End-to-End Lifecycle Considerations for Minerals Powering Critical Technologies

Angela Cleri, Ryan Spangler, Emilee Fortier
The Pennsylvania State University, Department of Materials Science and Engineering, University Park, PA
DOI hyperlink: https://doi.org/10.38126/JSPG220106
Corresponding author: ajc782@psu.edu
Keywords: critical minerals; critical technology; metal mining; circular economy; clean energy transition; industrialization; sustainability

Executive Summary: The United States (U.S.) is poised for a new wave of industrialization as it prepares to scale up domestic semiconductor manufacturing and widely implement clean energy infrastructure. With widespread application spaces beyond clean energy, such as communication, computing, healthcare, national security, and transportation, the scope of these endeavors is expected to be massive and long-term. The success of these initiatives is highly dependent on the non-renewable minerals used in critical technologies necessitating the adaptation of current business and legislative models to accommodate future long-term extraction and implementation needs**. Without these adaptations, advancements will likely be made at the expense of taxpayers, vulnerable communities, and ecological preservation efforts.** We propose policy recommendations to the U.S. federal government to minimize environmental and socio-economic harm resulting from metal mining and promote integration of circular economy principles in electronic product design. These recommendations are expected to have both domestic and international impacts in reducing harmful waste and increasing product longevity. Furthermore, these recommendations align with ensuring long-term U.S. leadership in the semiconductor and clean energy industries.

I. Introduction

i. Scaling up manufacturing of semiconductors and clean energy infrastructure

Since the beginning of its term, the Biden Administration has signed into law several major pieces of legislation aimed at combating climate change, addressing national security, investing in the country's infrastructure, and securing the nation's supply chains. The Inflation Reduction Act (IRA) included the largest investment in clean energy in U.S. history (roughly $370 billion). It promises to significantly reduce U.S. emissions (41% by 2030), create millions of jobs, and build a clean energy economy by implementing more sustainable energy infrastructure (Pub. L. No. 117-169 2022). The Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act invests heavily in reestablishing U.S. leadership in semiconductor manufacturing and limiting U.S. reliance on foreign production of electronic materials such as memory chips for computers (Pub. L. No. 117-167 2022). Scaling up production of clean energy infrastructure and semiconductor technology implies acquisition of the minerals required for manufacturing and demands a means for disposal after use. While these new laws have been applauded for their commitment to energy savings, supply chains, and national security, it is important to also consider the sustainability of the practices in place to extract, recycle, and dispose of the materials used in this technology.

ii. The socio-economic and environmental toll of mineral extraction and disposal

Most minerals exist in finite quantities in concentrated geographical locations around the world. Accessing raw materials is often an invasive and disruptive process to the environment and communities present. Many countries which house large supplies of the minerals in demand have weak labor and/or environmental protections (Roberts 2022). For example, the energy storage device industry (i.e. battery production) demands large quantities of cobalt. Most cobalt reserves are found in the Democratic Republic of Congo (DRC), a country which has experienced serious human rights violations related to metal mining (Calvão, Mcdonald, and Bolay 2021; Knierzinger 2014).

One effort to curb the spread of violence connected to mineral extraction and exportation is Section 1502 of the U.S. Dodd-Frank Act. This requires all Securities and Exchange Commission (SEC)-reporting companies to execute "due diligence" if tin, tantalum, tungsten, or gold (3TG) used in their products are sourced from the DRC or its nine adjoining countries (17 CFR § 240.13p-1 2012). The rule requires this information to be disclosed to the public with the intent of incentivizing companies to create conflict-free 3TG supply chains. However, the requirement is limited in scope as it only covers 3TG exports from a single geographic region comprising 10 countries. In order to power the clean energy transition, additional critical minerals such as lithium and cobalt must be extracted from many conflict-prone regions worldwide that should also be covered by these protections. Additionally, following the passage of the Dodd-Frank Act, a temporary *de facto* embargo on mining operations in the DRC occurred because companies reduced their purchasing from the region rather than engage in costly reporting requirements. This damaged the livelihoods of millions of local people (Matthysen and Montejano 2013). These shortcomings of current U.S. policy regulating critical minerals sourcing must be addressed to ensure that resource-rich regions are allowed to prosper because of their critical importance to the clean energy transition.

