Critical Minerals in Western States and Provinces

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I. Introduction

Mining is a historic aspect of the United States' economy, particularly in western states. Beginning in the 19th century, the Gold Rush spurred a century of record minerals production. New mines popped up in nearly every state, triggering economic development and the growth of mining "boom towns." As the United States further industrialized and transformed into a services-based economy largely reliant on imports, the mining sector is a shadow of what it once was. Today, about 50,000 past mining sites in the U.S. sit abandoned and waiting for reclamation (The White House, 2022). Mining, however, is moving back into significance in the U.S. due to the rising adoption of clean energy technologies. The buzz surrounding the transition away from fossil fuels and into renewable energy and electrification is not as simple as it seems. These clean energy technologies, such as solar PV panels and wind turbines, require a host of critical minerals that the U.S. does not currently mine. Canada, on the other hand, has a robust mining sector that contributes 5% of annual GDP (Mining Association of Canada, 2023), and it continues to be a leading global producer of minerals. The U.S. and Canada have vast mineral reserves and can establish competitive critical mineral value chains if they garner enough support. Critical minerals include lithium, cobalt, nickel, rare earth elements (REE), copper, zinc, graphite, and vanadium, among others. This report focuses only on the aforementioned minerals due to the feasibility of mining them in the Western United States, the economic importance of each, and their significant uses in clean energy technologies.

Defining critical minerals is highly dependent on a nation's priorities and the needs of their constituents. In the United States, two critical mineral lists dominate discussion from both the U.S. Geological Survey (USGS) and the Department of Energy (DOE). The USGS list includes 50 minerals that are deemed essential for U.S. economic and/or national security and have a supply chain vulnerable to disruption. They are also defined as being critical in the manufacturing of a product whose absence would have significant consequences for the nation's economy or security. The U.S. Department of Energy releases a smaller list of critical minerals that are defined by high supply chain risk and their essential functions in energy technologies. A degree of overlap exists within the respective agencies, and for this report the authors take both lists into consideration.

Figure 1. U.S. DOE Critical Minerals List	
Aluminum	Magnesium
Cobalt	Natural Graphite
Copper	Neodymium*
Electrical Steel	Nickel
Fluorine	Platinum
Gallium	Praseodymium*
Iridium	Terbium*
Lithium	Silicon, Silicon Carbide
*Rare Earth Element	

Source: U.S. Department of Energy

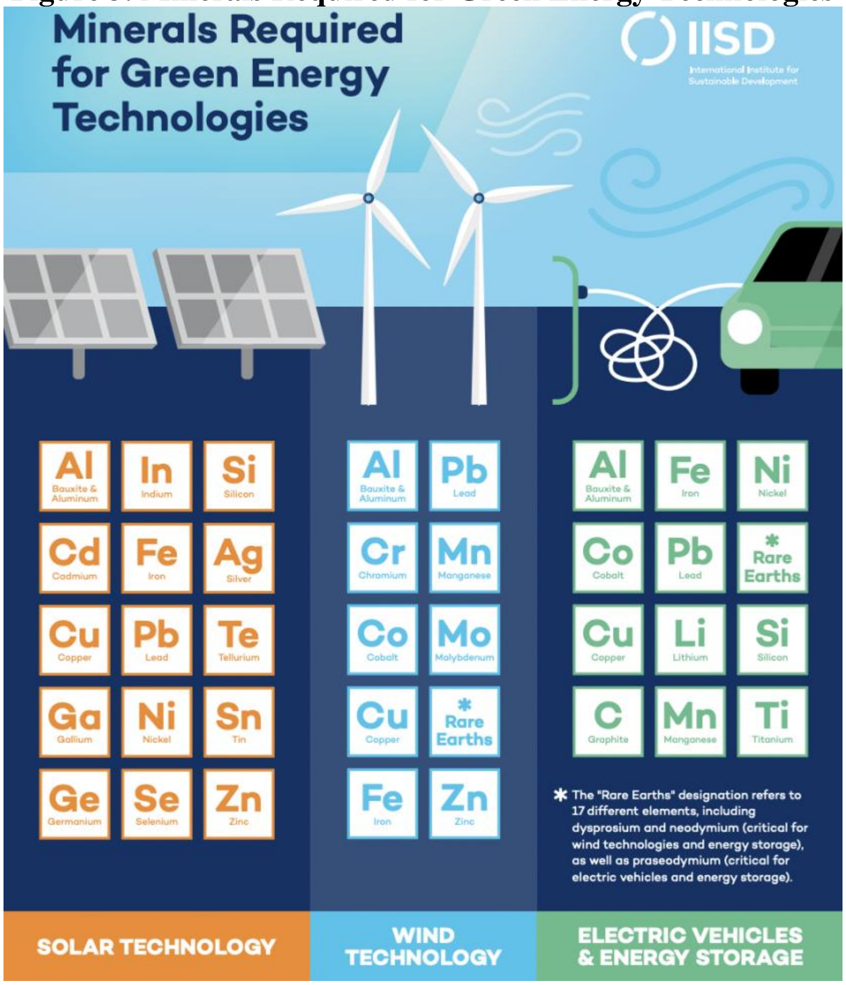
Figure 2. USGS Critical Minerals List		
Aluminum	Germanium	Rhodium
Antimony	**Graphite**	Rubidium
Arsenic	Hafnium	Ruthenium
Barite	Holmium**	Samarium**
Beryllium	**Iridium**	Scandium**
Bismuth	Lanthanum**	Tantalum
Cerium**	**Lithium**	Tellurium
Cesium	Lutetium**	**Terbium****
Chromium	**Magnesium**	Thulium**
Cobalt	Manganese	Tin
Dysprosium**	**Neodymium****	Titanium
Erbium**	**Nickel**	Tungsten
Europium**	Niobium	Vanadium
Fluorspar	Palladium*	Ytterbium**
Gadolinium**	**Platinum***	Yttrium**
Gallium	**Praseodymium****	Zinc
		Zirconium
Overlap with DOE Critical Minerals List		
*Platinum Group Metals		
**Rare Earth Elements		

Source: U.S. Geological Survey

Clean energy technologies are comprised of components that are derived from critical minerals. For example, wind turbines require aluminum and vanadium for framing, copper and tungsten for wiring, and rare earths for magnets. Solar panels require copper and tungsten for wiring, rare earths for magnets, silicon and zinc for energy conversion, and aluminum for framing.

