XPLORLABS

EXTRACTION TO E-WASTE

STUDENT NOTEBOOK

THE LITHIUM-ION BATTERY SUPPLY CHAIN

A STUDY OF BATTERY SCIENCE AND THE SUPPLY CHAIN TO SOLVE THE ISSUE OF E-WASTE

SCIENTISTS ASK WHY. ENGINEERS ASK HOW.

YOUR NAME

AGE GROUP
Secondary School

CATEGORY
Battery Safety

COMPLETION TIME
1–2 Class Periods

INTRODUCTION TO EXTRACTION TO E-WASTE

WELCOME TO THE LITHIUM-ION BATTERY SUPPLY CHAIN!

Safe and sustainable cities will depend on lithium-ion batteries to power our vehicles, store renewable energy, build smarter connected cities, and keep us connected through mobile phones. But what are the costs? Where do batteries come from before we get them, and where do they go once they are used? What are the hidden dangers and what can we do about the problem of e-waste?

Take the journey of a lithium-ion battery, like the one in your phone, from extraction to e-waste to understand what the risks are and what we can do about them.

BATTERIES AND SAFE CITIES

The United Nations (UN) estimates that globally we produce 50 million tonnes of e-waste every year. Too often this waste, including our phones and their batteries, are disposed of in ways that threaten human and environmental health. Surely, there must be a better way!

To better understand lithium-ion power and how it contributes to safe and sustainable cities, let's first explore how lithium-ion batteries work, why they are so important, what the risks are, and how we can start thinking about solutions.

LITHIUM-ION BATTERIES ARE POWERFUL.

The first mobile phone was released in 1973. It weighed 2.3 pounds (1.04 kg), and the battery lasted for 30 minutes. Recharging the battery took about 10 hours.

In 2020, mobile phones weigh 100-200 grams and the battery charge can last a day, taking less than an hour to recharge.

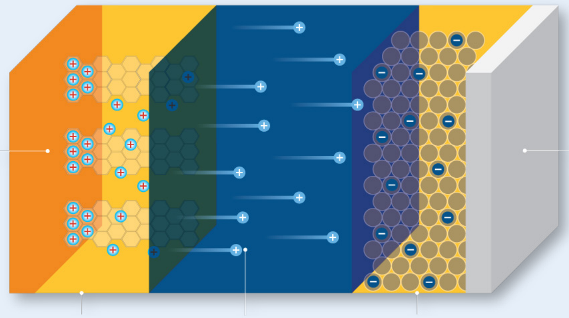
Mobile phones are one example of the demand for faster, lighter, and longer-lasting batteries, especially as more battery-powered devices move into our pockets, homes, and cities.

VIDEO: HOW DO LITHIUM-ION BATTERIES WORK?

The lithium-ion battery is an energy storage device that can both charge and discharge energy.

It works by moving lithium ions through an electrolyte (a liquid or a gel) from the negative electrode (the anode) to the positive electrode (the cathode).

A thin separator keeps the anode and cathode apart, while still letting ions move from side to side. The movement of ions from side to side creates electricity that can power devices such as phones, computers, and cars.



Li+ ions move between the battery's cathode and anode internally, and electrons move in the opposite direction in the external circuit. This migration is the reason the battery powers the device, because it creates the electrical current.

Electrode:	The positively and negatively charged ends of a battery. Attached to a current collector which transmits the current to the device.
Cathode:	The positive electrode
Anode:	The negative electrode
Current collector:	A conductive foil at each electrode of the battery. The current collectors transmit an electric current between the battery, the device, and the energy source that powers the battery.
Electrolyte:	A liquid or gel that conducts electricity.
Separator:	A porous plastic film that "separates" the electrodes while enabling the exchange of lithium ions from one side to the other.

Student reading: "Take a Look Inside." On the Mark, page 9

LITHIUM-ION BATTERY CREATORS WIN NOBEL PRIZE.

"The Nobel Prize in Chemistry 2019 rewards the development of the lithium-ion battery. This lightweight, rechargeable and powerful battery is now used in everything from mobile phones to laptops and electric vehicles. It can also store signiflcant amounts of energy from solar and wind power, making possible a fossil fuel-free society." – Nobel Prize Committee

Student reading: "Lithium-ion Timeline." On the Mark, pages 14-19

LITHIUM-ION BATTERIES ARE EVERYWHERE.

We power our cars, our houses, and a growing list of wearable devices like activity trackers, medical devices, and virtual reality headsets, watches and phones with lithium-ion batteries. And their use in our cities is only going to grow.

Click on the flashing beacons to see a few examples of lithium-ion batteries in the city.

Student reading: "It's a Lithium World." On the Mark, pages 4-7
Student reading: "Towers of Power." On the Mark, pages 26-28

HOW DO BATTERIES CONTRIBUTE TO SAFE AND SUSTAINABLE CITIES?

We all benefit from forming communities that are safe and sustainable. When we build cities to be safe and sustainable, they become resilient: able to recover from unfortunate circumstances. Sustainable cities are identified as the UN's Sustainable Development Goal 11.

