Abstract Title: Initiating Environmental Justice in K-12 Engineering Curriculum Design through StoryMaps.

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Abstract:

While engineers have been understood as people who protect and improve the safety, health, and welfare of people in/and the environment through the use of their knowledge and skillsets, the practice of engineering has often been misaligned with this understanding. Engineering has had and continues to have an active and uniquely central role in global environmental injustice, particularly through its maintenance of extractive industries and infrastructures such as fossil fuels. Transitioning from extraction-based, “cradle-to-grave” infrastructures towards environmentally just, sustainable “cradle-to-cradle” infrastructures is an imperative of engineering education.

Designing EJ engineering curriculum offers opportunities for engineering students to learn from this history of engineering environmental injustice and its present day impacts while forefronting examples of engineering that align with the 17 Principles of Environmental Justice. Through collaborations between universities and K-12 schools, the authors developed and worked with K-12 instructors to implement EJ StoryMaps modules focused on the intersection between transportation infrastructure and impacts on humans and the environment. These EJ StoryMaps were implemented through a Creative Engineering Design (CED) introductory-level high school course pilot and leverage ArcGIS StoryMap technology to explore real-world spatial environmental justice data. In this paper, we highlight how the principles of environmental justice guided the development and implementation of EJ StoryMaps related to air quality and public health, how transportation affects the environment and equity, and EJ impacts of lithium mining/extraction for electric vehicle batteries. We also discuss potential updates to those existing EJ StoryMaps modules that have been implemented and additional modules under development focused on transportation infrastructure that cleans water and heals land.

Introduction

While engineers have commonly been understood in the U.S. as people who protect and improve the safety, health, and welfare of people in/and the environment through the use of their knowledge and skillsets, the practice of engineering has often been misaligned with Environmental Justice (EJ) movements. Engineers have built unsustainable and inequitable processes and infrastructures sustaining a plethora of global environmental injustices. The centuries-long accumulations of these global injustices have led to a state that stresses the balance of global ecological, climate, and cultural boundaries. Transitioning from environmentally unjust “cradle-to-grave” infrastructure based on extraction and disposability that engineering sustains towards environmentally just “cradle-to-cradle” infrastructures that are sustainable and considerate of life and future generations is imperative for altering the relationships humans have to our environments.

Engineering education offers an opportunity for transforming the field of engineering to practice accountability for the historical harms caused and interrupt the injustices that continue to be enacted through engineering practices. As a movement rooted in spiritual interdependence to the sacredness of Mother Earth and the ecological unity of all species, EJ is a powerful force for transforming engineering education. Designing EJ engineering curricula offers opportunities for students and teachers in engineering courses to learn from historical and contemporary environmental injustices engineering has driven while speculating on forms of engineering that align with the *17 Principles of Environmental Justice* (EJ Principles, 1991). Bringing EJ into K-12 engineering education aligns with engineering habits of mind to support students, especially those that will become the next generation of engineers, in developing a strong foundation to point the future trajectories of engineering in new and equitable directions in addressing the world's wicked problems, such as climate change.

The mission of the ASPIRE (Advancing Sustainability through Powered Infrastructure for Roadway Electrification) ERC (Engineering Research Center) is to "improve health and quality of life for everyone by catalyzing sustainable and equitable electrification across the transportation industries," which on its surface would align with the goals of environmental justice movements. A key component of ASPIRE's Pre-College efforts is to provide K-12 curriculum development, outreach, and teacher professional development to support the center's Engineering Workforce Development and Diversity and Culture of Inclusion goals. The EJ StoryMap collection was developed as a core component of the NSF-funded Creative Engineering Design (CED) course, which is an introductory-level high school curriculum development project that focuses on the intersection between our transportation system and its impacts on people and the environment. CED is a project-based engineering course that engages students, especially those from underrepresented and underserved communities, in exploring ASPIRE's goal of widespread and accessible vehicle electrification as a solution to transportation-related air quality and climate change concerns. The course weaves threads of the engineering design process, engineering skills development, and environmental justice throughout. After the CED curriculum and the embedded EJ StoryMap collection were developed, educators were engaged in weekly check-ins to preview and provide feedback on the curriculum resources that were piloted in partnering high school classrooms. Teacher feedback is essential to refining the CED resources, including the EJ StoryMaps.

