CRITICAL MINERALS
# ALLIANCES

## Mission Critical Minerals

**Pentagon Backs Domestic Projects Vital to America's Economy, Defense**

## Inside: 32 Critical Minerals

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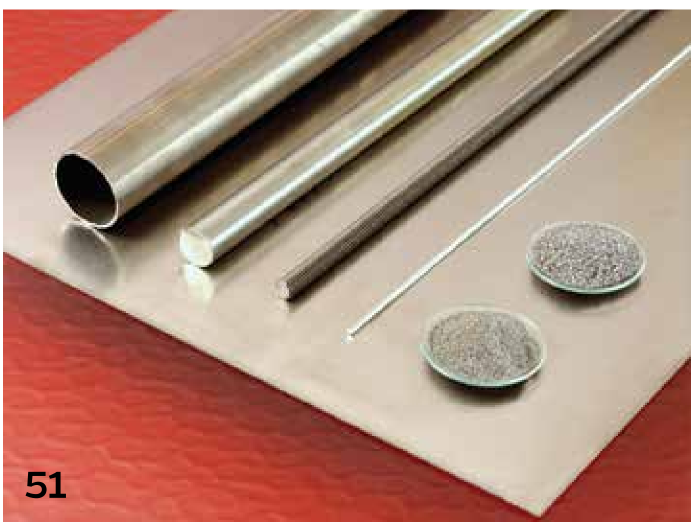
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Good Stories

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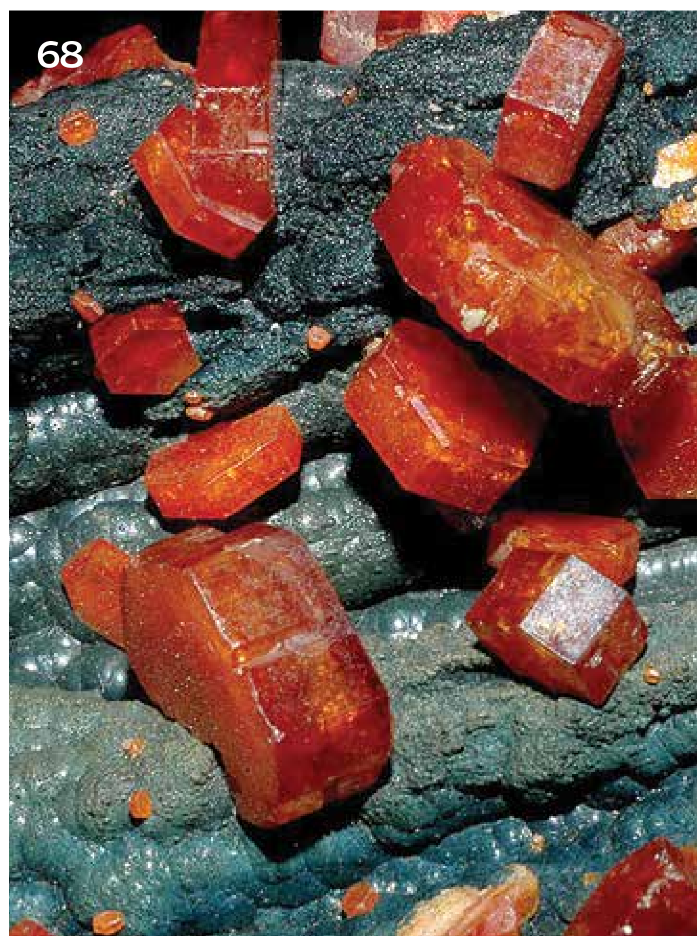
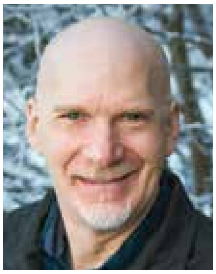


The Pentagon estimates that each F-35 fighter contains roughly 900 pounds of rare earths plus 24 other critical minerals.

MIKE MAREEN AT STOCK.ADOBE.COM

# Critical Minerals Alliances 2024

## Critical minerals security seen as national security issue



SHANE LASLEY

By SHANE LASLEY
DATA MINE NORTH

**WELCOME TO CRITICAL MINERALS ALLIANCES** 2024, the fourth installment of this annual magazine that provides in-depth insights into minerals and metals critical to a robust economy, national security, and the transition to clean energy.

For the Data Mine North news team, Critical Minerals Alliances is more than an annual update on the rapidly changing critical minerals markets and policies. From the very beginning, it has been our hope that this annual magazine will play some role in helping to build critical minerals alliances "that are not crippled by irreconcilable differences between organizations and individuals that do not always see eye-to-eye but strengthened by a spectrum of ideologies with a common goal – a healthy, prosperous, and exciting future for humankind."

Over the three years since the first edition of Critical Minerals Alliances rolled off the printing press, we have witnessed a growing number of researchers, conservationists, consumers, governments, investors, local stakeholders, manufacturers, and miners come together to forge cohesive strategies to sustainably extract, reuse, and recycle the elements of 21st-century innovation.

The coalescence of this broad range of expertise and ideals has largely been driven by a common goal of transitioning the way the world powers transportation, industry, and everyday living away from fossil fuels and toward new clean energy sources.

While the previous three editions of Critical Minerals Alliances were, to a large degree, centered on the minerals and metals critical to the transition to clean energy and transportation, this issue takes a deeper dive into another vitally important side of the critical minerals equation – national security.

In preparation for publishing the original official list of minerals critical to the United States in 2018, the U.S. Geological Survey defined critical minerals as *"non-fuel minerals or mineral materials essential to the economic and national security of the United States; vulnerable to supply chain disruptions; and serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for the U.S. economy or security."*

Due to the massive quantities of minerals needed to build electric vehicles, renewable energy sources such as wind and solar, and the infrastructure needed to transition from pipelines to powerlines, the shift to clean energy has dominated the critical minerals conversation since the original list of critical minerals under this definition was published.

While clean energy and transportation will be an enormous driver of critical minerals demand over at least the next two decades, this is only part of the story.

For the United States, which is dependent on imports for more than half its supply of 49 minerals and metals, there are also national security implications connected to being beholden to countries like China and Russia for critical minerals.

The criticality of minerals to America's clean energy future, economy, and national security are not mutually exclusive.

"Our ability to maintain our way of life, our ability to maintain our position in the world, our ability to fund our physical security – all of these things are dependent on a strong and robust economy," U.S. Department of Homeland Security Director Tim Moughon told industry leaders at the American Exploration & Mining Association conference last December. "The mining sector is critically important in this respect."

This is why Homeland Security is keeping close tabs on America's heavy dependency on critical mineral imports, and the Pentagon is investing heavily into reestablishing robust and reliable critical mineral supply chains in the U.S.

The urgency to establish a reliable domestic supply of the minerals essential to a strong and robust U.S. economy has been elevated by a growing number of restrictions on exports out of China, a country that dominates the global supply of critical minerals.

Since mid-2023, China has put policies in place that require government approvals for any gallium, germanium, graphite, and antimony exported out of the communist country.

Gallium and germanium are used in computer chips and are critical to America's tech sector; graphite is the single largest ingredient in the lithium-ion batteries powering EVs, and antimony is needed for munitions.

From the up to 20 pounds of lithium batteries carried by soldiers, to the electronic devices those batteries power and the ammunition in the magazine, all of these critical minerals are of strategic importance to the U.S. military.

Out of these four elements, only germanium is currently being mined in the U.S. This leaves American manufacturers beholden to China, which is the world's leading producer of 29 minerals deemed critical to the U.S. and other nations for their supply.

"China is weaponizing the world's access to critical minerals, and it's never been more urgent to secure the United States' critical mineral supply," said John Cherry, president and CEO of Perpetua Resources, a company that is advancing an antimony mine project in Idaho toward production.

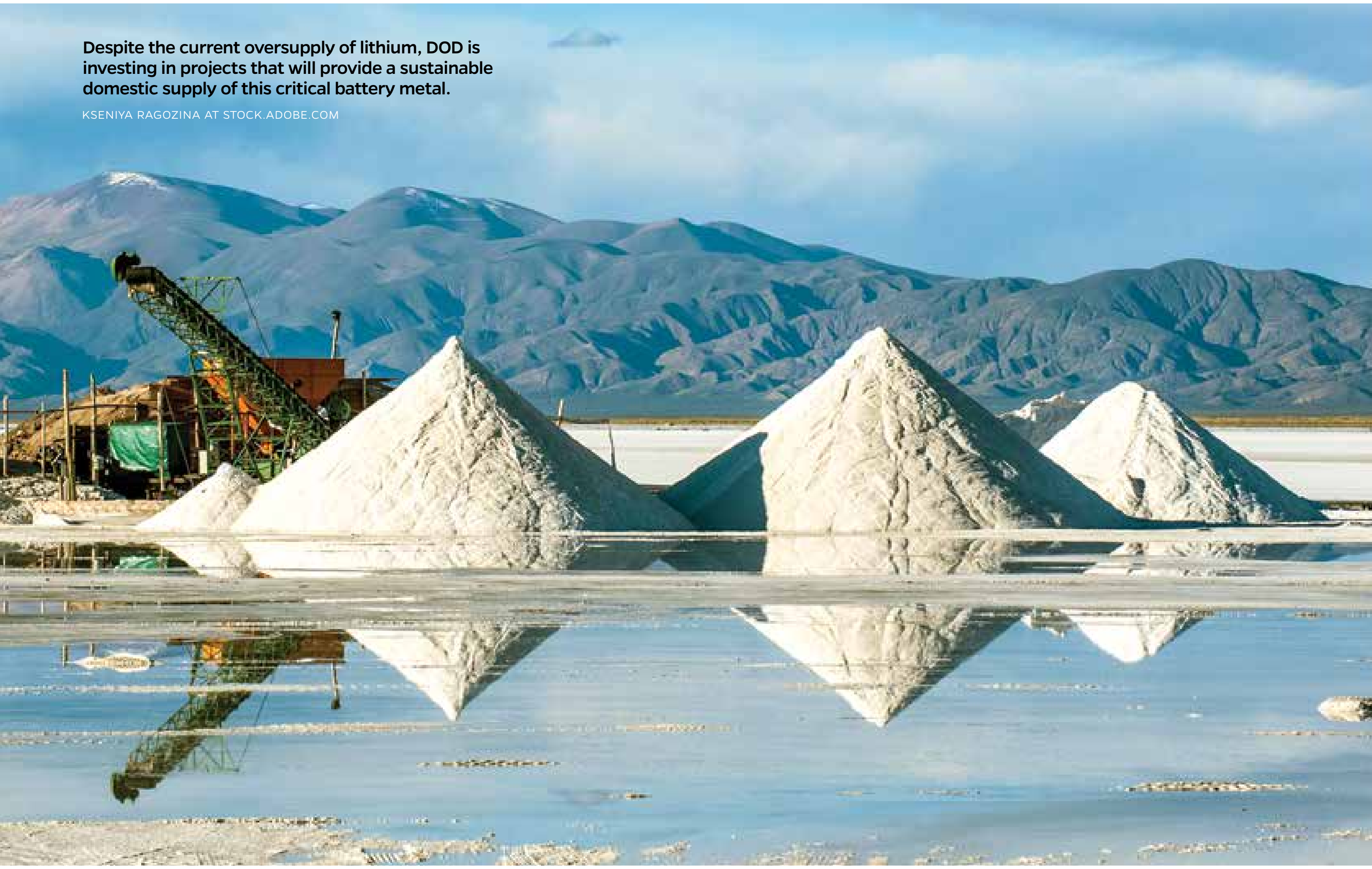
With the strategic view that critical minerals security is a national security issue, the U.S. Department of Defense is backing the development of Perpetua's antimony mine and other critical mineral projects on American and Canadian soil.

These investments by DOD are part of an emerging all-of-government strategy to make America less reliant on critical minerals imports.

This strategy includes billions of dollars being invested by the Pentagon, Department of Energy, and Export-Import Bank of the United States to establish all-American critical mineral supply chains.

Critical Minerals Alliances 2024 takes a deeper dive into this all-of-government strategy to establish reliable and secure sources of the minerals and metals critical to North America's economic well-being, national security, and clean energy ambitions.

On behalf of the entire Data Mine North team, I am proud to present Critical Minerals Alliances 2024 and invite your feedback on this magazine designed to provide in-depth insights into the elements of innovation and encourage partnerships across the mine-to-American supply chain.