Batteries are expected to assume a large share of critical minerals demand over the coming decades. If electric vehicles become more popular and further incentivized by the U.S. government, demand for battery minerals will begin to surge. Additionally, if clean energy implementation increases, so will long-duration battery storage technologies, which store excess energy generated from renewables and support overall grid stability. For example, the Energy Information Agency (EIA) forecasts that the U.S. will add 26 GW of battery storage capacity by 2030 in their reference case (EIA, 2023). Batteries can be short or long duration depending on their purpose and chemistry. Examples of short duration batteries include lithium-ion, nickel-cobalt, and zinc-manganese chemistries. Long duration battery chemistries include metal-air, vanadium-flow, aluminum-oxide, and others. Each type has differences related to battery life, rechargeability, recyclability, and safety concerns. The battery market is constantly evolving and new methods are researched every day. The market hasn't identified a best-case battery chemistry yet, so it is likely many different battery types will be utilized in the near term as the technology continues to evolve. Therefore, the U.S. will need to bolster a consistent supply of a variety of critical minerals if the energy transition will be domestically led and still successful.

Figure 3. Minerals Required for Green Energy Technologies



Source: International Institute for Sustainable Development

Another important component of the critical minerals discussion is supply chain risk. The United States is a net importer of 86% of minerals on the USGS list and completely relies on China for 16 of those minerals (Payne Institute of Public Policy, 2023). China dominates the downstream mineral value chain, which are processes like refining and smelting, as well as the battery supply chain. In 2022 the United States designated China as a Foreign Entity of Concern (FEOC) amidst trade concerns and geopolitical tensions, and thus the U.S. wants to reduce its imports from the country, particularly in critical minerals and battery components. The Inflation Reduction Act (IRA), passed in 2022, demonstrates U.S. reluctance towards China as it aims to incentivize both clean energy and electric vehicles with production tax credits for domestic producers. The legislation prioritizes "friend-shoring," and rewards producers that source raw materials and produce final products in the United States or a country with which the U.S. has a free-trade agreement.

Also included in the IRA are consumer tax credits worth up-to $7,500 if they purchase an electric vehicle, but the terms of vehicle eligibility are based on the critical minerals within the battery and specific battery components and get stricter as years pass. In 2025, for example, any critical minerals or battery components sourced from a FEOC will not be eligible for tax credits.

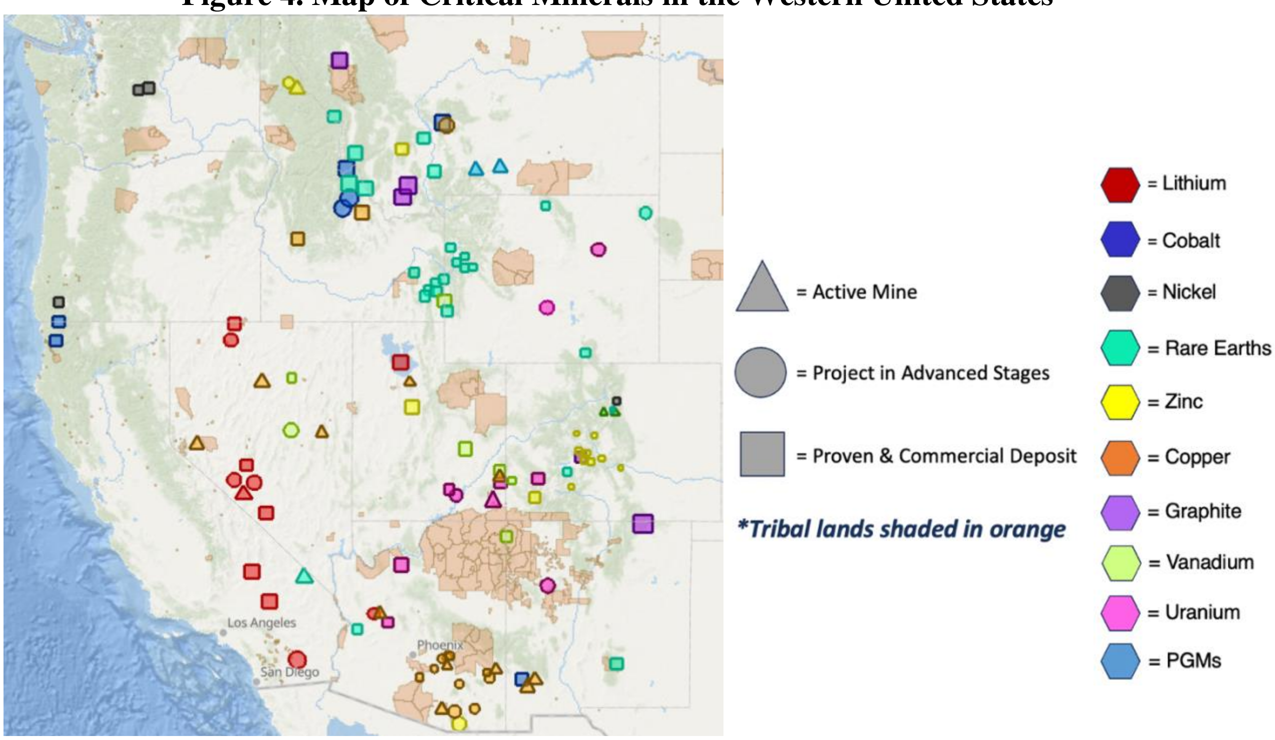
For additional details on battery sourcing requirements for IRA tax credit eligibility, see Appendix A-1.

The International Energy Agency (IEA) forecasts that clean energy technologies will account for 40% of global copper and rare earths demand, 60% of global nickel and cobalt demand, and 90% of global lithium demand in the next two decades (IEA, 2021). Therefore, the United States has two options: mine the minerals domestically or import the minerals from abroad. Neither option is a quick fix, and it will take a combination of both strategies to meet forecasted demand. The Western U.S. and Canada contain immense geological reserves of critical minerals, and mining these minerals is feasible. This report, prepared for the Western Interstate Energy Board in December 2023, will cover where strategic reserves of critical minerals are located, the mining methodologies associated with them, and the regulatory environment that governs building a mine in 2024.