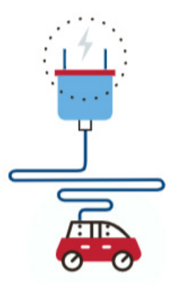
All communities need cleaner, more reliable energy. As cities become smarter, more resilient, and renewable, they will rely more and more on lithium-ion batteries.

Lithium-ion batteries empower us to construct cities that are safe and sustainable.

Student reading: "Rays of Light." On the Mark, pages 29-30
Student reading: "Getting on the Grid." On the Mark, pages 20-25

Electrifying our vehicles

We can replace the burning of fossil fuels with a safer, more sustainable alternative.



Empowering flexibility in electricity

Devices like electric vehichles can be double as banks of stored energy for our homes and for use during a disaster like a flood or earthquake.

Building a smarter city

With lithium-ion batteries, we can use devices to monitor and manage our energy usage.

Storing renewable energy

Lithium-ion batteries can store energy from renewable sources, even when they aren't available.

BUT, THERE ARE RISKS.

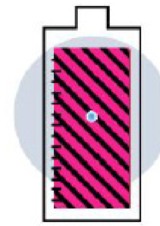
A lithium-ion battery, if not designed, manufactured, or used properly, can experience conditions that lead to internal short circuit and possibly thermal runaway, which can result in smoke, fire, and possibly explosion. Risks along the supply chain include:

Extraction risks

Lithium-ion batteries require raw minerals be extracted which have major environmental and health impacts.

Production risks

Lithium-ion batteries are volatile – hidden defects can cause internal short circuits, which can be dangerous.



Disposal risks

Toxins from lithium-ion batteries can seep into water, soil, and air causing major health and environmental risks.

Transportation risks

If not designed and used properly, lithium-ion batteries can smoke, catch fire, and explode, making them risky to transport.

Student reading: "Lithium-ion Issues." On the Mark, pages 36-37

TO DEVELOP SOLUTIONS, WE MUST FIRST UNDERSTAND THESE RISKS. TO UNDERSTAND THE RISKS, WE MUST UNDERSTAND THE SUPPLY CHAIN.

See what you learned!

- Name two devices that use lithium-ion batteries.
- How would you define thermal runaway?
- What are the benefits of lithium-ion batteries?
- What are the risks of lithium-ion batteries?

A supply chain is the series of steps a product goes through to reach an end user. Though every product has a supply chain, in this investigation we explore the supply chain of a mobile phone battery.

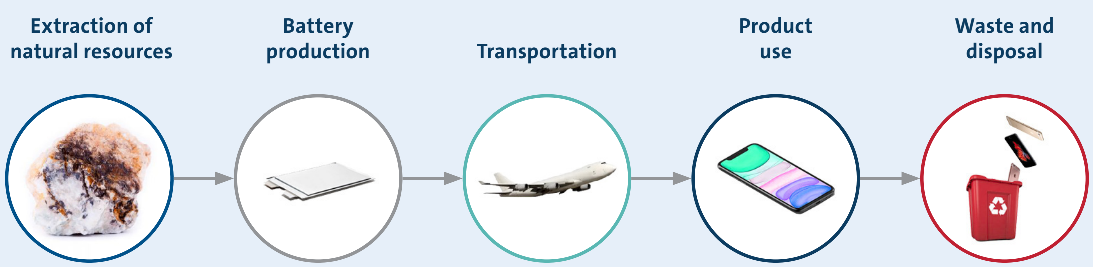


Diagram of supply chain

Extraction is the process of removing raw materials from the Earth to create the product.

Manufacturing is the process of creating the product.

Transportation is the process of moving the product from one place to another.

Use is when the product reaches the end user's hands.

Disposal is what happens when the product is no longer used.

1. RESOURCE EXTRACTION: WHERE THE SUPPLY CHAIN BEGINS

Lithium-ion batteries can have a variety of physical and chemical compositions based on a device's needs for battery size, power, and capacity. The average battery in a mobile phone requires over 70 different types of resources.

Two types of mining required to extract minerals for batteries are open-pit mining and brine extraction.

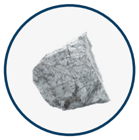
Open-pit mining:
Open-pit mining uses a descending set of ledges dug into the ground. Borers drill holes into the rock. Explosives are inserted into these holes to break the rock into boulders, which are then hauled away to be processed.

Brine extraction:
Brine extraction is a method in which miners pump groundwater to the surface that collects in ponds. Here, they wait for the water to evaporate under the sun's heat. Left behind is a sludge residue, which contains the desired mineral.

Student reading: "Lithium-ion Batteries by the Numbers." On the Mark, pages 11-13
Student reading: "The Green Scene." On the Mark, pages 42-45
Student reading: "Lithium-ion Issues." On the Mark, pages 36-37

LET'S EXPLORE A FEW OF THE RESOURCES THAT ARE IN YOUR PHONE'S BATTERY: COBALT, COPPER, LITHIUM, ALUMINUM, AND CARBON IN THE FORM OF GRAPHITE.