Despite the current oversupply of lithium, DOD is investing in projects that will provide a sustainable domestic supply of this critical battery metal.

KSENIYA RAGOZINA AT STOCK.ADOBE.COM

# DOD invests in mission-critical minerals

## Import-reliance a top concern for national security officials

By **SHANE LASLEY**
DATA MINE NORTH

**AMERICA'S HEAVY RELIANCE** on China and others for the minerals and metals critical to the nation's economic competitiveness, military strength, and clean energy future is high on the list of strategic concerns for top brass at the U.S. departments of Defense and Homeland Security.

While much of this concern is rooted in the fact that the United States' ability to defend its strategic interests at home and abroad would be severely crippled if China decides to cut supplies of the mined materials critical to a prolonged and high-tech war, the departments charged with America's security understand that there are much more fundamental reasons to become more self-reliant when it comes to the minerals that are the first link to nearly every American supply chain.

"Economic competitiveness is a national security issue," Tim Moughon, director of field intelligence at the U.S. Department of Homeland Security, said during a presentation at the American Exploration & Mining Association conference last December.

The raw materials foundation of America's economic competitiveness, however, eroded with a globalization strategy that favored inexpensive imports over supporting domestic supply chains. China, which can mine and manufacture goods much cheaper due to lower labor costs and environmental standards, has been happy to be the low-cost supplier of these goods and, at the same time, gain dominance in many of the world's supply chains.

"Over three decades the People's Republic of China became the global industrial powerhouse in many key areas – from shipbuilding to critical minerals to microelectronics – that vastly exceeds the capacity of not just the United States, but the combined output of our key European and Asian allies as well," the U.S. Department of Defense penned in its inaugural National Defense Industrial Strategy published in January.

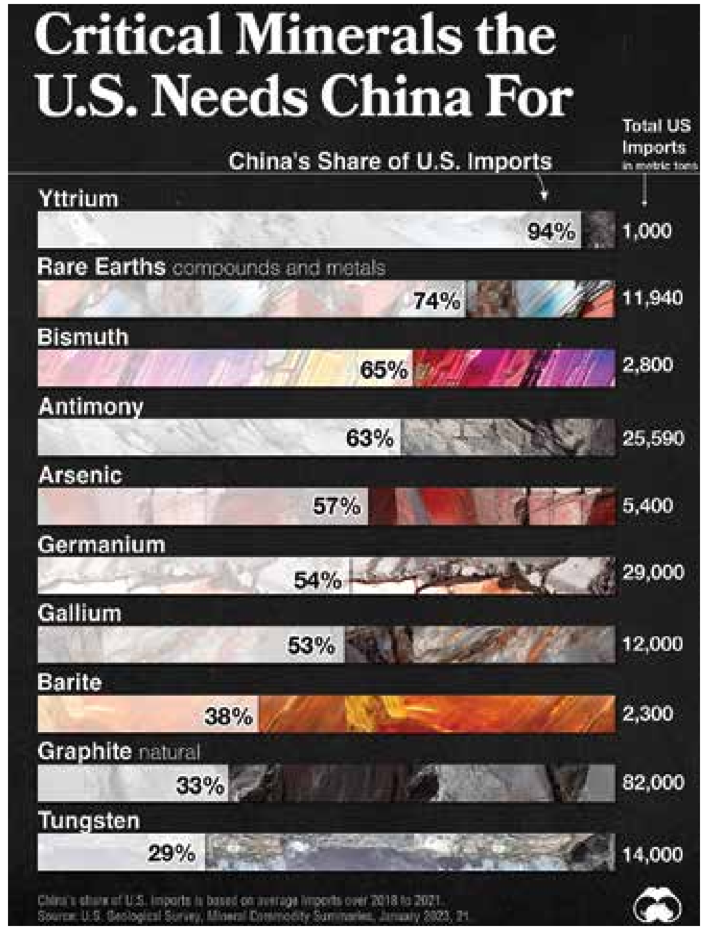
JOE BUCCINO

Homeland Security and the Pentagon both see the erosion of American supply chains and the mining industry that supports them as a major national security concern.

"Our ability to maintain our way of life, our ability to maintain our position in the world, our ability to fund our physical security – all of these things are dependent on a strong and robust economy," Moughon informed mining leaders gathered in Reno last December. "The mining sector is critically important in this respect."

Moughon's message was reinforced by an article penned by Joe Buccino, a retired U.S. Army colonel who served as the communications director for U.S. Central Command from 2021 to 2023, in a column published by RealClear Defense shortly after the Department of Homeland Security's presentation at the annual mining event.

"Establishing a fully domestic mineral supply chain, stretching from mining operations to the final market, is essential for ensuring security for long-term competition with China," Buccino wrote.




China is the leading producer of 30 of the minerals critical to the U.S.

## America's critical minerals myopia

The 2024 edition of U.S. Geological Survey's annual Mineral Commodity Summaries underscores the extent that America has traded its critically important mining sector in exchange for cheap goods from China and others.

According to the report published in January, the U.S. relies on imports for more than half its supply of 49 minerals that serve as foundational inputs to nearly every sector of the American economy and is 100% dependent on imports for 15 of them.

"Our mineral import dependence continues to be a gaping hole in our economic and national security and we're clearly not moving fast enough to course correct," National Mining Association President and CEO Rich Nolan said upon the release of USGS Mineral Commodity Summaries 2024.

This gaping hole includes being net-import reliant for 29 out of the 50 minerals that have been deemed critical to America's economy and security, including 100% dependent on other countries for 12 of them.

The USGS estimates that China is the world's top supplier of 30 out of the 50 minerals critical to the U.S. This list includes the 14 rare earth elements that are needed across an increasingly wide array of consumer, industrial, and military goods.

China's rise to dominance came during a time when American consumers and manufacturers embraced globalization, and the U.S. military took a "procurement holiday," a term given to a period of decreased DOD budgets and spending following the end of the Cold War.

"Before the 1980s, the United States was the global leader in the rare earths market. Since then, increasing environmental regulations and high labor costs moved much of the production abroad," Buccino wrote.

By the early 2000s, China had established a near complete global monopoly over the group of 14 tech metals known as rare earths. While some capacity has been outside of China, the communist nation still controls roughly 65% of rare earths mining and nearly 90% of separation and processing.

"China's foresight here is as clear as the United States' myopia," Buccino wrote. "Should China, in the leadup to an invasion of Taiwan, block exports of rare earths or processing technology, this would cripple the U.S.'s ability to produce the kinds of ammo required to sustain a long-term high-tech war."

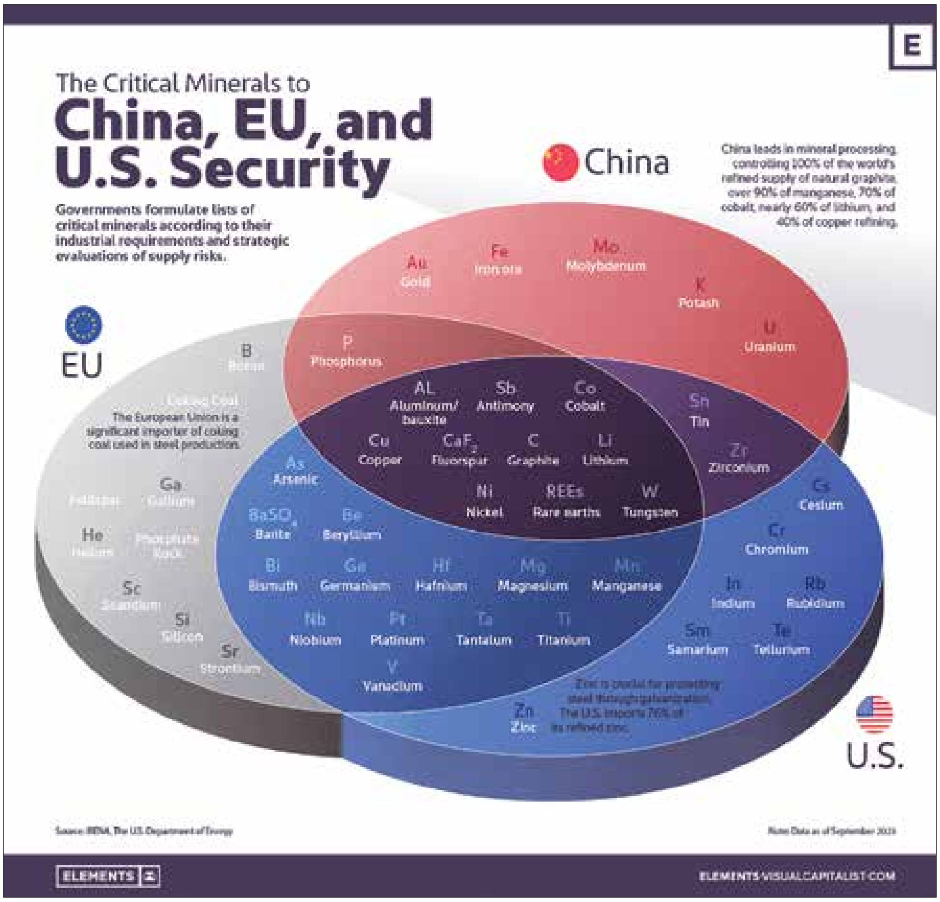
## China's monopoly power

While rare earths are a prime example, they are not the only critical minerals for which America's shortsightedness has resulted in a heavy dependence on China for its supply.

The list of critical minerals for which China is a top supplier includes:

- **Gallium**, the U.S. relies on imports for 100% of its supply of this semiconductor used in next-generation smartphones, telecommunication networks, and solar technologies.
- **Graphite**, the U.S. relies on imports for 100% of its supply of this mined material that is currently the single largest ingredient in lithium-ion batteries for electric vehicles.
- **Manganese**, the U.S. relies on imports for 100% of its supply of this mined material needed for steelmaking and in the cathodes of

VISUAL CAPITALIST




lithium-ion batteries.

• **Niobium**, the U.S. relies on imports for 100% of its supply of this metal essential to heat-resistant superalloys for hypersonic missiles and the broader aerospace sector.

• **Titanium**, the U.S. relies on imports for 95% of its supply of this light yet strong metal used in aerospace alloys, sports equipment, and now the Apple iPhone 15 Pro.

• **Platinum**, the U.S. relies on imports for 83% of its supply of this precious metal used as a catalyst to scrub pollutants from industrial and automotive emissions.

• **Antimony**, the U.S. relies on imports for 83% of its supply of this metalloid with a wide variety of civilian and defense applications and a top concern of the U.S. military.

Department of Homeland Security says China's dominance in the global supply of these and several other critical minerals can be used as an economic and geopolitical tool.

"With this monopoly power comes tremendous ability to target adversaries and to use this economic position to shape the behavior of other governments," Moughon said.

## Monopoly not hypothetical

China's ability and willingness to leverage its critical minerals dominance as a geopolitical tool and trade war weapon is not hypothetical.

Back in 2010, the communist country severely restricted rare earth exports as a means of punishing Japan during a dispute over the sovereignty of islands in the South China Sea.

As a result, the prices for these elements skyrocketed, and a global rush to discover and develop deposits outside of China erupted. At the height of this frenzy, China flooded the markets with rare earths it had been stockpiling during the embargo – driving many hopeful rare earth companies out of business and providing the communist nation an excellent opportunity to buy distressed rare earth assets around the globe at a discount.

In recent years, China has further solidified its control of critical mineral assets beyond its borders through the Belts and Road Initiative, a strategy to build up infrastructure in developing nations in exchange for ownership of mining projects.

"It is a great example of the Chinese government's efforts to go out and buy up critical minerals, critical resources. China has become the largest bidirectional lender in Africa in recent years," said Moughon.

The US-China Economic and Security Review Commission estimates that China has loaned 15 African nations a combined $140.6 billion under what some are calling the Chinese debt trap.

"China is also very involved with many of these enterprises – essentially, state-owned monopolies that can invest in the space, but invest in the space at a discount," the commission wrote.

The control over so many mining assets within and without its borders, coupled with state-owned mining companies that can forego healthy profits from mining in favor of the value-added products, strengthens China's monopolization of global critical mineral supplies along with the high-tech, clean energy, and other sectors they support.