II. Mapping Critical Minerals in Western States & Provinces

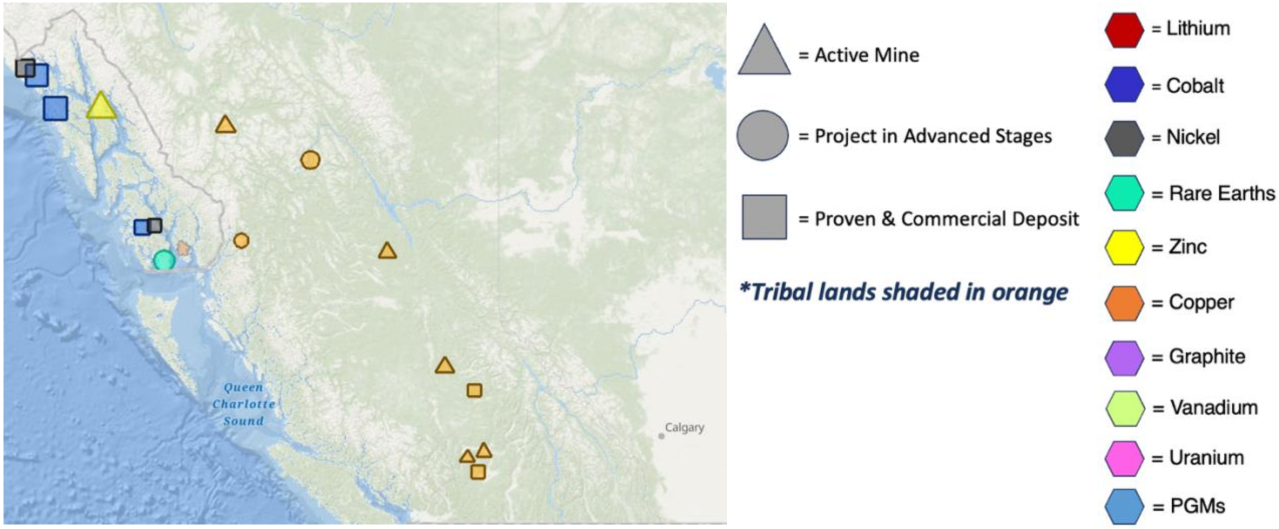
The Western United States and Canada has immense geologic potential. Significant reserves of critical minerals are found in these states and provinces, but little mining of these minerals occurs today. Out of the critical minerals on the USGS list, the U.S. and Canada mine the largest amount of copper as it is abundant and has a wide variety of uses in manufacturing. Other critical minerals important for clean energy technologies, such as bauxite[1] or graphite, are not found in high concentrations in Western States and thus not currently mined in these regions. The mineral map in Figure 4 displays active mines of critical minerals, projects in the advanced stages of the permitting process, and proven and commercial deposits that could feasibly be developed.

Figure 4. Map of Critical Minerals in the Western United States



[1] Bauxite is the base mineral for aluminum.

Figure 5. Map of Critical Minerals in Western Canada



In Canada, British Colombia is a major copper producer. While other large-scale critical mineral projects have yet to be identified in the region, they are expected to increase their copper production with new projects coming online. Alberta, on the other hand, does not currently mine critical minerals or have major projects in the pipeline.

It is important to note that minerals are often found together in the same deposit. For example, cobalt is usually found with copper, nickel is often found with platinum group metals, and copper can be found with gold. The color of the symbol on the map is coded according to the main mineral associated with the mine, plan, and/or deposit, but other critical minerals may be extracted as byproducts from the same site.

A. Active Mines

Critical mineral mines currently operate in the Western U.S. and Canada. Copper is the most commonly produced out of any other mineral on the lists, and its mining is concentrated primarily in southeastern Arizona and British Colombia. Lithium, a widely recognizable mineral lately for its uses in lithium-ion batteries that feed into electric vehicles, has only one mine in the United States: Silver Peak in Nevada. Zinc is abundant in the U.S. and Canada, and there are zinc mines in two western states: Idaho and Alaska. The only two U.S. platinum group metal (PGM) mines are located in Montana at Stillwater and East Boulder. The only rare earths mine is in Mountain Pass, California and it is currently the only processor of REEs in the United States as well. There is one active uranium mill in Utah at White Mesa, and operations fluctuate depending on the demand for nuclear energy. Minerals such as nickel, manganese, and aluminum are mined in small quantities in eastern regions of the U.S. but are not currently mined in the western regions or have plans to. There are no tungsten dominant mines in the U.S., but western reserves are plentiful, and it is commonly extracted as a byproduct of several other minerals. U.S. reserves of graphite are limited, but the Canadian-based mining company Graphite One recently received funding from the DOE to complete feasibility studies on a new graphite mine in Alaska.

B. Proposed Mines in the Permitting Process

The map includes projects that have commercial mineral reserves and have begun the permitting process to become a fully operational mine. Projects still in the exploration phase were not included, as these ventures do not yet have a confirmed commercial-grade deposit. Some mines represented on the maps have received their state and federal permits, but lawsuits delay their start date. For example, Thacker Pass, which is one of the largest lithium projects in the U.S., received its permits but is currently in litigation with nearby indigenous tribes and facing opposition over water rights. Many lithium projects are in based in Nevada, however lithium extraction is expanding outside the state's borders. For example, the Salton Sea project in California utilizes an innovative way to extract lithium with brine pools, which attracted Wall Street investors' attention when their methods were proven to be highly efficient. Cobalt, another controversial battery mineral, is often a byproduct of copper mining but there are no cobalt-dominant mines in the Western U.S. or Canada. There are two significant cobalt projects in the Idaho Cobalt Belt that are in the advanced stages of permitting and economic assessment, called Iron Creek and ICO. ICO halted production plans recently due to falling cobalt prices, however. Many copper projects are making their way through the permitting process as well. Most of the projects are located in Arizona, but there is one project in Montana, Black Butte, that is being debated inside the state government.

Permits are far from guaranteed for critical mineral mines. One example of a setback is with a REE mine in Wyoming at Bear Lodge. In 2013 the mining company Rare Earth Resources, owner of the lease at Bear Lodge, invested over $140 million into developing a REE mine and processing facility. In 2016, the project was indefinitely suspended, and the company cited regulatory and price concerns for the pause. In other words, the company struggled with both falling REE prices and faced hurdles with federal permits. However, Rare Earth Resources recently revived the project with new processing technology, and the company will move forward with reapplying for all necessary permits pending positive test results.

An example of a success is the Gibellini Project in Nevada. The vanadium mine will be the first of its kind in the United States, and it is expected to produce about 60% of total U.S. demand. The project efficiently underwent the permitting process and received its final permit from the Bureau of Land Management (BLM) in October. The mine was not delayed by any extenuating lawsuits which aided its swift journey through the permitting process. Moreover, the mine is expected to be powered by solar energy and battery storage, and they expect to utilize electric haul trucks as much as possible.

III. Innovative Mining Methods

Mines today face increasingly stringent regulations and environmental scrutiny before being granted approval. Past conventional open-pit and underground mines that were largely unregulated impacted the environment in ways that are still seen and felt today. For example, decommissioned underground mines can still release toxic compounds into ground water reservoirs when the water used to extract ore becomes contaminated with heavy concentrations of minerals or metals. Large-scale land displacement from the construction and operation of an open-pit mine can disturb wildlife and harm natural ecosystems. In-situ mining, a new and popular way of chemically extracting ore without large land displacement, can cause acid leaching into groundwater and contaminate local waterways, which then affects wildlife and threatens water quality. Therefore, innovative mining techniques are in the limelight as policy makers and environmentalists call for mining reform. The Biden-Harris Administration recently outlined a strategy for enacting sustainable mining in the U.S. and have been actively involved in permitting decisions of various controversial mining projects. A transition to renewable energy requires minerals and metals, but conventional mining methods have historically harmed natural habitats, which can offset the benefits of renewable energy in the goal to mitigate climate change.

In the next section, we will review each possible method of mining critical minerals and the feasibility of each.

