Changing Technology for a Changing Climate:

Knowledge is not always power, but power is rarely ignorant

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Abstract

In the 20th century, fossil fuels were the key source of power for economic and political transformation. The consequence of these power sources were a century of geopolitical turmoil and an increase in atmospheric carbon dioxide leading to climate change and a host of widespread societal impacts. Looking to the 21st century, renewable power sources could avert the climate crisis but rely on "critical minerals." These indispensable resources have unique material properties enabling power supply without carbon dioxide generation, but they have different political and environmental considerations than their carbon-based forebears. This unit engages students in hands-on activities demonstrating energy production of the past, impacts of greenhouse gases, and how to design and evaluate renewable energy sources considering engineering, production efficiency, environmental hazards, and human impacts. The culminating project is for students to communicate their findings with the world beyond the classroom.

Keywords

Critical minerals, green technology, greenhouse gases, climate change, renewable energy, power, fossil fuels, environment, geopolitics, hands-on experiments, social media

Unit Content

Curriculum Narrative

Green technology, including electric vehicles, solar panels, and wind turbines, is often hailed as an important development in climate change solutions. Because these technologies emit less carbon dioxide (CO_2) than their fossil fuel combusting counterparts, they may help reduce the greenhouse effect and global temperature increases over the next century, averting major human and environmental catastrophes. As urgently as a shift away from fossil fuels is needed, adopting these technologies comes with its own set of challenges and limitations. The materials for making electric batteries and efficient engines are subject to supply disruption (Chakarvarty, 2018) and environmental hazards from mining, manufacturing, and disposal (Mission 2016, 2012). At this critical time of transitioning away from CO_2-emitting technology, the world needs informed citizens who can grapple with complex solutions and their possible consequences.

Unfortunately, the same technologies that have enabled lithium batteries and global communication have also fostered a “Google-ification” of thinking. Instead of greater access to knowledge moving us toward deeper thinking, the dominant use of smartphones is for “ultra-brief social media,” like texts and tweets or visually-focused entertainment (Walter, 2012), like TikTok and Instagram. Rather than encouraging a rich synthesis of ideas from many sources, frequent use of social media and texting is correlated to less self-reflection (Annisette, 2017) and is associated with cognitive shallowness (Carr, 2010). Developing nuance and well-researched thinking takes time and an openness to the process. It’s an unfamiliar way of using one’s brain, sometimes challenging and confusing. Bearing those difficult emotions is even worse when hyper-stimulating, effortless entertainment could be had as easily as lifting a phone.

The goal of this project is to use hands-on experiments to get students off of their phones, but then utilize social media to creatively engage in science communication. By physically and emotionally involving the students, these lessons concretize complex and seemingly immaterial concepts like climate change, electricity, and critical minerals. By performing experiments first-hand and reporting their results as scientists, politicians, CEOs, and humanitarians, students have an opportunity to connect with the desires and conflicts at the heart of this global revolution. In the process, they will have to create their own data, evaluate whether or not the information fits the bias of their role, use multiple sources to argue their positions, and listen to other perspectives in order to better refute and defend their own.

Critical Minerals

One of the challenges in teaching critical minerals is the complexity of the issue. As mentioned, many different roles are involved, including scientists, engineers, politicians, large corporations, consumers, environmental groups, humanitarians and military advisors. Understanding each facet requires thoughtful background research, and an overall conclusions rely on a synthesis of stakeholder positions.

What makes a “critical” mineral?

In May of 2018, the United States Department of the Interior released a final list of 35 minerals deemed, “critical to the economic and national security of the United States” (Demas, 2018)[see Appendix]. A culmination of a year-long, multi-agency panel convened by executive order 13817 (U.S. DoI, 2017), this list was created by input from the Departments of the Interior, Commerce, and Defense to develop a mathematical evaluation of 77 nonfuel mineral commodities for “supply risk (R); production growth (G); and market dynamics (M)” (Fortier et al, 2018).

Called “The National Science and Technology Council Critical Mineral Early Warning Screening Methodology,” this method evaluated each mineral for:

1. Supply Risk – where are the major concentrations of these minerals and are those countries vulnerable to “trade wars, labor strikes, market bubbles, and natural disasters” or “unable or unwilling to supply the United States based on their political stability, adequacy of infrastructure, and availability of labor, as well as their trade, ideological, and defense ties with the United States” (Nassar and Fortier, 2020)
2. Production Growth – projects global demand and production of the mineral to establish on-going economic importance
3. Market Dynamics – examines volatility of price changes as a measure of reliably sourcing the commodity

Once assessed, the results were standardized on a scale from 0 to 1 and combined by geometric mean where higher values indicated higher criticality. Initial results were subject to open commentary before final revision and publication by the Department of the Interior, which was then subject to further testimony before Congress (Fortier, 2019).

