Securing America's critical minerals supply

ASU researchers develop new technologies to increase US critical minerals, essential to national security

By Monique Clement, ASU News
December 10, 2025

You may never have heard of gadolinium, praseodymium or dysprosium, but you use them every day in your smartphone's display. They are a few of the 60 elements and minerals known as "critical minerals." These materials power our lives and are vital to the economy, energy systems and national security.

Global supply chains that source, process and distribute these materials can be interrupted by trade issues, price swings or natural disasters. Losing access to even one critical mineral could disrupt entire industries, threaten U.S. energy security and production capacity, and put jobs at risk.

New federal initiatives seek to increase domestic supplies of critical minerals and reduce dependence on foreign sources. Arizona State University researchers are advancing exploration, mining, recovery, recycling and supply chain innovations to support these goals.

"Arizona is a mining state, and so I think it's important for Arizona to help the industry develop more efficient, more advanced technologies to recover minerals," says César Torres, a researcher in the ASU Biodesign Swette Center for Environmental Biotechnology and a professor in the School for Engineering of Matter, Transport and Energy who studies critical mineral recovery.

"ASU is helping develop the new generation of technologies that will be used by the industry. We have the facilities, the infrastructure to rapidly test different technologies and see whether they have economic viability, whether they have scientific merit."

Why this research matters

Research is the invisible hand that powers America's progress. It unlocks discoveries and creates opportunity. It develops new technologies and new ways of doing things.

Learn more about ASU discoveries that are contributing to changing the world and making America the world's leading economic power at researchmatters.asu.edu.

What are critical minerals?

Critical minerals are the foundational materials needed for U.S. manufacturing, the economy and national security — and that have supply chains vulnerable to disruptions. The U.S. Geological Survey analyzes vulnerabilities and updates a list of these minerals every few years.

Some critical minerals are familiar materials. Aluminum, for example, isn’t only for soda cans and wrapping leftovers. It’s also vital for defense, aerospace, transportation and energy uses. Graphite, a form of carbon, has a soft, layered structure that allows pencils to write and helps hold and release energy in lithium-ion batteries.

Others are less known but equally important. For example, gallium, a soft metal that can melt in your hand, is used in semiconductors.

What is a mineral?

According to the U.S. Geological Survey, a mineral is a material that:

- Is naturally occurring.
- Is inorganic, meaning it is not made from living things.
- Is either an element (the fundamental building blocks of all matter) or a compound (made up of two or more elements).
- Has an orderly internal structure, characteristic chemical composition and a crystal form.
- Has physical properties (such as hardness, density and cleavage patterns) that reveal its structure and composition, which help identify the mineral and determine how it can be used.

What is a rare earth element?

Also called rare earth magnets, rare earth elements are a subset of critical minerals that have special physical and chemical properties. You can find most of them on the second-to-last row, at the bottom of the periodic table. Some are especially strong magnets, and others have light-emitting properties or increase the rate of chemical reactions. These characteristics make them useful for electric motors, medical technologies, defense systems and other electronics.

Rare earth elements are not as rare as their name suggests. Many are more abundant than silver, gold and platinum — but you won’t find a nugget of samarium. They only appear in small traces mixed with other minerals. They’re also difficult to separate out, requiring complex chemical processes to pull them apart from less useful elements.

Where do critical minerals come from?

Some critical minerals are abundant, while others are rare and exist only in small amounts in specific places.

Magnesium, for example, is found in common rocks and even seawater. Iridium, on the other hand, is one of the rarest critical minerals. It is more often found in meteorites than in Earth's own rocks. Major iridium mines only exist in Canada, Russia and South Africa, with a potential site in Utah.

The U.S. and other countries depend on China for nearly all of their supply of rare earth elements and other critical minerals. China holds large reserves, extensive mining capacity and, most importantly, controls global refining. Even the rare earth elements from Southern California's Mountain Pass mine are shipped to China for refining.

Decades of Chinese investment in refining infrastructure and low production costs made it difficult for the U.S. to compete. Now, China's export restrictions and rising U.S. demand make finding alternative sources and building domestic refining capacity a priority.

How do we find new sources?