- Lithium-ion batteries are made from many different resources. We are investigating five of the elements that are in your mobile phone battery:



a. **Cobalt:** Cobalt is a chemical element often added to alloys, two or more metallic elements, to improve their strength at high temperatures.
Cobalt is used as part of an active material ($LiCoO_2$) that is applied to the **cathode** and acts as a lithium receptor in the electrochemical charge-discharge process.

b. **Copper:** Refined copper is a very ductile metal: it can be easily shaped into a thin foil, wire, or thread. Copper is also highly conductive, thermally and electrically.
Because of these qualities, copper foil is used as the **current collector at the anode** of a lithium-ion battery. In the lithium-ion battery of a mobile phone, current collectors take the form of a foil and must be conductive enough to receive the electrical current.

c. **Lithium:** Lithium is the lightest solid element in the periodic table.
   - Lithium in the form of lithium ions (Li+) moves between electrodes. The movement of Li+ is responsible for creating an electrical current.
   - Lithium in the form of an oxide ($LiCoO_2$, or lithium cobalt oxide) is used as the active component of the cathode.

   Li+ ions move between the battery's cathode and anode internally, and electrons move in the opposite direction in the external circuit. This migration is the reason the battery powers the device, because it **creates the electrical current.**

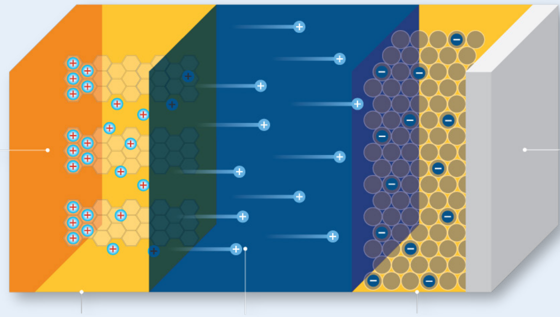
d. **Aluminum:** Aluminum is naturally occurring as the mineral bauxite (aluminum oxides and aluminosilicates). Aluminum metal is very ductile: it can be easily shaped into a thin foil, wire, or thread. Aluminum is also highly conductive, thermally and electrically moving heat energy.

   Because of these qualities, aluminum foil is used as the current collector at the cathode of a lithium-ion battery. In the lithium-ion battery of a mobile phone, current collectors take the form of foil and must be conductive enough to receive the electrical current.

e. **Carbon (in the form of graphite):** Carbon in the form of graphite, is used as a component of the anode. The porous graphite serves as the location where lithium ions migrate to and from when the battery cell discharges and charges.

Student reading: "Take a Look Inside." On the Mark, page 9

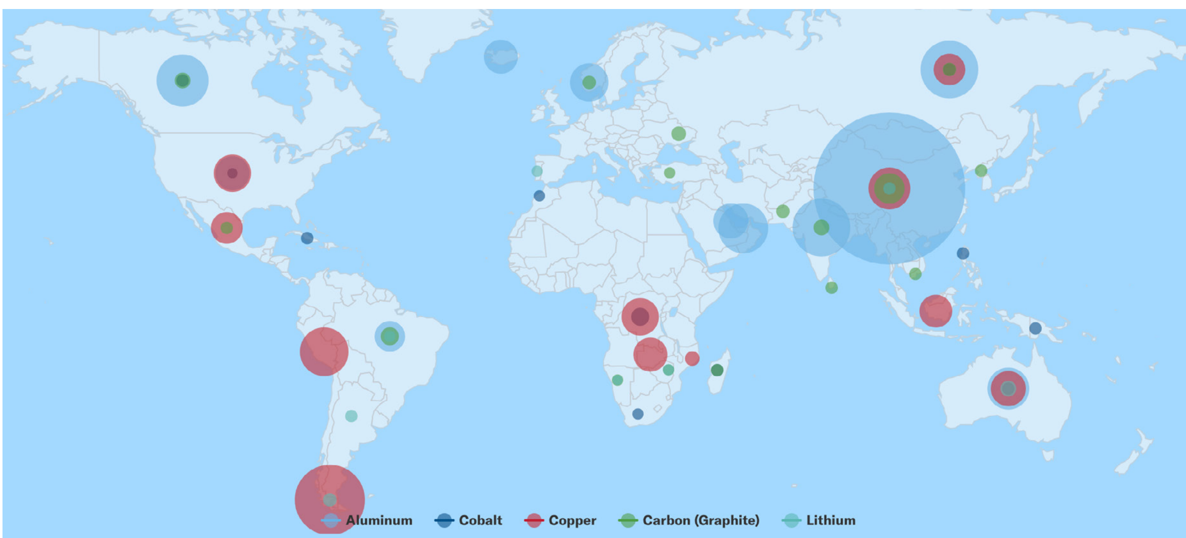
Using the illustration below, find the resources in the periodic table that make up each battery component:



Hot tip!

Next to each element name on the website, you will see the symbol that appears on the periodic table.

Where are these resources located?