Carbon Dioxide, Climate Change, and the Demand for “Green Technology”

Looking at future “production growth” for these critical minerals, a major category driving demand is transitioning to power sources that do not produce carbon dioxide (CO_2). As of 2021, nearly 80% of the world’s energy comes from the combustion of fossil fuels (EESI, 2021). The science of this is fairly simple. When a carbon-bearing fuel source combines with oxygen, a combustion reaction proceeds, emitting carbon dioxide, water, and energy in the form of heat and/or light (Figure 1). Humans design technologies to capture that energy and put it to productive use, e.g. combustion engines, electricity generation, and heat for buildings.

Natural Gas = Methane = CH_4

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

$\Delta H_{rxn} = -802.2$ kJ   50 kJ/g CH_4 55 g CO_2/MJ

Petroleum = *iso*Octane = C_8H_{18}

$$C_8H_{18(l)} + 12.5O_{2(g)} \rightarrow 8CO_{2(g)} + 9H_2O_{(g)}$$

$\Delta H_{rxn} = -5.06 \times 10^3$ kJ   44 kJ/g C_8H_{18} 70 g CO_2/MJ

Coal = Graphite = C

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

$\Delta H_{rxn} = -393.5$ kJ   33 kJ/g C   112 g CO_2/MJ

Coal = Anthracite = $C_{135}H_{96}O_9NS$

$$C_{135}H_{96}O_9NS_{(s)} + 156O_{2(g)} \rightarrow 135CO_{2(g)} + 48H_2O_{(g)} + NO_{(g)} + SO_{2(g)}$$

$\Delta H_{rxn} = -58.2 \times 10^3$ kJ   31 kJ/g $C_{135}H_{96}O_9NS$ 102 g CO_2/MJ [48]

Figure 1. Combustion reaction equations for fossil fuels (Guron, 2021)

Since the Industrial Revolution in the mid-18th century, and especially since the advent of globalization post-WWII, human emission of carbon dioxide has increased dramatically (WRI, 2019). This has global significance because carbon dioxide is a greenhouse gas. Greenhouse gases have a molecular structure that absorbs infrared radiation. When the radiation is absorbed, the molecule vibrates, transforming light energy into heat and increasing the temperature of the system (Mobius and Kroll, n.d.). For carbon dioxide, the most important wavelength of absorption is ~15µm (Figure 2), which is the wavelength emitted by radiation from the Earth (as opposed to incoming light from the sun).

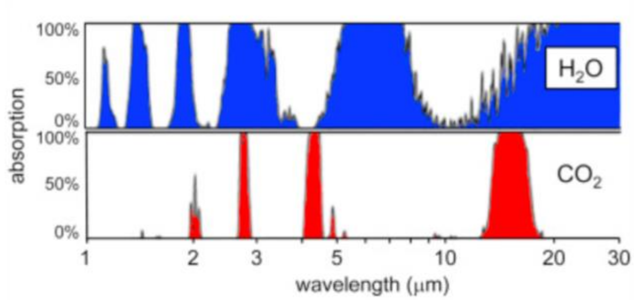

Figure 2. Absorption spectrum of H_2O and CO_2 (Anderson et al., 2016)

More carbon dioxide in the atmosphere means greater rates of trapping the radiation emitted by the Earth and storing it in the atmosphere. Because temperature is a major driver of the global climate system (Loubere, 2012), these changes have significant impact around the world, including melting ice caps, rising sea levels, and inducing more severe weather events (IPCC, 2019). These events have already created millions of "environmental refugees" as humans flee untenable living conditions; future changes in agriculture and water availability, as well as conflict resulting from scarcity, have the potential to "generate 143 million more climate migrants by 2050" (Podesta, 2019). Given the grave consequences of relying on fossil fuel combustion for energy, there are major research and investment initiatives to find new energy sources and reduce greenhouse gas emissions. Several of these "clean" energy solutions rely on critical minerals (Figure 3).

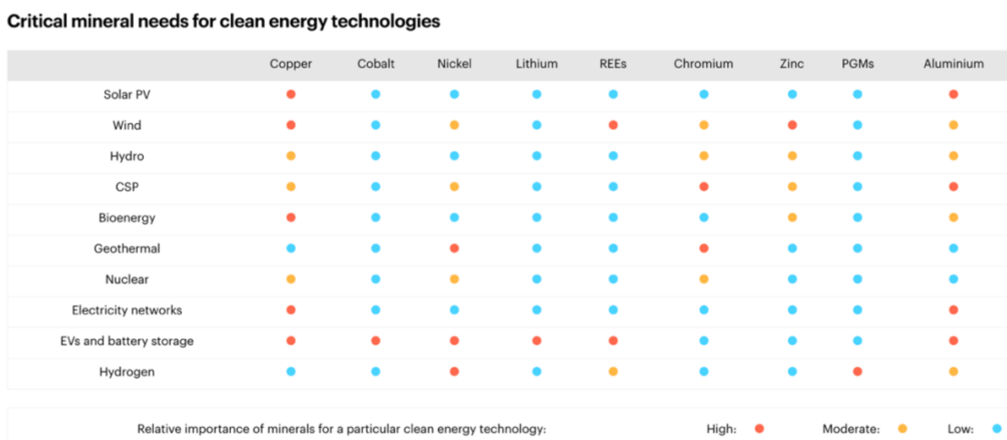

Figure 3. Relative importance of critical mineral in clean energy technology

Although different clean energies require different inputs of critical minerals, the most popular solutions rely on battery storage networks. Since taking office in early 2021, the Biden administration has made sweeping proposals for investing in solar (Penn, 2021) and wind energy (Grandoni, 2021). Because the wind does not always blow at the same speeds and solar energy only produces during the day, both of these solutions require battery storages to provide reliable power. Additionally, nearly all global automakers are releasing electrical vehicles, and the Biden administration has pushed for 50% of car sales to come from electric vehicles (EVs) by 2030 (Wayland, 2021).