In this paper, we present two of the EJ Principles that guided the development and implementation of the EJ StoryMap collection; provide a summary of the StoryMaps that explore EJ in relation to air quality, public health, transportation impacts on the environment and communities, and impacts of lithium-ion batteries for EVs on people and the environment; share feedback from high school educators that piloted the CED EJ StoryMaps; and next steps in the EJ StoryMaps and present recommendations for including EJ in engineering education.

Environmental Justice Principles

The 17 EJ principles were drafted and adopted by the Delegates to the First National People of Color Environmental Leadership Summit held on October 24-27, 1991, in Washington DC. The EJ Principles were referenced to inform the development of the EJ StoryMaps, and as neither

author is a seasoned practitioner of environmental justice, the choice was made to focus on the following principles to highlight the StoryMap main topic areas:

1. Environmental Justice mandates the right to ethical, balanced and responsible uses of land and renewable resources in the interest of a sustainable planet for humans and other living things.
2. Environmental Justice affirms the need for urban and rural ecological policies to clean up and rebuild our cities and rural areas in balance with nature, honoring the cultural integrity of all our communities, and providing fair access for all to the full range of resources.

K-12 EJ StoryMaps

Centered on the focus of the ASPIRE ERC's vision for widespread roadway electrification of all vehicle classes to reduce transportation greenhouse emissions and support equitable EV access within the United States, the EJ StoryMap collection focuses on the relationships between air quality, transportation, and engineering connections (Taylor, 2023). The EJ StoryMaps leverage the ArcGIS StoryMap tool to explore real-world spatial environmental justice data. Targeting high school audiences, the EJ StoryMaps offer an initial exploration into environmental justice. The EJ StoryMap titles establish the essential question and themes of each online resource, which are scaffolded in a suggested scope and sequence, as follows:

- What is air quality and why does it matter?
- How does poor air quality affect our health?
- Are air quality and transportation impacts equitable?
- How does transportation affect the environment?
- How do electric vehicle batteries impact our world?

EJ StoryMap 1: What is air quality and why does it matter?

StoryMap 1 offers an introduction to air pollution and its impacts. It leverages a video about visualizing air pollution to prompt questions about how fossil fuel-powered transportation affects air quality. Focusing on the sizes and sources of particulate matter lead to connections to how air pollution can vary depending on proximity to pollution sources. The StoryMap then provides resources for understanding how air quality is measured and how factors such as level of air pollution emissions and weather conditions impact air quality.

The StoryMap then guides students in using the AirNow Air Quality GIS map to look at air quality at and near their school, see Figure 1. Moving into an EJSceen interactive map, students are asked to locate and source particulate matter air pollution and vulnerable communities (e.g. low income, people of color), see Figure 2. After the GIS mapping, students are asked to discuss connections to engineering with examples of civil and environmental engineers tackling transportation-related pollution. The StoryMap closes asking students to reflect on and discuss how transportation-related pollution could be addressed.