With control of the upper end of the supply chain, China bolsters its economy and national security by upgrading critical minerals into higher-value products used in electric vehicles, high-tech electronics, military hardware, and an enormous array of consumer goods.

"The government of China has a critical position now in the critical minerals space, they dominate the market for processing critical minerals, from ore to refined products," said Moughon. "They use these products in both intermediate goods and then in finished goods."

In 2023, the communist government again leveraged its dominance by placing state-controlled restrictions on the exports of gallium, germanium, and graphite. All three of these mined materials are critical to the clean energy and tech sectors and, by extension, national security.

Hitting even closer to home when it comes to minerals critical to national security, China has placed similar restrictions on exports of antimony, a metalloid that is vital to manufacturing military communication equipment, night vision goggles, and ammunition.

China's Ministry of Commerce said the government controls on antimony exports, which went into effect on Sept. 15, are required "to safeguard national security and interests, and fulfill international obligations such as non-proliferation."

"So, these aren't hypotheticals," said Moughon. "We see adversaries use monopolistic power very intentionally to advance their own national interests."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**Above: Fire-resistant combat gear, night vision goggles, communications equipment, and ammunition are among the military gear that requires critical minerals. Right: DOD is investing in domestic mine projects that will provide secure supplies of materials needed for electric vehicles, such as this Hummer EV.**

### Concentrated energy supply chains

The enormous quantities of minerals required to build a green energy future in the U.S. add another layer of urgency to the need to develop domestic critical mineral supplies.

In a report published earlier this year, the International Energy Agency (IEA) estimated that an additional $800 billion needs to be invested in mining by 2040 to achieve net-zero emissions goals by mid-century.

"The world's appetite for technologies such as solar panels, electric cars and batteries is growing fast – but we cannot satisfy it without reliable and expanding supplies of critical minerals," said International Energy Agency Executive Director Fatih Birol.

In addition to expanding the volume of energy transition minerals entering global supply chains, IEA emphasized the need to diversify where that supply is coming from in order to curb the supply and geopolitical risks associated with the current overreliance on a handful of producing countries.

"Between now and 2030, some 70-75% of projected supply growth for refined lithium, nickel, cobalt, and rare earth elements comes from today's top three producers," the agency penned in its new report.

China is among the top three producing countries of the mined materials needed for EV supply chains:

- 85% of the world's refined lithium is produced in China (57%), Chile (15%), and Argentina (13%).
- 71% of the world's refined nickel is produced in Indonesia (44%), China (21%), and Japan (6%).
- 84% of the world's refined cobalt is produced in China (74%), Finland (6%), and Japan (4%).
- 92% of the world's rare earths are produced in China (77%), Malaysia (12%), and Australia (3%).
- 99% of the world's natural graphite anode materials are produced in China (79%), South Korea (13%), and Japan (8%).

"These high levels of supply concentration represent a risk for the speed of energy transitions, as it makes supply chains and routes more vulnerable to disruption, whether from extreme weather, trade disputes or geopolitics," IEA penned in its Global Critical Mineral Outlook 2024 report.

### COVID exposes U.S. reliance

The Pentagon says the global supply chain disruptions during the COVID pandemic underscore the risks of being overly dependent on global supply chains.

"The events of recent years dramatically exposed serious shortfalls in both domestic manufacturing and international supply chains," DOD penned in its National Defense Industrial Strategy. "The COVID-19 crisis demonstrated America's near wholesale dependency on other nations for many products and materials crucial to modern life."

The nation's heavy reliance on imports for minerals and metals essential to the nation's economy and military is high on the Pentagon's list of supply chain concerns.

Presidents Trump and Biden have both instructed the Pentagon to leverage a Cold War-era tool known as the Defense Production Act (DPA) to combat America's near wholesale dependency on critical mineral imports.

In 2019, President Trump leveraged presidential powers under DPA Title III to authorize the Pentagon to pursue the re-establishment of a mines-to-magnets rare earths supply chain in the U.S.

At the behest of a bipartisan group of lawmakers, Biden also invoked his DPA presidential powers to authorize DOD to invest in domestic battery material supply chains.

"The authorities provided to you as President under the Defense Production Act will help to ensure that America's critical mineral supply chains are strong, responsibly produced, and ethically sourced. Given the stakes, America cannot afford to wait any longer for that day to arrive," Senators Lisa Murkowski, R-Alaska, Joe Manchin, D-W.Va., Jim Risch, R-Idaho, and Bill Cassidy, R-La. penned in a 2022 letter to Biden.


JAMES COLLORD; COURTESY OF PERPETUA RESOURCES INC.

**U.S. Department of Defense has invested nearly $60 million into reestablishing a mine at Perpetua Resources' Stibnite gold-antimony project in Idaho, which is home to a historic critical minerals mine credited with saving the lives of 1 million American soldiers during World War II.**

## Mission critical minerals

Over the past four years, DOD has invested more than $870 million of DPA Title III funding to bolster North American supply of the minerals and metals critical to America's economy, defense, and energy transition.

Domestic critical minerals projects that have received Pentagon funding include:

- **Leidos Holdings Inc.** – $276 million to conduct research and development of critical minerals and materials for use in munitions and promote supply chain resiliency.
- **Lynas Rare Earths Ltd.** – $258 million in funding to establish a rare earths processing facility in Texas.
- **Albemarle Corp.** – $90 million to support the reopening of the Kings Mountain lithium mine in North Carolina.
- **MP Materials Corp.** – $44.6 million to commercially separate rare earth elements at its Mountain Pass Mine in California.
- **Perpetua Resources Corp.** – $59.4 million to reestablish a domestic source of antimony at the Stibnite Gold project in Idaho.
- **Graphite One Inc.** – $37.5 million to support a domestic graphite supply chain that includes a mine in Alaska and processing facility in Washington.
- **Talon Nickel Corp.** – $20.6 million to advance exploration and resource definition at the Tamarack project in Minnesota.
- **South32 Ltd.** – $20 million to jump-start the production of battery-grade manganese at the Hermosa project in Arizona.
- **Electra Battery Materials Corp.** – $20 million to complete construction and commissioning of the Ontario Cobalt Refinery.
- **Jervois Mining Ltd.** – $15 million to support the expansion of the Idaho Cobalt Operations.
- **Lithium Nevada Corp.** – $11.8 million to accelerate the extraction and processing of lithium carbonate at the Thacker Pass mine project in Nevada.
- **The Doe Run Resources Corp.** – $7 million to help scale up a cobalt and nickel processing plant in Missouri.
- **Lomiko Metals Inc.** – $8.3 million to advance a graphite mine and processing facility in Quebec.
- **Fortune Minerals Ltd.** – $6.5 million to advance studies for a cobalt-gold-bismuth-copper mine in Northwest Territories and refinery in Alberta.

DOD's investments in Lomiko and Fortune mark the first time that the U.S. and Canadian governments co-invested in the development of critical mineral projects in North America.

As part of the collaborative effort, Natural Resources Canada invested an additional US$9.2 million in these Canadian critical mineral companies.

"As some of the first awards to Canadian public mining and mineral development companies, these grants exemplify the critical importance of DPA funds, the Department's partnership with Canada, and our shared commitment to strengthening North American material supply chains," said U.S. Assistant Secretary of Defense for Industrial Base Policy Laura Taylor-Kale.

At the same time, these investments help support the Pentagon's mission to mitigate the risks associated with being heavily dependent on China for the minerals and metals critical to North America.

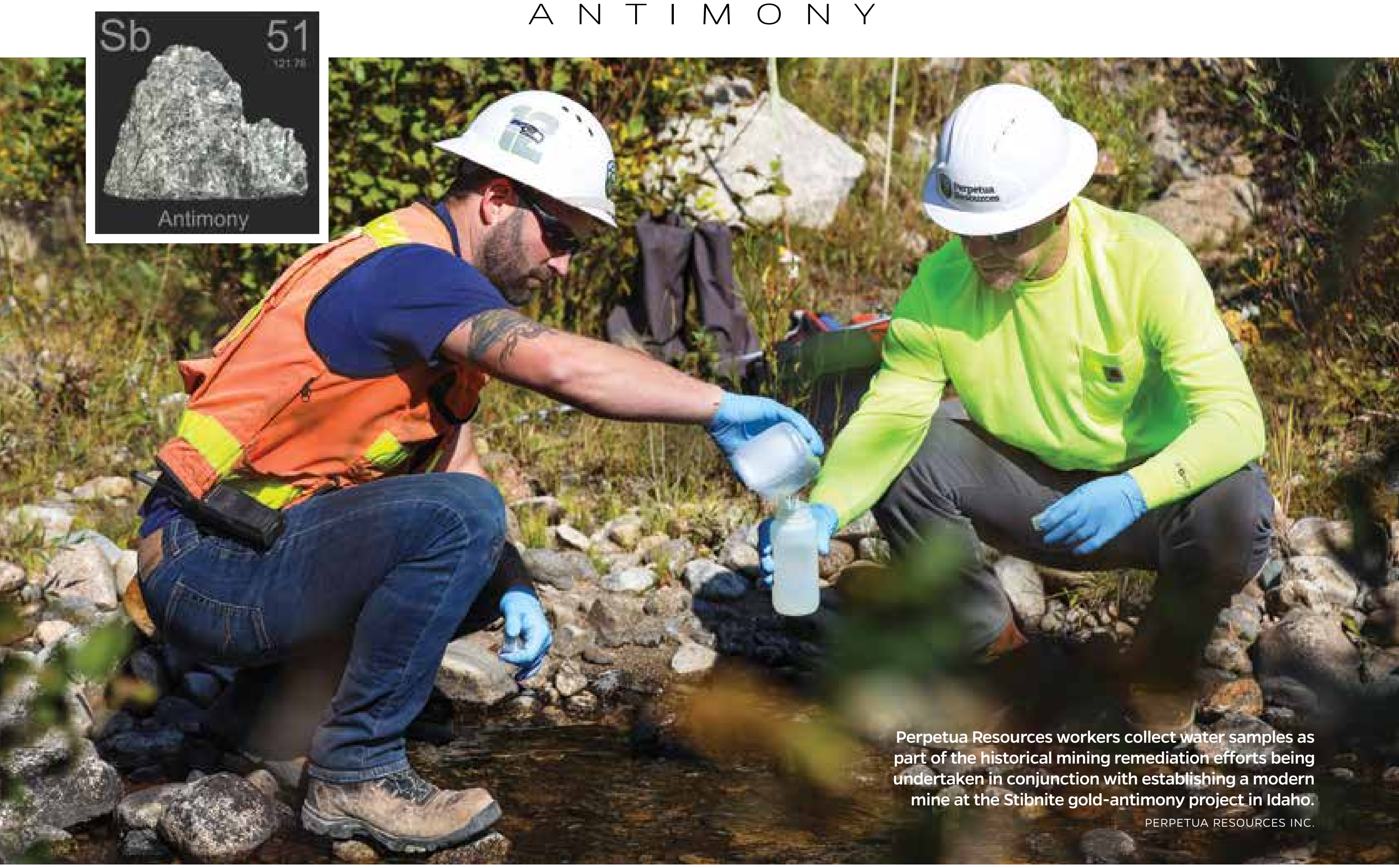
The importance of this mission was underscored by the $276 million grant awarded to Leidos, a Fortune 500 innovation company that provides technical data management and research for DOD and federal government users.

Leidos is applying the Pentagon funding for research and development of critical minerals and materials and to promote energetics (propellants, explosives, and pyrotechnics) supply chain resiliency.

"A resilient energetics supply chain will help ensure our warfighters are ready for any conflict, while reducing our nation's reliance on foreign sources," said Mike Diggins, senior vice president and homeland and force protection business area leader at Leidos. "Our team will help the DOD synthesize and scale-up domestic minerals and materials production."

A mission that is increasingly critical to the Pentagon.

"It is critical that we shore up reliable and sustainable domestic supplies of strategic materials," said Taylor-Kale.




Perpetua Resources workers collect water samples as part of the historical mining remediation efforts being undertaken in conjunction with establishing a modern mine at the Stibnite gold-antimony project in Idaho.
PERPETUA RESOURCES INC.

# Antimony is high on DOD mineral concerns

## Pentagon turns to Idaho gold mine for strategic domestic supply

By **SHANE LASLEY**
DATA MINE NORTH

**FALLING IN THE GREY AREA** between between metals like zinc and nonmetals like carbon, antimony is a semi-metal that possesses some interesting properties that make it a vital ingredient in a wide range of household, industrial, high-tech, and military goods.