The U.S. Geological Survey is identifying areas where new mineral sources could be found, including a key region in Arizona.

Arizona is well positioned to be a crucial corridor for critical mineral activity. The state produces about 70% of U.S. mined copper — a resource added to the 2025 U.S. critical minerals list because of its importance to the energy sector. And where there's copper, there are other critical minerals like lithium, tantalum and molybdenum.

ASU geoscientists are contributing to the discovery of new critical mineral deposits. They study the fundamental processes that form the rocks that contain critical minerals. That knowledge shapes how we look for mineral deposits.

"We need to find new deposits, so we need new ideas about how they're formed, preserved and distributed. That allows us to improve our understanding of current prospects and leads us to discover new ones," says Ramon Arrowsmith, a professor and the interim school director of the ASU School of Earth and Space Exploration.

"We create and test geologic models that help find more, find the rest of an existing deposit or find new pathways for critical mineral concentrations to form. We have a standard model for critical mineral formation, but there could be new pathways that open up a new resource."

ASU researchers are also mining data — from digitized historical records to new satellite and sensor data — for new ideas using artificial intelligence. AI tools help uncover patterns and connections that reveal new places to look for critical minerals.

Arrowsmith adds that the search for critical minerals isn't limited to Earth. Space exploration opens up new possibilities — and new critical resources like water on the moon. ASU researchers are studying the potential to mine resources from Mars, asteroids and other extraterrestrial objects.

> **“Arizona is a mining state, and so I think it's important for Arizona to help the industry develop more efficient, more advanced technologies to recover minerals.”**
>
> —
>
> **César Torres**
> ASU researcher and professor who studies critical mineral recovery

How can we mine more responsibly?

Critical minerals are essential for modern technology and energy security. But extraction and refining can damage landscapes, contaminate water and displace people.

In Chile’s Atacama Desert, for example, lithium extraction uses up limited groundwater and threatens the health of this unique environment. Yet the demand for lithium continues to grow.

“In your phone or electric car, you don't see the lithium. It's not visible. So it's really out of sight, out of mind,” says Datu Buyung Agusdinata, an associate professor in the ASU School of Sustainability who studies mining in Chile, Indonesia and Arizona. “When we try to extract these minerals domestically, we have to deal with the impacts more closely.”

He says that sustainable mining has to account for local communities and their livelihoods as well as protecting the environment. His work explores methods to build more collaborative partnerships that promote fair, sustainable extractions and supply chains that benefit everyone.

In Indonesia, he’s studying the use of AI tools that give residents a voice in how lithium mining operations affect them. For example, people could upload photos of water issues or report harm to wildlife, and AI would analyze the data to reveal real-time impacts. The results could guide company and government decisions and help rebuild trust.

“Here, there might be an opportunity for more involvement of the local communities and Indigenous people to bridge power asymmetries between them and the mining companies,” Agusdinata says.

Can we recover and recycle critical minerals?

These impacts, along with rising mining and critical minerals costs, mean it’s increasingly important to maximize the value of mine operations.

One approach is to extract minerals from mining waste, such as leftover rock or wastewater. But mining companies need new technologies to do this effectively.

Anca Delgado, a researcher in the Biodesign Swette Center for Environmental Biotechnology and an associate professor in the School of Sustainable Engineering and the Built Environment, studies methods to remove contaminants from water. She says mining companies have historically treated mining wastewater only to meet water quality standards. Recovering critical minerals during this process is only now being seriously considered.

Delgado and Torres are among the researchers at ASU developing new systems that use bacteria to pull metals from wastewater in economically valuable quantities.

Water-cleaning bacteria produce economic benefits

Read about how another ASU researcher, Bruce Rittmann, uses bacteria to recover critical minerals from industrial wastewater.

Bacteria consume certain substances from wastewater and release a gas that grabs onto metal. With the right systems in place, these metals can be collected in a pure form. Recent reports suggest that recovering and processing even a small amount of minerals from waste could significantly cut imports.

Another opportunity lies in recycling. Instead of sending solar panels, lithium-ion batteries or microchips to landfills, we can return critical minerals to manufacturing — creating what is known as a circular economy.