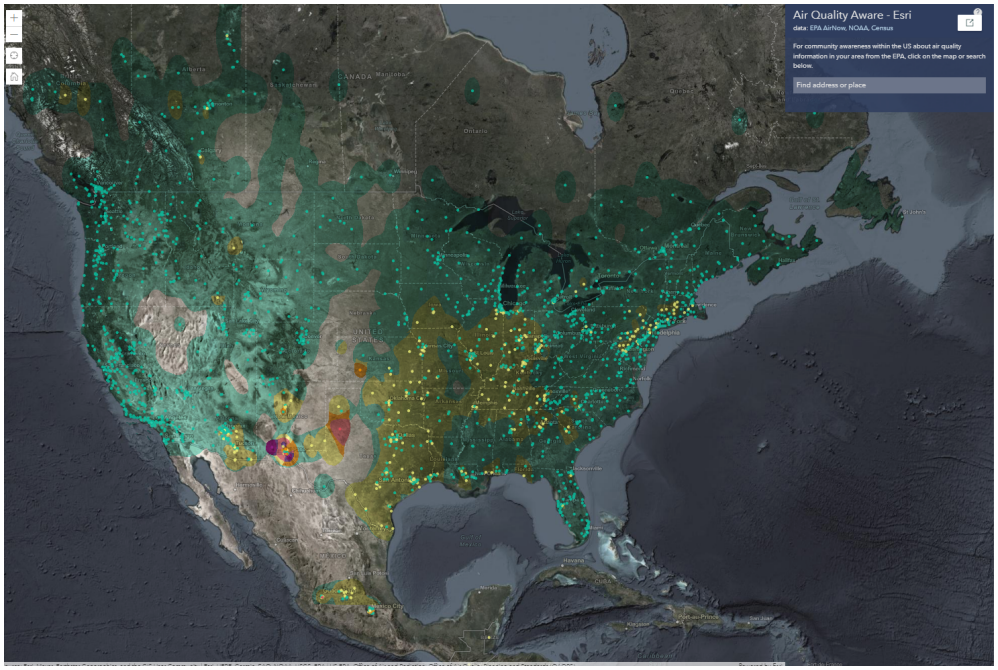

Figure 1: Image of AirNow.gov Air Quality Real-Time Data along with prompts students were asked to use.

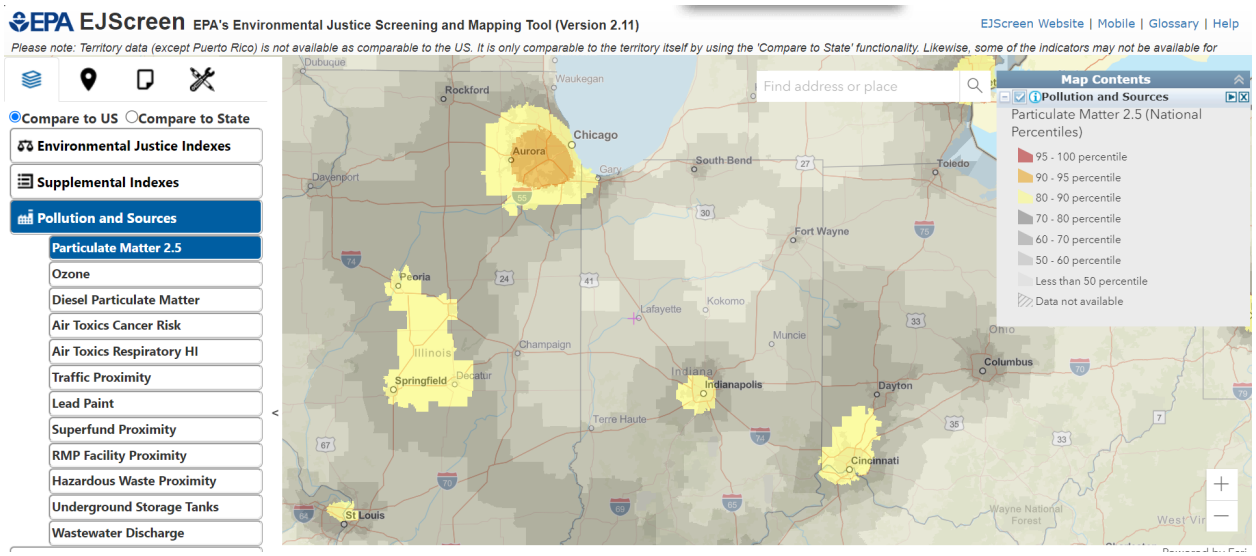

Figure 2: EPA EJScreen of PM 2.5 Data.