Despite its widespread uses, many people have never heard of antimony and fewer still realize that this intriguing metalloid is considered critical to America's economy and security.

According to the U.S. Geological Survey, American manufacturers use more than 50 million pounds of antimony each year for fireproofing compounds, batteries, ammunition, electronics, specialty glass, and other products.

Approximately 18% of America's demand for antimony came from recycling internal combustion engine vehicle batteries. Without any domestic antimony mines, however, the U.S. must depend on overseas suppliers for the remaining 45 million lb.

And the countries that dominate antimony supply are not high on America's friendshoring list.

According to the USGS, China, Russia, and Tajikistan accounted for roughly 80% of the antimony produced globally during 2023.

A heavy dependence on Russia and China for a metalloid that is both critical to the American economy and strategic to its military is not something that many U.S. lawmakers and military officials are comfortable with.

In a 2022 report, the U.S. House Armed Services Committee said it "is concerned about recent geopolitical dynamics with Russia and China and how that could accelerate supply chain disruptions, particularly with antimony."

These worries over potential antimony supply disruptions have been validated by China's new state-controlled restrictions on antimony exports that went into effect on Sept. 15.

China's Ministry of Commerce said the government controls on exports of antimony needed for civilian and military purposes are required "to safeguard national security and interests, and fulfill international obligations such as non-proliferation."

"It's a sign of the times," said Christopher Ecclestone, a mining strategist at the consulting firm Hallgarten & Company in London. "The military uses of Sb (antimony) are now the tail that wags the dog. Everyone needs it for armaments, so it is better to hang onto it than sell it."

With only a limited supply of already circulating antimony to hold onto, over the past couple of years, the U.S. Department of Defense has backed a mine in Idaho that would provide a secure and reliable source of antimony on American soil.

### Critical and strategic metalloid

Antimony is one of six elements on the periodic table classified as metalloids – boron, silicon, germanium, arsenic, and tellurium are the others. Sharing properties with metallic and nonmetallic brethren, this specialty class of elements is often used in alloys, catalysts, flame retardants, optical storage, semiconductors, and electronics.

"Antimony is … vital to our military's effectiveness and has been since it was labeled as crucial to the war effort during World War II," U.S. Army Major General (retired) James "Spider" Marks penned in a 2020 column published in The Washington Times.

An antimony-based fireproofing compound applied to tents and vehicle covers is credited with saving countless lives during World War II.

Over the eight decades since the end of World War II, this critical metalloid has continued to save innumerable lives – from soldiers in the field to families on a road trip – by lending its flame-resistant properties to personal protective equipment, mattresses, electronic devices, aircraft, and automobile seat covers.

In addition to its widespread flame-resistance applications, antimony imparts increased hardness and mechanical strength into an alloy known as antimonial lead.

Bullets and shot, bearings, electrical cable sheathing, printing machines, solders, and pewter are among the products made of alloys that contain some amount of antimony.

The most common application for antimonial lead, however, is improving the plate strength and charging characteristics in the lead-acid batteries that have been used to start most ICE vehicles for more than a century.

Antimonial lead (43%) and flame retardants (35%) continue to be the largest uses for antimony in the U.S.

Another major use for antimony is to make high-quality glass used by both civilians and soldiers. For example, a small amount of antimony oxide has the ability to remove bubbles from super-clear glass used to make lenses for binoculars and similar optical equipment, as well as the glass screens of smartphones and other electronic devices.

"Antimony is a key ingredient in communication equipment, night vision goggles, explosives, ammunition, nuclear weapons, submarines, warships, optics, laser sighting, and much more," Marks wrote.

Given antimony's critical and strategic applications, Pentagon officials are not comfortable with the U.S. being beholden to Russia and China for its supply of this critical and strategic metalloid.

BJÖRN WYLEZICH AT ADOBE.STOCK.COM

**A high-grade sample of stibnite, an antimony sulfide mineral.**

### Focused on Stibnite Gold

DOD's investments in a secure, domestic supply of antimony have thus far focused on Perpetua Resources Inc.'s Stibnite Gold project in Idaho, home to a historic mine credited with saving the lives of a million American soldiers during World War II.

The name of this project underscores a critical and precious metals relationship that is key to future domestic supplies of antimony. Stibnite, an antimony mineral that is a primary source of this critical metalloid, is found alongside gold.

The value of the stibnite, however, typically pales in comparison to gold and is often discarded in favor of the precious metal. This dynamic, however, reversed at gold mines in Idaho and Alaska when antimony's strategic value increased during the World Wars.

This is particularly true for Stibnite Gold, which shifted its focus to recovering tungsten and antimony to support the needs of the U.S. military during World War II.

From 1941 to 1945, Stibnite singlehandedly produced 90% of the domestic antimony and 40% of the tungsten needed to support America's wartime effort. This strategic metal mine's contribution is credited with shaving an entire year off the global conflict.

"In the opinion of the munitions board, the discovery of that tungsten at Stibnite, Idaho, in 1942 shortened World War II by at least 1 year and saved the lives of a million American soldiers," according to the March 7, 1956, U.S. Senate Congressional Record.

With geopolitical tensions between the U.S. and the world's top two antimony suppliers on the rise and China installing a government-controlled spigot on nearly half of the world's supply, DOD is once again looking at the historic Idaho mine to ensure secure supplies of the strategic metalloid.

"China is weaponizing the world's access to critical minerals, and it's never been more urgent to secure the United States' critical mineral supply," said Perpetua Resources President and CEO Jon Cherry. "For a vast, secure source of American-made antimony, Perpetua Resources' Stibnite Gold project is the clear solution."

## Whole-of-government approach

To break America's dependence on China and Russia for the antimony needed for ammunition, fireproofing compounds, night vision goggles, and other military hardware, the Pentagon's investments in Stibnite Gold began with $200,000 in grants to see if military-grade antimony trisulfide could be produced from the Idaho project.

Following this initial 2022 study, DOD has awarded Perpetua $59.4 million in Defense Production Act (DPA) Title III funding to complete environmental and engineering studies necessary to finalize permitting and then advance the gold-antimony project to construction readiness.

With the Pentagon helping to advance the Stibnite Gold frontline to the brink of development, the Export-Import Bank of the United States (EXIM) has extended an offer to loan Perpetua $1.8 billion to build a mine that will deliver a domestic supply of antimony.

"We are seeing a whole-of-government approach to bring antimony production home," said Cherry. "From EXIM's potential financing of up to $1.8 billion to the multiple Department of Defense's multi-million-dollar awards to Perpetua, there is a profound recognition that we need domestic antimony production now."

The critical significance of antimony and America's dependence on imports from countries like China and Russia makes Stibnite Gold a prime candidate for funding under EXIM's "Make More in America" initiative, a tool established to improve the resiliency of U.S. supply chains and level the playing field for American companies competing in overseas markets.

In addition, Stibnite Gold is likely also eligible for special considerations under EXIM's "China and Transformational Exports Program," which offers reduced fees and extended repayment periods for projects that must compete with companies backed by Chinese government subsidies.

EXIM is conducting the due diligence necessary to determine if Stibnite Gold meets all the requirements for a final loan commitment. Loan eligibility requirements include the completion of federal permitting under the National Environmental Policy Act, which is expected by the end of the year.

"The EXIM debt funding could fund a substantial portion of the estimated costs to build the Stibnite Gold Project," said Cherry.

A 2020 feasibility study estimated that it would cost roughly $1.66 billion to build the Stibnite Gold Mine. Inflation over the past four years, however, has likely pushed the development price tag higher.

Once in production, the mine proposed to be developed at Stibnite Gold is expected to produce roughly 35% of America's antimony needs.

## An Alaska antimony alternative

The Pentagon's push to pivot America's antimony reliance away from Russia and China has encouraged mineral exploration companies to take a closer look at this metalloid's association with other gold deposits in the U.S.

Besides Idaho, the USGS has identified Alaska, Montana, and Nevada as the best states to explore for domestic supplies of antimony.

Alaska, in particular, is both a past supplier and potential future source of antimony.

"It has long been known that stibnite, the sulfide of antimony and the principal source of that metal, is widely distributed in Alaska," Alfred Brooks penned in a 1917 USGS report titled "Antimony deposits of Alaska."

Brooks' early 20th-century investigation identified 67 stibnite occurrences in Alaska, most of which are found in areas also rich in gold.

One such occurrence is the historic Scrafford mine, which provided the U.S. with a strategic source of antimony during both World Wars.

Intermittent mining at Scrafford from 1915 to the 1970s produced an estimated 1.08 million kilograms (2.4 million pounds) of antimony from 2,800 metric tons of hand-sorted ore averaging 38.6% stibnite.

Today, Felix Gold Ltd. is exploring the potential of establishing a gold mine on the Treasure Creek project where the historic Scrafford Mine is found that could also provide a byproduct supply of antimony.

Over the past couple of years, Felix has been focused on building a gold-antimony resource at NW Array, an area about a mile northwest of Scrafford Mine.

"While antimony is often found in lower concentrations alongside gold deposits, the extraordinary high-grade nature of this antimony discovery presents opportunities to assess the independent potential of antimony operations," said Felix Gold Executive Director Joseph Webb.

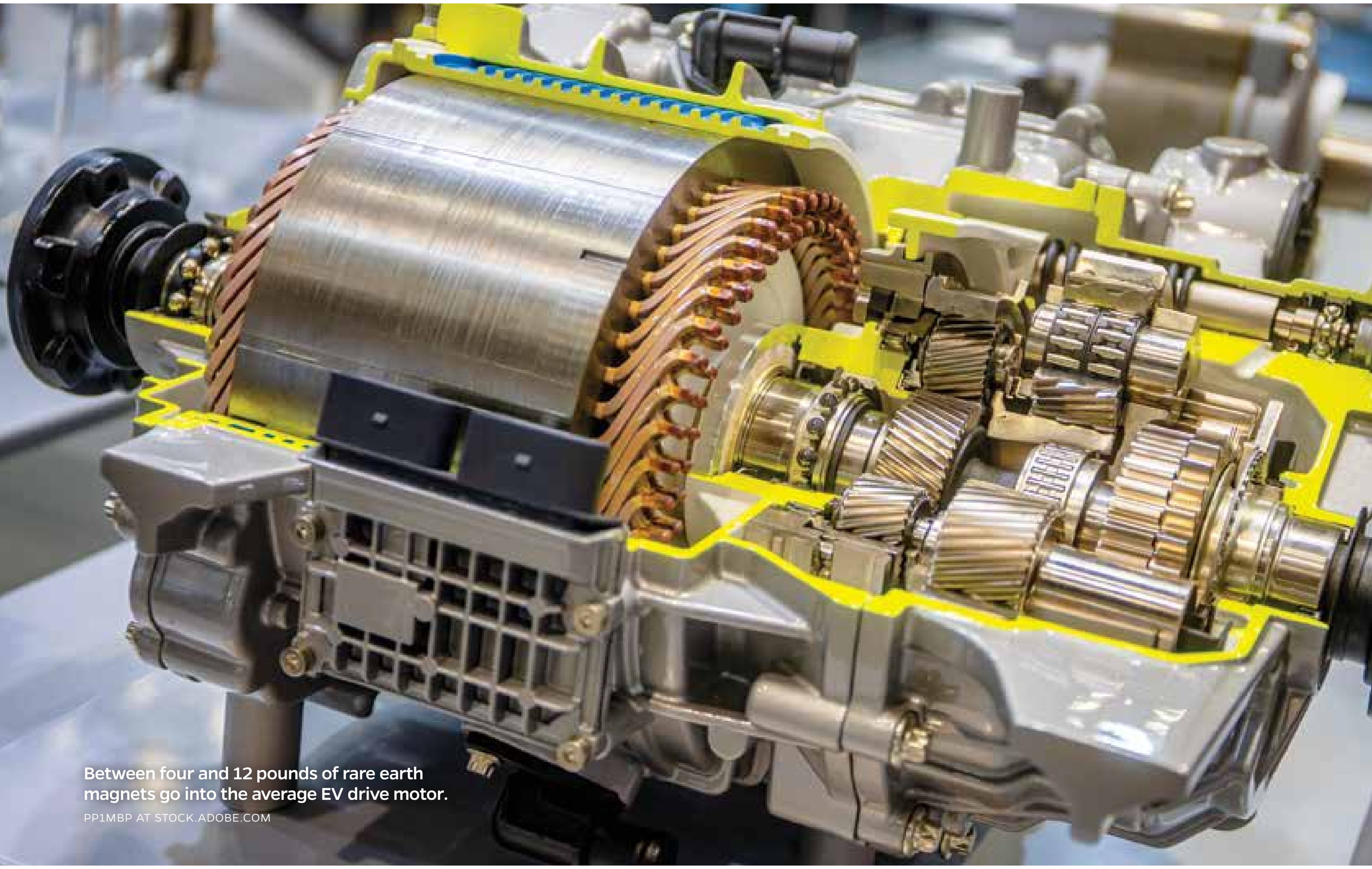
Nova Minerals Ltd. has also identified high-grade antimony alongside the 9.9 million ounces of gold that it has outlined so far on its Estelle project about 100 miles northwest of Anchorage, Alaska. While Nova Minerals' exploration at Estelle has primarily focused on gold, an expansive sampling program carried out across the 198-square-mile property in 2023 discovered widespread antimony, copper, and silver associated with gold at several sites across the Estelle property.