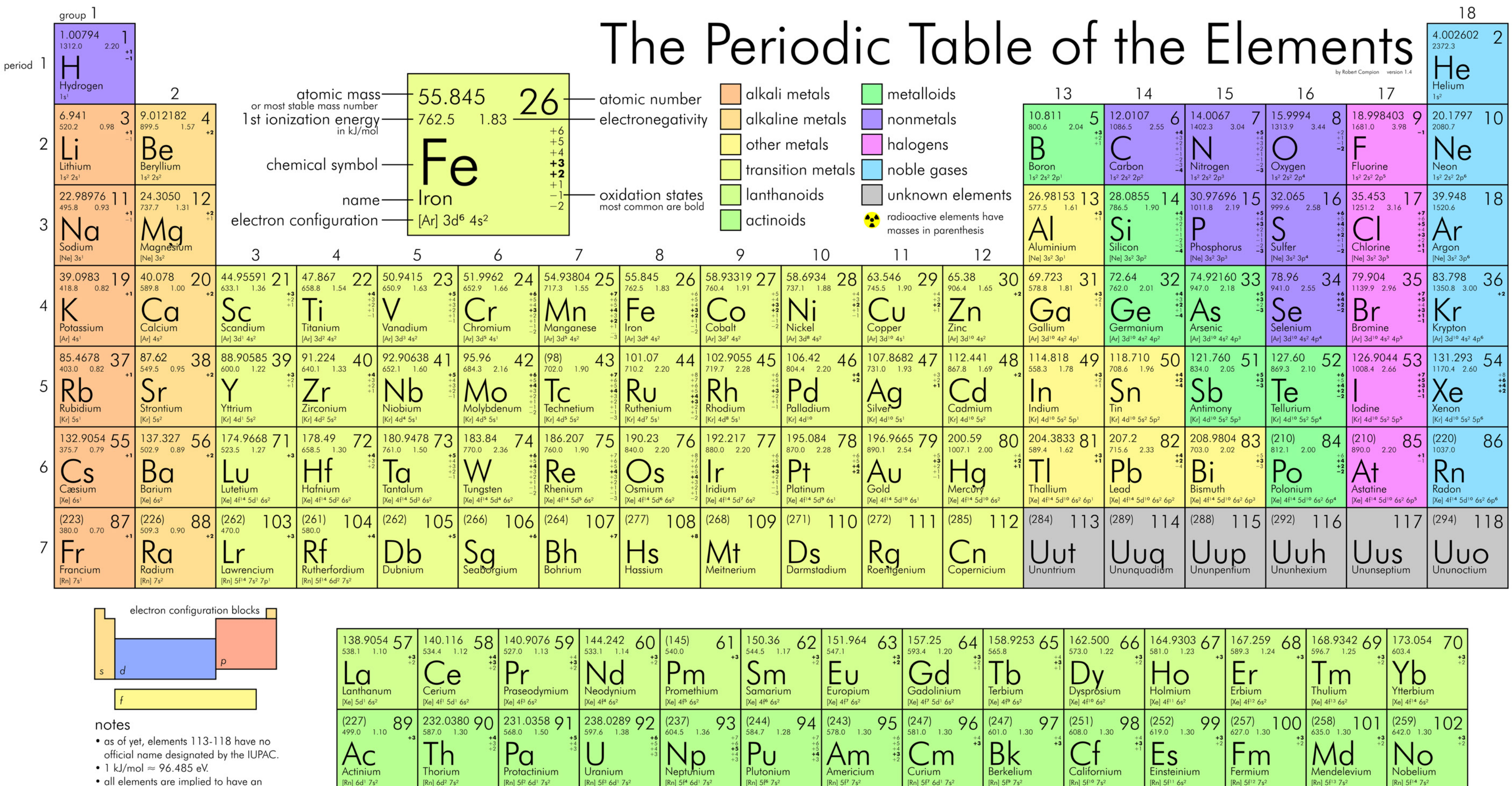


Source: U.S. Geological Survey, Mineral Commodity Summaries 2019

See what you learned!

- How would you compare open pit mining and brine extraction mining methods? (set up as T-chart or open response)
- What impacts on the land did you observe at the open-pit mines over time? What year did the changes increase? What else was happening at that time? What are the risks of lithium-ion batteries?

The Periodic Table of the Elements



notes

- as of yet, elements 113-118 have no official name designated by the IUPAC.
- 1 kJ/mol ≈ 96.485 eV.
- all elements are implied to have an oxidation state of zero.

2. FROM RAW MATERIALS TO BATTERY CELLS

There are many shapes (or “formats”) of lithium-ion cells and batteries for many types of products. Remember, a battery is defined as one or more cells in an electrical circuit. A mobile phone is often powered by a pouch cell, which helps make the slim shape of the phone possible and reduces the battery’s weight.

The process of manufacturing a mobile phone pouch cell battery is closely controlled and monitored.

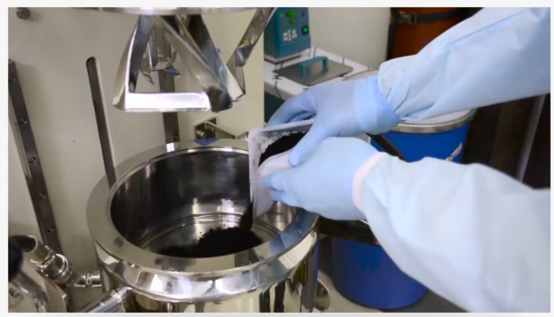
Let’s take a look.

MANUFACTURING: HOW ARE LITHIUM-ION CELLS MADE?

