Lithium – The 3rd Element

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Abstract

This module introduces Lithium as a critical material in energy production, its utilization, and the alternatives and realities if Lithium supply or accessibility is diminished. Battery chemistry is demonstrated through an animation and Lithium-ion (Li-ion) battery chemistry, geometry, and applications are illustrated with examples. Through a research activity and post research presentation, learners discover the pros and cons of Li-ion battery recycling as compared and contrasted to current "closed loop" battery recycling. In addition, alternatives to both current mining and recycling efforts along with the possibilities of repurposing used Li-ion battery cells are explored using various articles and reference material.

Key Questions Addressed (Why we are doing this module)

- What is a Li-ion battery, why is it important?
- How much are we going to use?
- What materials are important in the Li-ion battery?
- How much can we recycle or reuse Li-ion batteries and consequences if we can't recycle or reuse?

Module Objective

Advance knowledge about responsible use of (critical) materials in energy (battery) production and utilization.

Objectives/SLOs

- Explain (or compare) the capabilities, limitations, and basic principles of Lithium-ion battery recycling to traditional (closed-loop) battery recycling.

- Evaluate the current fundamental short comings of Li-ion battery recycling.
- Identify, explain, prioritize some of the challenges related to Li-ion battery recycling and to potential reuse of Li-battery cells.

Module Data

Key words: Lithium, Li-ion batteries, battery chemistry, battery geometry, sustainable energy, battery recycling

Audience: Introductory level technical programs (grades 9 – 14)

Type of module: Lecture/discussion with out-of-class research

Time required: One class period with one or more outside-of-class problem-based activities

NGSS and Core Competencies for Engineers and Technicians

O.A Demonstrate good communication skills

a1 Demonstrate ability to listen and comprehend instructions

4.A Demonstrate effective work with teams

A1. Work effectively in a team environment

5.B Demonstrate knowledge of chemistry fundamentals

b2 Demonstrate knowledge of chemical symbols and the periodic table of the elements

6.B. Apply basic concepts of heat and thermal conduction

B1 apply concepts of temperature, conduction and specific heat

7.J Demonstrate how material properties are used in engineering design

j3 Explain the process of designing materials for specific applications

j4 Explain how and why a designer chooses properties of materials

19.A Demonstrate processers to promote quality management

a1 recognize and address quality and safety issues

Lithium – The 3rd Element

Background

Li-ion batteries were introduced commercially by Sony in 1991 for use primarily in consumer products. Since then, they have become the most widely used battery technology. Li-ion batteries have the versatility to handle smaller-scale applications, such as powering handheld electronic devices to powering electronic vehicles (EVs), as well as grid-level applications requiring megawatts of power for hours at a time.

Li-ion is used commercially today in several other applications: Soluble Li compounds are widely used in medicine to combat mood and bipolar disorders. Insoluble Li in the form of Lithium Fluoride is used in radiation detection in solid crystalline form. But to be sure, the largest, albeit most important use of Li is running our electronic and energy devices. Li metal is used to produce key electrode and electrolyte materials for Li-ion batteries, which are widely used in today's cell phones, computers and electric vehicles.

Lithium, element #3 on the periodic chart, has an atomic mass of 6.942. Li is very reactive and for that reason it is never found in nature as just elemental Li. Li is found with other elements in a combined form, often as lithium chloride salt dissolved in highly concentrated salt water (called "brine"), or in minerals such as Spodumeme, a mineral of Lithium Aluminum Inosilicate, $LiAl(SiO_3)_2$.

Electrolytic methods for extracting Li from salt solution are well known and therefore brine salt deposits in Chile, China and Argentina are major sources of Li today. However, there are large deposits of Spodumeme in Australia and elsewhere that may become an important source of Li in the future. Sources also exist in the U.S., but are not currently in active production.

Pursuit of a domestic supply of Li has become very important as the need for production of our portable electronics and the race to "green" energy has intensified. Mining is one way to increase our supply, recycling is another. Both processes present challenges:

- While Li deposits are present in the U.S. the main issue of excavation is the huge amount of ground water required in the process and the potential/reality of waste and potential contamination mining causes when it leaves behind the by-products of salts and metals. For example, groundwater contamination with metals includes antimony and arsenic.