The minerals most necessary for these applications are copper, cobalt, nickel, lithium, REEs (rare earth elements), and aluminum (Figure 3). Although the Department of Interior critical minerals list was drafted prior to the publication of many of these plans, they were long anticipated, and market projections for the components of EVs and battery storage are significant (Figure 4).

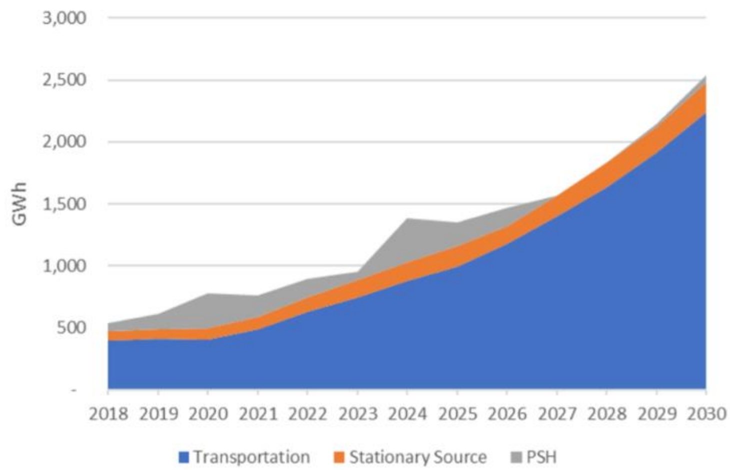

Figure 4. Global energy storage market (DoE, 2020)

PSH stands for "pumped storage hydropower"

Sociopolitical Aspects of "Supply Chain Risk"

As societies transition away from fossil fuels toward battery-based electricity storage systems, some of the most necessary materials to accomplish these goals may not be reliably available to the United States. A key aspect of the term "critical" is that it only applies to the U.S., and it refers to both economic and security interests. Economic interest in energy and transportation are clear. In addition to these daily necessities, this technology transition may hold grave military consequences. Paralleling a century earlier, Winston Churchill laid the bones of the 20th century by committing the British Navy to transition from coal fired ships to oil (Yergin, 1991). As the major imperial power of the time and with no domestic access to oil, the number one military in the world became dependent on obtaining cheap and reliable sources of fuel for its navy. As this mantle of empire was later taken up by the United States post-WWII, the quest for oil and its attendant benefits has been the cause of countless deaths and a century of military interventions (Andreas, 2015). Facing a new source of military and economic dominance, the U.S. must maintain reliable access to these materials if they are to sustain their preeminence into the 21st century. "Mastery itself," is once again "the prize of the venture." Already, the quest for lithium has directed imperialist strategy in the 21st century. Remembering that motivations for the Iraq War were waged on "false intelligence" (Left, 2004) it is important to note that following the U.S. invasion of Afghanistan in 2003, the nation's 2004 application to join the World Trade Organization specified foreign investor protections from the "Minerals Law 2014" for the U.S. and its allies (Canada, the European Union, Japan, Korea, Norway, Chinese Taipei, Thailand, Turkey)(WTO, 2016). An internal Pentagon memo from 2010 called Afghanistan "the Saudi Arabia of lithium" (Risen, 2013), and access to its trillions of dollars of mineral wealth would be a huge economic and strategic boon for the United States.

More recently, and following a long history of U.S. interference in Latin American elections (Andreas, 2015), the first indigenous president of Bolivia was ousted based on flawed reports of election fraud from U.S.-backed Organization for American States during elections in October 2019 (Kurmanaev & Trigo, 2020). These reports came around the same time then-president Morales cancelled a $250 million dollar December 2018 export agreement with the German corporation ACI Systems Alemania which supplies batteries for Tesla's electric vehicles(Weindling, 2019).

Recognizing that critical minerals, by definition, include a significant military component, the definition of supply risk proposed by Nassar and Fortier (2020) acknowledges several sociopolitical limits to resource availability. They named "trade wars, labor strikes, market bubbles" and countries who "unable or unwilling to supply the United States based … ideological, and defense ties with the United States." Although these concerns apply to many nations for a variety of reasons, some nations are more prominent than others. Surveying the top 25 countries with a major role in the lithium-ion battery supply chain (Fig. 5) reveals that by 2025, China is expected to refine more than 75% of all global raw materials involved in the supply chain. This advantage is well recognized in China, and a wide-spread quote from former Chairman Deng Xiaoping in 1992 stated, "中东有石油，中国有稀土," translated to English, "The Middle East has oil and China has rare earths" (Xinhua, 2011).