Images courtesy of Pacific Northwest National Laboratory (PNNL)

1. Electrode slurry
Powders containing the active materials in electrodes are mixed in a big bowl with binding materials, which act like a glue to create what scientists call a slurry, or a paste.

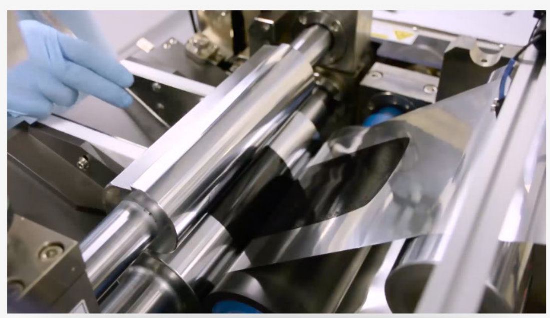
In your mobile phone battery, the electrode active materials are likely lithium cobalt oxide and carbon at the cathode, and graphite at the anode.



VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

2. Electrode coating
The slurry is then spread out onto a very long piece of foil, which slowly rolls through high heat. This heat (300° F, 149° C) bakes the electrode into a solid and sticks the paste to the foil. The foil becomes a current collector attached to the electrode paste.

In your mobile phone battery, the foil is made of aluminum at the cathode, and copper at the anode.



VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

3. Electrode stamping
The baked electrode roll is cut into smaller pieces, which are placed under a super-sharp, rectangular die. With a sudden movement, the die quickly pushes down on the electrode sheet and cuts out an individual electrode battery piece.

VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

4. Electrode stacking

An automated machine uses suction to pick up and release sheets of cut-out electrode material and wrap an insulating layer in between each sheet. The components are laid flat to look like layers in a cake. These layers include the anode, separator, cathode, and another separator.

The result is a credit card-sized electrode stack, which is spit out of the machine with the turn of a metal arm.

VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

5. Pouch making

A special plastic, moisture-resistant barrier material is pressed to create rectangular pouches. The electrode stack is inserted into the resulting pouch to create a pouch cell.

VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

6. Electrolyte injection

Liquid electrolyte is injected into an open battery pouch. In your mobile phone battery, the electrolyte is made of organic carbonates and a salt.

VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

7. Battery sealing

The electrolyte-soaked battery pouch is heat-sealed and placed in a vacuum chamber, which removes gasses from inside the pouch.

VIDEO PROVIDED COURTESY OF PACIFIC NORTHWEST NATIONAL LABORATORY

Most pouch cell batteries are produced in manufacturing locations in China, South Korea, and Japan. Look at the map to see the percentages of production by country.

WHAT ARE THE RISKS?

Lithium-ion technology is generally safe when quality battery manufacturers take exhaustive steps to minimize design flaws, vet material suppliers and control quality of production.

To prevent damage and ensuing fires or explosions, manufacturers take special precautions and follow exact procedures.

When making lithium-ion batteries, attention is focused on avoiding any hidden defects that could be formed in the cell during the manufacturing process. This hidden defect can gradually create an internal short circuit while the battery is in use. An internal circuit can cause thermal runaway.

The defects come from contaminants such as water, foreign objects such as dust, and metal particles such as iron. When something gets into or damages the pouch, that becomes a problem.

For instance, too much moisture in the room can allow water to enter the cell pouch. When water makes contact with the electrolyte, the chemical reaction will cause the battery pouch to swell and eventually fail . If pouch cell components are cut with a dull knife, the electrodes will have jagged edges, called “burrs”; those burrs can puncture the separator and cause an exothermic reaction.

The manufacturing process is complete.

Afterwards, all cells must undergo a charge-cycling procedure. During the first instance when a battery cell is charged and discharged, Li+ ions forge tiny pathways in the solidified paste of the electrode layers. This process “trains” the cells to charge and discharge later on.

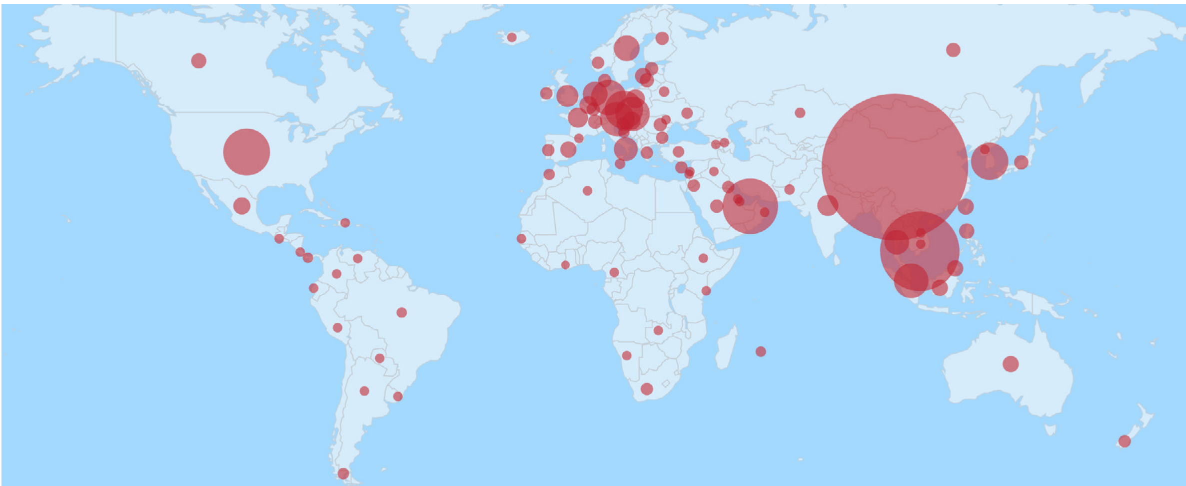
The next step is to test for safety and performance. Was the pouch cell manufactured without any defects, is it safe to transport, and is it safe to use?