First, however, we need new strategies to more efficiently and cost-effectively separate critical minerals out of waste sources.

“From a national security perspective, we need to look at recycling minerals more seriously,” says Dwarak Ravikumar, an assistant professor in the School of Sustainable Engineering and the Built Environment who leads research on solar panel recycling. “Research in universities like ASU can help in reducing the recycling costs and formulate policies (to divert valuable materials from landfills)."

Ravikumar says one benefit of recycling materials is that they can be recovered at higher concentrations than when pulling them out of the ground. Arizona’s high concentration of microelectronics and solar energy manufacturers makes the state an ideal location to develop these processes.

Are there alternatives to critical minerals?

We use critical minerals because they have unique and valuable properties. Lithium, for example, is one of the lightest and highest-performing materials that can store and release energy. But it’s not irreplaceable.

Nick Rolston, an assistant professor in the School of Electrical, Computer and Energy Engineering, is exploring the possibilities of sodium-ion batteries as an alternative to lithium-ion batteries. By replacing lithium with sodium, these batteries can rely on more abundant elements and avoid using several critical minerals.

This swap causes trade-offs in weight and performance. That might be a deal breaker for an electric vehicle if using different battery materials cuts its range in half. But they can be potentially useful for stationary energy storage to support the power grid.

“We can't just say we're going to stop using lithium entirely, or we're going to just replace any of these materials a hundred percent, but we can make steps that will allow us to decrease our reliance on specific critical minerals,” Rolston says. “The cool thing is there's the ability to be creative and to engineer around some of these constraints.”

How can we enhance the supply chain?

These solutions will help make critical minerals more readily available. But the U.S. still depends on foreign sources of critical minerals and likely always will to some extent.

Building domestic extraction and refining capacity will take years. Today, operations are limited to a few states, including Arizona. While logistical, cost, labor and environmental challenges remain, Arizona’s established mining industry and research expertise make it a strong candidate for new recovery and recycling opportunities.

In ASU's W. P. Carey School of Business, researchers are developing critical mineral supply chain strategies that increase production and resilience and minimize community and environmental impacts. The school has a demonstrated history of creating adaptable, evidence-based supply chain solutions for copper mining and semiconductors.

The Phoenix area’s rich semiconductor industry ecosystem relies heavily on critical minerals. It can leverage ASU’s expertise to serve as a living lab to study resource bottlenecks, vulnerabilities and resilience.