A. Open pit mines

The most common kind of mine is an open-pit, where large swaths of rock are removed from an area and drilling goes deeper and deeper until the cut-off grade[2] is realized. Open-pit mines are best for shallow deposits and low-grade ore and are less expensive than other common mine types. Open-pit mines generate considerable amounts of waste in the form of tailings and overburden. Overburden is the displaced rock that is not processed, while tailings are the residual rock left after the valuable ore is separated from the uneconomic ore in a processing facility. The left-over fine particles are mixed with water to create a slurry, that can either be stored elsewhere or dumped back into the open-pit mine. Environmental concerns associated with tailings management and the land displacement that occurs during open-pit mining has led to stricter environmental regulations and divisive opinions towards mining in recent years.

B. Underground Mines

Underground mining is another historic conventional mining method that involves digging shafts deep under the Earth's surface. It is more expensive than open-pit mining due to the complex infrastructure and engineering required for construction of the mine. Additionally, miners must take measures to ensure safety measures are in place and waste is properly managed. Underground mining is best used for reserves that are too deep beneath the surface for open-pit mining and high-grade ore that is economically worth the cost of extraction. An advantage of underground mining is the lessened ground footprint left on the mine site, but there is a heightened risk of ground water contamination with the chemicals used to extract the ore underground. Many critical minerals are mined via underground mining, such as zinc, cobalt, copper, nickel, rare earths, manganese, uranium, and vanadium.

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[2] A cut-off grade refers to the boundary between ore and waste rock that is economically viable.

C. In-situ leaching

In-situ leaching is an increasingly popular method for chemically extracting ore from hard rock. The process includes first drilling wells beneath the surface to the deposit, then releasing a chemical through the well and to the targeted mineral. The chemical dissolves the mineral in place and pumped to the surface, where it is processed and separated from waste rock. This is an appealing method because there is no mass land displacement required and if done properly, minimal damage to ecosystems or disturbance of wildlife. Technical challenges may limit in-situ mining, however. The mineral in question must be leachable with a highly permeable ore body, and the deposit must be below the water table for the chemicals to viably reach the ore.

In-situ leaching has several benefits such as lower capital and operating costs, a safer work environment, minimal tailings and visual disturbance, and a comparatively lower environmental impact. It is an innovative method to mine low-grade deposits, but only very few reserves have the geology to be mined this way. The reserve must be deep underground with the precise characteristics prime for in-situ leaching. There is additional room for error for groundwater contamination. Extensive geological assessments and environmental impact tests must be conducted before implementing it for commercial production. Minerals commonly mined via in-situ leaching include uranium, lithium, and rare earths.

D. Tailings Recycling

Technological advancements in mining engineering have promoted innovative ways to recover critical minerals from old tailings piles. Hydrometallurgical processes can recover raw minerals through dewatering tailings piles and stacking them. The stacks are then leached with hydrochloric acid to extract the targeted mineral and even byproduct minerals if the geology is right[3]. For example, iron ore tailings can produce copper, aluminum, and manganese via acid leaching. Other techniques such as solvent extraction and bioleaching, similar concepts to acid leaching, may also be used on dry stacked tailings with the correct geology. New technology is currently being developed to remove potentially toxic metals from the leached solution, which will mitigate the risk of contaminating ecosystems. As mining has become more efficient over time, old tailings piles are likely to produce a greater quantity of critical minerals than present tailings. The critical minerals of today had limited use in past years and were largely discarded, and thus there is strong evidence for high concentrations of key minerals in old tailings. At present, tailings recycling is being researched for the commercial production of cobalt, rare earths, copper, lithium, and tungsten.

Tailings recycling has various economic benefits as well. There is minimal excavation needed to develop these projects, as old mine infrastructure remains intact at many abandoned sites, and it helps address reclamation concerns from mines that have been waiting for reclamation for decades. It has a smaller impact on the environment than opening a new mine and produces comparatively less carbon emissions. There is potential to generate considerable revenues from the extraction of recoverable minerals

[3] Acid leaching is only feasible for highly permeable rock.

coupled with the production from pre-existing mines. Additionally, recycling tailings creates jobs in former mining communities and helps bolster domestic supply chains.

It is important to recognize that this technology is still being researched, and present techno-economic and environmental challenges constrain commercial production. Significant water and energy consumption occurs during hydrometallurgical processes, and the pollution risk is high from the toxicity of the leaching solvent. If uranium is present in tailings, there is additional radioactivity risk.

Tailings recycling has potential for profitability but is currently a high-cost option. The capital needed for the necessary hydrometallurgical processes is expensive, operating costs can fluctuate depending on the specific operation, and the high energy usage may result in high costs. In addition, mining as an industry is highly dependent on market prices that can sway production. Unfavorable prices may lead to a halt in production and continued loss on capital costs via depreciation.

E. Brine Extraction

Brine extraction is a method of extracting lithium from salt flats. Wells are drilled to reach underground salar brine deposits, where the brine is then pumped to the surface and directed into large evaporation ponds. The water evaporates via solar evaporation, leaving behind a concentrated brine that contains commercial-grade lithium and sodium. The evaporation process takes months or years depending on the mineral concentration and climate conditions. Once the solution has reached a proper concentration, the brine is pumped to a lithium recovery facility where it is treated and filtered into a commonly sold form of lithium. The remaining brine is returned to the underground reservoir.

Methods to speed up the evaporation process are being tested in different exploration phases. The most notable method is direct lithium extraction (DLE), coined by Dr. John Burba. The process includes the use of a DLE module to separate the lithium molecule from the brine immediately. The remaining brine is reinjected to the underground reservoir, while the lithium molecules are sent to a treatment facility to eventually be exported. This process has high efficiency, lower operating costs, and a lower land area requirement than the conventional method. The DLE module decreases the evaporation time from multiple months to days or hours and yields a higher lithium recovery rate. DLE extraction is being tested at the Salton Sea geothermal brine pool in California. There is limited publicly available data on the economics behind the project, but Energy Source Minerals plans to open the plant for commercial production in the recent future, pending permitting decisions.

Lesser-known projects include reverse osmosis, a process used to speed up the evaporation process using membrane filtration, and lithium extraction from recycled geothermal brines or oil-field brines. These technologies are not yet economically feasible due to high input and energy costs, but the potential for profitability in lithium brine extraction is very high given the vast demand coming online in the next 20-30 years, and the prospect of continued technological innovation.

F. End-of-Life Battery Recycling

An additional sustainable method of extracting critical minerals is via battery recycling. An electrified economy requires high-powered batteries used in electric vehicles (EVs) and power generation. Therefore, recycling end-of-life batteries to extract lithium, cobalt, nickel, and graphite is a pressing opportunity and recently received $3 billion in funding from the Bipartisan Infrastructure Law. Recycling end-of-life batteries requires high energy intensity and storage facilities, which can be an expensive capital cost.