EJ StoryMap 2: How does poor air quality affect our health?

StoryMap 2 builds on StoryMap 1 and focuses on health effects of particulate matter. Students watch a video describing how particulate matter moves through the body and look at the scope of air pollution impacts through global premature deaths caused by air pollution. This scope zooms in to discuss groups differentially vulnerable to premature death caused by air pollution such as young people, older adults, and low income people. A video describes actions to take when air quality is poor.

Leveraging the AirNow Air Quality GIS map, students are invited to compare and contrast air quality in their location and different areas. Students are then guided to use the EJScreen interactive map to connect socioeconomic indicators like race and income to asthma risk, see Figure 3. The StoryMap closes with a connection to biomedical engineering as a field where engineers seek to assess and improve people's health and questions about how transportation and vehicle electrification may impact particulate matter pollution and air quality.

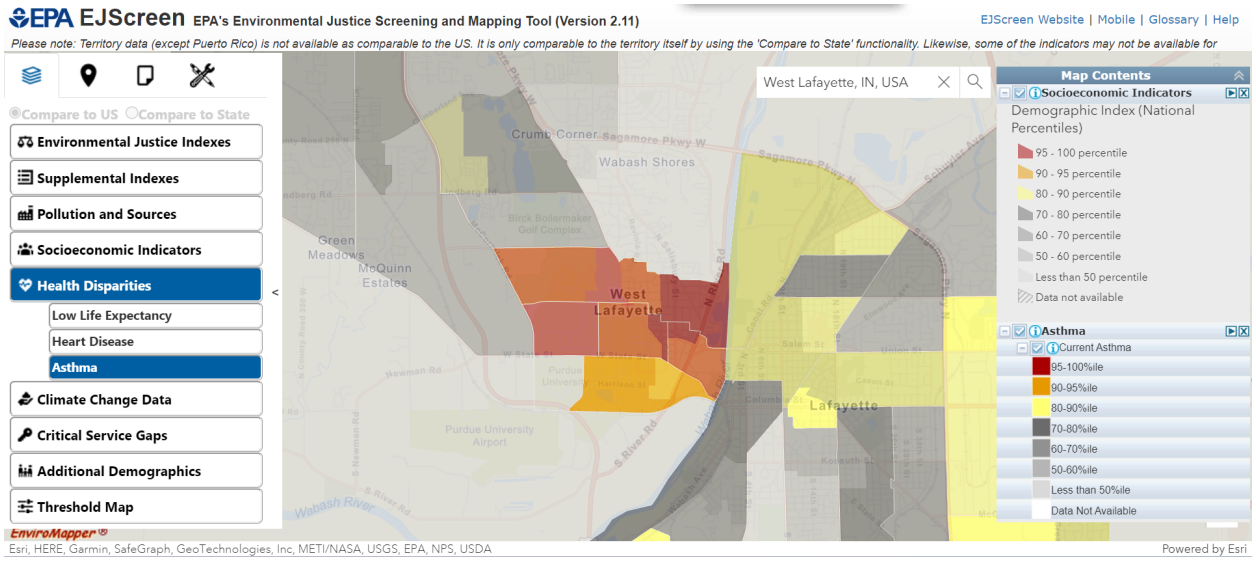

Figure 3: EJScreen map comparing asthma risk and income data.

EJ StoryMap 3: Are air quality and transportation impacts equitable?

StoryMap 3 is the space where environmental justice is formally introduced and explained in the StoryMaps. Students are introduced to local grassroots action and national policy action as two avenues environmental justice practitioners leverage to transform conditions driving air pollution and its inequitable impacts.

The StoryMap then turns toward transportation related emissions accounting for more than half of all air pollution in the U.S. and reinforces prior StoryMaps detailing how race and ethnicity disproportionately correlate to air pollution. This focus on transportation related air pollution is contextualized with background on how transportation within the U.S. became dominated by cars and trucks. Students watch a video and discuss how auto corporations drove U.S. highway construction, transforming U.S. transportation to center cars while disrupting and dividing BIPOC urban communities and enabling white communities to segregate themselves in developing suburbs and commute to cities for work.