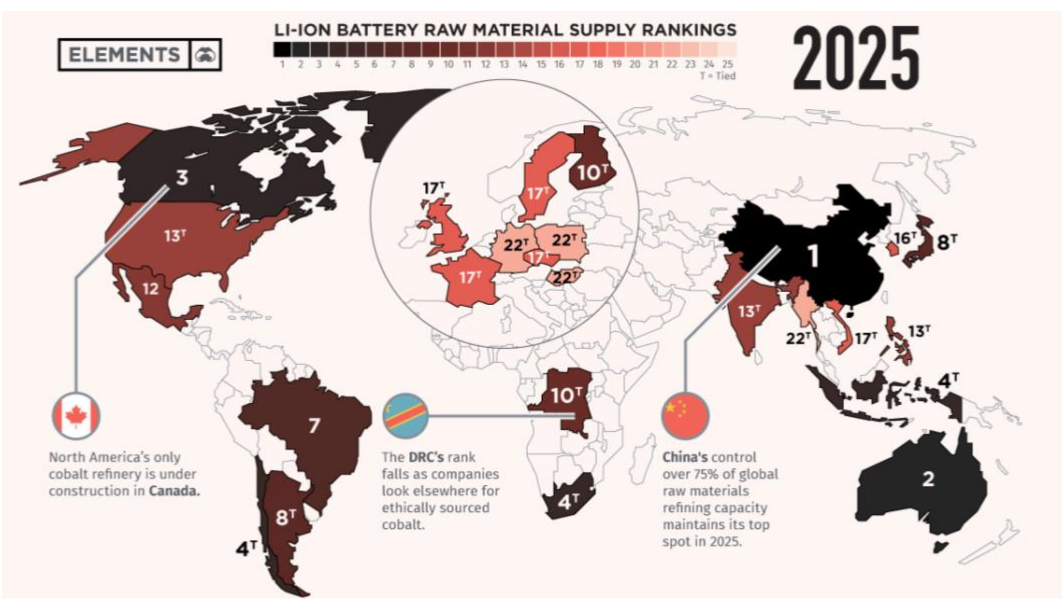

Figure 5. Lithium-ion Battery Raw Material Supply Rankings (Bhutada, 2021)

Although the relationship between these two political powers is complex beyond the scope of this paper, recent years have seen a "general souring of attitudes toward the

China market" (Swaine, 2019). This newest rise in tension comes after several decades of Chinese government policy using rare earth minerals to support nationalist interests. In 2010, a Chinese fishing trawler entered contested waters around the Japanese controlled Senkaku Islands and the captain was arrested by members of the Japanese Coast Guard (Bradsher, 2010). Following the detention of the captain, China allegedly halted export of rare earth elements to Japan, disrupting commercial contracts and "emphasiz[ing] the need for geographic diversity of supply." In 2012, China significantly restricted its exports of rare earths, sending global prices soaring and initiating a World Trade Organization complaint from the Obama administration (WTO, 2015).

The longer history is how China came to wield such political leverage by decades' worth of societal planning. At the time of the trawler incident, China mined "93 percent of the world's rare earth minerals, and more than 99 percent of the world's supply of some of the most prized rare earths" (Bradsher, 2010). That market dominance emerged over a several decade span of investment starting in the 1970s (Veronese, 2015). Although China only holds 1/3rd of global rare earth reserves, it invested heavily in mining and refinery infrastructure, allowing it to produce high-quality, low-cost rare earths that significantly undercut the global market and forced other mines to close their operations. Some fifty years later, China holds a relative export monopoly on the 17 rare earth elements and a few other critical industrial minerals. Although politically advantageous to the U.S., the goal of increasing "geographic diversity of supply" is undermined by continued investment from the Chinese government and less restrictive environmental and labor regulations reducing costs relative to mining operations in countries with a stronger regulatory statutes (see author's note on bias under Teaching Strategies).

Environmental Hazards of Mining Critical Minerals

When China limited rare earth exports in 2012, it cited environmental concerns as a major policy driver. Observing that rapid production puts short-term profit over long-term sustainability, and amidst widespread reports of rare earth contamination from mining areas in Inner Mongolia and Guangdong and Jiangxi (Morrison and Tang, 2012), the environmental hazards of mining critical minerals are relevant for global producers of rare earths and critical battery storage components looking to diversity the supply chain.

Figure 6. Bayan Obo world biggest rare earths mine, Baotou, Inner Mongolia, China

There are several different methods of extracting rare earth minerals depending on the depth and quality of ore body (Mission 2016, 2012). The risks and consequences of environmental damage vary considerably by extraction method, presence of oversight agencies, and extent of financial investment in health, safety, and infrastructure. Because of how rare earths are formed in the crust of the earth, they often coexist with radioactive elements which can be released into the air, water, or soil upon extraction.