In the case of domestic mineral extraction, the Mining Law of 1872 (30 U.S.C. § 2 1872) allows private entities to mine metals and other minerals on public lands without paying royalties – an incentive originally intended to encourage settlements westward (Mintzes 2022). This has resulted in major disturbances to public lands and displacement of indigenous populations. In addition, current policy by the U.S. Bureau of Land Management on hardrock mining (43 CFR Part 3800 et Seq. 1980) has proven insufficient in regulating modern operation and waste management of critical mineral mines on public land. Over the years, hazardous waste mismanagement has created thousands of contaminated sites across the country, the most dangerous of which are identified by the U.S. Environmental Protection Agency (EPA) Superfund National Priorities List. Superfund sites tend to exist in underserved rural communities, with more than one in four Black and Hispanic Americans living within three miles of a site, indicating a need for environmental equity policy (USA EPA 2015). Statistics provided by the EPA Toxic Release Inventory identifies metal mining as the leading industry contributor to toxic releases and disposals (Lim et al. 2010). This is especially concerning because the metal compounds that primarily contribute to metal mining waste do not pose notable toxicity concerns until improperly disposed of in excess, which indicates significant and widespread mismanagement of waste (Driussi & Jansz 2006; Lim et al. 2010).

iii. The need for sustainability policy

While metal mining is currently the primary means of sourcing critical minerals, efforts should also be made to promote acquiring minerals from recycled materials. Although such processes have historically been quite costly and complex, significant progress has been made to improve the effectiveness and sustainability of recovering semiconductor electronic materials. Starting from the source and incentivizing manufacturers to adopt product designs that are easier to recycle can enable a circular economy approach to critical technology industries. Further investments in research and development in this area can facilitate this transition as well.

Mining has not historically been approached with the environment or materials' end-of-lifetime in mind. The U.S. is paying for it now in lives lost due to cancer from water pollution and in billions of dollars allocated to reclaiming abandoned mines. Recently, the Infrastructure Investment and Jobs Act invested $3.5 billion towards remediating environmental damage and addressing legacy pollution from highly contaminated sites (Calvino 2022). As the country upscales metal mining efforts during the current wave of semiconductor and clean-energy infrastructure development, it is crucial that U.S. legislation is adapted to recognize the irreversible damage that improper operation and waste management in the metal mining sector can have on local environments and communities. This necessary step will also forecast the success of the U.S. in maintaining technological leadership.

II. Policy Recommendations

The three overarching policy recommendations outlined here focus on sustainability and equity concerns that the U.S. should address in its plans to scale up production of clean energy infrastructure and semiconductor electronics. These recommendations are directed towards the U.S. federal government and encompass both domestic and international operations.

i. Prioritize sustainable and equitable mining practices to extract critical minerals

We advocate for reformed mining regulations such as those proposed in the **Clean Energy Minerals Reform Act of 2022** (H.R.7580 2022), introduced by House Natural Resources Committee Chairman Rep. Raul Grijalva (D-Ariz.). This would update the Mining Law of 1872 to secure a domestic supply of critical minerals that adheres to high environmental and safety standards (including end-of-life reclamation), equitably rewards taxpayers, and provides local groups, including Native communities, with influence over development and permitting decisions.

Advantages:

- Reduce the negative environmental and social impacts on communities near mining sites
- Collect at least an estimated $2 billion over 10 years in public revenue through establishment of a 12.5% royalty on new mining operations and an 8% royalty on existing operations which may be used to expand mine reclamation efforts (House Natural Resources Committee 2021)
- Protect special places, including sacred sites, from being destroyed by hardrock mining
- Require consultation prior to the establishment of mining activities that may substantially and directly impact lands or interests of Native nations

Challenges:

- May slow down development of a strong domestic supply chain of critical minerals
- Stronger regulations may increase operating costs of domestic mines
- Opposition to royalties and regulations from well-funded mining interests has historically made it difficult for such policies to gain support in Congress

ii. Promote a circular economy for critical technology by encouraging recycling and sustainable product designs

We recommend gradually **implementing extended producer responsibility (EPR) programs,** which hold producers responsible for the full lifespan of a product. This is intended to shift the burden of disposal or recycling from users or waste companies to the entities designing and manufacturing the products (Sovacool et al. 2020). This will encourage manufacturers to adopt product designs that are more durable and with components which can more easily be repaired or recovered. A successful EPR program in Europe, PV Cycle, has stimulated a used photovoltaics market and resulted in 30,000 metric tons of recycled material. The program has even influenced international companies such as First Solar which designs materials with the end-of-lifetime in mind. By selecting materials that are compatible with their recycling process, they allow recovery of 90% of the materials used in their photovoltaics (Held and Ilg 2011; Sovacool et al. 2020).

