Business & Technology Surveillance

The Increasing Role of Lithium-ion Batteries in Today's Industry and the Importance of Battery Recycling

By Michael Zachary Lasek, Intern, Business and Technology Strategies

SEPTEMBER 2018

NRECA
America's Electric Cooperatives

Business & Technology Surveillance

The Increasing Role of Lithium-ion Batteries in Today's Industry and the Importance of Battery Recycling

By Michael Zachary Lasek, Intern, Business and Technology Strategies

SEPTEMBER 2018

SUBJECT MATTER EXPERT ON THIS TOPIC

Jan Ahlen
Program and Product Line, Manager – Renewables and Distributed Generation
jan.ahlen@nreca.coop

This article is a product of the **Distributed Energy Resources Work Group**

SNAPSHOT:

WHAT HAS CHANGED IN THE INDUSTRY?

Battery energy storage systems (BESS) are starting to play a key role in the modern grid. BESS can provide peak demand reduction, resiliency, energy arbitrage, and stability for the intermittency of renewables. At the same time, demand for electric vehicles (EV) continues to rise, requiring improved battery performance that can enable EV's to travel further and charge faster. While battery technologies continue to emerge, lithium-ion is the worldwide market leader.

There are many different material make-ups of lithium-ion batteries, and new technologies are being researched every day. While some materials are plentiful, others such as cobalt are scarcer, requiring specific material sourcing to ensure lowest battery cost. As battery storage becomes more viable and production increases, the process of recycling lithium-ion batteries will increase in economic feasibility due to the large increase in demand for the required rare earth metals.

In the transportation industry, the price of oil continues to rise [1]. This creates a larger consumer interest, both economically and environmentally, for electric vehicles. Estimates suggest that by 2020, EVs are likely to account for more than 7 percent of the global transportation market, however, there is a concern that reduced supply of critical elements such as lithium and cobalt will slow adoption [1]. These issues highlight the increased interest in battery recycling.

NRECA
America's Electric Cooperatives

WHAT IS THE IMPACT ON COOPERATIVES?

BESS are becoming more attractive and feasible for electric cooperatives, especially as intermittent renewable resources continue to grow. Also, the popularity of EVs is increasing because of their environmental benefits and improved performance. Currently, many batteries will be dumped in a hazardous waste landfill. This will accelerate the scarcity of materials, maintain international hard labor, and create environmental concerns, such as ground water contamination, through improperly maintained landfills, or spontaneous fires caused by damaged batteries. Electric cooperatives can help pioneer the switch to battery recycling by being a presence in the process. Recycling batteries can also provide an economic benefit of costs saved in the production of a new battery.

WHAT DO COOPERATIVES NEED TO KNOW/DO ABOUT IT?

As co-ops start utilizing battery storage and consumer-members start adopting electric vehicles, it is important to establish a plan specific to lithium-ion battery recycling. Batteries at this scale have not existed long enough to reach an end of life, so there are currently minimal regulations and requirements in place that guide consumers to properly dispose of spent lithium-ion batteries. The lack of recycling systems and infrastructure is partly from minimal nationwide education. That education starts with how batteries are made and from where the materials are sourced. With that knowledge, it is easier to see the overall benefits of recycling compared to disposal. Co-ops will be able to create an end of life plan for batteries used in grid storage. This could either mean partnering with companies who are familiar with the li-ion battery recycling process or establishing infrastructure for li-ion collection for the prevention of their entrance into the solid waste stream of their communities.

Our current infrastructure is not prepared for today's influx of lithium-ion batteries.

Damaging fires can occur when disposed batteries become punctured or crushed.

Recycling

THE SCIENCE

There are two main phases in lithium-ion battery recycling: physical separation and leaching (chemical separation). The first phase is physical separation, which is when different components of the battery are disassembled. The plastics and metals from the housing and internal structure, as well as the copper and aluminum coatings, are separated and recycled [8]. Also, because the anode is made entirely of graphite, there is no other process it must go through to be recycled. The only issue is that the recycled graphite cannot be reused in batteries again unless it is purified, so it is mostly used for other graphite purposes like steelmaking. Unlike the anode, the cathode must be chemically separated due to its variety of rare earth metals. Since the cathode is an alloy of multiple metals, chemical processes must be used to isolate each element. Pyrometallurgical and hydrometallurgical processes are used to recover materials from the batteries. Table 1 shows each of the processes used when recycling batteries and what material comes out of each step.

POLICY

In the United States, there are currently no major standards for disposing or recycling lithium-ion batteries beyond categorizing them as a hazardous waste. The issue is that when batteries are improperly disposed of, any form of puncturing or crushing of the battery in garbage or recycling trucks can cause the battery to catch fire and cause significant damage.

TABLE 1: Steps of the Battery Recycling Process and the Resulting Materials

	Pyrometallurgical	Hydrometallurgical	Directly
Temperature	High	Low	Low
Materials Recovered	Co, Ni, Cu **(Li and Al to slag)**	Metals or salts, Li_2CO_3 or LiOH	**Cathode**, anode, electrolyte, metals
Feed requirements	None	Separation desirable	Single chemistry required
Comments	New chemistries yield reduced product value	New chemistries yield reduced product value	Recovers high-value materials

Source: EPA Sustainable Materials Management

Such fires are being reported in the news with greater frequency, due to the increasing number of li-ion batteries in the world today. Our current infrastructure is not prepared for this influx of lithium-ion batteries. Several companies have taken it upon themselves to assist in this process, as has the recently formed LI Battery Recycling Response Group, which is currently working on a communications draft on lithium-ion recycling [13].

ECONOMIC BENEFIT

Economics has always been a boulder blocking the path to lithium-ion recycling, because it has always been cheaper to buy new minerals from other countries than it is to establish a lithium-ion recycling plant. Plus, the efficiency of older recovery processes produced minimal material extraction. Due to rising costs of raw minerals and cheaper, more efficient methods for the separation of battery components, recycling is becoming the more economically viable option.

One of the major costs avoided when recycling is the cost of properly disposing of the battery. Typical disposal costs fall in the $4,000–$5,000 range [10]. That cost includes shipping to site and processing within a hazardous waste landfill. Since it is classified as a hazardous waste, the cost of safe disposal and efforts associated with regulatory compliance would be avoided by recycling. Another cost to consider is the reduced need of transportation. For new batteries, materials are sourced from around the world, needing barges and on land transport to deliver. With recycling, only land transport is needed, which reduces total transportation distance.