Students are then asked to use the AirNow Air Quality GIS map to overlay air quality with race, population age, workforce risk, and asthma rates. Students transition to look at traffic proximity by location. Students are then asked to use EJScreen interactive maps to look at traffic proximity with the locations of communities of color and then the locations of low income

communities, see Figure 4. After using the GIS map, students are reminded that engineers are supposed to follow professional ethics to protect and improve the safety, health, and welfare of people and the environment. Environmental engineers are posed as engineers focused on solving environmental problems before the StoryMap closes asking students to discuss solutions to create environmental equity.

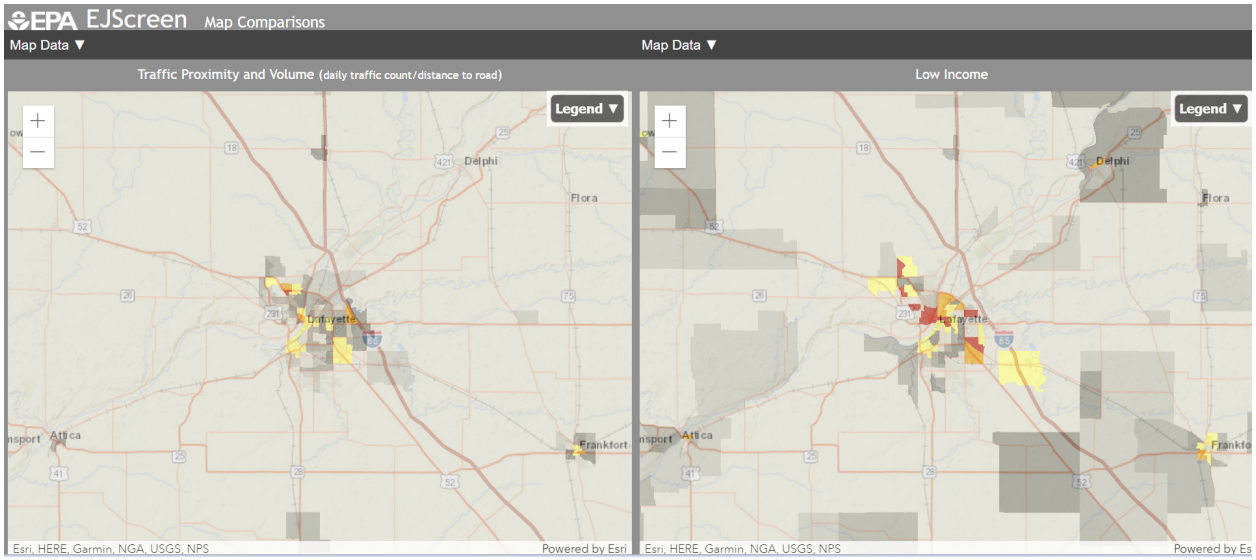

Figure 4: EJScreen maps showing traffic proximity and volume (left) to the location of low income communities (right).

EJ StoryMap 4: How does transportation affect the environment?

StoryMap 4 connects different types of motorized vehicles to air quality and human-caused sources of climate change. Students are introduced to how a fossil fuel powered vehicle works by producing exhaust emissions directly from the vehicle to move.

Students then are introduced to how an electric vehicle works by charging and discharging batteries which do not produce exhaust emissions directly from the vehicle to move. This comparison then pivots toward discussing the greenhouse effect and linking emissions to global warming. The StoryMap then shows data on which greenhouse gasses are primarily emitted and how the three main sources are transportation, electricity, and industry. The StoryMap moves to illustrate that personal vehicles are predominantly used in the U.S. and that personal cars and trucks use the overwhelming majority of fuel and produce the majority of CO_2 greenhouse gas emissions in the country. Students are then introduced to how most trips taken are less than 6 miles in distance, and that most people drive alone to get to work.