Some of the best samples collected during this campaign contained:

- 12.7 g/t gold, 1,600 g/t silver, and 2.1% antimony.
- 1.2 g/t gold and 19% antimony, and 0.9 g/t gold and 21.7% antimony.
- 2.4 g/t gold, 500 g/t silver, 1.6% copper, and 2.5% antimony.
- 0.7 g/t gold, 588 g/t silver, and 16.8% antimony.

"While Nova's primary focus continues to be on the gold, the discovery of high-grade stibnite, a primary ore source for antimony, associated with the gold system emerging at Estelle, represents a significant development for the company as antimony is listed as a critical and strategic mineral to U.S. economic and national security interests by the U.S. Department of Interior," said Nova Minerals CEO Christopher Gerteisen.

With the Stibnite Gold project in Idaho expected to meet roughly 35% of America's current antimony demand, recovering stibnite as a byproduct from future mines at these gold deposits in Alaska could offer additional alternatives to China and Russia for this critical and strategic metalloid.



Between four and 12 pounds of rare earth magnets go into the average EV drive motor.
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# Making rare earths separation less rare

## Separation and processing are the master link of US supply chain

By SHANE LASLEY
DATA MINE NORTH

**FROM TECH DEVICES** such as smartphones and computer monitors to clean energy products like electric vehicles and wind turbines, household goods like vacuum cleaners and refrigerators, and military hardware such as F-35 fighters and communications equipment, rare earths have a critical role to play in nearly every facet of America's economy and security.

The United States, however, currently relies on China for nearly all its supply of rare earths. This dependence is not due to the lack of domestic sources of this suite of 14 technology elements; in fact, the U.S. has abundant sources, and one mine in California produces roughly 12% of the global supply of these elements, which are not as scarce as their name implies.

The real paucity when it comes to establishing a rare earth supply chain in the U.S. is technologies capable of efficiently and sustainably separating this suite of elements into individual oxides and metals that can be used by high-tech, clean energy and other manufacturers.

China, which began monopolizing rare earths separation and processing during the 1990s, continues to control roughly 85% of this key link of global rare earths supply chains – until recently, only individual plants in Malaysia and Estonia offered commercial alternatives.

The Middle Kingdom's dominance of the global rare earth supply chain master link has former and current Pentagon officials worried.

"China's foresight here is as clear as the United States' myopia," said Joe Buccino, a retired U.S. Army colonel who served as the communications director for U.S. Central Command from 2021 to 2023. "Should China, in the leadup to an invasion of Taiwan, block exports of rare earths or processing technology, this would cripple the U.S.'s ability to produce the kinds of ammo required to sustain a long-term high-tech war."

At the end of 2023, China announced such an export ban on the technologies to separate and process this suite of tightly bonded technology metals, according to a report published by the Center for Strategic & International Studies, a Washington-based policy advisor.

"The United States' delay in developing processing capacity will hinder its ability to build both national, energy and economic security," Gracelin Baskaran, author of the report, wrote.

Understanding the economic and security implications of America's heavy dependence on China for rare earths, the U.S. Department of Defense is investing heavily in establishing the separation and processing technologies needed to develop a complete domestic supply chain for these essential elements.

MP MATERIALS CORP.

Dysprosium and terbium are scarce and expensive heavy rare earths used to increase the durability of magnets for EV motors, wind turbines, and an array of high-tech applications.

## Magnetic rare earth concerns

In a world transitioning to clean energy, the top use for rare earths is to produce the powerful magnets that allow wind turbines to transform a breeze into low-carbon electricity, EVs to convert that electricity into whisper-quiet acceleration, MRI machines to generate powerful magnetic fields that create detailed images of organs and tissues, and a wide range of other high-tech, household, and military devices.

"Rare earth element magnets enable a variety of dual-use technologies, including high-power motors in electric vehicles and flight control actuation systems in military aerospace systems," said Moshe Schwartz, a senior fellow for acquisition policy at the National Defense Industrial Association.

As an extension of its rare earths separation and processing dominance, China produces nearly 90% of the world's neodymium-iron-born (NdFeB) rare earth magnets. This provides the country with an advantage when it comes to manufacturing EVs and the innumerable other devices that these magnets go in.

"China's market dominance across the supply chain has been a topic of concern," Schwartz added.

According to a 2022 investigation by the U.S. Department of Commerce, sintered neodymium-iron-born magnets (NdFeB) are "required for critical infrastructure" and "irreplaceable in key defense applications," yet the U.S. is "essentially 100% dependent on imports" for the rare earth magnets.

To help "protect American manufacturers from China's unfair trade practices," the Biden administration placed a 25% tariff on rare earth magnets and a 100% tariff on EVs imported from China.

"With extensive subsidies and non-market practices leading to substantial risks of overcapacity, China's exports of EVs grew by 70% from 2022 to 2023 – jeopardizing productive investments elsewhere," the White House penned in a May briefing on the tariffs.

The White House's attempt to level the playing field and spur domestic rare earth magnet manufacturing comes amidst a sharp rise in the global demand for rare earth magnets, which is expected to triple by 2035 as automakers increase EV manufacturing, according to critical minerals analyst Adamas Intelligence.

## Innovative and exciting alternatives

Critical mineral and trade policy experts in Washington are worried that China will cut off supplies of rare earth magnets and other critical materials before the U.S. has established viable alternatives.

The communist nation has already demonstrated its ability and willingness to restrict exports of several critical minerals and technologies.

"The rollout of major export restrictions for graphite, gallium, germanium, rare earth extraction, and separation technologies in less than one year should be a powerful signal to U.S. policymakers that although they are late to the critical minerals game, there is a significant need to both build domestic capabilities and leverage international cooperation to facilitate rapid sourcing and developing of processing capacity," Baskaran wrote.

However, China's rare earths separation technology export ban may not have an enormous impact on the efforts to establish processing and separation plants in North America.

The reason for this is threefold:

- The solvent extraction technology used to separate rare earths in China was developed in the U.S. nearly 70 years ago and is not proprietary, though China has likely perfected aspects of this method over the ensuing decades.
- The traditional vat-based mixer-settler solvent extraction method used in China involves a long and arduous process that is considered too labor-intensive and environmentally challenging to be viable for most North American applications.
- North American companies are already scaling up more modern, efficient, and sustainable rare earth processing technologies.

"Innovative and exciting technological alternatives to the environmentally destructive Chinese methods of processing and refining have been developed in the United States," said Drew Horn, CEO of GreenMet, a Washington-based firm that provides a conduit between private capital, government, and critical mineral innovation in the U.S.

In fact, on the same day that China announced its ban on the export of rare earth processing technologies, Ucore Rare Metals Inc. and Rare Element Resources Ltd. each announced major milestones in the advancement of two separate rare earth processing technologies.

### Ucore's modern SX upgrade

Ucore has been working on establishing a North American rare earth supply chain that is independent of China for nearly two decades.

This endeavor began with work aimed at establishing a mine at its Bokan Mountain rare earth project in Southeast Alaska. Due to a lack of technologies outside of China to process any rare earths produced at Bokan, the company pivoted toward the development and commercialization of a more efficient and cleaner way to separate rare earths, a key to establishing a supply chain that is independent of China.

Ucore's quest for an economically and environmentally viable rare earth separation technology led to the development of RapidSX, which is basically a 21st-century upgrade to the solvent extraction technology on which China built its dominance of the rare earth sector over the past five decades.

Independent testing has shown that the innovative column-based RapidSX platform can separate rare earths nearly 10 times faster within a footprint that is about one-third the size required for the mixer-settler SX units that China has traditionally used for rare earths separation.

Commissioning of Ucore's RapidSX demonstration plant in Kingston, Ontario, was completed at the end of 2023.

The company is now moving toward the installation of this innovative rare earths separation platform at the Louisiana Strategic Metals Complex (SMC), which is developing at a former U.S. Air Force base in the heart of The Pelican State.

Once scaled up to full capacity, the Louisiana SMC is expected to produce up to 7,500 metric tons of rare earths from six different feedstocks from U.S. and allied sources.

Ucore Rare Metals COO Mike Schrider says the tariffs imposed by the White House are leveling the playing field as it scales up operations.

"We expect this to be of significant benefit as we increase production from 2,000 tonnes (metric tons) per annum to our planned total nameplate production of 7,500 tonnes per annum over our first few years of production and subsequently expand our footprint across North America," he said.

The RapidSX technology is also being backed by the Pentagon, which provided Ucore with $4 million in funding to determine that its demonstration plant can upgrade heavy and light rare earth feedstock sources to salable individual rare earth products.

The Canadian government provided an additional US$3.1 million to support Ucore's demonstration of this modern rare earth separation platform.

Finalization of the RapidSX demo plant commissioning marked the start of the DOD demonstration program.

"The objectives of this program are to establish a direct techno-economic comparison between conventional solvent extraction and RapidSX for separating heavy and light rare earth elements and to establish RapidSX technology for commercial deployment in North America," said Schrider.

Ucore expects to surpass several milestones along the path to installing its RapidSX rare earth separation technology at the Louisiana SMC over the coming months.

Once it has established its rare earths processing technology in the U.S., the company plans to shift some of its focus back on developing a mine at its heavy rare earths enriched Bokan Mountain project in Alaska.

### Rare Element's Wyoming demo plant

As Ucore marches ahead with the commercialization of RapidSX, the U.S. Department of Energy has authorized funding for the construction of a processing and separation demonstration plant to be developed by Rare Elements Resources in Wyoming.

The processing plant is a key facet of the company's plans to develop a mine at Bear Lodge, a high-grade project in northeastern Wyoming that hosts 1.2 billion pounds of rare earths.

Bear Lodge is not only large and high-grade, but it also happens to be enriched with neodymium, praseodymium, dysprosium, and other rare earths used to make powerful permanent magnets.

A roughly 900-metric-ton sample of high-grade rare earths material from Bear Lodge has been transported to Upton, Wyoming, to be fed through an innovative rare earths processing and separation technology pioneered by General Atomics, a division of General Dynamics.

To speed up the installation, crews have been building components of the rare earths processing demo plant that can be quickly installed at the Upton facility.

Inflation, however, has driven up the costs and slowed development of this plant. In July, Rare Elements announced that the project team led by partner General Atomics estimated that the costs for completion would be around $53.6 million, about 21% higher than originally estimated.

The company has requested that DOE support the larger budget on the same 50% cost-share basis as previously agreed.

"All activities are moving us toward the goal of plant startup in the next few months," said Rare Elements Resources CEO Ken Mushinski on July 1.

### MP's supply chain takes shape

Already operating the largest rare earths mine outside of China and the second largest in the world, MP Materials is the frontrunner when it comes to developing a complete mine-to-magnets rare earths supply chain in the U.S.

The company's Mountain Pass Mine in California's Mojave Desert produced 41,557 metric tons of rare earth oxides during 2023, which accounts for approximately 12% of the rare earths mined globally last year.

USA RARE EARTH LLC

**This mountain at USA Rare Earth's Round Top project in Texas hosts enormous quantities of rare earths, plus seven other minerals critical to the U.S.**

Until recently, however, concentrates produced at Mountain Pass had been sent to China for separation and processing.