As fully transitioning to recyclable critical technology products is not immediately feasible due to a lack of fully developed processes, we further recommend that the **highest level of authorized funds ($400 million) be appropriated to the Department of Energy for Critical Minerals Mining and Recycling Research and Development** as outlined in Sec. 40210 of the Infrastructure Investment and Jobs Act (Pub. L. No. 117-58 2021; Zimmermann 2022). This section aims to issue federal grants "to support basic research that will accelerate innovation to advance critical minerals mining, recycling, and reclamation strategies and technologies" (Pub. L. No. 117-58 2021). It is imperative that a multidirectional approach to improving recovery and recycling operations in the U.S. is pursued. This must encompass the *integration* of new technologies with current facility processes, the *innovation* of recycling processes for conventional materials and architectures, and the *incorporation* of reprocessed materials back into manufacturing processes.

Advantages:

- Improve long-term sustainability of critical technology manufacturing processes
- Incentivize both domestic and global industries to design electronic products with end-of-lifetime considerations
- Reduce need for expanding both domestic and international mining operations
- Maintain the U.S. as a technological leader by paving the way for advanced technology in critical mineral recycling

Challenges:

- Upfront costs for research and development in mineral recycling technology
- Initial slow-down of production to integrate sustainable product designs into manufacturing processes
- Anticipated pushback from relevant companies due to financial responsibility of developing recovery infrastructure

iii. Revise regulations on sourcing minerals from politically unstable regions

To reduce the role that sourcing minerals from conflict-afflicted countries has in escalating that conflict, **we recommend revising Section 1502 of the Dodd-Frank Act**. By broadening the scope of due diligence requirements to include more critical minerals (lithium, cobalt, etc.), we can more responsibly source the raw materials most important for the low-carbon energy transition. In addition, to minimize the likelihood of unintentional *de facto* embargoes, we recommend expanding the due diligence requirements to cover mining operations in all at-risk countries. The EU, when drafting its own conflict minerals legislation, included such a global scope for this reason (Koch and Burlyuk 2020; EU Regulation 2017/821 2017). This recommendation of broadening the Dodd-Frank Act, however, is insufficient to responsibly source the clean energy transition. **Comprehensive plans for resource development in each region must be devised in collaboration with local leaders to ensure that region-specific needs are met.** For instance, a plan for the DRC should include investments in transportation and communication to and from isolated regions, which have struggled to rebound following the *de facto* embargo (Matthysen and Montejano 2013).

Advantages:

- Decrease the effect that critical mineral mining has on escalating conflict and human rights abuses in certain regions of the world
- Reduce the likelihood of further *de facto* embargoes by implementing comparable due diligence requirements globally

Challenges:

- Due diligence reporting can be costly to companies
- Repeated challenges to Section 1502 of the Dodd-Frank Act have led to the SEC suspending enforcement of the requirement to conduct a due diligence audit. Thus, any revisions to the rule must resolve these legal difficulties

III. Conclusions

We have proposed a multi-pronged approach towards securing a sustainable and responsible supply of metals and minerals that will be critical for the transition to clean energy. Firstly, we support reformation of the antiquated federal mining law in order to steward our natural resources more responsibly. Secondly, we have recommended implementing EPR programs and investing in recycling technologies to improve resource usage and minimize waste. Finally, we advocate to broaden the scope of due diligence requirements for foreign sourcing of critical minerals and to devise region-specific plans to develop conflict-free supply chains.

References

Calvão, Filipe, Catherine Erica Alexina Mcdonald, and Matthieu Bolay. 2021. "Cobalt Mining and the Corporate Outsourcing of Responsibility in the Democratic Republic of Congo." *The Extractive Industries and Society* 8 (4): 100884. https://doi.org/10.1016/j.exis.2021.02.004.

Calvino, Soledad. 2022. "EPA Secures $13 Million under Bipartisan Infrastructure Law to Ensure Cleanup at Argonaut Mine Superfund Site Continues Full Force." News Release. California. https://www.epa.gov/newsreleases/epa-secures-13-million-under-bipartisan-infrastructure-law-ensure-cleanup-argonaut.

Clean Energy Minerals Reform Act of 2022, H.R.7580, 117th Cong., 2nd sess., introduced in House April 26, 2022.

Chips and Science Act, Pub. L. No. 117-167, 136 Stat. 4392 (2022).

Driussi, Catherine, and Janis Jansz. 2006. "Technological Options for Waste Minimisation in the Mining Industry." *Journal of Cleaner Production* 14 (8): 682-88. https://doi.org/10.1016/j.jclepro.2004.01.013.