Teaching Strategies

Before introducing the science, it is important as an author and educator to acknowledge my own upbringing and biases in reporting the economic and sociopolitical significance of critical minerals. I am a U.S. citizen who only speaks English, and I exist in a jingoistic culture with powerfully self-interested corporate media entities. This paper is not meant to simply reduce the United States and China to antagonistic competitors for economic and military dominance. However, my narrative is deeply informed by limited experience and desire for a concise retelling. Students in the School District of Philadelphia, but especially Furness High School, have lives and experiences reflecting an incredible diversity of backgrounds. Intentionally discussing bias and perspective before research and presentations may better cultivate nuanced and respectful conversations in the classroom.

Hands-On Laboratory Experiments

Although it is common sense that utilizing professional science practices in the classroom would be more effective than memorizing facts and concepts, this intuition has significant support from recent psychology publications. In a bold summary of research at the University of Chicago's Human Performance Lab, "Students who physically experience scientific concepts understand them more deeply and score better on science" (Ingmire, 2015). Using functional MRIs on college physics students, psychologist Sian Beilock demonstrated that students who physically manipulated the components of an experiment utilized sensory and motor regions of the brain which were then activated during assessment tests. Students who watched videos or manipulated virtual components did not experience the same multisensory encoding and did not perform as well on assessment metrics.

Translating this research to the high-school classroom is not just substantiated by research but is urged by the Next Generation Science Standards (NGSS, not yet adopted in Pennsylvania). These standards identify eight key science and engineering practices, including planning and carrying out investigations and analyzing data (NGSS, 2013). More NGSS practices may be incorporated into hands-on experiments depending on how an instructor wants to adjust their research, assessment, and presentation of findings. By conducting research using the skills of professional researchers, more students are intellectually engaged, better prepared for careers in science and technology, and equipped with tools for thoughtful and reflective citizenship.

Accessibility via Social Media

A culminating step in the scientific method is to publish and discuss research findings. At the professional level, there are rigorous standards for formatting and submitting to peer reviewed journals. However, these venues are increasingly inaccessible to scientists, let alone interested citizens, and this inaccessibility has consequences for who is able to participate in research and scientific progress (Schmitt, 2019). By allowing students the option to adapt their research for popular media like Twitter or TikTok, it harnesses communication skills and creative practices that are not always utilized in the science classroom. Adding an element of competitive "influencer" aspect with the lure of bonus points to the team with the top engagement increases the likelihood that students will think meaningfully about data presentation and potentially increase science engagement beyond the classroom.

Despite the limited depth of subject matter that can be addressed in social media, it can provide searing insights (Figure 7) and dark comedy (Figure 8) that are not available in the traditional lab report format.

Figure 7. Elon Musk tweet responding to allegations of U.S. intervention in Bolivia

Figure 8. Screenshot of TikTok video showing a list of countries whose governments the U.S. has tried to overthrow since World War II

Classroom Activities

Hands-On Experiments

The following hands-on experiments are designed to be conducted in order, but not all of them are required and may be altered or adjusted based on time, materials, or appropriateness for student age and ability.

Comparing Combustion Reaction of Fossil Fuels

Where does our energy come from now? Direct instruction and note taking emphasize society's current reliance on fossil fuels for energy. This experiment allows student to confirm that combustion reactions release energy and carbon dioxide and make comparisons about energy density across fuel sources. May be conducted over the course of 90 minutes or two, 45 minute classes. Experiment adapted from Ortiz (2013).

Materials:

- Muffin tin
- 1 tsp. each of diesel, gasoline, and ethanol
- Matches or lighter
- Water
- Beaker
- Glass or metal container
- Clamp stand and clamps
- Vernier GoDirect CO_2 (Carbon Dioxide) Gas sensors
- Vernier GoDirect Temperature sensors
- Computer
- Timer

Procedure:

WARNING This experiment requires open flame. Conduct this experiment away from flammable materials and on heat-resistant surfaces.

- Collaborate with team to prepare working stations with appropriate supervision for use of flames and combustible materials
- Install "Vernier Graphical Analysis" software and calibrate temperature and CO_2 measurement equipment
- Measure one teaspoon of a fossil fuel into one pan of the muffin tin

- Suspend glass or metal container above muffin tin and affix glass or metal containers with equal amounts of water for each combusted fossil fuel
- Measure temperature change of the water for each combustion as well as CO_2 released near the flame while keeping the instruments at appropriate distance
- Analyze rate and absolute values measurements
- Option to create formal lab report or publish findings via social media

Demonstrating Relationship of Carbon Dioxide and Temperature

In this hands-on activity conducted over 90 minutes, students experimentally demonstrate the relationship between increased carbon dioxide and increased temperature.