Students are then walked through the history of the electric vehicle, seeing how cheap gasoline vehicles outcompeted electric vehicles in the early 1900s to dominate the automobile market and that advances in battery technology in the past couple decades has increased the popularity of electric vehicles. Students are then asked to compare the cost of electric cars to

gas powered cars, invited to take a virtual test drive of a Tesla, and shown a video describing how electrified roadways could link the electric grid with electric vehicles.

To reinforce the connection between fossil fuel powered vehicles, emissions, and air quality, students were asked to use the AirQuality Interactive Map to compare air quality in urban and rural areas. Students then used the EJScreen interactive map to connect respiratory health risks in communities of color with the locations of roads. After framing the problem as fossil fuel burning vehicles, connections are made to the work mechanical and electrical engineers are doing to develop electric vehicles. Students are then asked to discuss clean energy transportation solutions.

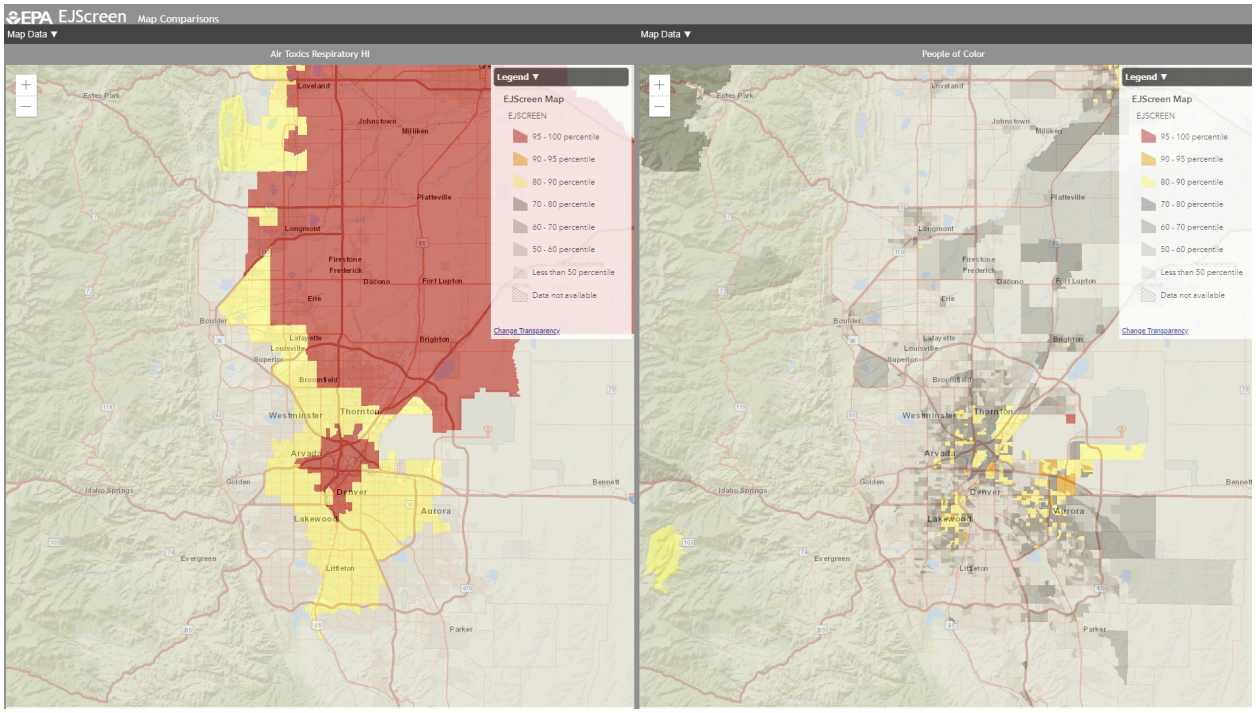

Figure 5: EJScreen map comparisons of pollution sources and air toxics risk (left) and socio-economic and communities of color (right).