Inflation Reduction Act, Pub. L. No. 117-169, 136 Stat. 4392 (2022).

Infrastructure Investment and Jobs Act, 23 U.S.C. § Pub. L. No. 117-58, 135 Stat. 429 (2021).

Held, Michael, and Robert Ilg. 2011. "Update of Environmental Indicators and Energy Payback Time of CdTe PV Systems in Europe." *Progress in Photovoltaics: Research and Applications* 19 (5): 614–26. https://doi.org/10.1002/pip.1068.

House Natural Resources Committee. 2021. "Committee Approves $25.6 Billion Reconciliation Measure to Fund Climate Corps, Coastal Protection, Wildfire Management, Tribal & Territorial Needs." Press release. Washington, D.C. https://naturalresources.house.gov/media/press-releases/committee-approves-256-billion-reconciliation-measure-to-fund-climate-corps-coastal-protection-wildfire-management-tribal-and-territorial-needs.

Knierzinger, Johannes. 2014. "The Socio-Political Implications of Bauxite Mining in Guinea: A Commodity Chain Perspective." *The Extractive Industries and Society* 1 (1): 20–27. https://doi.org/10.1016/j.exis.2014.01.005.

Koch, Dirk-Jan, and Olga Burlyuk. 2020. "Bounded Policy Learning? EU Efforts to Anticipate Unintended Consequences in Conflict Minerals Legislation." *Journal of European Public Policy* 27 (10): 1441–62. https://doi.org/10.1080/13501763.2019.1675744.

Lim, Seong-Rin, Carl W. Lam, and Julie M. Schoenung. 2010. "Quantity-Based and Toxicity-Based Evaluation of the U.S. Toxics Release Inventory." *Journal of Hazardous Materials* 178 (1): 49-56. https://doi.org/10.1016/j.jhazmat.2010.01.041.

Matthysen, Ken, and Andrés Zaragoza Montejano. 2013. "'Conflict Minerals' Initiatives in DR Congo: Perceptions of Local Mining Communities." *IPIS*.

Mining Claims Under the General Mining Laws, 43 CFR Part 3800 et Seq. (1980)

General Mining Act of 1872, 30 U.S.C. § 2, ch. 152, 17 Stat. 91 (1872).

Mintzes, Aaron. 2022. "Harmful Mining Provisions in the Inflation Reduction Act." *Earthworks*. https://earthworks.org/blog/harmful-mining-provisions-in-the-inflation-reduction-act/.

Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum, and tungsten, their ores, and gold originating from conflict-affected and high-risk areas [2017] OJ L130/1.

Requirement of report regarding disclosure of registrant's supply chain information regarding conflict minerals, 17 CFR § 240.1p-1 (2012).

Roberts, David. 2022. "Here Are the Minerals We Need for Batteries, Solar and Other Clean Energy Tech" *Canary Media*. https://www.canarymedia.com/articles/clean-energy/the-minerals-used-by-clean-energy-technologies.

Sovacool, Benjamin K., Saleem H. Ali, Morgan Bazilian, Ben Radley, Benoit Nemery, Julia Okatz, and Dustin Mulvaney. 2020. "Sustainable Minerals and Metals for a Low-Carbon Future." *Science*. https://doi.org/10.1126/science.aaz6003.

US EPA. 2015. "Superfund National Priorities List (NPL)." Overviews and Factsheets. August 2017, 2015. https://www.epa.gov/superfund/superfund-national-priorities-list-npl.

Zimmermann, Alessandra. 2022. "R&D Funding Breakdown: Infrastructure Investment and Jobs Act." *AAAS*.

Angela Cleri is a Materials Science and Engineering Ph.D. candidate at Penn State University. Her thesis research focuses on fabricating high mobility thin film oxide materials for nanophotonic applications. She is the President of the Science Policy Society at Penn State, which she uses as a platform to pursue and share her passions for advocacy, science communication, and community building.

Ryan Spangler is a Ph.D. candidate in the Department of Materials Science and Engineering at The Pennsylvania State University and a member of the on-campus Science Policy Society. His research includes thin film synthesis and nanophotonics with a special focus in enhancing energy transport in microelectronics.

Emilee Fortier is a Ph.D. student in the Department of Materials Science and Engineering at The Pennsylvania State University researching PLD synthesis and characterization of novel ferroelectrics for application in FeRAM. She is a member of the Science Policy Society at Penn State and a 2023 AGU local science partner.

Acknowledgements

We thank the Science Policy Society at Penn State for providing a platform for students to learn about science policy issues, develop writing skills, and collaborate on meaningful advocacy projects.