Materials:

- Two bottles or sealable vessels
- Two caps or stoppers
- Vernier GoDirect Temperature sensors
- Vernier GoDirect CO_2 (Carbon Dioxide) Gas sensors
- Computer
- Clay
- Water
- Alka Seltzer tablets
- Beaker
- Infrared heat lamp, plant lamp, incandescent bulb, sunlight, and/or heater

Procedure:

- Collaborate with team to prepare working stations with appropriate access to outlets and recording materials
- Install "Vernier Graphical Analysis" software and calibrate temperature and CO_2 measurement equipment
- Measure equal volumes of water into two sealed containers adding alka seltzer into one of them to mimic increased carbon dioxide in the atmosphere
- Collect temperature data for one hour, then measure CO_2 at end for both experimental conditions
- Analyze rate and absolute values of increased measurements
- Option to create formal lab report or publish findings via social media

Measure Electricity

Before instructing students in design of renewable energy sources utilizing critical minerals, students need to learn the basics of measuring electricity. ~5 - 15 minutes.

Materials:

- Digital multimeter
- Red and black lead wires with probes (or alligator clips)

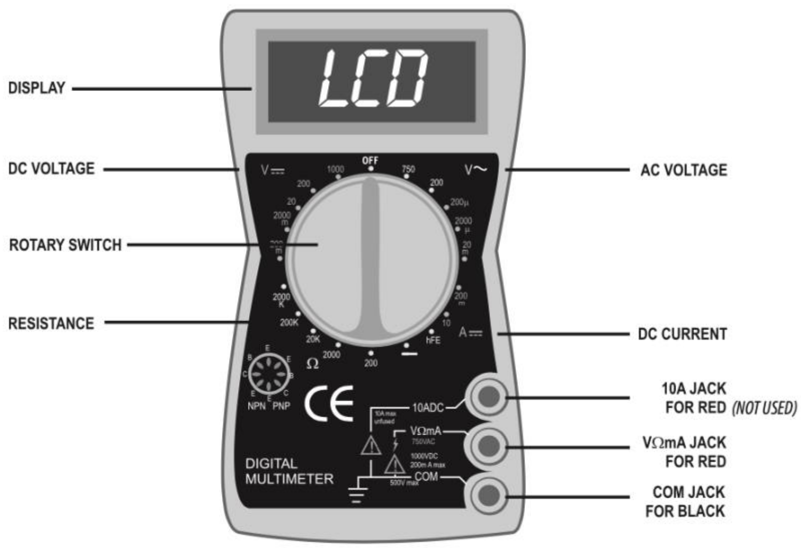

Fig. 9. Basic features of a digital multimeter (NEED, 2020)

1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to highest setting on DC VOLTAGE scale (1000).
3. Connect probe tips to a battery to be tested (may use alligator clips if a battery housing is provided as in some high-school electronics kits).
4. Adjust ROTARY SWITCH to lower settings until a satisfactory reading is obtained.
5. With the hydropower turbine, usually the 20 DCV setting provides the best reading.

Build a Generator without Generating Carbon Dioxide

Adapted from "How to Build a Simple Electric Generator" from wikiHow Staff (2021).

Materials:

- Digital multimeter
- Red and black lead wires with probes (or alligator clips)
- Carboard
- Scissors
- Ruler
- Iron nail (or other metal
- 200' enamel coated copper wire (#30 magnet wire) per group
- Wire stripper
- Red LED, #49 miniature bulb, or 1.5V grain-of-wheat lamp
- Ceramic magnets
- Hot glue or epoxy

1. Build a cardboard frame to house the magnet.
2. Insert a nail or other piece of metal through the frame
3. Wind 200' of copper wire around the frame as tight as possible. Leave 15" free on both ends to attach a bulb.
4. Glue magnets onto the nail so that they can spin within the frame
5. Attach bulb to wires to complete the circuit
6. Rotate the magnets to produce current and light the bulb.
7. Students may attach the multimeter to measure voltage in the wire.

Build a Better Generator using Renewable Resources

The experiment in this section was developed by the National Energy Education Development (NEED) Project and shared through the PECO PECO "PEEP" workshop (details in Appendix: Classroom Materials for Hands-On Projects).

In this section, the class may be divided into two to eight teams depending on size of the classroom and resource availability. Teams will research wind power as means for electricity generation without producing greenhouse gases. Teachers may assess student engagement with the background material or simply require an application step where students improve on electricity generation from the previous experiment.

Complete the previous experiment but now task students with designing blades and improving the magnet and frame to increase voltage in the system while reducing material use and overall mass.

Materials:

- reuse materials from “Simple Electric Generator
- cardboard
- pencils
- wooden dowels
- binder clips
- paper clips
- duct tape
- bar magnets
- horseshoe magnets
- ring magnets
- rare earth magnets, e.g. neodymium iron boron or samarium cobalt
- any other materials students may source for their design
- Tool for documenting photos and videos of the process

Accessibility via Social Media

A culminating step in the scientific method is to publish and discuss research findings. At the professional level, there are rigorous standards for formatting and submitting to peer reviewed journals. However, these venues are increasingly inaccessible to interested (Schmitt, 2019).

Creating Guidelines for Respectful Conversation

This activity introduces the discussion and presentation portion of the unit and is adapted from Moran (2020). In order to support students to speak respectfully on potentially sensitive subjects, they discuss what guidelines should guide that respect and develop a sense of empathy for how words can be hurtful when used thoughtlessly.