Lastly is the value of the material obtained through the recycling process. Research conducted by Argonne National Lab shows that around 40 to 50 percent of the cost of a new battery can be saved by recycling the cathode of an old battery. A breakdown of the basic costs associated with a lithium-ion battery is provided in **Figure 1**.

The materials needed to produce the battery are over half of the cost of a battery (Figure 1).

The cathode of the battery is where most of the costs come from because it is made of a variety of rare earth metals (Figure 2).

ENVIRONMENTAL BENEFIT

Recycling lithium-ion batteries provides several environmental benefits. First, it reduces the quantity of minerals needed to be mined, as well as the number of ores needed to be processed, which in turn reduces NO_x and SO_x produced through these processes. That also prevents dependence on foreign labor for procurement of materials. Generally, recycling saves natural resources and energy for other purposes, so designing a simple method of lithium-ion recycling can increase the likelihood that people will take part. This leads to the reduction of fires at waste processing plants, preventing potential release of other contaminants into the atmosphere due to burning. Lastly, any emissions produced by transportation or use of electricity in any process are reduced, whether that be the actual mining process or transportation of materials across continents.

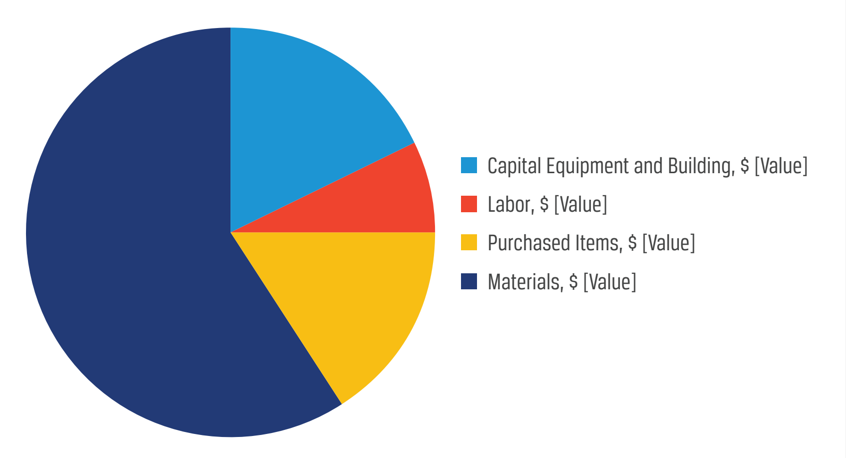

FIGURE 1: Basic Costs Associated with a Lithium-ion Battery (Source: Argonne National Lab: Recycling of Automotive Li-ion Batteries)

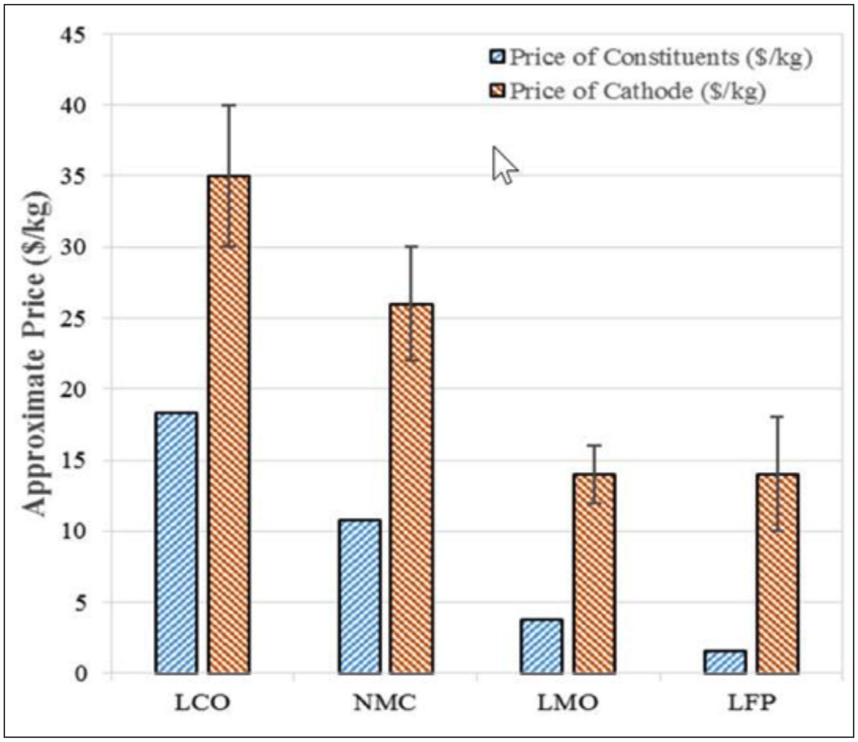

FIGURE 2: The Cost of the Cathode vs. the Remaining Components of a Lithium-Ion Battery in Different Material Make-Ups (Source: Argonne National Lab: Recycling of Automotive Li-ion Batteries)

WHERE IS IT DONE TODAY?

Tesla has designed a closed loop battery recycling process in partnership with Umicore, which currently recycles batteries in Europe [9]. There is also a plan to start a similar process in the United States.

Retrieve Technologies, formally known as TOXCO Inc., received funding from the U.S. Department of Energy (DOE) to establish recycling facilities for advanced lithium-ion batteries [9]. Not only do they provide recycling, but they also offer consulting services to help bring clarity to regulations, ordinances, and statutes.

American Manganese is a company that deals with rare earth metals in British Columbia and Arizona. They have created a process without heat and furnaces, claiming they can recycle 100 percent of the cobalt and 87 percent of lithium from batteries. Their mission statement is "to recycle valuable cathode materials for the global lithium electric vehicle battery industry." [9]

There are also companies located outside of the United States that are involved with recycling. Li-cycle is a private, start-up company located in Canada that is looking to tackle the future issue of recycling lithium-ion batteries. Neometals is located in Australia and is a mineral company focusing on de-risking and developing lifelong projects that will provide sustainable mineral and material solutions to customers. In addition, Umicore, located in Belgium, is a global materials technology and recycling group. Umicore's overriding goal of sustainable value creation is based on an ambition to develop, produce, and recycle materials in a way that fulfils its mission: materials for a better life. [9]

The following sections provide a conceptual perspective of the li-ion battery lifecycle, looking at different material make-ups, the sourcing and costs of materials, the manufacturing process, and a simple view of degradation.