Toward its goal of establishing a vertically integrated mine-to-magnets supply chain in the U.S., MP is ramping up commercial rare earths separation capacity at its Mountain Pass Mine in California. This work is being backed by DOD, which has invested $45 million to support the development of heavy and light rare earth separation technologies at Mountain Pass.

"In 2023, we commissioned and began producing separated rare earth products at the collocated refinery at Mountain Pass," MP Materials Senior Vice President of Communications and Policy told Data Mine North in an email.

Over the first half of 2024, this facility produced 403 metric tons of neodymium-praseodymium oxide for magnets, along with 582 metric tons of other rare earth products, including mixed heavy rare earth oxide.

Neodymium-praseodymium oxide and other rare earth products are being shipped to MP Materials' 200,000-square-foot rare earth metals and magnets plant in Fort Worth, Texas.

The 2022 groundbreaking ceremony for this rare earth metal, alloy, and magnet facility was attended by Texas lawmakers and executives from General Motors, which is a foundational customer of the rare earth magnets produced at the Texas facility.

"The new MP Materials magnetics facility in Fort Worth, Texas, will play a key role in GM's journey to build a secure, scalable, and sustainable EV supply chain," GM Ventures Managing Director Anirvan Coomer said during the groundbreaking.

In April, DOE awarded MP Materials a $58.5 million tax credit under the federal Advanced Energy Project Credit (48C) program to be applied toward the completion of the Texas magnet and metals plant.

The first magnets rolling out of the Texas plant, expected next year, will mark the completion of a complete mine-to-magnets rare earths supply chain in the U.S.

MP Materials' agreement with GM extends this supply chain to America's automotive sector and consumers.

PEGGY GREB, U.S. DEPARTMENT OF AGRICULTURE

**Developing efficient technologies to separate are earths into individual oxides, like the powders in the photo above, is a critical link to establishing an all-American rare earths supply chain.**

### USA Rare Earth supply chain

USA Rare Earth LLC is also working toward establishing a complete mine-to-magnets rare earths supply chain on American soil. This company, however, is starting at the magnet end and working its way back to the mine.

In 2022, USA Rare Earth purchased a 309,0000-square-foot building in Stillwater, a city in Oklahoma that boasts a growing high-tech economy, to house a rare earths processing and magnets plant.

Even before the building was secured, USA Rare Earth had acquired the neodymium-iron-boron permanent magnet manufacturing equipment that would be installed there. The company was able to buy this equipment in the U.S. from Hitachi Metals America, which briefly used the equipment in North Carolina when China cut off exports of rare earths to Japan a little over a decade ago.

The Oklahoma factory is one link in a complete rare earths mine-to-magnets supply chain that USA Rare Earth is endeavoring to establish in the U.S.

The first link of this chain is the Round Top rare earths and critical minerals mine project in Texas.

Being advanced toward production under a joint venture between USA Rare Earth (80%) and Texas Mineral Resources Corp. (20%), the Round Top project southeast of El Paso hosts an enormous deposit of minerals critical to the U.S.

A preliminary economic assessment for Round Top outlines plans for a mine that would produce 2,212 metric tons of rare earths per year, plus seven other minerals critical to the U.S. – beryllium, gallium, hafnium, lithium, magnesium, manganese, and zirconium.

The suite of rare earth elements produced at Round Top will include six REEs used in magnets – neodymium, praseodymium, dysprosium, terbium, gadolinium, and samarium.

The future Texas mine is also expected to produce roughly 10,000 metric tons of lithium each year, which further increases Round Top's potential as a domestic supplier of the metals needed for a nation transitioning to EVs charged with low-carbon electricity.

While Round Top is being permitted, funded, and developed, USA Rare Earth is securing other sustainable sources of rare earths for its Oklahoma factory.

With its sights set on producing magnets by the end of the year, USA Rare Earth entered into an agreement to purchase rare earths mined at Australian Strategic Materials' (ASM) Dubbo project in Australia and processed in South Korea.

"ASM provides us with predictable access to a non-Chinese supply of rare earth metals, which allows us to ramp-up our initial production and accelerate our goal of generating revenue, while we continue to construct our own mine," said USA Rare Earth CEO Tom Schneberger.

In March, the company entered into a deal to buy ultra-pure rare earths produced at ReElement Technologies Corp.'s state-of-the-art refining facility in Indiana.

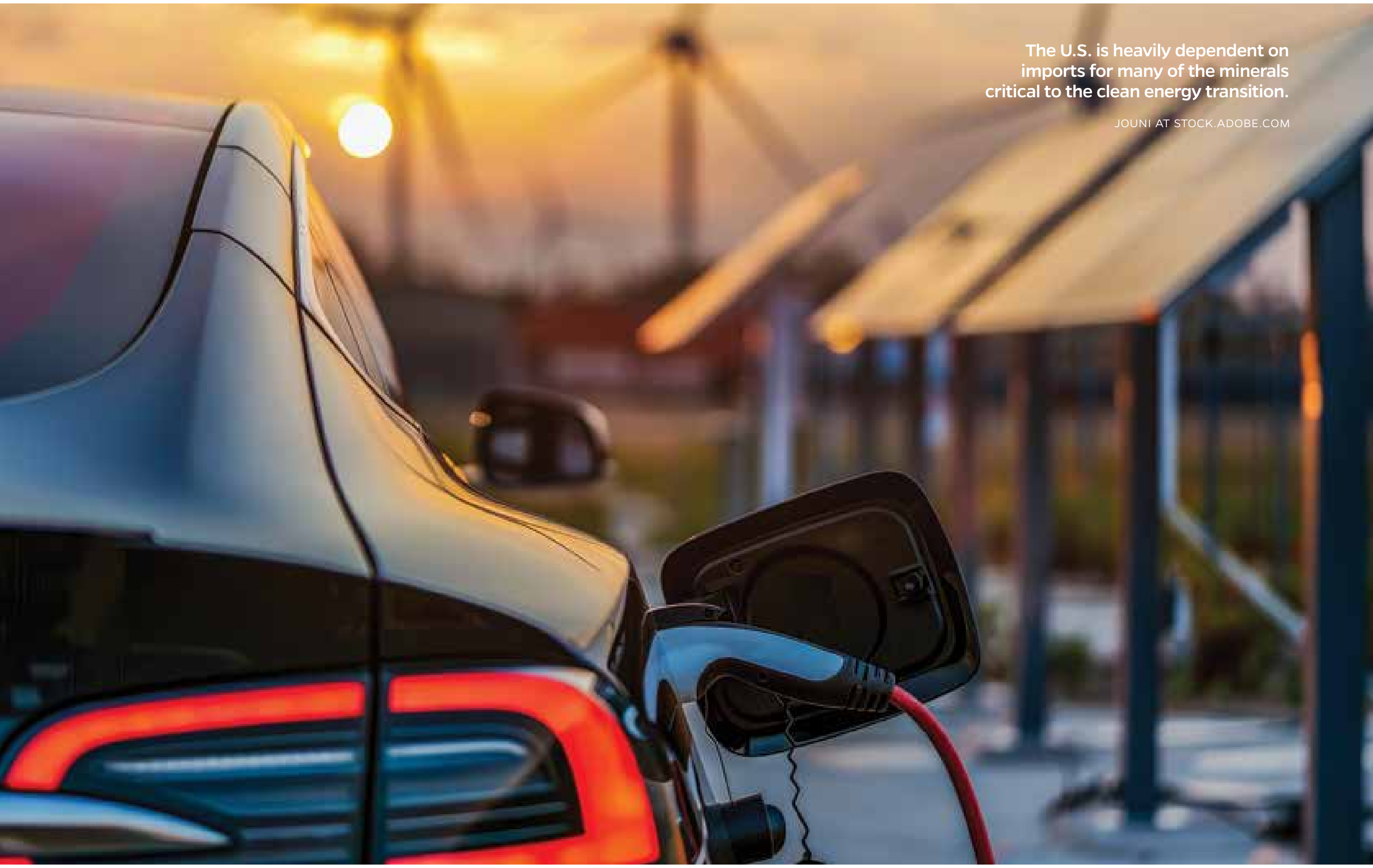
Utilizing a patented technology developed in partnership with Purdue University, ReElement recovers rare earths and other critical minerals from recycled permanent magnets and lithium-ion batteries, as well as processing ore and coal waste streams, to create a low-cost, sustainable, and circular source of rare earths and battery materials.

"As the leading domestic producer of ultra-high purity rare earth oxides, we couldn't be more excited to further our relationship with USA Rare Earth and their amazing team for the fully domestic production of permanent magnets from rare earth elements," said ReElement Technologies CEO Mark Jensen.

Under the agreement, USA Rare Earth will begin purchasing rare earth oxides from ReElement's Kansas processing and recycling plant in 2025.

"In conjunction with our other supply agreements, ReElement will enable us to ramp up production quicker and in a more environmentally friendly manner while we continue to build out our own mine in Texas," said Schneberger.

A mine that would anchor a second mine-to-magnets rare earths supply chain in the U.S.



The U.S. is heavily dependent on imports for many of the minerals critical to the clean energy transition.

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# Unlocking America's critical minerals

## An all-of-government strategy is beginning to unfold in the US

By SHANE LASLEY

DATA MINE NORTH

**OVER THE FIRST TWO YEARS** following the passage of the Bipartisan Infrastructure Law and Inflation Reduction Act, the U.S. Department of Energy has invested billions of dollars into establishing a clean energy supply chain in the United States. These heavy investments, however, have neglected one vital link – the domestic mines needed to supply the processing facilities, battery plants, and other energy transition infrastructure that DOE has worked so hard to build.

Senators Lisa Murkowski, R-Alaska, and Joe Manchin, D-W.Va., both of which helped to author the domestic mining provisions in the BIL and IRA, are concerned that the White House's strategy is putting the U.S. in a situation where it becomes even more beholden to China and other countries for minerals and metals critical to the clean energy future.

LISA MURKOWSKI

"You've got an administration that is approaching how we deal with this with one hand deliberately tied behind our back – and we are talking about the critical minerals that go into this," Murkowski said while questioning DOE Deputy Secretary David Turk during a January Senate Energy and Natural Resources Committee hearing on EV supply chains.

Turk indicated that DOE's hands are also tied when it comes to supporting domestic battery materials mining projects.

"We are trying to be as creative as possible with the tools and the authorities that we have got," the DOE deputy secretary told the committee.

The tools available to DOE were expanded with an updated guidance released in April that allows the department's Loan Programs Office (LPO) to finance domestic critical mineral mining projects under the Title 17 Clean Energy Financing Program.

DAVID TURK

"The United States has substantial critical minerals resources, but we must do more if we want to lead in the mining or processing of most critical minerals. Many of the supply chains for these minerals are concentrated in just a few countries, most notably China," DOE wrote in a post announcing the updated Title 17 guidance. "This raises risks for investors and businesses, eroding U.S. economic power, weakening our energy security, and increasing our reliance on unreliable foreign sources, which are often produced with lower environmental or labor standards.

Murkowski says the new guidance is a good start.

"What we need now is for the department to go beyond words, beyond funding projects that lock in long-term mineral imports from abroad, and to instead support domestic projects – in states like Alaska – that will strengthen our economy and security," Murkowski said.

> >> *"We are trying to be as creative as possible with the tools and the authorities that we have got."*
>
> *–DOE Deputy Secretary David Turk*

Thus far, DOE has been reluctant to tap into the roughly $72 billion of loan guarantees available under Title 17 to support domestic mining projects. The U.S. Department of Defense and the Export-Import Bank of the United States (EXIM), however, are leveraging their own authorities to bolster the first link of America's clean energy supply chain.

The DOD grants and EXIM loans are beginning to reveal an all-of-government strategy to establish complete mines-to-clean energy supply chains in the U.S.

### Strategic DOD grants

When compared to the billions of dollars DOE has poured into battery materials processing, manufacturing, and recycling, DOD's investments in domestic critical minerals projects have been relatively small but strategic.

In 2019, then-President Donald Trump authorized the Pentagon to utilize funding available under Title III of the Defense Production Act (DPA) – a tool established during the Cold War to ensure the U.S. could secure goods needed for national security – to support the re-establishment of a rare earths supply chain in the U.S.