Procedure:

- Think-Pair-Share, “What phrases, images, and emotions come to mind when you hear the word ‘dominance’? Why do people try to dominate each other? How is domination different when it’s between different governments?”

- Introduce, "We have classmates with knowledge and experience from many different countries and cultural backgrounds." Ask students to discuss at their tables what a supportive classroom environment would look like when having conversations about international politics. "What kind of tone, words, and attitudes would be present in the classroom? How do you hope people respond to different viewpoints? How can the teacher help support an environment that feels safe and inclusive?"
- Students write and publish their responses to an anonymous interactive board such as Lumio (formerly SLSO).
- Students discuss at tables and vote to adopt or reject the proposed resolutions until the whole class can reach a consensus on respectful discussion guidelines

"Influencing" Science Talk

In this culminating project over the course of three, 90 minute class periods, students will work in teams to analyze existing social media posts about climate and energy awareness, then compete against each other to design and produce social media campaigns vying for "top influencer" status. Each team will have three to four students. One or two students document research about fossil fuels, carbon dioxide, and climate change. Two students summarize research findings about electricity generation and their design process for more efficient energy production. One or two students may be doubly tasked with a "journalism research component" to gather information about geopolitical issues and human rights abuses associated with extraction and implementation of these minerals. Together, they design, produce, and promote "social media material" citing their research and have 24 hours to get the most views and likes (1 like = 1.5 views).

Rubric for evaluating social media posts:

Is it factual? Verify the information in the post with one other reputable source	It is interesting or compelling? What aspects make it more relatable.	Is it relevant? Does it have information specific to the topics of our class?	Is it class appropriate? Videos may not contain inappropriate language or imagery.

Existing social media posts for evaluation:

- Afghanistan events to impact the stock market
- Electric trucks?
- Global warming is heating the oceans (funny, not informative)
- Antarctica and ice melting

- Climate doesn't have to change (funny, not informative)
- What are rare earth minerals (difficult to understand because of edits)
- How big is a wind turbine?
- Different shape of wind turbine
- Ocean fires due to oil spills
- Summary of IPCC report
- Gaslighting and politics around climate change
- Wildfires in California

Using existing social media posts as a guide and the rubric above, students construct two to three TikToks or Instagram live posts, each 15 to 60 seconds long. Before releasing their content, they must demonstrate to the teacher that they have covered each of the four rubric points above – is their material factual, interesting, relevant, and school appropriate? Students may post to twitter or other media sites after consultation with teacher. Students who post earlier have an advantage of getting more views in the week of designing and implementing.

Assessment Rubric

Teachers may elect to add bonuses for groups who engage the most likes, most views, most creative presentation, best evidence, etc..

GRADE	CONTENT	ORGANIZATION	ORIGINALITY	WORKLOAD
4	Topic is covered in–depth with many details and examples. Subject knowledge is excellent.	Content is very well organized and presented in a logical sequence.	Presentation shows much original thought. Ideas are creative and inventive.	The workload is divided and shared equally by all members of the group.
3	Presentation includes essential information about the topic. Subject knowledge is good.	Content is logically organized.	Presentation shows some original thought. Work shows new ideas and insights.	The workload is divided and shared fairly equally by all group members, but workloads may vary.
2	Presentation includes essential information about the topic, but there are 1–2 factual errors.	Content is logically organized, but with a few confusing sections.	Presentation provides essential information, but there is little evidence of original thinking.	The workload is divided, but one person in the group did not do his/her fair share of the work.
1	Presentation includes minimal information or there are several factual errors.	There is no clear organizational structure, just a compilation of facts.	Presentation provides some essential information, but no original thought.	The workload is not divided, or several members are not doing their fair share of the work.

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Appendix

A description of how your unit implements the academic standards; and additional materials you wish to provide, such as handouts, evaluation rubrics, etc.

Standards Alignment

In the context of Environmental Science in the School District of Philadelphia, this lesson will follow the Office of Content Instruction's "Year-at-a-Glance" planning document. Quarter 3 ends with an exploration of how climate change works, while the focus of Quarter 4 is a human impact research project that evaluates and refines solutions for reducing those impacts. Implemented over a series of weeks, there are mini-lessons for how to evaluate information alongside scientific content lessons about what makes critical minerals so "critical." Pennsylvania state standards include **BIO.B.4.2.4** **"**Describe how ecosystems change in response to natural and human disturbances" and **BIO.B.4.2.5** "Describe the effect of limiting factors on population dynamics and potential species extinction." Although Pennsylvania has not officially adopted Next Generation Science Standards (NGSS), the OCI planning document aligns to **HS-LS2-7** **"**Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity."

Classroom Materials for Hands-On Experiments

All supplemental materials and hands-out for experiments are available below. If conducted experiments in the School District of Philadelphia, many of the data collection tools are available by request from the PSD Science Lending Library.