How a Lithium-Ion Battery Works

There are four major components in a lithium-ion battery: the anode, the cathode, the electrolyte, and the separator (see Figure 3).

- The anode is the negatively charged electrode of the battery.
- The cathode is the positively charged electrode of the battery.
- The electrolyte is a fluid that separates the two and helps in the flow of lithium from one side to the other.
- The separator is made of a material that allows for lithium to pass through but prevents electrons.
- The cathode and anode are connected in a circuit which allows electrons to flow.

During the charging process, lithium-ions pass from the anode to the cathode through the electrolyte and the separator, and electrons move from the anode to the cathode in the circuit. When a load is placed on the battery and discharging occurs, electrons and lithium-ions move the opposite direction, and the electrons power the device.

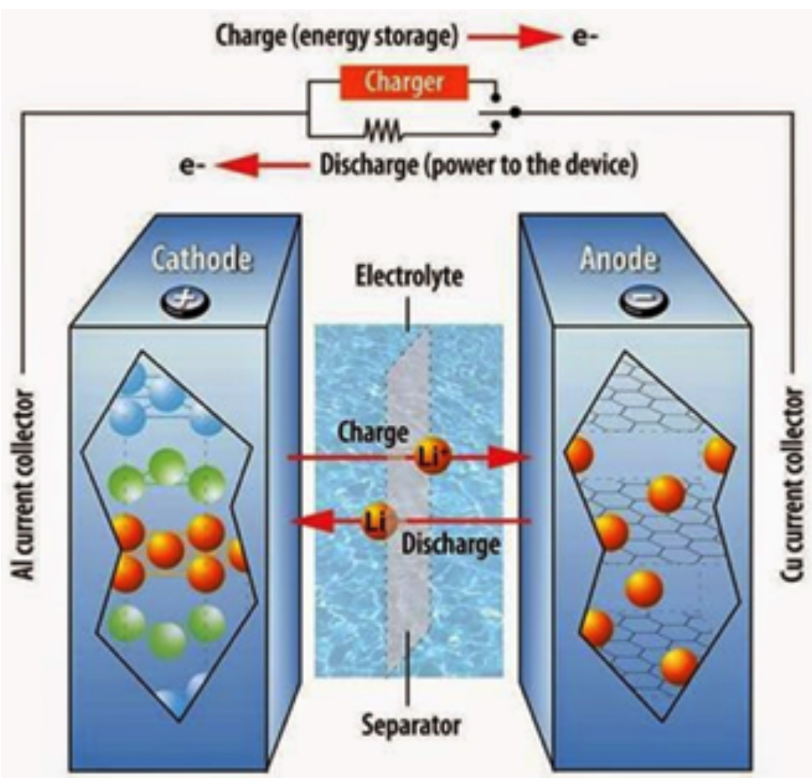

FIGURE 3: How a Lithium-ion Battery Works (Source: EEE Community)

Component Material Make-up

After visualizing how a battery works, it is important to understand the material composition of the battery, since it plays a role in the battery's service life, energy density, and power density.

CATHODE

The cathode of the battery can be made up of many different elemental compositions each with its own advantages and disadvantages (see **Table 2**).

For utility and residential storage, one of the most commonly used make-ups, especially by Tesla, is the NMC due to its all-around good performance and moderate cost. For electric vehicles (EVs), aluminum is also included.

ANODE

Most current lithium-ion batteries use graphite as the anode, due to its stability when accepting lithium-ions. They can be made from either natural or synthetic graphite, but must be in the purest possible form. Research and development teams across the country are working towards using different materials for the anodes, ones with a higher specific capacity allowing for the anode to hold larger amounts of lithium-ions and increasing the capacity of the battery. [4] The major element researched right now is silicon. However, it becomes unstable when it absorbs too many lithium-ions, leading to the destruction of the battery.

TABLE 2: Advantages and Disadvantages of Lithium-ion Cathode Material Make-ups
(Source: Argonne National Lab: Material and Energy Flows)

Different Lithium-ion Cathode Material Make-ups					
Material	**Abbreviations**	**Specific Energy** (Wh/kg vs.Li-metal)	**Capacity** (mA/g)	**Advantage**	**Disadvantage**
Lithium Magnanese Oxide	LMO	405	100	Low Cost High Power Density	Lower Energy Density Accelerated Capacity Fade
Lithium Cobalt Oxide	LCO	610	150	High Energy Density	High Cost Moderate Stability
Lithium Iron Phosphate	LFP	515	150	High Power Density Very Stable	Lower Energy Density
Lithium Nickle Magnanese Cobalt Oxide	NMC	675	150	Performs well for all metrics	Moderate Cost Moderate Stability
Lithium and Magnanese Rich Metal Oxide	LMR-NMC	940	250	High Energy Density Low Cost	Not Commercial Degrades Quickly

The electrolyte can come in three forms: liquid, solid state, or polymer.

Modern batteries have shutdown processes to prevent 'thermal runaway' that could otherwise lead to a fire.

ELECTROLYTE

The electrolyte can come in three forms: liquid, solid state, or polymer, each with advantages and disadvantages. Most of the liquids used are organic solvents and easily accessible; however, the main tradeoff is between flammability and electrochemical performance. The best performing liquid electrolytes have low boiling points and have flash points around 30°C. Electrolyte decomposition and highly exothermic side reactions in lithium-ion batteries can create an effect known as "thermal runaway," which is a positive feedback set in motion by the rising temperature which eventually leads to a fire. [3]

Polymer electrolytes are ionically conductive polymers. They are often mixed in composites with ceramic nanoparticles, resulting in higher conductivities and resistance to higher voltages. Due to its high viscosity and quasi-solid behavior, polymer electrolytes could prevent lithium dendrites from growing and could help in preventing thermal runaway. [3]

Solid electrolytes are lithium-ion conductive crystals and ceramic glasses. They generally have poor low-temperature performance because of how difficult lithium-ion passage is, and are more expensive than the other two types due to the treatment required to provide acceptable behavior. They do, however, eliminate the need for separators and reduce the risk of thermal runaway. [3]

SEPARATORS

The purpose of the separator is to isolate the electrodes from each other to prevent short circuiting. It is generally made with a foam material that is soaked in the electrolyte material that surrounds it. It must match three requirements to be an acceptable separator. It must be an electronic insulator while having minimal electrolyte resistance, have maximum mechanical stability, and have chemical resistance to degradation in the highly electrochemically active environment. [3] More modern batteries also have shutdown processes that separators follow when temperatures get too high to prevent thermal runaway.