See what you learned!

- Describe how a pouch cell battery is made?
- What is an exothermic reaction?
- What are the defects that can cause a short circuit?
- How would this be a problem later on in the supply chain, or when the device is in your hands?

3. SHIPPING AND TRANSPORTING BATTERIES TO ASSEMBLE YOUR MOBILE PHONE

Once lithium-ion pouch cells are completed, they are packaged and shipped for the next step of the supply chain – to the mobile phone manufacturing facilities for assembly. Transportation of lithium-ion batteries creates new challenges for many stakeholders including safety scientists, packaging and shipping companies, cargo carriers, and manufacturers. Safety scientists investigate the safest way to package and ship batteries.



Because lithium-ion batteries can short-circuit and cause thermal runaway, they are considered dangerous goods on cargo and passenger planes by the International Civil Aviation Organization (ICAO) and tightly regulated by the UN and the International Air Transport Association (IATA).

LITHIUM-ION BATTERIES CAN SHORT-CIRCUIT AND CAUSE THERMAL RUNAWAY.

An internal or external short circuit is one of the major risks when transporting batteries. This happens when the battery terminals come into contact with other batteries, metal objects, or conductive surfaces.

To address the safety and performance of the batteries before they can be transported, batteries are put through rigorous safety tests including: **crush tests**, altitude simulations, **nail tests**, short circuit simulations, **projectile tests**, thermal, vibration, shock, impact and **overcharge tests**, and a forced discharge test.

Student reading: "The Mark of Safety." On the Mark, pages 38-41

When a sampling of batteries pass these tests without any signs of mass loss, leakage, rupture or fire, that model of battery has met the UN's shipping criteria and guidelines. The rest of the batch is ready to be packaged and shipped to the mobile phone manufacturer.

Packaging and shipping batteries includes very specific demands for safe transport. The following criteria must be met:

- Batteries must be no more than 30% state of charge.
- Packages must be secured to protect batteries from shifting, short-circuiting, activating, and being damaged by other package contents.
- Packages that contain lithium-ion batteries must be clearly marked. Lithium-ion batteries outside of a device must be in a container that weighs less than 30 kg (66.14 lbs) and passes a 1.2 meter (3.94 ft) drop test.

Once the batteries are packed into phones, the phones themselves then need to be shipped. Most phones are transported by air.

Source: New York Times

WHAT ARE THE RISKS?

As we have seen, when a lithium-ion battery is not designed or handled the right way, the battery can undergo thermal runaway. In this state, the lithium-ion battery can smoke, catch fire, or explode. If that battery is in the cargo hold of a plane, the fire is difficult to reach. If that battery is near other lithium-ion powered devices or dangerous goods, it is a more difficult problem to solve.

See what you learned!

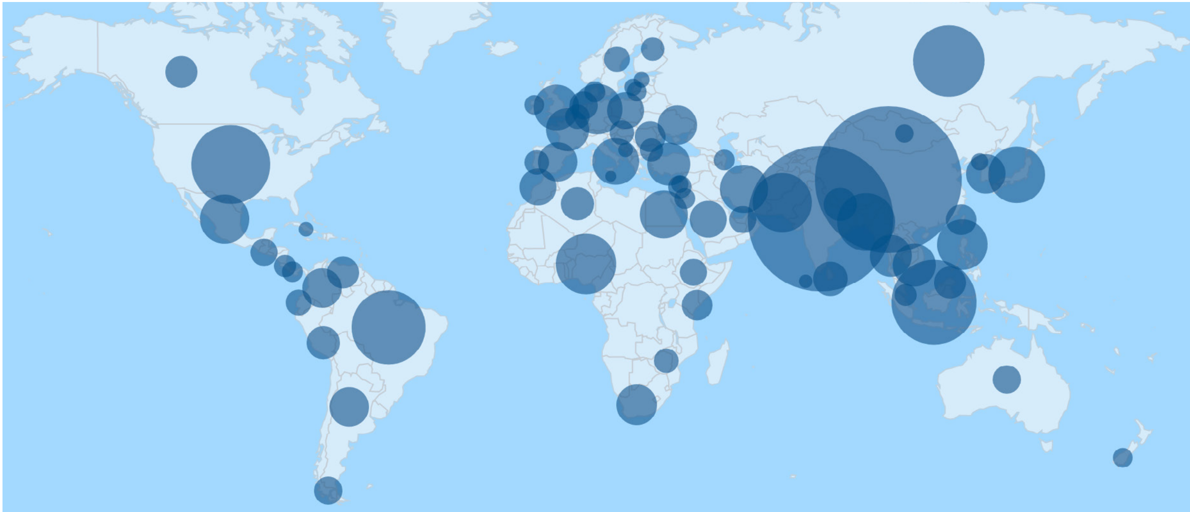
- Why is it necessary for shippers to follow specific rules when it comes to shipping lithium-ion batteries?