- Both Lead-acid and Li-ion battery recycling depend on pyrometallurgical (extremely high temperature melting) and hydrometallurgical (chemical leaching) processes. In addition, closed loop recycling policies have been established for lead-acid batteries, but not for Li-ion batteries.

Finally, the reactivity of Li means that its application must be carefully designed and developed, leading to less reactive and safer Li metal compounds being used while maintaining Lithium's primary use in batteries. For this reason, Li-ion battery chemistry and geometry is an evolving pursuit.

Outline –

Li-ion Battery Application – Slide 2

Pointing out application of Li can be an effective way to engage and educate at the same time how comprehensive battery usage is in our society. Li-ion battery use exists in our hand-held devices, cars, appliances. Grid-level battery "stacks" run our buildings and homes.

How an Li-ion Battery Works – Slides 3 and 4 Animation

When a battery is fully charged, the anode develops an abundance of negatively charged electrons from the chemical reaction at the anode terminal. These stored electrons are just waiting to get out because of the potential difference between cathode and anode. An electrolyte membrane (the "separator) prevents the electrons from going direct from the anode to the cathode through the battery.

When the outside circuit is closed (when the battery is connected and device is turned on), the electrons flow from the negative anode to the positive cathode through the outside circuit. Thus, the current flows from the cathode to the anode.

When the chemical reaction that creates the electrons is completed, the battery can no longer provide electrons to the outside circuit.

With rechargeable batteries (as shown in slides 3 and 4 animation), the reverse happens. When charging, the electrons are pushed into the anode, basically reversing the chemical reactions, causing the ions to flow from the cathode back to the anode in the battery. This effectively "resets" the battery to its original state. Since there are always losses like entropy in both electrical and chemical reactions, and these losses are irreversible , the ability for a rechargeable battery to generate the electrons diminishes as the battery is cycled over time.

Li-ion Battery Types – Slide 5

Since the 1980s the **coin** battery cell has powered portable compact devices such as phones, security and medical devices. Most of this battery type is non-rechargable, however, and other battery types have become more popular.

The three most popular battery cell types: prismatic, cylindrical, pouch, have similar geometries consisting of an: anode, cathode, electrolyte, and separator. The **prismatic** battery cell came about in the 1990s as an answer to the need for thinner sizes. The battery's thinner size enabled flexible design of electronic devices required for modern mobile phones, tablets and laptops. Its components are layered in "sheets," rolled and flattened in a "jelly roll" fashion then stuffed inside a metal (e.g.: aluminum) box and the separator is soaked in the liquid electrolyte. Even though this type of cell is preferred to conserve space, it is not as efficient as the cylindrical type.

The anode, separator and cathode, sheets of the **cylindrical** battery cell are layered and then rolled up and packaged in a "can," the liquid electrolyte is added and the can sealed. The round shape gives this type of battery an advantage by creating a venting system that enables it to stand up to temperature and pressure, making them more stable. For this reason, this battery is popular and very much in use. Notably this cell format is used in the design of the Tesla EV battery pack.

The layers of the **pouch** battery cell are stacked (not rolled) and wrapped in foil. This offers the advantage of flexibility but without a rigid enclosure it also opens itself up to damage, this battery is susceptible to swelling. This cell format is used in design of the Bolt EV battery pack.

When multiple battery cells are enclosed (in a housing frame/structure) modules are formed. The enclosure has a battery management system to monitor safe and efficient battery operation, and an enclosure/case. Battery modules came into popularity to provide portable energy to devices and vehicles such as e-bikes.

Packs start with battery modules consisting of cell groups of either prismatic or pouch battery formats. Packs include: a cooling system surrounding the battery modules, a battery management system to monitor safe and efficient battery operation, and a structure frame that holds the modules together. The modules are sealed from water and insulated from fire.

BMS – Battery Management System

Li-ion batteries typically store more energy, charge faster, are lighter, and more efficient than most other battery chemistries. However, if improperly charged or discharged, they are susceptible to damage, even becoming unsafe. A BMS is designed to manage the characteristics of the battery to ensure safety, maximum life and energy potential. The BMS monitors the battery, at a minimum, ensuring that it is not over charged, or over discharged. They can also be more sophisticated, monitoring battery temperature, short circuits, or other physical anomalies. When parameters are exceeded, the BMS has the responsibility of effectively "disconnecting" the battery or cell. The BMS is comprised of a micro controller circuit board; one per cell or governing multiple cells.