MISCELLANEOUS

While the four parts listed above are the main components of batteries, there are other pieces that still play a significant role in the battery structure. The most important is the battery housing, the internal structure of the battery that holds each of the pieces in place. This is mostly made of plastic and steel, so it is easily recycled and the sourcing of materials for its production is simple and inexpensive. Similarly, the wiring used in batteries is very common. Therefore, it does not play as large of a role in this document because of its simplicity in obtaining and recycling.

Material Sourcing and Cost (USGS Mineral Resource Program)

The chemistry of cathodes is different based on the purpose of the battery. For example, a Tesla Model S battery cathode consists of cobalt, nickel, and aluminum (Figure 4). This document will focus on those materials used in the Tesla Powerwall, because that same cathode make-up is used for utility storage as well. The sourcing and cost will focus on the following elements: lithium, nickel, cobalt, manganese, and graphite.

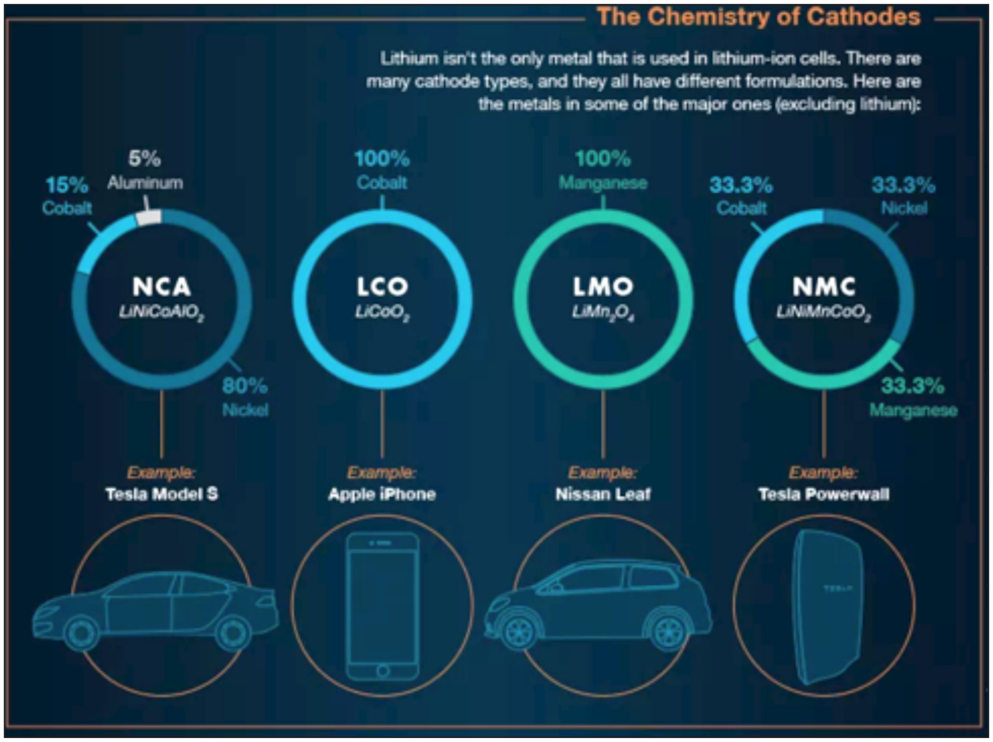

FIGURE 4: The Different Chemistries of Cathodes Used in Everyday Technologies (Source: https://electrek.co/2016/11/01/breakdown-raw-materials-tesla-batteries-possible-bottleneck)

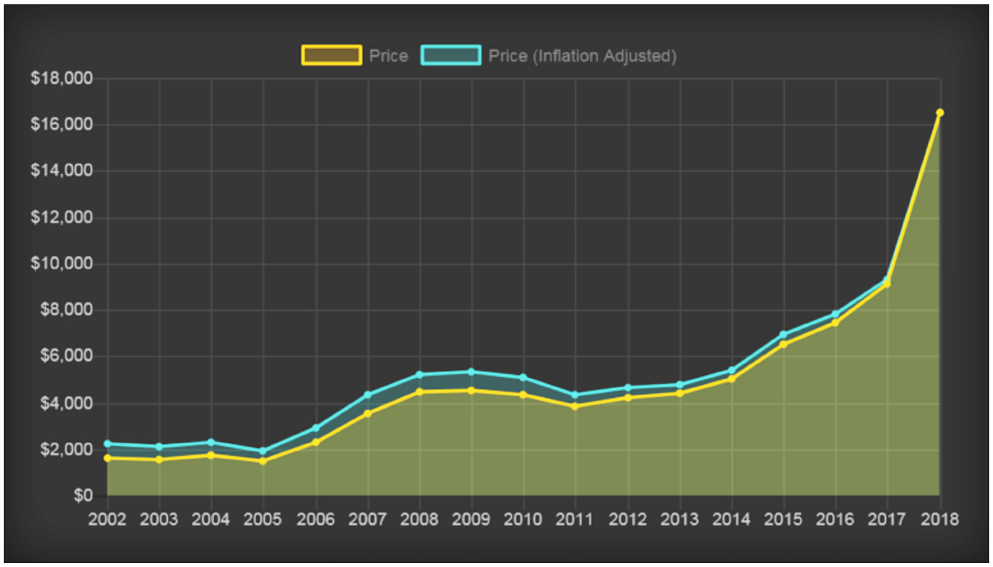

Figure 5: The Price of Lithium per Metric Ton Over the Last 17 Years (Source: Metalary.com)

LITHIUM

Lithium is plentiful on earth, but some methods of extraction are easier and cheaper than others. Currently, lithium is most widely captured through evaporation of brine pools in deposits located in Chile and Australia. It can also be mined, which is becoming more economically viable. Plus, there is current interest in technologies allowing for its extraction from ocean water.