4. THE MOBILE PHONE HAS FINALLY ARRIVED

While we have been solely focused on the mobile phone battery, mobile phones are built from many individual parts, also made all over the world. The many parts of a mobile phone each have a supply chain.

Each part, including the lithium-ion battery, is shipped to a location where mobile phones are assembled, packaged, and transported to finally arrive in your mailbox or at the store.

Student reading: "Getting on the Grid." On the Mark, pages 20-25



The battery supply chain ends with you, or does it?

See what you learned!

- What is the first thing people commonly do when they get a new phone?
- What are some ways that short-circuiting and thermal runaway can be triggered?
- How can you use your mobile phone to avoid these risks?
- Based on what you have seen so far throughout the supply chain, what are some unintended consequences that come with getting a new phone?

5. WHAT HAPPENS TO BATTERIES AND OUR DEVICES WHEN WE NO LONGER USE THEM

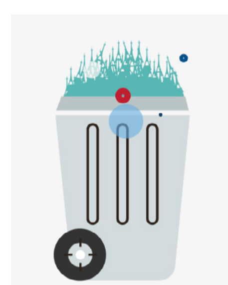
E-waste means any electronic device that has been disposed of. This includes mobile phones. Globally, we create over 50 million tonnes of e-waste every year, which poses significant risks to the environment and human health. Mobile phones and their batteries are one of the fastest growing categories of e-waste. Let's see what happens when you dispose of your phone.

The way we dispose of batteries matters

E-waste is a rapidly growing issue related to how, where, and when we dispose of our devices.

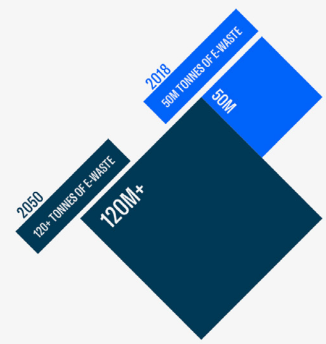
According to the UN, we create over 4,500 Eiffel Towers worth of e-waste by weight each year.

Source: World Economic Forum



MOBILE PHONES ARE DISPOSED OF MORE FREQUENTLY, OR AT A FASTER RATE, THAN OTHER TYPES OF DEVICES.

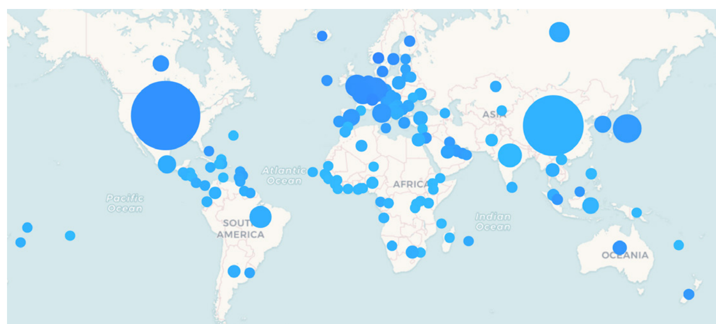
MOBILE PHONES, THEREFORE, ARE A MAJOR CONTRIBUTOR TO E-WASTE. A UNITED NATIONS STUDY REPORTED THAT ABOUT 50 MILLION TONNES OF E-WASTE WERE DISCARDED IN 2018. IN 30 YEARS, IT IS EXPECTED TO MORE THAN DOUBLE.



Source: BBC

Source: World Economic Forum

Check out the map of global e-waste flows. How much e-waste does your country generate every year? Where does this e-waste end up?



OF ALL THIS WASTE, 80% IS NOT DISPOSED OF PROPERLY.

That means that 80% of e-waste is disposed of in a way that can't be properly recycled, like being placed in the trash. This has serious consequences.

WHAT ARE THE SAFETY RISKS OF DISPOSAL?

Devices like our mobile phones contain toxic materials including lead, mercury, and arsenic. When we leave mobile phones in landfills, this can have disastrous environmental consequences.

Over time toxic metals seep into the surrounding water, soil, and plants. This is called "leaching." When toxic metals leach into the water, soil, and plants, people and animals suffer from health impacts. People can develop chronic diseases in their circulatory systems, respiratory systems, and brain functions.

Lead (Pb) is used in mobile phone circuitboards. Lead is a neurotoxin and exposure to the metal from drinking contaminated water can result in high blood pressure, heart and kidney disease in adults, and neurological damage in children.