Minerals such as aluminum and platinum are highly recyclable, with 90% of industrial aluminum currently recycled (Payne Institute, 2023). Nickel and copper are also being recycled to a high extent with one third of global nickel supply recycled (Gielen, 2021). Lithium, cobalt, and rare earths will be a new focus for battery recycling as demand for the minerals increases in coming years, providing a new market opportunity for not only mining companies, but auto and battery manufacturers as well.

Currently, there are not enough lithium-ion batteries or nickel batteries coming offline for there to be enough recyclable material for scaled commercial operations. Redwood Materials opened a cathode manufacturing facility in Nevada that is exploring the possibilities of recycling retired cathodes and the innovation in maintaining battery-grade quality minerals. In the next 15 or more years, there is high potential for end-of-life battery recycling which may attract a flow of private investment into the market.

G. Rare Earths Extraction from Coal Waste

Particulates of rare earths elements can be found in coal fly ash and waste rock which has driven government investment into the feasibility of extraction. In the United States, rare earths are abundant in the Earth's crust but in very low concentrations, making mining them a difficult task. The Mountain Pass Mine in California is the leader in rare earths innovation with their new processing facility and the only one in the United States. Thus, the opportunity to extract rare earths from coal wastes, of which demand will grow significantly over the medium term for their use in magnets, is an attractive technology for mining stakeholders. The DOE estimated that nearly six million metric tons of rare earths could potentially be mined from select western coal basins in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona, which could complement the production coming out of Mountain Pass Mine. The DOE states that "the actual amounts that could be recovered would be a function of mining practices and the economics of recovery from operations actively producing, processing, and utilizing newly mined coal" (Department of Energy, 2017, pg. 9). The agency funded projects at Pennsylvania State University to investigate the feasibility of extracting REEs from Appalachian coal communities in West Virginia and Pennsylvania. The study produced viable methods for extraction, such as froth flotation techniques, and the research is ongoing. However, the low concentration of REEs in coal ash and coal byproducts mean extraction is not economically feasible with current techniques, as operating costs are too high for a low output value.

The DOE continues to fund research and development that examines new processes for utilizing coal fly ash, but environmentalists have raised concerns about the production of increased particulate dust and waste products. The toxicity of chemicals used to extract the REEs from waste are a risk to human health and polluting streams and groundwater. Additionally, environmental groups argue there are not enough REEs contained in coal ash and/or waste to justify the impact of extra processing and increased energy use.

H. Deep-Sea Mining

There are significant critical mineral deposits contained in the deep-sea floor, and throughout the last decade many countries and mining companies have explored the possibility of mining them. Specifically, the Clarion-Clipperton Fracture Zone in the Northwest Pacific Ocean contains cobalt, nickel, copper, manganese and rare earths in dense and large quantities. International and environmental laws restrict exploration and extraction of these areas, so much is unknown about the future of deep-sea mining. The International Seabed Authority has postponed a decision on regulations until 2025, and until then all proposed projects are stalled.

Capital costs include a collection device, lift pump, and support vessels at the very least. Excavating equipment may be required as well, and operating costs are projected to be extremely high. These factors combined insinuate that the profitability of deep-sea mining is unlikely with current technology.

Environmentalists oppose current processes for deep-sea mining due to their significant impacts on the ocean floor. That part of the Earth's crust has not been thoroughly explored and the potential damage to the seafloor are considerable risks to both studied and unknown ecosystems.

IV. Technological Advancements in Mining Equipment

Calls for mining reform have triggered innovation in sustainable mining techniques and recycling. Various firms that specialize in mining high-end technology are beginning to make a splash in the market as their technology helps companies reduce their environmental footprint. This service is in high demand as environmental responsibility is currently at the forefront of public opinion, and a possible restriction on carbon emissions in the future may impact status-quo operations.

The firm Nth Cycle has patented a new way to refine minerals on-site. Their small modular refining system, called "The Oyster," can be placed anywhere, and uses only electricity and water to extract high-purity metals from ore. The electro-extraction technology can produce battery-grade lithium, nickel, cobalt, copper, and rare earths with purity yields of 90-95% (Nth Cycle, 2023). The module can be used on raw ore, scrap metal, tailings, end-of-life batteries, and e-waste. The IRA outlined specific procurement requirements for EV battery sourcing, and Nth Cycle meets these requirements with modular reactors that can be installed at any U.S. mine. The use of these modules can bolster domestic supply chains while reducing dependency on refineries in China. Nth Cycle recently opened a battery recycling plant in Ohio and, contingent on its success, could open similar plants in the Western U.S. Potential benefits include lessened operating costs from shipping ore to overseas refineries, reduced carbon emissions, and the opportunity to extend mine life. Implementing "The Oyster" would require an expensive capital investment, and financial analysis would have to be conducted to determine if any potential cost savings or increased revenues are enough to generate a company's minimum rate of return on the investment.

Electrifying mining is on the horizon, and companies have taken advantage of that fact. A major player in the mining equipment market is Eprioc, who produces mining machinery. They produce battery-powered loaders, which can greatly reduce emissions. Differences are felt especially in underground mines, where diesel emissions threaten worker safety and thus slow operations. Caterpillar, another mining equipment company, plans to produce electric haul trucks which they claim are more efficient than their diesel counterparts due to less lost heat energy. Cripple Creek Gold Mine in Colorado will host the first electrified fleet from Caterpillar, but details such as battery life and charging infrastructure are still in development. While firms can save on fuel costs, the largest disadvantage of electric equipment is battery life. Today's batteries need to be replaced during a 12-hour shift, which can be expensive and wasteful. Currently, investing in a battery-powered mining fleet is more costly than diesel equipment, but changing regulations and further innovation may soon change that.

Epiroc has also broadened their product offerings to include data analytics packages. A few examples of their new software line includes a mine and tunneling intelligence platform, which is an underground radar that tracks every component of an underground mine, including workers and equipment. A "pocket mine," which is a small device that can fit in your pocket like a phone, provides workers a snapshot of the radar so all employees are informed of processes in real time. Other firms offer competing packages, such as Caterpillar's MineStar and Orica's BlastIQ. The software they offer optimizes operations within mines through a customizable interface, which can improve occupational safety, efficiency, and profitability.

Other technical innovations include TerraCore's Core Imaging Spectrometer which can scan up to 1500 meters of ore per day. Once the scan is complete, the spectrometer uploads minerology maps and abundance data online which is remotely viewable. This technology is useful for companies exploring remote, hard-to-reach regions and can result in cost savings. The TOMRA Mining XRT is an ore-sorting process that can separate valuable minerals from waste using X-ray technology. This specific process helped recover one of the largest diamonds in recorded history at a mine in Botswana. Not only is this technology primed for low-grade ore and can reduce operating costs, but it may also make extracting byproducts easier, resulting in increased revenues. Metallurgical advancements such as electrochemical extraction, stack cell technology, and smart sensors are exciting for the mining industry and continue to be researched, with the goal of one-day scaling these processes for commercial use.