As the demand for electric vehicles and battery storage continues to rise, the demand for lithium will increase as well. The upward price trend of lithium is shown in Figure 5.

The price of lithium has almost doubled since 2017, currently sitting at $16,500/metric ton. We may see new emerging sources and methods of harvesting lithium for batteries once the cost reaches a certain point.

Overall, when it comes to the amount of lithium needed to accelerate battery storage, the lithium exists. It is simply a matter of economic accessibility, which is where recycling will play a large role. There are currently 16 million metric tons of lithium in the world. That number is constantly increasing thanks to the discovery of new sources and methods. From an electric vehicle perspective, that current reserve is enough lithium to produce batteries for 10 billion Nisan Leafs or 3 billion Teslas, which is above the current use of approximately one billion total vehicles on the road. Also, the International Energy Agency states an expected rise from 3 million electric vehicles on the road today, to 125 million by 2030 globally. [11] The lithium reserve would meet requirement needed for all the vehicles currently on the road, as well as this expected increase in electric vehicles.

COBALT

Sixty three percent of all cobalt is produced in the Democratic Republic of the Congo. There are three main ores of cobalt: erythrite, glaucodot, and skutterudite. However, most cobalt is obtained by reducing the cobalt by-products of nickel and copper mining and smelting.

Lithium-ion batteries remain expensive because cobalt is not plentiful.

One of cobalt's primary uses is cathode material in lithium-ion batteries. The main issue is that cobalt is not as plentiful as other materials, which is the reason why lithium-ion batteries are still so expensive (see Figure 6). Beyond batteries, cobalt is mostly used for its color in the dyeing process.

There are currently 7.1 million metric tons of cobalt reserves left in the world, but as this number continues to decrease and the demand for cobalt continues to rise, the price of cobalt will keep increasing.

In the news recently, there has been a moral argument on cobalt importing, because most of the cobalt mined in the Democratic Republic of Congo is done through cheap child labor. [12] Also, because over half of the cobalt in the world comes from one country, it creates volatility in the battery market. While many battery producers are looking for substitutes for cobalt, recycling can play a part in reducing dependence.

NICKEL

There are two main kinds of nickel ore. The first is sulfide ore, which is the most common and pristine. It is mostly prepared by mechanical means, such as flotation or pyro metallurgical processes of simply smelting or roasting. The second type is laterite ore, which is a mixture of nickel copper and iron. It is a little more difficult to separate due to non-homogenous elemental contents. Most methods of preparation involve leaching the ore with ammonia or sulfuric acid. The ore is purified and produces nickel sulfides that can be converted into a sulfate solution.

About 59 percent of nickel is imported from countries such as Canada and Norway, and the rest is produced in the United States. Nickel is a relatively plentiful resource on earth, so the cost per metric ton is not as high as other precious metals (see Figure 7).

Nickel is primarily used in other processes, 48 percent in stainless and alloy steel products, 40 percent in nonferrous alloys and super alloys, 8 percent into electroplating, and 4 percent into other uses such as batteries. Since these processes have a steadier supply and demand, fluctuations in price are more obvious than other metals used. The current world nickel reserves are around 74 million metric tons, which must be split among these processes. Battery developers are

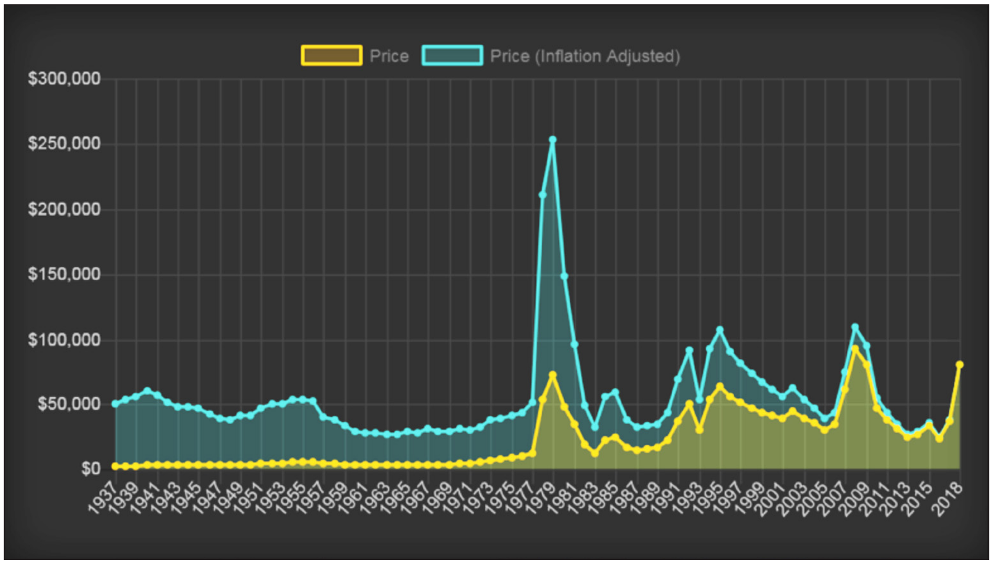

FIGURE 6: The Price of Cobalt per Metric Ton Over the Last 83 Years
(Source: Metalary.com)

< PREVIOUS VIEW >

Graphite must be in its purest form for optimal battery performance.

looking into reducing the amount of cobalt in the battery in exchange for a higher percentage of nickel, due to the major difference in cost and less volatility in sourcing.

MANGANESE

Manganese ore has not been produced in the United States since 1970, so all manganese currently used in the U.S. is imported. Because of this, the United States Geological Survey has categorized manganese as a "critical mineral." Of the total amount of manganese used in the United States, a small fraction is dedicated to batteries. It is mostly used in iron and steelmaking for a variety of purposes, such as construction, transportation, and machinery. However, as battery storage becomes more common, there is an expected increase in manganese consumption in the United States. The pricing for manganese over recent years is shown in Figure 8.

GRAPHITE

Graphite is a common form of carbon, both naturally and in its synthetic form. The only issue is that for batteries, the graphite must be in its purest form for optimal battery performance. Its high surface area and layered crystalline structure in its purified form allow for easy acceptance of lithium ions. Graphite can be purified through hydrometallurgical processes, such as the flotation method utilizing the floatability of graphite or pyrometallurgy, such as heating the graphite to high temperatures, taking advantage of the low boiling points of impurities. [5] Both natural and synthetic graphite can be used in the anodes of batteries.