Battery Safety

The MDR or Maximum Discharge Rate for a battery is the rating at which the battery can be discharged safely during use (current draw), usually listed in amps, and remain within its rated temperature. Exceeding the MDR will overheat the battery, causing premature failure, including the potential for fire.

Charging/Discharging Rate "C:"

The "C" rate is a charge or discharge rating based on the storage potential of the battery. For example, a 1 amp-hr cell with a 1C discharge rate can discharge safely at a maximum rate of 1 amp for 1 hour. Another 1 amp-hr cell may have a discharge C of 5, which means it can be discharged at 5 amps for 12 minutes (1/5 of an hour).

Examples:

- Prismatic 800 – 4,000 mAh or .8 – 4 Ah
- Cylindrical 1,200 – 3,000 mAh or 1.2 – 3 Ah

Typical Li-ion Battery Composition/Chemistry – Slide 6

Typical Li-ion battery cells as discussed here contain two electrodes: the Anode (graphite based) and the Cathode (metal oxide solid), a polymer Separator, and liquid Electrolytes (Lithium salts).

Anode materials are necessary in Li-ion batteries because Li metal forms dendrites. Dendrites are microscopic spiky structures called "whiskers" that can grow inside a battery, puncture the separator and cause serious problems such as a short circuit, and even catch on fire. For this reason, materials used must be carefully considered. The anode is typically graphite based, made up of lithium ions dissolved in carbon or graphite. Graphite has a platelet/plane structure that lends to the stability, conductivity and transport of Li. Also, graphite's availability and low cost make it valuable in this composition.

Li-ion batteries use a variety of materials in its cathodes and electrolytes. The two most popular cathodes are made up of lithium cobalt-oxide ($LiCoO_2$) or lithium manganese-oxide ($LiMn_2O_4$). The role of Co and Mn is to create just the right transition metal oxide compound to yield high rates of storage capacity, discharge voltage and good cycling performance. Both Co and Mn have issues with thermal stability however, and Co, like Li, is categorized as a critical material due to accessibility (not abundance). As long as

Co and Mn are used in the Li-ion battery chemistry, management is warranted, and reduction in use for future battery chemistries should be explored.

Most commonly a liquid electrolyte of lithium salt is used due to the conducting ability of salt. Typically, electrolytes are a combination of: LiPF6, LiBF4, or LiClO4, in an organic solvent, such as ether. The electrolyte functions as a conductor of ions but is an insulator to electrons. During discharge Li-ions leave the anode and migrate through the electrolyte to the cathode. While the electrolyte material must enable the free transport of Li-ions, there are safety considerations. The electrolyte is the area most susceptible to “thermal runaway,” as has been demonstrated in fires from older types of Li-ion batteries. Therefore, there is a delicate balance between performance and safety when considering electrolyte material.

The separator separates the anode and cathode (i.e.: the electrodes) physically from each other and is soaked in the liquid electrolyte material. The material used is typically a polyolefin polymer, which is chemically stable and does not interfere with the operation of the battery. The primary function of the separator is holding the electrolyte in place and preventing short circuits caused by dendrites. The separator is said to be the most expensive part of the battery’s anatomy.

Researchers are continually trying to enhance the output of Li-ion batteries by changing battery chemistry, and are also researching other potentially promising compounds, additives, and coatings that could at some point become more important than the Li-ion battery chemistry as discussed here, But for now, Li-ion batteries have a significant advantage over nickel or other chemistries in size, weight, and amount of energy provided. Li-ion batteries also have an advantage in the range of temperatures in which they can perform.

Materials Demand - Production Dilemma – Slide 7

Future demand for Li is increasing very fast. Production capacity for Li, Co and Ni, the primary components in Li-ion battery chemistry, can be measured in millions of tons. Estimates indicate that we could in the most likely scenario need to triple the production of Li and to double the production of Co by 2040 to fulfill expected consumption.

Compared to our production capacity, we may not be able to keep up! In the worst-case scenario, even if we find alternatives for Li, we could keep up, but not for Ni and Co.