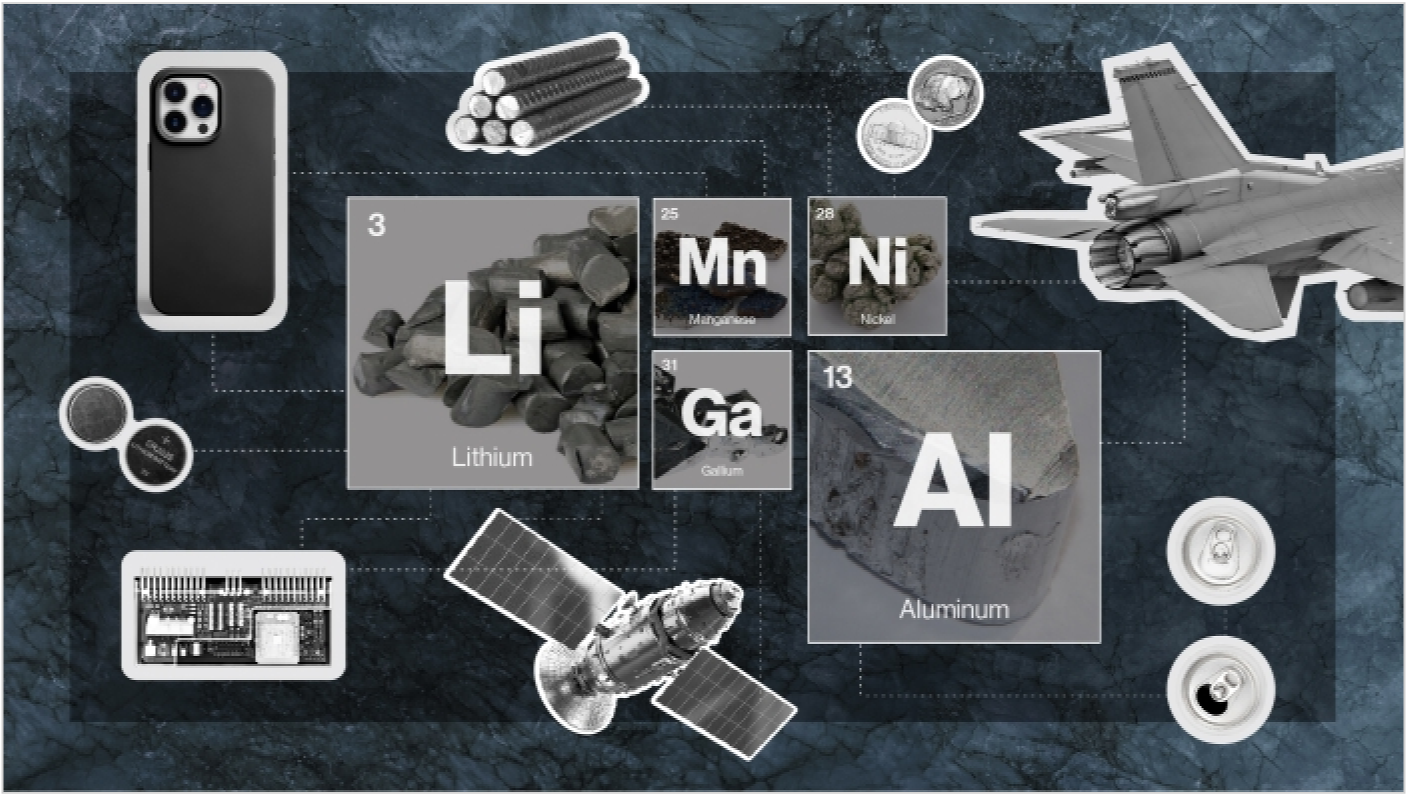
Adegoke Oke, a professor and chair of the NASPO Department of Supply Chain Management, says: “ASU's leadership in the use of AI and machine learning, relevant research centers such as the Center for Responsible Supply Chain Management and our geographical advantage with proximity to critical minerals sources are strengths that can support the nation’s critical mineral goals."

The School of Sustainability is part of the Rob Walton College of Global Futures, which is the learning space within the Julie Ann Wrigley Global Futures Laboratory.

The School of Electrical, Computer and Energy Engineering, the School for Engineering of Matter, Transport and Energy and the School of Sustainable Engineering and the Built Environment are part of the Ira A. Fulton Schools of Engineering.

This story originally appeared on ASU News.