Natural graphite is known to be the cheaper option of the two, and it produces less waste. As of January 2018, no natural graphite was produced domestically. However, the inferred graphite resource from the rest of the world is around 800 million tons. Natural graphite is primarily used in brake linings, lubricants, and steelmaking, with batteries starting to create an impact on usage in the U.S. In 2017, the main U.S. import sources of natural graphite were China, Mexico, Canada, Brazil, and Madagascar, which combined accounted for 99 percent of the tonnage and 94 percent of the value of total imports.

Synthetic graphite is manufactured by high temperature processing of amorphous carbon

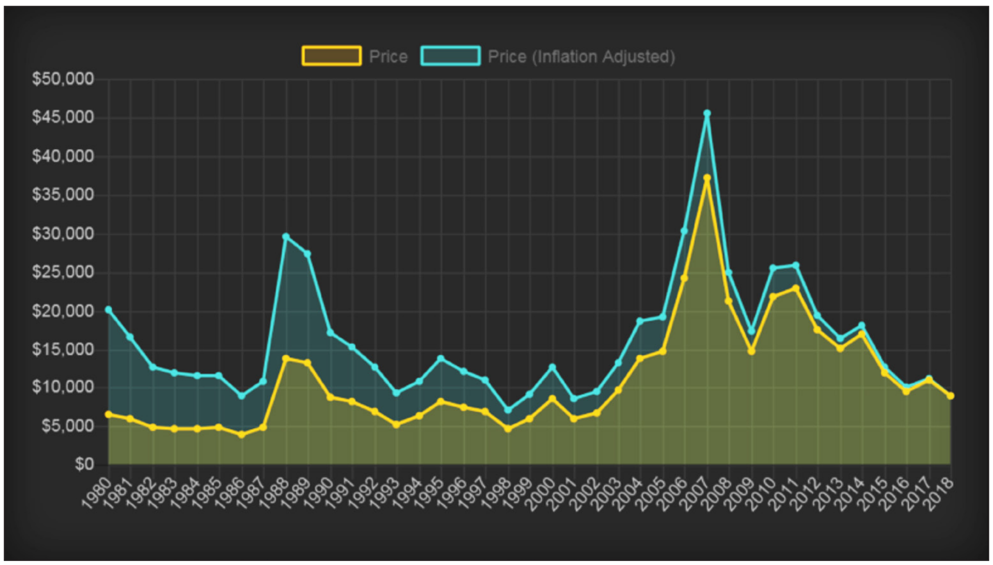

FIGURE 7: The Price of Nickel per Metric Ton Over the Last 40 Years
(Source: Metalary.com)

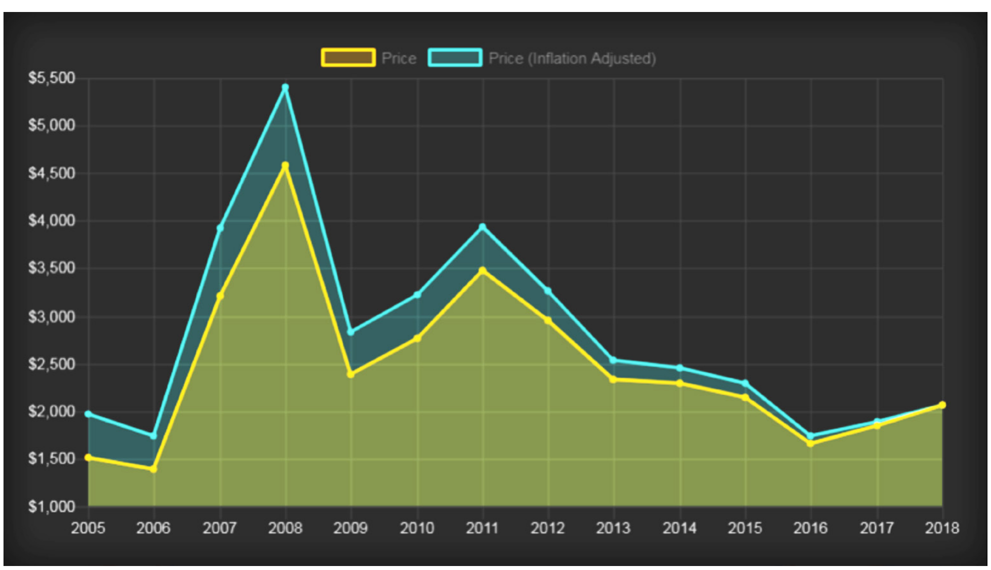

FIGURE 8: The price of Manganese per Metric Ton Over the Last 13 Years
(Source: Metalary.com)

materials, such as petroleum coke. For graphite to be formed naturally, the amorphous carbon material must be exposed to 750°C temperature and 75,000 psi for 10 years. However, the time and pressure requirements make it difficult, so at ambient pressure, the carbon must be heated up to anywhere between 2,300-3,000°C. [6] There are a variety of ways to make synthetic graphite, but most methods are far too complex to go into detail in this article.

Battery Manufacturing

The manufacturing process of lithium-ion batteries is similar to that of most general batteries.

Figure 9 gives an overview of how lithium-ion battery cells are created. The steps in brown/dark blue are those in preparation of the cathode and anode, and the teal colored steps are those in the assembly process.

- **Parts Mixing**: Cathode and anode materials are initially delivered in powdered form. They must be mixed along with a binding agent in order to form a mixture that is eventually baked into a solid.
- **Coating**: The anode and cathode are then coated (the anode with copper and the cathode with aluminum), for conductivity and charge management purposes.
- **Drying/Compressing**: The purpose of drying and compressing is to minimize porosity to prevent cracking and battery performance loss.
- **Calendaring**: The smoothing of the material for homogeneous thickness, which helps ensure high battery performance.
- **Slitting**: The electrodes must be slit precisely to create similar width amongst all the electrodes in the batch.