As new technology evolves the mining sector and makes it more efficient, there will also be a need for operations research and process control. Ensuring that these technologies are implemented effectively and truly reduce operating costs is no easy task and may require the expertise of operations researchers and systems engineers.

V. Permitting & Other Risks Facing the Mining Industry

The mining industry faces countless challenges in the 21st century. Public opinion of mining is historically low, stricter environmental regulations make operations more expensive, and bureaucratic processes are taking increasingly longer. These issues are just a few examples of the barriers mining companies face in getting a mine to steady-state operation. Ernst & Young (EY) recently released a paper outlining the biggest risks facing metals and mining in 2024, in which they surveyed over 150 executives from global mining companies (Mitchell, 2022). The survey found that the most important risk threatening mining is environmental social governance (ESG) rules and regulations. ESG can harm mining as firms must quickly establish plans to reach net-zero emissions which requires significant time and resources. Additionally, companies must simultaneously adopt community and social impact, tailings management, and water stewardship plans. These processes are expensive targets to achieve. Mining companies globally will start to alter their long term goals, invest in new green technology, and be subject to stricter reporting standards. As such, it's difficult to balance fulfilling ESG requirements and generating necessary rates of returns for stakeholders. It is also important to note that risk factors can vary significantly based on market conditions and geopolitics. To illustrate, a similar report released by White & Case in 2022 stated the biggest risk factors facing mining in 2023 were inflationary pressures and geopolitics, followed by ESG and energy costs (Campbell et al., n.d.). In 2023, the sector is clearly facing different risks than predicted.

The next two most important risks defined by the EY report are access to capital and license to operate. In the United States, the Federal Reserve has raised rates in its most aggressive tightening campaign since the 1980s. Access to capital is now harder to obtain as banks' willingness to loan gradually subsides. At the same time, exploration budgets are increasing as the push to source critical minerals gains global attention, especially in the United States and Canada. A high interest rate environment that lingers for longer than expected may hinder junior mining companies' ability to identify key reserves and senior mining companies' efforts to commercialize production. Conversely, if interest rates are cut in early 2024, the sector could see an influx of investment. For example, over $40 billion in capital costs have already been announced for copper projects since January 2020 and over $16 billion announced for nickel projects. Most of these projects are still in the feasibility stages, however, and may be affected by elevated interest rates compared to 2020-21. Currently iron, steel, and gold attract the most investment overall, but investment is rising in critical minerals such as nickel and lithium as their uses grow. Bloomberg estimates the lithium-ion market to be worth $182 billion in 2030 (Campbell et al., n.d.). The battery minerals, such as nickel, lithium, copper, cobalt, and rare earths, are receiving a large increase in investment inquiries due to the IRA's investment tax credits for battery factories and battery storage.

The license to operate risk is large and is comprised of many different factors. Mines need to formulate a mine plan that not only meets operational goals, generates a positive net present value, and complies with federal and state regulations, but also must meet environmental and social needs. This report breaks down license to operate risk into four categories: federal permits, state permits, tribal considerations, and public opinion.

A. Federal Permitting

The General Mining Law of 1872 set basic standards for the location, recording, and patenting of mineral claims in the United States during the height of the Gold Rush. The law is still intact today and allows mining companies to stake claims on public lands for exploration or for purchase. Notably, the law does not require companies to pay royalties to taxpayers for the extraction or sale of minerals on public lands and there aren't any specified environmental or reclamation regulations. However, the law does not include any national parks, monuments, or protected lands and projects require Bureau of Land Management's (BLM), one of the primary agencies responsible for mine permitting, approval if the site disturbs more than five acres. This law has shaped mineral exploration in the U.S. for over a century and continues to do so. Although in the modern era, the government has tacked on a slew of permits through the passage of supplemental legislation.

The federal permitting process for new mines is usually lengthy. According to the Payne Institute, the permitting process from start to finish averages 7-10 years. In contrast the BLM claims the process averages only 4 years. In reality, timelines vary widely based on the size of the project, type of mine methodology, and if any controversial land rights or environmental concerns are involved that may cause lawsuits. Many of the critical mineral mines currently seeking permit approvals in the Western U.S., such as Thacker Pass in Nevada, are also tied up in litigation over a variety of disputes which has significantly delayed the project.

Figure 6: Federal Permits Required for Mine Operation

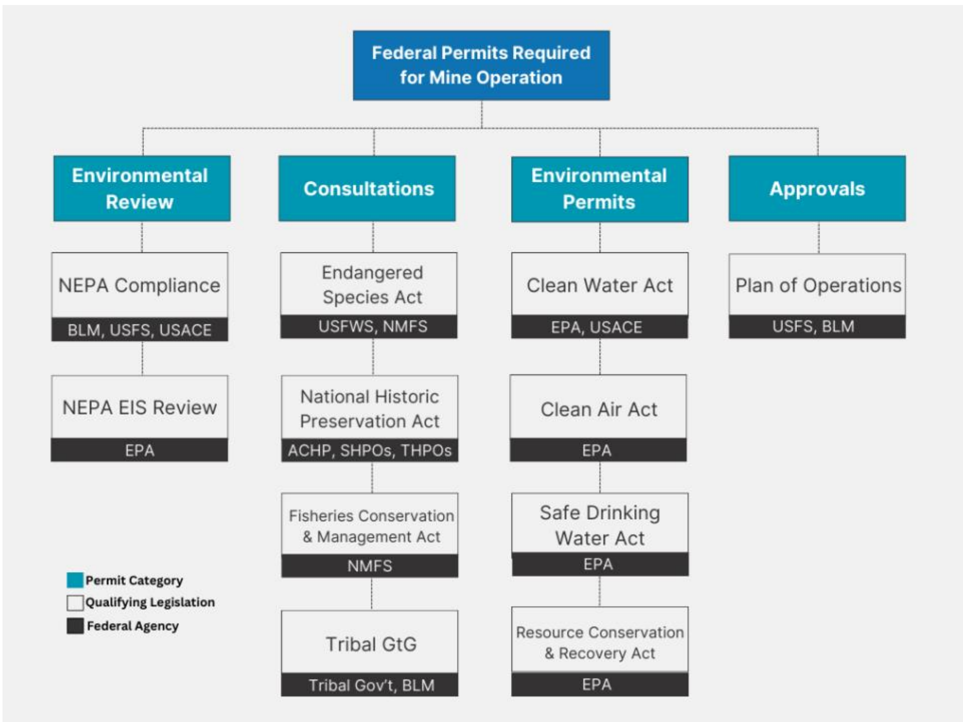


Figure 6 outlines the U.S. federal permit structure for operating mines. The permits are lumped into 4 broad categories. Environmental review is largely a byproduct of the National Environmental Policy Act (NEPA) where mines must comply with NEPA regulations surrounding their land and water use. Mines must also submit an Environmental Impact Statement (EIS) which is reviewed and given feedback from the Environmental Protection Agency (EPA). An EIS will influence a mine's eligibility for environmental permit approvals, so this is considered to be a crucial document in the feasibility phase of mine planning.