Main image

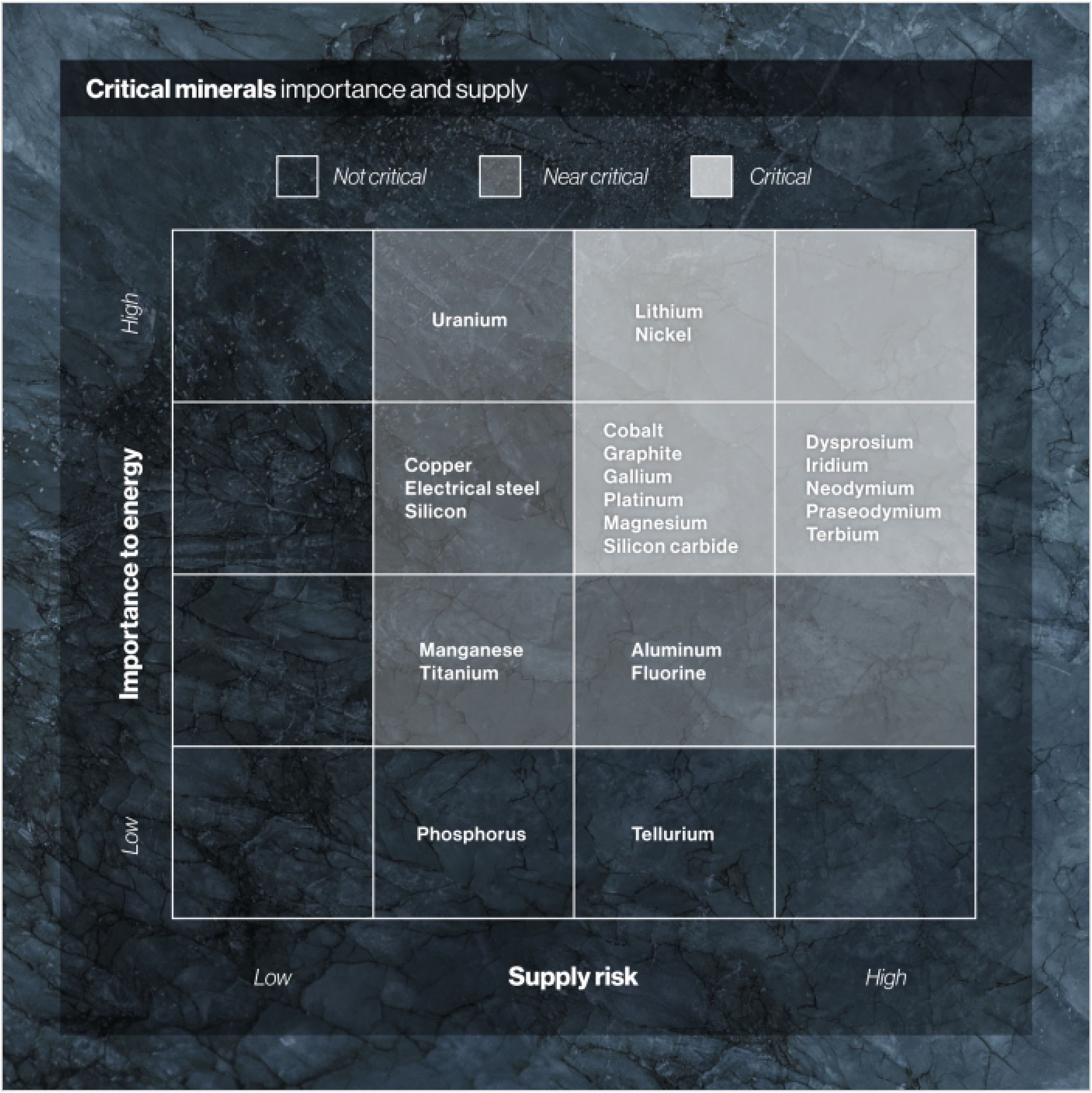


Lithium, manganese, gallium, nickel and aluminum — used in products that affect our daily lives — are some of the many materials known as “critical minerals." Critical minerals are essential to U.S. economic, energy and national security applications, but have vulnerable supply chains. Researchers at Arizona State University are innovating in areas that will help secure sustainable domestic supplies of these vital materials. Graphic by Andy Keena/ASU

Text image(s)

In 2025, the U.S. Geological Survey created an updated critical minerals list, which includes elements found on the periodic table and additional minerals that contain one or more elements. This list guides national strategy to secure materials vital to manufacturing, energy and national defense. Graphic by Andy Keena/ASU (data from the U.S. Geological Survey).

Critical mineral distribution around the world varies from country to country. Where these minerals come from is based on natural deposits in rock as well as processing infrastructure to refine them for use in manufacturing. Learn more about each country's mineral production in the U.S. Geological Survey's interactive Critical Minerals Atlas. In addition, a 2023 USGS report shows active production and potential critical mineral resources for Arizona and the U.S. Western region. Arizona's copper-rich geology also suggests likely critical mineral reserves, including aluminum, bismuth, germanium, indium, potash, tellurium, titanium and vanadium. Graphic by Andy Keena/ASU (data from the U.S. Geological Survey).



An important reason that materials are selected as critical minerals is their supply chains are vulnerable to disruptions. Losing access to a critical mineral would have profound effects on the U.S. economy. The U.S. Department of Energy identified the importance of certain minerals for energy applications alongside the risk of supply chain disruptions in the near future. Graphic by Andy Keena/ASU (data from the U.S. Department of Energy).