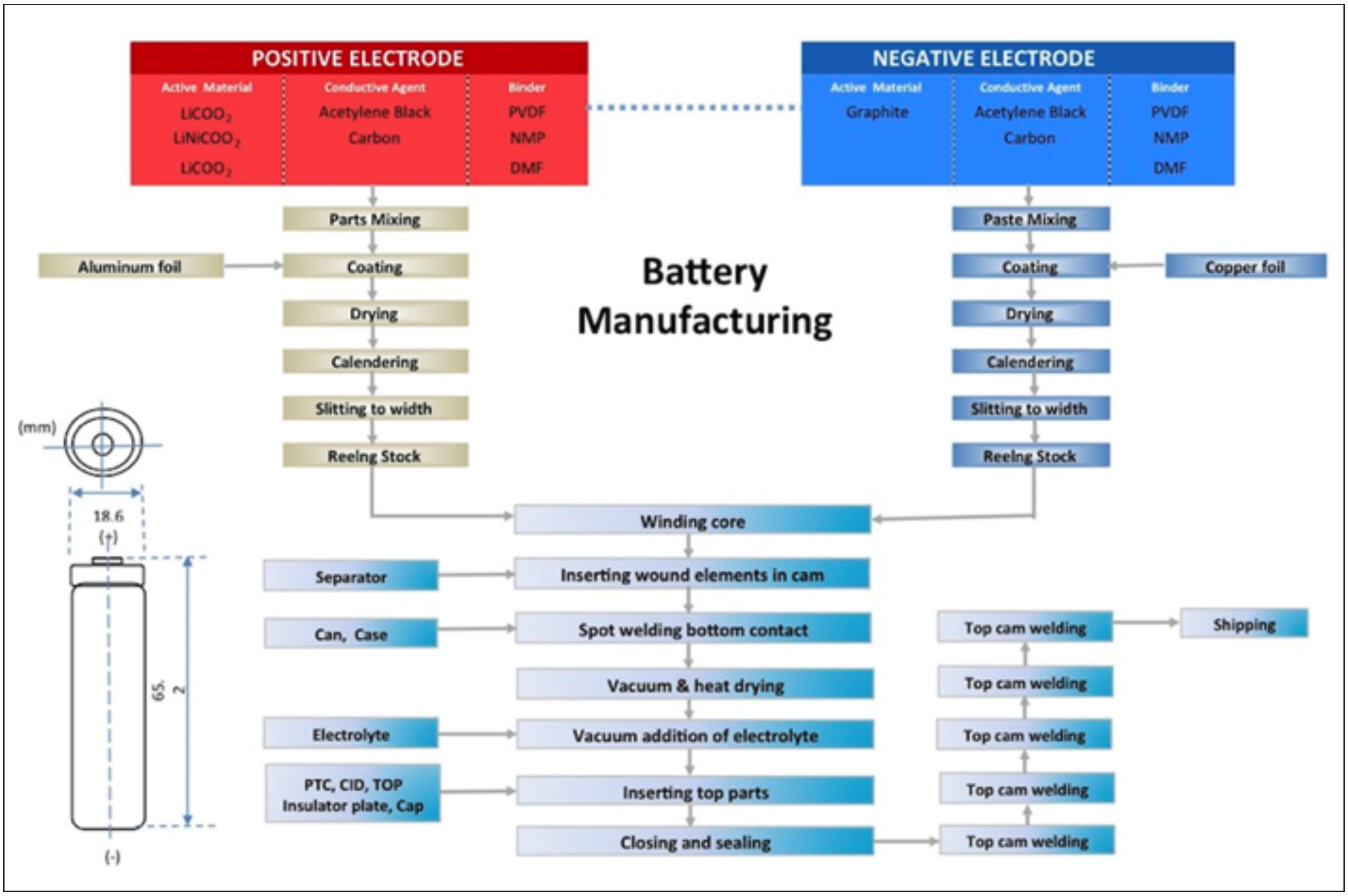

FIGURE 9: The Manufacturing Process of a Li-ion Battery (Source: Chris Hillseth Enterprises: About li-ion Manufacturing)

The rest of the steps include assembly of the components and preparation for shipment of the battery. The critical step in the latter phase of manufacturing a battery is vacuum filling the electrolyte to prevent atmospheric interaction, contamination, and potential premature thermal runaway. Also, the formation and aging of the materials is critical before shipping, which consists of charging and discharging the battery at set voltages for an established amount of time to certify proper battery performance.

Degradation

There are three general forms of degradation:

- Cathodic and anodic surface film formation occurs every time the battery discharges. The irregularities on the anode and cathode get smoothed over, similar to how rust covers steel. Not only are the irregularities necessary for ideal battery performance, but the crust formed also acts as an insulator. [2]
- Second is dendrite formation, which can form anywhere within the battery. This causes a disruption in performance. Figure 10 provides illustration of how this formation can occur shown as extensions coming off the anodes in the yellow, orange, and teal color.
- Lastly is physical damage caused by other processes, which consists of cracking, corrosion, and decomposition. These can occur anywhere, similar to dendrite formation, and creates a loss of contact between components.