The next category is mandatory consultations. Figure 4 displays the relevant legislation that must be considered when a mine plan is submitted to the BLM. These consultations give federal and state agencies sufficient space and time to comment on the mine plan and its effects. The National Historical Preservation Act, for example, requires mines to allow sufficient time to receive feedback from Councils on Historic Preservation in U.S. states and sovereign tribes before commencing operations.

The largest category is environmental permits. These permits are usually approved by the EPA and have very limited exceptions. Figure 7 outlines the specific permits associated with each piece of legislation shown in Figure 6.

Figure 7: Environmental Permits Subject to EPA Approval

Legislation	Permit
Clean Water Act	CWA 402 – NPDES Permit CWA 404 – Wetlands & Waste CWA 401 Certification
Clean Air Act	CAA 109 – NAAQSs CAA 111 – NSPSs CAA 111 – PSD Provisions NESHAPs
Safe Drinking Water Act	Underground Injection Control (UIC) Permit
Resource Conservation & Recovery Act (RCRA)	Subtitle C – Hazardous Waste Area of Contamination Policy Corrective Action Management Units Corrective Action Temporary Units

The permits in Figure 7 apply to steady-state production, tailings facilities, and any secondary generated waste. They also apply to any land, water, or organism indirectly affected by the mine's operations, even if it is not on the mine's specified land. These laws were passed in between the 1960-70s and aimed to regulate mines' environmental impact in the United States. RCRA is a particularly detailed law that aims to clean up remediation wastes and it applies to abandoned superfund sites as well. Not all mine waste is hazardous, so certain operations may not be subject to the full extent of RCRA. However, most mines do produce a modest amount which adds another level of complexity to EPA regulations.

Lastly, the BLM and U.S. Forest Service (USFS) must approve a Plan of Operations for the mine that includes reclamation efforts and closure plans if it's on federal land. Most mine sites are on leased BLM land so this provision applies to most mines in the U.S. If any part of the Plan of Operations changes that impacts any of the permits or considerations listed in Figure 4 or Figure 5, the permits must be re-evaluated with the change. Permits may be revoked at any point with the discovery of new information or any change to the mine plan.

The U.S. federal government has taken some measures to reform the mining permitting process this year. In September, the Federal Improvement Steering Council designated critical minerals as a FAST-41 covered sector in mining. The goal of FAST-41 is to streamline and speed up the permitting processes for projects that are deemed critical to the nation's improvement. Currently, only the South32 Hermosa Zinc Mine in Arizona is a FAST-41 covered project. If more projects are added to this program, projects may see some reduction in permitting wait times and begin operations more quickly.

The Fiscal Responsibility Act of 2023 also includes some provisions for the mining sector. These sections are meant to help cut through the dynamic regulatory framework that was born out of the IRA and other proposed climate bills. One such provision places 2-year limits on preparing environmental impact statements, and a 1-year limit on the environmental assessment. Funding was granted to the Federal Improvement Steering Council for FAST-41 and other initiatives to help reduce wait times and make the processes more concise. While the bill isn't expected to make significant headway in permitting reform today, it does help steer future legislation.

Permitting can be a lengthy endeavor, so it is important that a mining company's leadership has sufficient plans in place and deep knowledge of the permitting process. Additionally, it is helpful for the mining company to establish productive relationships with communities and/or tribes and implement their feedback so that the company can avoid lawsuits in the future.

B. State Permitting

Mines are also subject to state and province permitting in the United States and Canada, and policies vary widely depending on its constituents and history of mining in the state. For example, 20 different states require an Environmental Review and Plan of Operations to be submitted to a state agency for another approval, like California for example, and some also require a specific state permit that model the federal ones. British Columbia also requires additional environmental permits after a tailings dam failure in 2014 polluted local waterways (BritishColombia.gov, n.d.). Examples of state permits in the U.S. include a CWA NPDES and 404 permit, CAA permits, and UIC permits in the state where the mine is located. Other considerations that typically arise during the federal consultation phase, such as water rights, fish habitats, endangered species, and waste management are also state issues. The approvals and consultations at both the federal and state level take multiple years to complete, and large mines may have to redraft an EIS and refile permits before obtaining final approval.

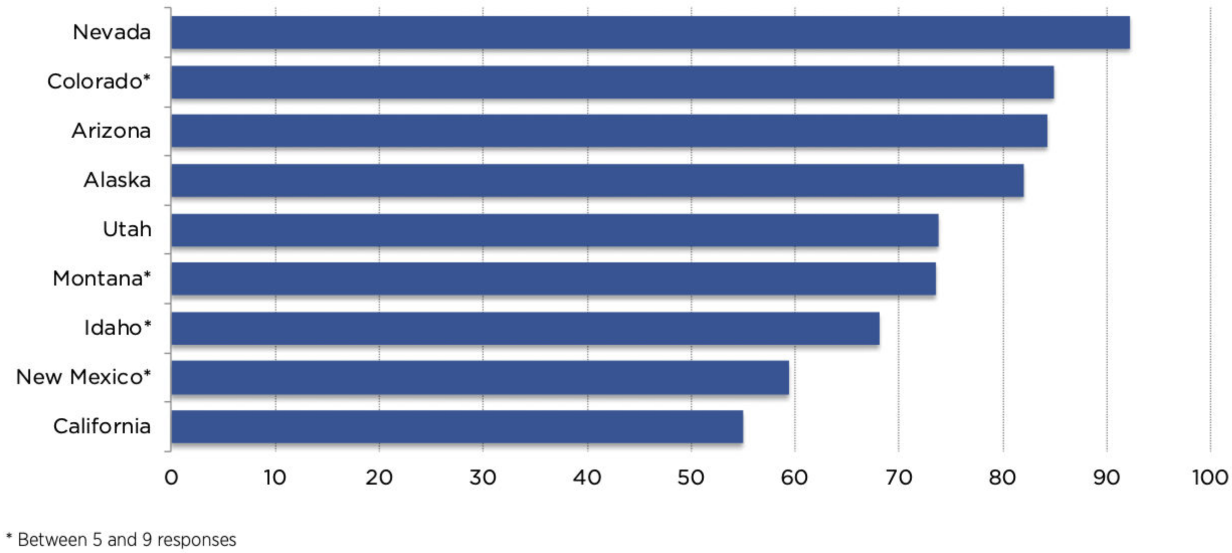
The Fraser Institute recently released their Annual Survey of Mining Companies 2022. The report surveys mining executives from consulting firms, exploration companies, and global producers about various public policies and investment climates in 62 different jurisdictions around the world. The goal of the report is to gauge the overall attractiveness of mining in different areas and how local policies affect investment decisions. Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, and Utah were included in the report as a jurisdiction, as well as British Colombia and Alberta.