EJ StoryMap 5: How do electric vehicle batteries impact our world?

StoryMap 5 complicates the narrative that EVs are a sustainable transportation solution since EVs are usually framed by their zero greenhouse gas exhaust emissions, but the current battery that charges EVs is the lithium-ion battery and lithium is a finite natural resource making it a limited climate solution.

The StoryMap starts with students watching a video where a mother explains how the expansion of the nickel mining industry that provides materials for EV battery production near her home village has negatively impacted the health of her family and contaminated the surrounding air and water. The video finishes by framing how sustainable geothermal energy

could alleviate emissions from nickel processing that is used in electric vehicle battery production.

The StoryMap then provides a primer on batteries and the different components and materials used in batteries. The lithium-ion batteries are then introduced and explained as the main battery power source for EVs. This sets the stage for students to look at how dramatically lithium demand and consumption has grown due to the growth in electric vehicles, and location of reserves and primary producers of lithium around the world. Students are then introduced to global impacts of lithium mining through a graphic comic *Salt to Stars* about the indigenous Andean communities in the Atacama Desert of South America. (CIEJ, 2021). The comic describes how lithium mines are located on sacred cultural sites, explains the water-intensive brine extraction process used by lithium mining companies, and the destructive impacts this practice has on the desert ecosystem that indigenous people's way of life.

The StoryMap then turns to existing lithium-ion batteries and how used electric vehicle batteries can be repurposed for grid energy storage. After, students watch a video describing recycling techniques for lithium-ion batteries to reduce the need and impacts on lithium mining. The wireless electric vehicle charging technology being developed in ASPIRE is then shown as one electric vehicle solution that requires less lithium along with other battery chemistries like sodium-ion batteries. Students are then shown a graphic depicting how smaller battery sizes, reduced car ownership rates, and widespread battery recycling can greatly reduce anticipated lithium demand for a U.S. transition to electric vehicles.

An interactive map is used to display lithium deposits, lithium mines, and lithium mineral regions in the U.S., see Figure 6. Students are invited to hear stories about lithium mining in California, Nevada, Arkansas, and North Carolina. Students watch videos and read articles from mainstream and indigenous news story perspectives to gain understanding on what is valued by white and tribal communities, local governments, and mining companies. An open-ended class discussion on ideas for creating sustainable and equitable solutions to the real-world wicked problem of lithium-ion battery production for use in electrified transportation gives students a glimpse of the importance for developing strong ethical frameworks and consciousness as engineers in making values-aligned decisions that affirm and sustain the ecological, cultural, and spiritual life cycles of all peoples.

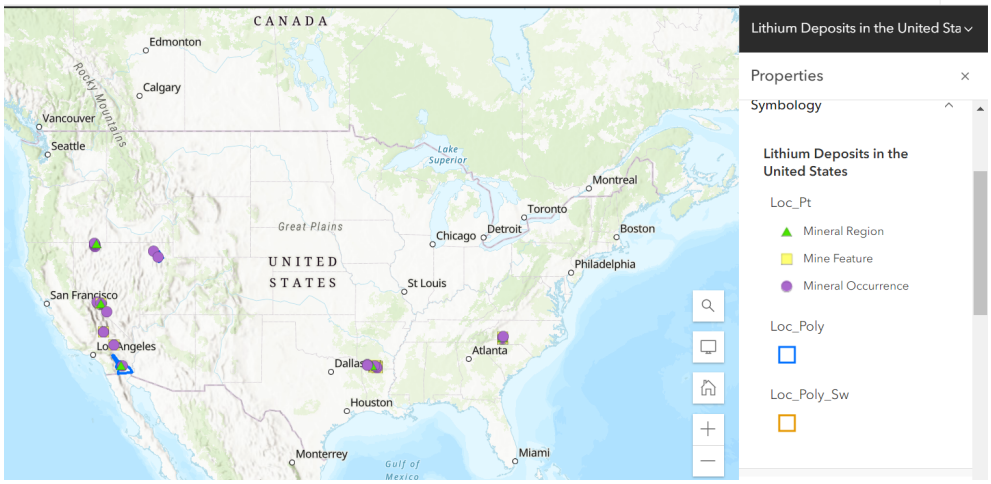

Figure 6: Map showing locations of lithium deposits and mines in the United States.