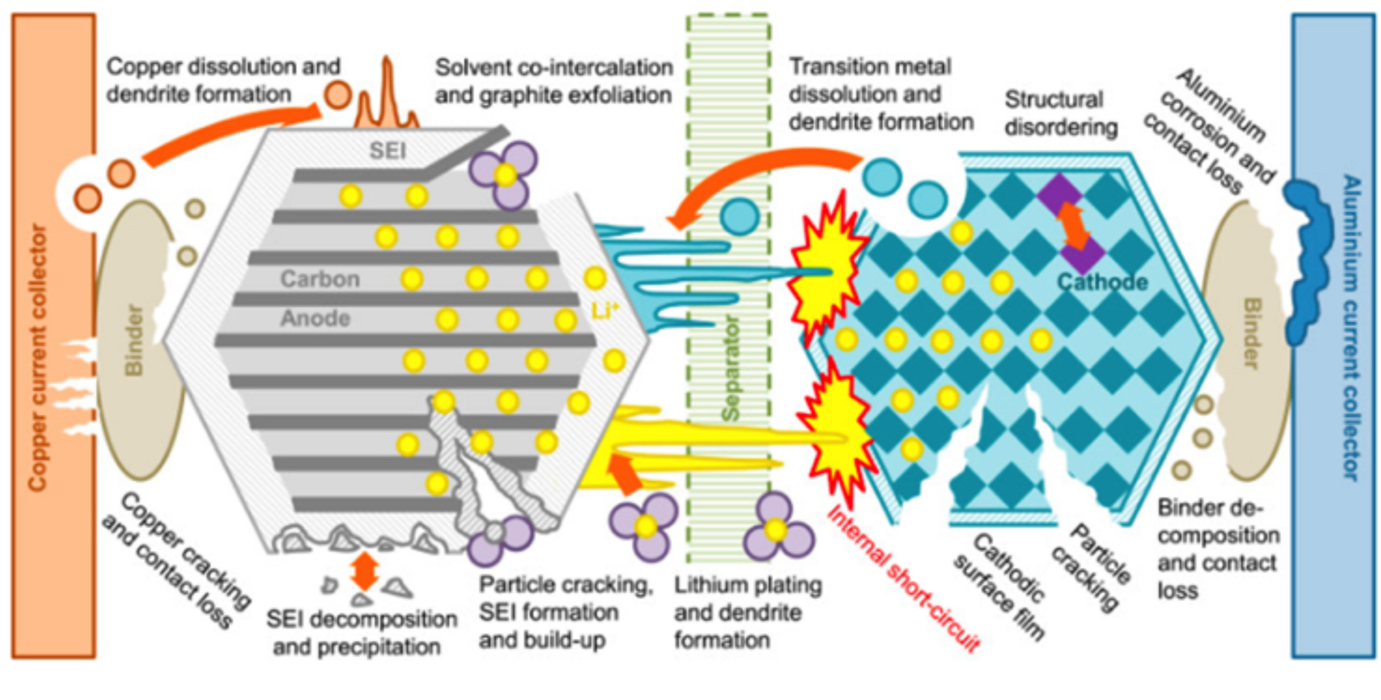

Figure 10: The Different Forms of Degradation on a Li-ion Battery
(Source: "Degradation Diagnostics for Lithium-ion Cells")

Looking Towards the Future

Currently, lithium-ion batteries are the most popular technology for grid storage and electric vehicles. Researchers around the world are looking into other make-ups, even different kinds of batteries. The major problems with lithium-ion are that it is not easily scalable and it uses rare earth metals, so the cost is going to continue to increase until there is a change in accessibility. While there are plenty of materials to support the growth of li-ion, accessibility of those minerals is limited, due to costs of starting up a lithium or cobalt operation.

Redox-flow batteries are starting to emerge as a promising technology. These use liquid electrolytes to hold the lithium in the battery, making it theoretically infinitely scalable. Using pressurized air to store and produce energy is also starting to emerge. Even though new technologies are developing, lithium-ion batteries are here to stay, which is why it is critical to prepare for their end of life, as well as recycling those already spent for the safety and protection of cooperative resources, communities, and the environment. ■

RESOURCES

1. https://waste-management-world.com/a/1-the-lithium-battery-recycling-challenge
2. https://www.greencarreports.com/news/1092854_why-lithium-ion-batteries-degrade-with-repeated-charging
3. http://www.tms.org/pubs/journals/jom/0809/daniel-0809.html
4. http://learn.stanford.edu/Future-of-Batteries.html?utm_source=industrydive&utm_medium=email&utm_campaign=eiet-wbn-0518
5. https://www.linkedin.com/pulse/main-methods-graphite-purification-mary-zhang
6. https://asbury.com/technical-presentations-papers/materials-in-depth/synthetic-graphite
7. https://www.epa.gov/smm/sustainable-materials-management-smm-web-academy-webinar-introduction-lithium-batteries-and
8. https://www.researchgate.net/publication/312625450_Lithium_battery_recycling_management_and_policy
9. https://seekingalpha.com/article/4139266-look-lithium-ion-battery-recycling-industry-companies?page=2
10. https://anl.app.box.com/s/7lgwlmm5isrsyfae13dwxlz1bn9gjxhi
11. http://www.iea.org/gevo2018
12. https://www.cbsnews.com/news/cobalt-children-mining-democratic-republic-congo-cbs-news-investigation
13. https://www.epa.gov/sites/production/files/2018-03/documents/timpane_epa_li_slides312_ll_1.pdf

ABOUT THE AUTHOR

Michael Zachary (Zach) Lasek
Zach Lasek was the Distributed Energy Resources Intern this past summer for the Business and Technology Strategies Department at NRECA. He is a senior at James Madison University, majoring in Integrated Science and Technology with a Concentration in Energy. He enjoys sharing his passion for renewable energy and battery storage.

QUESTIONS OR COMMENTS

- Jan Ahlen, Program and Product Line, Manager, Renewables and Distributed Generation: **jan.ahlen@nreca.coop**
- To find more resources on business and technology issues for cooperatives, visit our **website** and sign-up for our twice-monthly newsletter, **Business and Technology Update**.

DISTRIBUTED ENERGY RESOURCES WORK GROUP

The Distributed Energy Resources (DER) Work Group, part of NRECA's Business and Technology Strategies department, is focused on identifying the opportunities and challenges presented by the continued evolution of distributed generation, energy storage, energy efficiency and demand response resources. For more information, please visit **www.cooperative.com**, and for the current work by the Business and Technology Strategies department of NRECA, please see our **Portfolio**.

LEGAL NOTICE

This work contains findings that are general in nature. Readers are reminded to perform due diligence in applying these findings to their specific needs, as it is not possible for NRECA to have sufficient understanding of any specific situation to ensure applicability of the findings in all cases. The information in this work is not a recommendation, model, or standard for all electric cooperatives. Electric cooperatives are: (1) independent entities; (2) governed by independent boards of directors; and (3) affected by different member, financial, legal, political, policy, operational, and other considerations. For these reasons, electric cooperatives make independent decisions and investments based upon their individual needs, desires, and constraints. Neither the authors nor NRECA assume liability for how readers may use, interpret, or apply the information, analysis, templates, and guidance herein or with respect to the use of, or damages resulting from the use of, any information, apparatus, method, or process contained herein. In addition, the authors and NRECA make no warranty or representation that the use of these contents does not infringe on privately held rights. This work product constitutes the intellectual property of NRECA and its suppliers, and as such, it must be used in accordance with the NRECA copyright policy. Copyright © 2018 by the National Rural Electric Cooperative Association.