The Institute's Policy Perception Index assesses the attractiveness of local mining policies, and serves as a "report card" of sorts for governments. The index ranges from 0-100 and assigns a score based on the ease of mining as a result of clear policies. Nevada came in first place in the world with a perfect 100 score, and Utah, Colorado, Alberta, and Arizona were represented in the top ten leaderboard. Every Western U.S. state scored above a 73, except for California who scored a 40.

The Best Practices Mineral Potential Index (BPMP) measures geological potential assuming a "best case" policy scenario. Nevada and Colorado both scored in the top ten globally, and Idaho and New Mexico scored the lowest out of the represented U.S. states.

Lastly, the Investment Attractiveness Index is a composite index that combines the Policy Perception Index and BPMP Index, with a 40% weight placed on policy perception and 60% weight on BPMP. Nevada came in first place once again, followed by Colorado and Arizona in the top 10. California scored the lowest out of U.S. states.

Figure 8: Investment Attractiveness Index in the United States



Source: Fraser Institute, 2022

Nevada is widely considered to be a "friendly" mining state. Much of this sentiment is due to Nevada's straightforward permitting process that incentivizes investment. Additionally, Nevada has an abundance on minerals in its unique geology that gives it immense potential for commercial production. The state has a long mining history dating back to the early 1800's and its involvement in the Gold Rush. Nevadans consider mining to be important for economic development and the industry has historically provided many jobs to locals. The government benefits from large tax revenues and exports that boost its international status and reputation. Additionally, minerals and metals manufacturing are top exports in Nevada. In 2019, the state exported about $100 million in metal ores to Canada and led all U.S. states in mineral manufacturing (Trade.gov, n.d.). The Nevada BLM office manages over 180,000 claims, which is 49% of all federal claims in the U.S. There are 198 authorized mining plans of operation and 282 active exploration notices (BLM, n.d.). Clearly, the state is attracting mass investment and interest. This is due to the government's clear permitting guidelines and efficient approvals process, favorable industry tax rate, and the broad support of local Nevadans for mining ventures.

California, on the other hand, scored the lowest out of the mining states in policy perception and investment attractiveness. California has adopted strict environmental policies over the past decade which hinder many mine plans, as it is extremely expensive to comply with some of the new regulations. Californian's perception of mining is unfavorable as well. These factors all contribute to California's low scores and without a major shift in public opinion, the status-quo will likely remain as-is.

C. Tribal Rights and Considerations

In the United States, recognized tribal nations have a legal right called retained inherent authority, which recognizes that tribes pre-date the U.S. government and can act as a sovereign entity. There are many stipulations and a lot of nuance surrounding the interpretation of this right in court, and every tribe has a different relationship with the U.S. government. For the most part, however, tribes have their own law-making authority and are not subject to federal taxation.

Five different kinds of tribal lands exist in the U.S.: trust land, fee land, allotted land, split estates, and federal/state reservation lands. Laws surrounding natural resource extraction and property rights differ based on the type of land the party is interested in and will vary with the individual tribe's laws. Right-of-way laws, such as access roads or railways to a mine site, also differ based on the type of land. Therefore, regulations surrounding natural resource extraction on tribal lands are often unclear and decided on a case-by-case basis. Court decisions do set a degree of precedence in some areas, but litigation constantly occurs in tribal law which ever-changes the business landscape.

Tribes possess the authority to charge their own taxes, and thus mines may be subject to double taxation if any part of the leased lands cross both federal and tribal borders. Some mining friendly states, like Nevada for example, have agreements with tribes to share tax revenue rather than disincentivize mining in the state. Additionally, the Indian Mineral Development Act allows tribes to negotiate mineral development agreements and its terms. The Act allows tribes to have more oversight in the operations of extraction and promote their workforce, which was a big win for tribes who wanted more control over their lands.

Regarding permitting, mines must comply with all applicable federal and state permits. Tribes have the authority to set more stringent regulations on reservation lands if they wish to do so, or they can accept the federal and state permits as-is. Again, permits and the permitting timeline varies on a tribe-by-tribe basis and their sentiment towards natural resource extraction. A significant issue that is beginning to make its way through courts is how off-reservation activity impacts reservation land, and what degree of power tribes have over that activity. For example, a mine on BLM land 20 miles away from a tribe that pollutes a waterway that flows into a reservation may be subject to additional regulations from the affected tribe, but the extent of the tribe's jurisdictional power in these situations has yet to be fully decided in court.

Operating on tribal lands is achievable and holds immense potential, but companies need to complete due diligence and sufficient outreach to the tribal members before investing. There is complex interplay between government agencies and entangled authorities in regulations and procedures, but the best resource to start research is with the Bureau of Indian Affairs.

VI. Recommendations

Creating a competitive supply of critical minerals in the Western States and Provinces is attainable. Mines are large-scale operations that require a plethora of oversight and permissions. Therefore, the process to open a new mine is often costly and time-consuming, which can hinder the United States and Canada's goal to become a top supplier of critical minerals and further bolster downstream supply chains for clean energy technologies. Recommendations to improve both permitting timelines and public opinion of mining include:

A. Advocate for FAST-41 Covered Projects.
B. Help mining companies complete their due diligence, both in the permitting process and stakeholder engagement.
C. Encourage public-private partnerships in mining research and development.
D. Promote innovative ways to lower mines' total environmental impact.

The Western States and Provinces represented by the Western Interstate Energy Board are primed to increase critical mineral production and become a top destination for foreign and domestic investment. The geologic potential is there, infrastructure is ready to go, and western research continually discovers new ways to improve efficiency while mitigating environmental impacts. Thus, the future of mining in these regions is encouraging. If states and markets undertake these recommendations in a timely manner, the West can help alleviate supply chain bottlenecks, mitigate geopolitical concerns, and enable increased use of clean energy as a top critical minerals supplier.

VII. Appendix

A-1. IRA Critical Minerals Sourcing Requirements for Tax Credit Eligibility

Critical Minerals: Sourcing Requirements	2024	2025	2026	2027
CM Domestic Percentage	50%	60%	70%	80%
FEOC Requirement	No	Yes	Yes	Yes

A-2. Interactive ArcGIS Map Link
https://csmgis.maps.arcgis.com/home/item.html?id=4d4e6263e33c4674942736d29c2b2bcd

A-3. Mainland Alaska Critical Minerals Map

A-4. U.S. Federal Agency Acronyms: Figure Key

Acronym	Federal Agency
BLM	Bureau of Land Management
USFS	United States Forest Service
USACE	United States Army Corp of Engineers
EPA	Environmental Protection Agency
USFWS	United States Fisheries & Wildlife Service
NMFS	National Marine Fisheries Service
ACHP	Advisory Council on Historic Preservation
SHPOs	State Historic Preservation Offices
THPOs	Tribal Historic Preservation Offices

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