Comments from Teachers

Teachers piloting the CED course shared their reflections on the EJ StoryMaps, as follows:

Teacher 1 noted how they enjoyed the format and student reactions to the background knowledge-building formative assessment questions as they went through the StoryMaps,

> “I absolutely loved the format. The combination of a brief amount of text, followed by short videos, was perfect for my students. The videos were really high quality and well done. I also loved the GIS mapping features. Some of my students really got into this, while others seemed to just want to find the info in the relevant map layer that they needed to answer that CFU [Check for Understanding] question. In general, I thought the CFU questions were manageable and appropriate, and I think totally necessary to hold students accountable. Their most important impact to my teaching, I’d say, is that they brought the environmental justice component of engineering to the forefront. This is really important.”

Teacher 2 noted how the StoryMaps offer ways to connect students with what is happening around them and learn about different options to engineer in,

> “More often nowadays, the kids become disconnected in what is happening around them. It is great for them to be involved in discussions with each other about the impacts their own generation has on the future. At first, they struggled to dig deeper in their conversations, because it was so new, but once they were able to research a bit and build a connection, they became more open to the topics. These story maps have impacted the way I teach engineering, because they need to know that engineers do much more than just make robots, they shape the world around us in every way. Having the kids know that there are different options for them to engineer in, they have become more interested in the engineering fields.”

Teacher 3 noted how the StoryMaps helped them to teach ethical components of engineering,

> “I was really impressed with the content of the EJ story maps. The information was clear, easy to understand for the students, impactful, and covered essential ethical topics related to my class. At first my students struggled with this learning style. They are used to finding the "right" answer and moving on as quickly as possible. … Over time as they got used to the way the story maps were supposed to be used they got more engaged and interested in the story maps - we would check the air quality almost daily as a class. I've always struggled finding ways to teach the ethics side of engineering and I really like how the story maps were set up. They gave me access to information that I needed and probably wouldn't have been able to find/compile on my own.”

Recommendations and Next Steps

Thoughtful and relevant inclusion of EJ in engineering education provides a strong foundation for connecting students’ learning and understanding of STEM concepts, especially in engineering, and in fostering their passion to engage in solving problems to help make our planet a better place for all living things. It is essential to focus on solutions versus problems in STEM education, especially content focused on wicked problems like climate change that can increase students’ anxiety and sense of hopelessness. Implementing place-based learning opportunities to explore and apply STEM and EJ related concepts can help students relate what is learned in the StoryMaps to their lived experiences in a real world context (Schwartz, 2021). Connecting teachers and students with EJ practitioners and organizations can amplify place-based learning by rooting it in environmental injustices faced in their communities, understanding why those injustices exist, and acting together to find solutions.

While these EJ StoryMaps were focused around two of the 17 EJ Principles, teachers are encouraged to connect more principles to the engineering education they do based on the needs of communities they are enmeshed in. The National Academy’s engineering habits of mind can offer a way to structure those connections, as noted:

> “Principle 3. K–12 engineering education should promote engineering habits of mind. Engineering “habits of mind” align with what many believe are essential skills for citizens in the 21st century. These include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations” (NAE, 2009).

The final EJ StoryMap under development will be titled ‘Envision a Sustainable and Equitable Transportation Future!’ This StoryMap will build on the content learned in StoryMaps 1-4 and questions posed in StoryMap 5 about the sustainability of electric vehicles to help students envision forms of transportation that clean water, air, and heal land. The series of six EJ StoryMaps will be piloted with a final cohort of high school educators during the 2023-24 school year. As before, teacher feedback will be incorporated into refining the collection prior to the CED being published on the *TeachEngineering* digital library website.

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