- Mercury (Hg) is used in mobile phone circuitboards. Mercury poisoning can cause muscle weakness, numbness, and, at high levels, can cause the skin to turn pink and peel, especially in children.
- Arsenic (As) is used in mobile phone microprocessor and camera chips. If arsenic is in the body for a brief period of time, it can cause vomiting and severe abdominal pain. Long-term exposure can lead to skin, lung, bladder, and kidney cancer.
- When toxins leach into the water system, pollution can run downstream into agricultural sites, drinking water, and ecosystems. What do you think the impacts might be on people and wildlife?

Unfortunately, sometimes non-repairable mobile phones are sold illegally as e-waste to scrap yards in developing countries. At these waste sites, people take apart electronics by hand and scavenge for valuable pieces of material.

When components are glued in mobile phones, the electronics are burned in order to dissolve the glue and remove the components. The valuable parts, like gold or copper, are sold.

- The people who burn recycled electronic devices are especially vulnerable to severe health hazards, and so are the people who live near these sites.
- Constantly inhaling the smoke, dust, and toxic fumes from burning e-waste is dangerous as it can cause chronic respiratory illnesses and other diseases.
- Exposure to toxins in the air is linked to birth defects and chronic illnesses, especially in children.

E-waste is truly a global problem and waste sites like these exist all over the world. Many of these sites are in the poorest areas of the world where health and safety protections are too expensive and difficult to enforce.

- Little to no precautions are available to people who work in these sites as they include some of the poorest people on the planet.
- Fire can cause severe risks to people working in garbage facilities as they can be hard to control.
- Burning in these sites is common to try to expose the valuable materials.

Burning sites often have the presence of heavy smoke in the air and heavy metals (copper and lead) in the soil. Rainwater carries these contaminants into water supplies (lakes, ponds, and reservoirs), and crops grown near these areas will store the contaminants.

- Pollution doesn't just stay in the area where it is started. Chemicals from burning waste can easily reach the food supply as pollution in smoke can be infused directly into nearby crops. The smoke and pollution can cause long-term health impacts on people and animals.

- Water sources are usually near food crops. Toxins in smoke from burning waste move through the soil. This can poison the local water supply and last for generations of people living nearby.
- In 2008, 80% of children experienced respiratory ailments and were especially at risk of lead poisoning in Guiyu, China, pictured here.

The long term health and environmental impacts of e-waste are seen in both the poorest and richest countries in the world. This is a problem that affects all countries.

Investigate the photo of Utah, United States. E-waste is not just limited to phones but includes all electronics including large ones such as televisions, computers, and car parts. This is an image from the United States. What do you see? What is the main electronic in this burned e-waste? What do you think are the health impacts?

Investigate the photo of Lagos, Nigeria. E-waste is sometimes piled up with other trash. Investigate this photograph. What are the electronics? What other trash do you see? Without judgment of the people who live there, make some predictions about the environmental and health impacts of this scenario.

As we have seen, e-waste is a major problem now and it is expected to get worse. As we go from producing 50 million tonnes a year to 120 million tonnes in the next 30 years, what will the impacts be? Are there ways to reduce the amount of e-waste we produce? Are there better approaches to the extraction, manufacturing, transportation, use, and disposal of our mobile devices and other electronics that can make a difference?

See what you learned!

- Based on your observations of the battery supply chain, which part of that chain do you think requires the most urgent or immediate attention?
    - Resource extraction
    - Battery manufacturing
    - Transport
    - Disposal
- Why? Explain your answer.
- See how these issues are being solved right now! (click through to solutions page)

6. SOLUTIONS

LITHIUM-ION BATTERIES POWER OUR LIVES.

This dependence will only increase into the future as new technologies often require light-weight, powerful energy supplies. And with benefits come challenges. And with challenges come opportunities to engineer solutions.

After watching the videos, what are actions you can do to help solve the problem of e-waste? What solutions are others working on that inspire you? What do you find interesting? What do you still have questions about?

7. GLOSSARY

Anode: The negative electrode of a battery.

Battery: One or more cells in an electrical circuit.

Cathode: The positive electrode of a battery.

Current collector: A conductive foil at each electrode of the battery. The current collectors transmit an electric current between the battery, the device, and the energy source that powers the battery.

Delivery: The stage of the supply chain when the product reaches the end user.

E-waste: Electronic waste; any electronic device (powered by a battery or cord) that has been disposed of.

Electrode: The positively or negatively charged end of a battery. Attached to a current collector that transmits the current to the device.

Electrolyte: A liquid or gel that conducts electricity. The electrolyte allows the continuous movement of Li+ ions during cell operation.

Exothermic reaction: A type of chemical reaction that releases heat.

Extraction: The process of removing raw materials from the Earth to create a product.

Internal short circuit: When the anode and cathode of the battery cell come into contact with each other.

Lithium-ion battery: A type of battery that is powered by the movement of lithium ions between electrodes. Lithium-ion batteries have many uses, one of which is powering our mobile phones.

Manufacturing: The process of creating a product.

Separator: A porous plastic film that "separates" the electrodes while enabling the exchange of lithium ions from one side to the other.

Supply chain: The series of steps a product goes through to reach an end user.

Thermal runaway: A rapid, uncontrolled increase in temperature causing additional increases in temperature, usually resulting in a hazardous situation.

Transportation: The process of moving a product from one place to another.

Tonne: A metric ton equal to 1,000 kilograms.