TMY350, CREATIVE COMMONS 4.0

**MP Materials' Mountain Pass Mine in California produces about 12% of the global rare earth supply.**

Over the ensuing five years, DOD has awarded more than $439 million to establish domestic rare earth element supply chains.

Among the companies involved in the Pentagon's "mine-to-magnets" initiative is MP Materials, which operates the Mountain Pass rare earths mine in California.

So far, MP has been awarded more than $103 million to establish a fully integrated rare earths supply chain. These investments include nearly $45 million in grants from DOD to develop separation facilities at Mountain Pass and $58.5 million in tax credits from DOE for a rare earth magnets and metals plant being developed in Texas.

The largest DPA Title III investment made so far into America's rare earths supply chain is a $288 million grant to a U.S. subsidiary of Australia-based Lynas Rare Earths Ltd. to establish a commercial-scale rare earth oxide production plant in Texas.

The DOD has also made small investments in several other domestic rare earth initiatives. This includes $4 million for Ucore Rare Metals Inc. to demonstrate the capabilities of RapidSX, an innovative rare earths separation technology that the company plans to install at the Louisiana Strategic Metals Complex it is building at a former U.S. Air Force base in the Pelican State.

"DOD's strategic investments are building capability at multiple stages of the rare earth supply chain and will provide a clear signal to private capital that the time is right to build additional resiliency," said Danielle Miller, who worked in the DOD acquisitions office before moving into the private sector as a strategic analyst. "We are on track to meet our goal of a sustainable, mine-to-magnet supply chain capable of supporting all U.S. defense requirements by 2027."

In 2022, a group of senators urged President Joe Biden to authorize the Pentagon to tap into DPA funds to bolster domestic supplies of other critical minerals.

"The authorities provided to you as President under the Defense Production Act will help to ensure that America's critical mineral supply chains are strong, responsibly produced, and ethically sourced. Given the stakes, America cannot afford to wait any longer for that day to arrive," Sen. Lisa Murkowski, R-Alaska, Joe Manchin, I-W.Va., Jim Risch, R-Idaho, and Bill Cassidy, R-La. penned in a letter to Biden.

TIMON AT STOCK.ADOBE.COM

Export-Import Bank of the United States has emerged as a heavy lifter when it comes to providing loans to fund the development of mines to feed critical minerals into American supply chains.

Biden agreed, and over the two years since receiving a directive from the White House, the Pentagon has invested more than $260 million of DPA Title III funds into the mining side of the critical minerals equation.

Domestic mining projects that have received DPA funding over the past couple of years include:

• **Albemarle Corp.** – $90 million to support the reopening of the Kings Mountain lithium mine in North Carolina.

• **Perpetua Resources Corp.** – $59.4 million to re-establish a domestic supply of antimony at the Stibnite Gold mine project in Idaho.

• **Graphite One Inc.** – $37.5 million to support a domestic graphite supply chain that includes a mine in Alaska.

• **Talon Nickel Corp.** – $20.6 million to advance exploration and resource definition at the Tamarack nickel-cobalt mine project in Minnesota.

• **South32 Ltd.** – $20 million to jump-start the production of battery-grade manganese at the Hermosa project in Arizona.

• **Jervois Mining Ltd.** – $15 million to support the expansion of the Idaho Cobalt Operations.

• **Lithium Nevada Corp.** – $11.8 million to accelerate the extraction and processing of lithium carbonate at the Thacker Pass mine project in Nevada.

• **Doe Run Resources Corp.** – $7 million to complete a demonstration-scale cobalt and nickel processing plant at their mining operations in Missouri.

These investments have been strategically placed to get the domestic critical minerals projects across make-or-break technical thresholds that will make them more attractive to investors.

## EXIM does the heavy lifting

The Export-Import Bank of the United States has emerged as the federal government's heavy lifter when it comes to funding domestic critical mineral mining projects.

In April, the export credit agency for the U.S. government extended an offer to loan Perpetua $1.8 billion to fund the development of a mine at its Stibnite Gold project in Idaho that would provide the only domestic source of antimony critical to America's economic and national security.

The antimony to be produced as a byproduct of gold at Stibnite is of strategic interest to the Pentagon, which is why it invested nearly $60 million to advance this mine project from the start.

In a letter inviting Perpetua to submit a loan application, EXIM said the Idaho antimony project may be eligible for funding under the U.S. export bank's "Make More in America initiative."

The proposed EXIM loan would provide the funding to build the antimony-gold mine that the Pentagon has backed through the engineering and permitting phases.

"We are seeing a whole of government approach to bring antimony production home," said Perpetua Resources President and CEO Jon Cherry. "From EXIM's potential financing of up to $1.8 billion to the multiple Department of Defense's multi-million-dollar awards to Perpetua, there is a profound recognition that we need domestic antimony production now."

A month after the invitation to Perpetua, EXIM offered a similar but smaller $800 million loan to NioCorp Developments Ltd. to fund the development of a mine at the Elk Creek project in Nebraska that would provide a domestic source of 17 minerals deemed critical to the U.S.

"Our goal is to make North America less dependent on foreign suppliers for the critical minerals we need to transition to a clean energy and less carbon-centric economy," says NioCorp Developments Chairman and CEO Mark Smith.

To achieve this mission, the company plans to produce niobium and titanium, key ingredients in an emerging rapid-charging solid-state battery technology; scandium used in lightweight and durable alloys for automotive, aerospace, and defense applications; and 14 rare earths essential for numerous high-tech, military, and everyday applications.

Global automaker Stellantis has already agreed to offtake future neodymium, praseodymium, dysprosium, and terbium produced at Elk Creek. These rare earths are key ingredients in the powerful magnets that go into the motors driving EVs, including electrified versions of the automaker's Jeep, Dodge, and Ram brands that are popular in North America.

The EXIM loan would cover about two-thirds of the $1.2 billion currently estimated cost to develop Elk Creek. The total costs, however, will likely be higher with the completion of an updated feasibility study for Elk Creek that includes the recovery of rare earths, which is expected later this year.

"As I see it, the stars are increasingly aligning behind our Elk Creek project and 2024 promises to be a momentous year for NioCorp," said Smith.

The stars are also aligning for U.S. Strategic Metals (USSM) and the battery materials mining, processing, and mining project it is developing in neighboring Missouri.

In August, EXIM invited USSM to apply for a $400 million loan to fund the construction of a state-of-the-art plant to recover metals from concentrates and recycled lithium-ion batteries.

This potential loan will add to the nearly $230 million in funding commitments from affiliates of Appian Capital Advisory LLP announced by USSM late last year, as well as around $250 million in previous funding from Glencore and others.

"Appian is excited to partner with USSM to develop its cobalt-nickel mine and battery recycling and mineral processing operation in Missouri," said Appian Capital CEO Michael Sherb. "USSM will shape the battery recycling landscape in the U.S. and play a critical role in establishing a domestic supply of essential minerals for the energy transition."

### Filling a gaping hole

As DOE, DOD, and EXIM invest in domestic supplies of minerals essential to the energy transition, the Biden administration has rolled out a plan to levy heavy tariffs on a wide range of goods from China, including critical minerals.

"Despite rapid and recent progress in U.S. onshoring, China currently controls over 80% of certain segments of the EV battery supply chain, particularly upstream nodes such as critical minerals mining, processing, and refining," the White House inked in a briefing on the tariffs unveiled in May.

According to the U.S. Geological Survey's Mineral Commodity Summaries 2024 report, the U.S. is more than 50% reliant on imports for 49 minerals and metals and is 100% dependent on foreign suppliers for 15 of them.

This list includes being 100% import-reliant for the graphite and manganese that go into EV batteries; 95% for the rare earths used in EV motors, wind turbine generators, and a lengthy list of other products; 83% for the platinum for hydrogen fuel cells; and 82% for the antimony critical to military hardware.

RICH NOLAN

America's heavy dependence on countries like China, which was the leading supplier of 24 of the minerals for which the U.S. is net-import-reliant, and Russia, a significant global producer of others, is worrisome to many Washington policymakers and industry leaders.

"Our mineral import dependence continues to be a gaping hole in our economic and national security and we're clearly not moving fast enough to course correct," said National Mining Association President and CEO Rich Nolan.

In addition to cutting off supplies of the minerals critical to America's economy and clean energy ambitions, China can use its dominance to oversaturate global supply chains and make it uneconomical for emerging competition.

The tariffs introduced by the Biden administration are meant to insulate American mining, refining, and manufacturing companies "from China's unfair trade practices."

The tariffs related to critical minerals and energy transition supply chains include:

- 25% tariff on graphite and certain other critical minerals.
- 25% tariff on rare earth permanent magnets.
- 25% tariff on lithium-ion batteries.
- 50% tariff on solar cells.
- 100% tariff on electric vehicles.

The White House says these tariffs are to "encourage China to eliminate its unfair trade practices regarding technology transfer, intellectual property, and innovation."

"The President has also established the American Battery Materials Initiative, which will mobilize an all-of-government approach to secure a dependable, robust supply chain for batteries and their inputs," the White House penned in its tariffs briefing.

Core from drilling through a high-grade lens at the Graphite Creek project in Alaska, home to the largest known deposit of graphite in the United States.

GRAPHITE ONE INC.

# Trifecta of graphite disadvantages for US

## Rising demand, lack of domestic supply, and China's dominance

By SHANE LASLEY

DATA MINE NORTH

**WHILE GRAPHITE HAS NOT CAPTURED** the same level of media attention as some of the other mined materials critical to the clean energy transition, the strategic nature of this largest ingredient in lithium-ion batteries powering electric vehicles is high on the list of concerns for American automakers, Washington policymakers, and the Pentagon's top brass.

These worries are based on a trifecta of graphite disadvantages for the United States – global demand for this battery and industrial material is expected to triple by 2030, this critical and strategic material is not currently mined in the U.S., and China dominates global graphite mining and refining.

Adding to the anxiety over whether America will be able to source adequate supplies of graphite for its burgeoning EV sector, China emplaced state-controlled restrictions on exports of nine types of high-purity and high-density artificial graphite, natural flake graphite, and related products.

"This bold and unexpected move by China in graphite has taken us by surprise, arriving far sooner than anyone could have predicted," Kien Huynh, chief commercial officer at Alkemy Capital Investments, a United Kingdom-based company that specializes in the critical minerals and energy transition sectors, said of the export controls that went into effect late in 2023.

"This turbocharges the urgency for the West to forge their independent supply chains, charting a course toward self-sufficiency in both the raw materials and the downstream components necessary to meet their own ambitious battery industry growth strategies," he added. "The race is on, and the stakes have never been higher."

To get into this race, the U.S. government is implementing an all-of-government strategy that includes the Department of Defense investing in accelerating domestic graphite mining, the Department of Energy backing domestic graphite processing, and the White House helping to level the playing field by placing heavy tariffs on the imports of graphite from China.

### Extraordinarily high risks

While graphite has long been an industrial material tied closely to the steel industry, the rise of this carbon material to critical status is tied to its importance to the lithium-ion batteries powering EVs and storing renewable energy.

This criticality is due to graphite being the primary material used in the anodes of lithium-ion battery cells, making up about 28% of all the minerals and metals going into these batteries. As a result, the battery pack of the average-sized passenger EV requires roughly 115 pounds of graphite, while full-size electric pickups and SUVs need 500 lb of graphite for their batteries.

Even though consumer enthusiasm for EVs has cooled somewhat, analysts continue to forecast that global graphite demand will reach 5 to 6 million metric tons per year by 2030. This is more than three times the 1.6 million metric tons mined globally during 2023.

What makes this situation even more precarious for American automakers transitioning to EVs and the U.S. military's increased reliance on battery-powered technologies is that, as of 2023, China accounts for 77% of all mined graphite and more than 90% of the world's graphite anode material production.

Due to China's near-complete dominance of global mining and refining of graphite, the International Energy Agency (IEA) believes this largest lithium-ion battery ingredient poses extraordinarily high geopolitical and supply risks to the global energy transition.

IEA, however, does not foresee global battery-grade graphite supply chains making a sudden shift away from China. In its Global Critical Mineral Outlook 2024 report, the energy agency forecasts that the communist nation will account for more than 95% of the growth of this critical material between now and the end of the decade.


LUCID MOTORS

Lucid Motors has struck a deal with Graphite One to purchase anode material for the batteries going into its award-winning Air and upcoming seven-passenger Gravity electric vehicles.