The primary options are to increase supply of these elements or go to an alternative battery chemistry to reduce demand on Li as noted earlier. For example, the development of batteries using sulfur and iron phosphate can significantly reduce the demand for Co and Ni. Another answer is to recycle Li-ion batteries!

Can Recycling Be the Answer? Activity – Slide 8

Because production cannot keep up with demand, alternatives must be found. One such alternative is recycling. While recycling lead-acid batteries has existed for years, this is not true for Li-ion. Comparison of the two processes could reveal some solutions or uncover barriers.

Lead-acid vs. Li-ion Battery Recycling – Slide 9

When compared, lead-acid battery recycling and Li-ion battery recycling are somewhat similar.

Some things you might find that they have in common include:

- There is a whole deconstruction process involved to ensure proper recycling. Exception with Li-ion recycling is that it requires more intense processing.
- They both require pyrometallurgical and hydrometallurgical processes

Some things you might find different include:

- There are only four parts of lead-acid batteries that are actually recyclable, that is the plastic case, the lead content, the sulfate crystals, and the electrolyte.
- The Li-ion battery has many more parts and pieces, including metals in the container, components of the cathode and anode, the separator and the electrolyte.

The main difference, and perhaps the most important is that the lead-acid cycle is a closed-loop system due primarily to policy and chain stores to reclaim. A closed-loop system does not exist currently for Li-ion batteries. Additionally, current Pb-acid battery recycling is based on years of industry practice. There is no such information or standard for Li-ion batteries, recycling is just getting started. Finally, Li-ion battery recycling so far has proven to be very expensive. Clearly, new technology needs to be developed.

Potential for Recycling – Slide 10

The potential recycling market in the World is going to increase drastically in North America, Europe and Asia Pacific regions. It is difficult to collect this data, but projections show that up to 30% of the material supply could be displaced by recycling material using traditional Li-ion battery chemistries, but more than 50% of the materials supply could be displaced by recycling using alternative chemistries such as LiS (Lithium-Sulfur) but the lack of supply problem with Li and Co can be alleviate only if we pick it up with recycling and if alternate battery designs are developed.

Is Recycling the Only Alternative? – Slide 11

Because Li-ion battery recycling has proven to be costly, other alternatives are getting some attention. Are there better, more environmentally friendly means of extracting Li from ores and from solution? What about reusing Li-ion batteries? Both are possible.

Alternatives to mining/extraction

When extracting raw materials like Li, Co, and Ni that are essential to our energy technologies, there are often threats to the land, water, wildlife and people.

Recall that lithium chloride salt or in Spodumeme, a mineral of Lithium Aluminum Inosilicate, $LiAl(SiO_3)_2$ is the source of Li. Both salt and metals have a deleterious effect on our ground and water. According to federal documents, groundwater contamination with metals includes antimony and arsenic.

Some alternatives are being explored such as self-contained systems where Li and the other required materials are extracted from naturally occurring salt sources. One such alternative has lithium extracted by mixing clay dug out from the mountainside with as much as 5,800 tons a day of sulfuric acid. This whole process would alleviate some contamination, but it would also create 354 million cubic yards of mining waste.

Potential in repurposing Li-ion battery cells

The typical Tesla battery contains up to 8,256 individual battery cells divided into 16 modules to make up the full battery pack. The battery typically weighs 1,200 pounds and lasts up to 500,000 miles. However, after 500,000 miles, typically the battery has lost about 20 percent of its original power, meaning that 80% remains. Some modules last longer than others and some modules are replaced as needed. The question here is whether individual battery cells or individual modules can be re-used for other applications.

The answer is YES, and several experiments have shown that these cells can be reused for less intensive purposes. While new uses are just being explored, real applications include: battery backups for many systems in case of power outages, and battery storage related to solar or wind power to provide power at night or in calm weather.