An additional resource available to teachers are PECO PEEP Workshops conducted in partnership with the National Education Energy Development (NEED) Project workshops available to 3 - 12 teachers in the Greater Philadelphia Area. As of the 2021 school year, these workshops introduced teachers to current energy practices and hands-on activities for students as well as providing a stipend and free classroom activities kits (valued up to $550) for exploring renewable or nonrenewable energy sources.

Comparing Combustion Reaction of Fossil Fuels

- Complete laboratory summary

Demonstrating Relationship of Carbon Dioxide and Temperature

- Pre-lab introduction EdPuzzle: The Greenhouse Gas Demo
- CO_2 and Temperature Lab Handout

- NASA Global Temperature Change Graphing Assignment (graphically demonstrate global temperature increases during the one-hour data collection period)
- Lab Report Format
- Post-lab Questions

Measuring Electricity

- Using a digital multimeter

Renewable Energy Background Information

- Water
- Wind

Generate Electricity with Magnets

- Build a Simple Electric Generator

List of 35 Critical Minerals

- Aluminum (bauxite), used in almost all sectors of the economy
- Antimony, used in batteries and flame retardants
- Arsenic, used in lumber preservatives, pesticides, and semiconductors
- Barite, used in cement and petroleum industries
- Beryllium, used as an alloying agent in aerospace and defense industries
- Bismuth, used in medical and atomic research
- Cesium, used in research and development
- Chromium, used primarily in stainless steel and other alloys
- Cobalt, used in rechargeable batteries and superalloys
- Fluorspar, used in the manufacture of aluminum, gasoline, and uranium fuel
- Gallium, used for integrated circuits and optical devices like LEDs
- Germanium, used for fiber optics and night vision applications
- Graphite (natural), used for lubricants, batteries, and fuel cells
- Hafnium, used for nuclear control rods, alloys, and high-temperature ceramics
- Helium, used for MRIs, lifting agent, and research
- Indium, mostly used in LCD screens
- Lithium, used primarily for batteries

- Magnesium, used in furnace linings for manufacturing steel and ceramics
- Manganese, used in steelmaking
- Niobium, used mostly in steel alloys
- Platinum group metals, used for catalytic agents
- Potash, primarily used as a fertilizer
- Rare earth elements group, primarily used in batteries and electronics
- Rhenium, used for lead-free gasoline and superalloys
- Rubidium, used for research and development in electronics
- Scandium, used for alloys and fuel cells
- Strontium, used for pyrotechnics and ceramic magnets
- Tantalum, used in electronic components, mostly capacitors**
- Tellurium, used in steelmaking and solar cells
- Tin, used as protective coatings and alloys for steel**
- Titanium, overwhelmingly used as a white pigment or metal alloys
- Tungsten, primarily used to make wear-resistant metals**
- Uranium, mostly used for nuclear fuel
- Vanadium, primarily used for titanium alloys
- Zirconium, used in the high-temperature ceramics industries

Political Cartoon

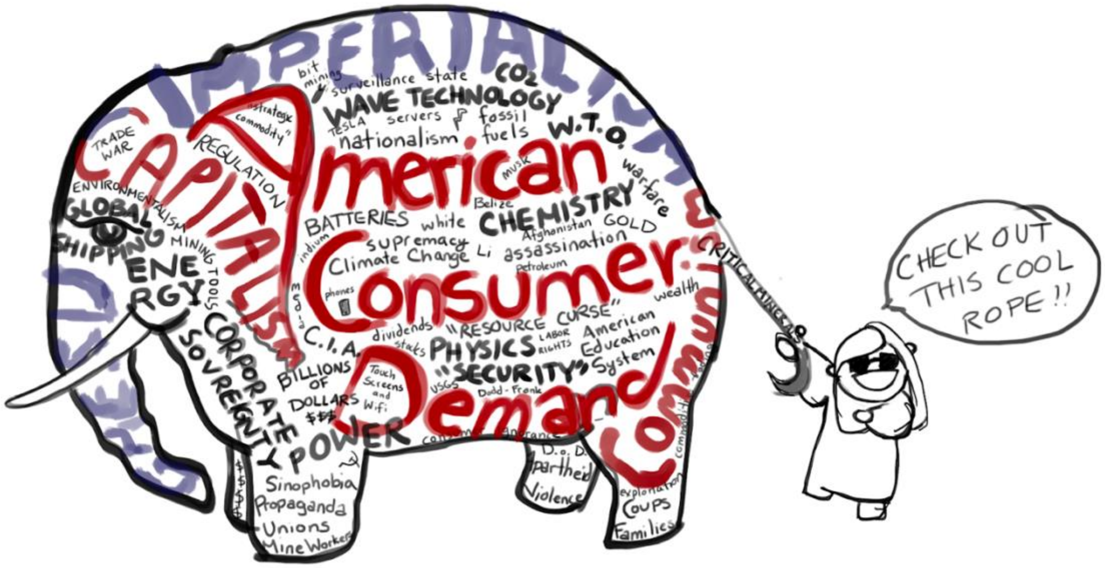

Figure 10. The Elephant in the Room