] These applications require relatively simple operating conditions and low battery performance requirements.[20] Such battery repurposing practices provide great environmental advantages superior to recycling, as current LIB recycling technologies have yet to be proven technically or economically viable at scale, largely due to the lack of considerations for end-of-life disassembly and material recovery in battery design.[21]

Once the vehicle fails or is deemed no longer serviceable, it should be determined – in line with a zero waste management hierarchy – whether a battery life can be extended through repair and continued to be used in a vehicle before it is removed for a second life application or discarded and recycled. Recognizing this, the manufacturers' emphasis must shift towards designing for a zero waste management system, alongside other design decisions such as cost, functionality, production, aesthetics, and liability.

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See GAIA's Battery Info Sheet Series at: www.no-burn.org/batteries.

18 Abdelbaky, Mohammad, Jef R. Peeters, and Wim Dewulf. 2021. "On the Influence of Second Use, Future Battery Technologies, and Battery Lifetime on the Maximum Recycled Content of Future Electric Vehicle Batteries in Europe." Waste Management 125 (April): 1–9. https://doi.org/10.1016/j.wasman.2021.02.032.

19 Casals, Lluc Canals, B. Amante García, and Camille Canal. 2019. "Second Life Batteries Lifespan: Rest of Useful Life and Environmental Analysis." Journal of Environmental Management 232 (February): 354–63. https://doi.org/10.1016/j.jenvman.2018.11.046.

20 Sun, Shiqiang, Chenxi Jin, Wenzhi He, Guangming Li, Haochen Zhu, and Juwen Huang. 2021. "Management Status of Waste Lithium-Ion Batteries in China and a Complete Closed-Circuit Recycling Process." Science of the Total Environment 776: 145913. doi:10.1016/j.scitotenv.2021.145913. https://www.sciencedirect.com/science/article/pii/S0048969721009803.

21 (U.S. Department of Energy).