Curriculum Overview and Procedure Notes for Instructor

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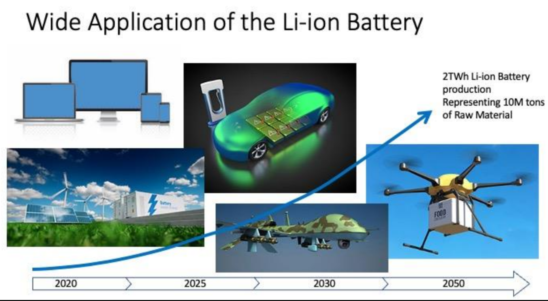
Slide 2



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Wide Application of the Li-ion Battery

- Slide shows how comprehensive battery usage is in our society.
- Provide some statistics to drive home the market growth for cell phones, etc.
- Make the connection that batteries are essential components of most electrical devices.
- Call attention to those pictured in graphic, discuss learner's observations/experiences with batteries.

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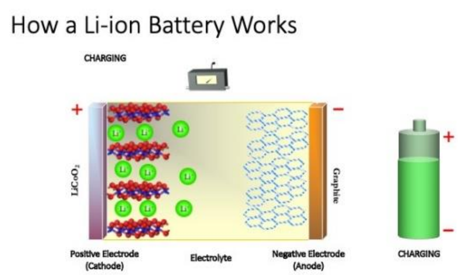
Slide 3



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How an Li-ion Battery Works – Charge

- This in slide animation introduces basic concepts of battery operation: energy storage/transfer, and geometry: anode, cathode, electrolytes.
- Use animation to show charging: Click on the green ball Li, moves from left to right, cell shows charge up and down.
- Use animation to show discharging: Click on the green ball, moves from right to left, cell shows discharge.

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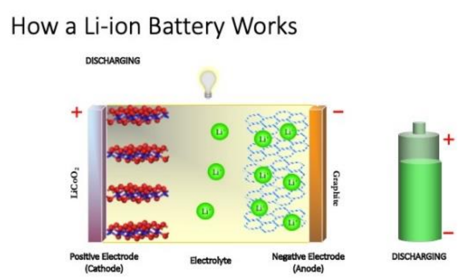
Slide 4



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How an Li-ion Battery Works – Discharge

- Discuss: A lithium-ion battery is a type of rechargeable battery commonly used in laptops and cell phones. To create power, lithium ions move from the negative anode through an electrolyte to the positive cathode.
- When recharged, the chemical reaction is reversed.

See References 1 and 3 for more information.

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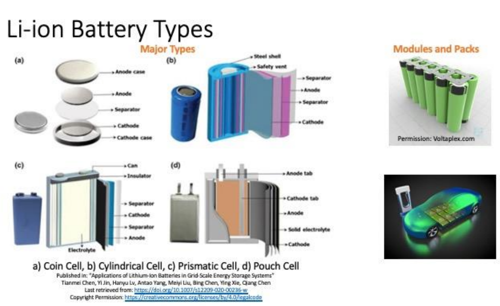
Slide 5



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Li-ion Battery Types

- Simple concept shows size smallest to largest of variety of battery types.
- Discuss examples on slide:
  - Coin Cells
  - The 3 major Li-ion forms showing the internal components:
    - Pouch cells
    - Cylindrical cells
    - Prismatic cells
  - Modules: when multiple (and variety) of cells are combined.

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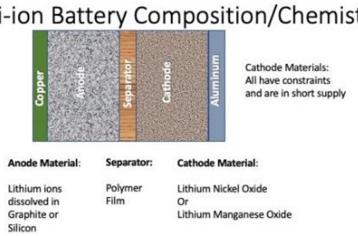
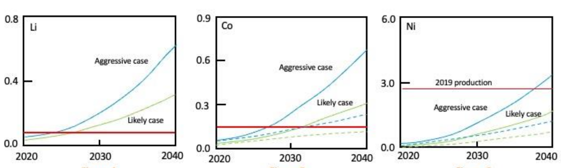
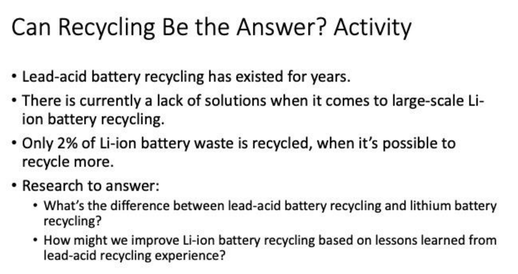
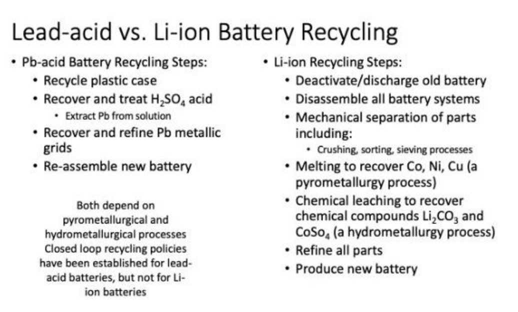
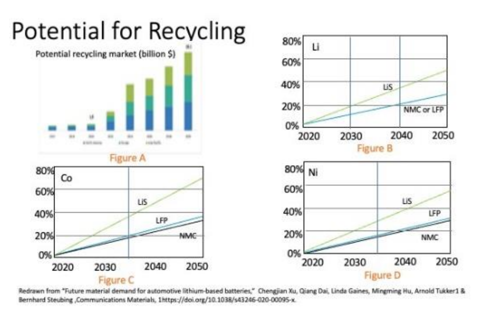
	○ Packs include: the cells, the cooling system, the battery as shown in the car. ▪ NOTE: Management system, all in the structure frame. Examples of packs for both the Tesla and Chevy Bolt can be used to illustrate (NOTE copyrights apply to this image): http://www.teslaupdates.co/2016/07/tesla-model-s-x-battery-pack-explained.html https://www.youtube.com/watch?v=4JiDZVO9NdM
Slide 6 Typical Li-ion Battery Composition/Chemistry 	**Li-ion Battery Composition/Chemistry** ▪ Slide introduces Li chemistry/composition and materials used. ▪ Use slide to discuss the important materials found in the cathode, anode, electrolytes. ▪ Use the graphic to point out the Li graphite/carbon and LiCo components, referred to as the electrodes. ▪ Point to the copper and aluminum foils. ▪ Explain that: ○ The separator – a polmer sheet is placed between the electrode components ○ All sheets are rolled up and placed in a container and the Li Salt solution (the electrolyte) is added ▪ Point out the direction of charge and discharge explaining that: ○ The reaction that takes place in the negative anode creates electrons ○ The reaction that takes place in the positive cathode absorbs electrons ○ The end result is electricity
Slide 7 Materials Demand – Production Dilemma  Demand for Li-ion batteries shown in million tons vs. 2019 production (horizontal red lines). Both Li and Co may exceed the current production capacity within the next 10 yrs. Developing alternate approaches using LiFP or LiS will significantly reduce the demand for Co and Ni (dashed lines). Redrawn from "Future material demand for automotive lithium-based batteries," Chengjian Xu, Qiang Dai, Linda Gaines, Mingming Hu, Arnold Tukker1 & Bernhard Steubing ,Communications Materials, 1https://doi.org/10.1038/s43246-020-00095-x.	**Production-Demand Dilemma** ▪ 3 Graphs show demand and production capacity for Li, Co, and Ni, "How many million tons (Y axis) will be needed for years 2020 – 2040." ▪ Horizontal red line shows 2019 production capacity. ▪ Solid curved lines show future demand, it's increasing very fast. ▪ In Figure A, intersection of the horizontal red line and green line for 2020-2030 shows we are ok for Li so far. ▪ Looking at the 3 graphs we see that Ni projected demand/supply is ok, Co is in worst case scenario. ▪ Dashed lines show what could happen if we go to alternate battery chemistry – labeled LiS. See reference 9 for current possibilities. ▪ Going to alt doesn't solve Li problem but does solve problem for Co and Ni. Discuss why.

	▪ Options are to increase supply or go to alternative (to reduce demand).
Slide 8 	**Can Recycling be the Answer? Activity** This can be an Internet research or literature review assignment, out-of-class (2 hours). This problem-based activity requires students to investigate recycling processes, materials used in processing, etc. then compare findings to suggest some solutions. ▪ Lead in with: "Lead-acid battery recycling has existed for years." ▪ Read the problem statement: "There is currently a lack of solutions when it comes to large-scale Li battery recycling, only 2% of Li-ion battery waste is recycled, when it's possible to recycle more." ▪ Instruct students to research the state of recycling using open-ended questions: o What's the difference between lead-acid battery recycling and lithium battery recycling? o How might we improve Li-ion battery recycling based on lessons learned from lead-acid recycling experience?
Slide 9 	**Lead-acid vs. Li-ion Battery Recycling** Use this slide to discuss student research findings about the recycling process for lead-acid vs. Li-ion. Discuss the following and any other findings not listed here: Similarities: ▪ Both have a deconstruction process ▪ Both use pyro and hydro-metallurgical Differences: ▪ Closed-loop system Discuss cost and other barriers that students may have investigated
Slide 10 	**Potential for Recycling** ▪ Figure A shows estimate of possible recycling market in the World, broken down into area (North America, Europe, Asia-Pacific), showing projected trends. ▪ Figures B, C, and D show percentage of materials that can be displaced by recycling. Future Li-based batteries technologies (LiS) could help a lot (some are discussed in reference 9). NOTE: this data is difficult to collect, not intended to be precise. ▪ Compared to slide 7, future demand, recycling can displace production demand by the percentage shown in the graphs on slide 10. ▪ Compared to slide 7 we can show that the lack of supply problem with Li and Co can be

	alleviate but only if we pick it up with recycling and if alternate battery designs are developed.
Slide 11 	**What's the Alternative?** See References source material for articles related to recycling and alternatives. Review then assign one or more of the articles for reading. If working with younger learners, choose one article to discuss.

Appendix

Resources for the Instructor

What is a problem-based instruction model?

Problem-based and project-based pedagogies employ an "inductive" instruction methodology. In inductive instruction, students are first introduced to complex and realistic problems before being exposed to relevant information. Inductive teaching methods include inquiry-based learning, problem-based learning, project-based learning, case-based teaching, and just-in-time teaching.

This method has evolved from models used in medicine

Example

Deductive: Patient has high blood pressure, right side paralysis, etc., etc. What is your diagnosis?

VS.

Inductive: diagnosis is heart failure, what is the treatment? Guiding them to learn the content, reduce blood pressure, etc.

Problem-based and project-based are often confused as they are both grounded in the pedagogical approach of providing students self-directed learning opportunities via an open-ended question, challenge, etc.

A key difference between them is that the outcome from project-based is a concrete and explicit artifact (e.g.: a model, manufactured object, etc.) requiring students to be focused on synthesis and application of knowledge, whereas problem-based is focused more on the acquisition of knowledge.

This problem-based approach aligns with Bloom's Taxonomy level: Collect and organize data, Evaluate.

References

Li-ion battery composition, types and operation:

1. https://www.powerelectronics.com/technologies/alternative-energy/article/21864146/six-lithiumion-battery-chemistries-not-all-batteries-are-created-equal
2. https://www.allaboutcircuits.com/news/three-major-lithium-ion-battery-form-factors-cylindrical-prismatic-pouch/

General information about batteries:

3. https://batteryuniversity.com/learn/
4. https://www.saveonenergy.com/how-batteries-work/

General information about trends including supply and demand, recycling and alternatives:

5. https://www.sciencedirect.com/science/article/pii/S1369702114004118
6. https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28
7. http://cleanenergywiki.org/index.php?title=Main_Page#Energy_Storage
8. http://fullmeasure.news/news/cover-story/e-waste
9. https://energystorage.pnnl.gov/battery500.asp
10. https://www.nature.com/articles/35104644
11. https://www.nature.com/articles/s41598-018-38238-3

Student Evaluation

1. Question: Explain (or compare) the capabilities, limitations, and basic principles of lithium battery recycling… to lead-acid battery recycling…
    a. Answer: Up to 30% of the material supply could be displaced by recycled materials using traditional Li-ion battery chemistries, but more than 50% materials supply could be displaced by recycling using alternate chemistries denoted by LiS.
2. Question: Evaluate the current fundamental short comings of lithium battery recycling…
    a. Answer: Current recycling effort is very fragmented and cannot keep up with the rapid increase of the marketplace.
3. Question: Identify, explain, prioritize some of the Li-ion recycling/supply-demand challenges…
    a. Answer: Li, Co and Ni supplies have the potential to reach the production capacity limit, with Co facing the most serious challenges.
    b. An integrated recycling approach will most likely eliminate the supply-demand problem.
4. Question: Li-ion batteries are finding wide applications.
    a. Answer: Yes, detailed information depends on information searched/shared.

Acknowledgments

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