Based on projects currently in the development pipeline, supplies of battery-grade graphite available outside of China are projected to only meet about 10% of global demand by 2030.

This means that the communist nation will continue to control the global graphite supply, and the state-controlled graphite export restrictions put in place at the end of 2023 provide a spigot.

In addition to shutting down graphite supply outside of China, the nation can open the spigot to flood the markets and drive down prices. This tactic, which China has previously used to maintain control of rare earth markets, could be used to impact the economics of projects endeavoring to scale up alternative graphite sources in the West.

To help level the playing field for companies developing graphite mines and refineries in the U.S., President Biden introduced 25% tariffs on natural graphite imported from China starting in 2026.

"Concentration of critical minerals mining and refining capacity in China leaves our supply chains vulnerable and our national security and clean energy goals at risk," the White House penned in a May 14 briefing on broad package of tariffs aimed at countering China's unfair trade practices.

### All-American supply chain

America's dependence on China for graphite is not due to the lack of quality domestic deposits. Instead, it has more to do with the economics of globalization – domestic mines and refineries cannot compete financially with materials produced in countries with lower environmental and labor standards.

This left the door open for China and its longer-term strategy to control the markets for graphite and other critical minerals, along with the manufacturing of products made from these mined materials.

In mid-2023, the U.S. Department of Defense stepped in to help break America's heavy dependence on Chinese graphite by providing a $37.5 million grant to help fund a feasibility study that is accelerating Graphite One Inc.'s plans to develop an all-American mine-to-EVs graphite supply chain.

The Pentagon's decision to help accelerate the completion of an engineering and economic study for Graphite One's planned supply chains follows a 2022 presidential determination by Biden that designated graphite as a Defense Production Act Title III material "essential to the national defense."

"This Department of Defense grant underscores confidence in our strategy to build a 100% U.S.-based advanced graphite supply chain – from mining to refining to recycling," said Graphite One President and CEO Anthony Huston.

This supply chain will be anchored by Graphite Creek, a project in western Alaska that hosts the largest known graphite deposit in the U.S. and one of the largest in the world, according to the U.S. Geological Survey.

The graphite mined in Alaska will be upgraded to battery-grade anode material and other materials at a processing plant to be built at a former national defense critical minerals storage stockpile site in Ohio.

A large and previously industrialized property with ready access to roads, rail, barging facilities, and plentiful electricity, the old national defense stockpile site checks off all the boxes for Graphite One.

"Ohio is the perfect home for the second link in our strategy to build a 100% U.S.-based advanced graphite supply chain – from mining to refining to recycling," said Huston.

While Graphite One is advancing its Ohio plant and Alaska mine in parallel, it is expected that the processing facility will be finished ahead of the mining operation.

This timing, however, is advantageous.

While waiting for natural graphite from its planned mine in Alaska, which will take longer to permit and build, the Ohio plant will produce synthetic graphite anode material for lithium batteries. This will allow Graphite One to begin offering a domestic supply of this critical battery material while the mine is being developed, and the synthetic graphite can be used to augment and enhance the natural graphite delivered from Alaska.

"With the U.S. currently not producing any natural and synthetic anode materials, Graphite One has formulated a fast-track path-to-production strategy jump-starting our battery anode material production," Huston explained.

### A Lucid link to EVs, customers

Graphite One's strategy to build the Ohio processing plant before graphite from its Alaska mine is available received a major boost with a July agreement to supply California-based EV manufacturer Lucid Motors with battery-grade graphite anode material as soon as the Ohio plant comes online.

"We are committed to accelerating the transition to sustainable vehicles and the development of a robust domestic supply chain ensures the United States, and Lucid, will maintain technology leadership in this global race," said Lucid Motors CEO and Chief Technical Officer Peter Rawlinson. "Through work with partners like Graphite One, we will have access to American-sourced critical raw materials, helping power our award-winning vehicles made with pride in Arizona."

The supply agreement with Lucid, which manufactures its award-winning luxury EVs at a factory in Arizona, provides a key link to extending Graphite One's envisioned supply chain to EVs and the American consumers that drive them.

"This is a historic moment for Graphite One, Lucid and North America: the first synthetic graphite supply agreement between a U.S. graphite developer and U.S. EV company," said Huston.

Policymakers across the emerging supply chain hail the graphite supply agreement as a win for their constituents and the nation.

"By combining the resources from the new Ohio facility with the natural graphite mined in Alaska for Lucid's cars manufactured in Arizona, we are showcasing the importance of developing critical mineral supply on American soil," said Ohio Rep. Dave Joyce.

"The partnership between Lucid Motors and Graphite One will strengthen our economy, bolster our domestic supply chain of critical minerals, and reduce our reliance on foreign entities for the materials needed to build electric vehicles," added Juan Ciscomani, an Arizona congressman whose district is home to Lucid Motors' AMP-1 EV factory.

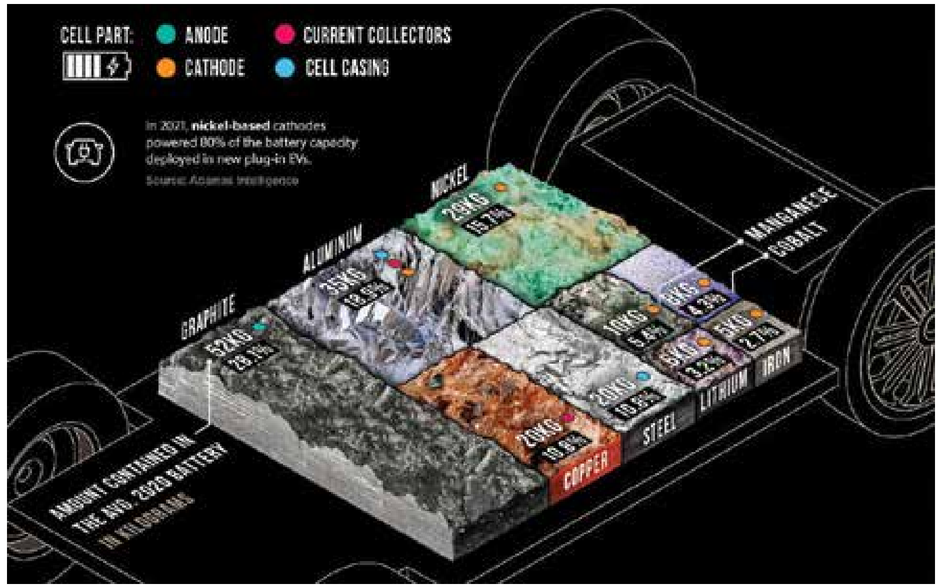
During its initial phase, the Ohio plant will have the capacity to produce 25,000 metric tons of synthetic anode material per year, which will then be scaled up to 100,000 metric tons to meet demand and process graphite from the Alaska mine.

Lucid has agreed to buy up to 5,000 metric tons of advanced anode material per year from Graphite One for the first five years after the Ohio plant begins producing synthetic graphite, which is expected in 2026.

"I'm pleased that Graphite One and Lucid Motors are partnering to create a domestic supply chain for electric vehicles made in America from materials mined in Alaska," said Sen. Lisa Murkowski. "These companies represent the start and the end of the supply chain, and they have the right vision to help strengthen our economy, our competitiveness, our security, and our commitment to true sustainability."

Graphite One hopes to get the Graphite Creek mine at the front end of the supply chain through the permitting and development in time to begin feeding American-mined graphite to the Ohio plant around the end of the decade, which aligns with expected growth in demand for this critical lithium-ion battery material.

A feasibility study that outlines the engineering and economic parameters of the Graphite One supply chain is expected by the end of the year.




As the primary anode material, graphite accounts for an average of around 28% of all the minerals and metals that go into lithium-ion batteries for electric vehicles and clean energy storage.

ELEMENTS.VISUALCAPITALIST.COM

## DOD invests in Canadian graphite

The Pentagon's investments into alternatives to China for mined graphite also extend into Canada.

In 2020, the U.S. and Canada unveiled a joint action plan to strengthen North American production of minerals critical to defense, aerospace, clean energy, communication, and other key industries.

Under this collaboration to expand critical minerals production, DOD and Natural Resources Canada (NRCan) are investing a combined $12 million to support Lomiko Metals Inc.'s endeavors to advance toward developing a mine at its La Loutre project in Quebec.

Lomiko Metals CEO Belinda Labatte said the bilateral funding in support of feasibility studies for La Loutre is a major milestone for the company and North American graphite supply chains.

"It is a win for Quebec, Canada, and the United States as we approach this next phase of studies with an exceptional opportunity with the DOD and the Canadian government to build a collaborative, inclusive approach to responsible energy transition and supply chain resilience in North America," she said.

According to a 2023 calculation, the deposit outlined so far at La Loutre hosts 3.6 million metric tons of graphite.

The $6.4 million of DPA Title III funding from DOD and the $3.6 million NRCan investment will support a three-phase strategy to advance La Loutre graphite to a definitive feasibility study.

"Canada is positioning itself as a global leader in the supply of responsibly sourced critical minerals for the green and digital economy," said Canada Minister of Energy and Natural Resources Jonathan Wilkinson. "Through our work with the United States and other allies, we are developing secure critical minerals value chains that will power a prosperous and sustainable future."

Lomiko was one of two Canadian companies to receive co-investments from DOD and NRCan in May. Fortune Minerals Ltd., which is advancing a critical minerals supply chain centered on its NICO cobalt-gold-bismuth-copper project in Northwest Territories, is the other.

"As some of the first awards to Canadian public mining and mineral development companies, these grants exemplify the critical importance of DPA funds, the department's partnership with Canada, and our shared commitment to strengthening North American material supply chains," said U.S. Assistant Secretary of Defense for Industrial Base Policy Laura Taylor-Kale.

## DOE focused on processing link

As DOD invests in accelerating the re-establishment of a North American supply of mined graphite, the U.S. Department of Energy is investing heavily in the processing link in the middle of the supply chain.

This includes roughly $320 million in loan guarantees and grants from DOE to help establish Syrah Resources Ltd.'s Vidalia graphite anode materials plant in Louisiana, which began production in February.

Capable of producing 11,250 metric tons (nearly 25 million lb) of graphite anode material per year during its initial phase of operations, Vidalia has begun to offer American automakers an alternative to China for EV battery anode material.

Most of the initial production from Vidalia is going to Tesla Inc., which has an agreement to buy 8,000 metric tons (17.6 million lb) of anode material from Vidalia per year, subject to the plant ramping up to adequate production and the output meeting the EV maker's qualifications.

As Syrah ramps Vidalia up to full capacity, which is expected by mid-2025, the Australia-based company is already working toward a major expansion that would nearly quadruple the Louisiana plant's anode material output.

To fund this expansion to 45,000 metric tons (99 million lb) per year, Syrah applied for an additional $350 million loan guarantee under DOE's Advanced Technology Vehicles Manufacturing program.

Last year, Syrah was also approved for a $150 million loan from the U.S. Development Finance Corp. for the Balama mine.

Sen. Murkowski is concerned that the U.S. government's heavy investment into stamping Mozambique graphite as "Made in America" due to it being processed in Louisiana comes at the expense of developing graphite mines on American soil.

"How can you tell me that the administration is really committed to domestic sourcing when we are not putting our resources there?" the Alaska senator asked DOE Deputy Secretary David Turk during a January Senate Energy and Natural Resources Committee hearing on EV supply chains.

"Right now, China absolutely dominates the graphite processing market," Turk responded.

In its highest demand projection, DOE forecasts that global graphite demand could be more than eight times current production by 2035.

"[G]lobal production capacity of graphite will still struggle to meet the high demand projections," DOE penned in its 2023 Critical Materials Assessment.

While graphite demand is not likely to hit the top-end eightfold increase figure cited by DOE due to a diversification of anode materials and battery technologies, even a doubling of demand would require more than 3 billion lb of new graphite supply in just over a decade.

For perspective, this is 300 times the anode-producing capacity of the Vidalia expansion proposed by Syrah.

>> *"By combining the resources from the new Ohio facility with the natural graphite mined in Alaska for Lucid's cars manufactured in Arizona, we are showcasing the importance of developing critical mineral supply on American soil."*

*–Ohio Rep. Dave Joyce*

As a result, North American battery manufacturers and automakers will need all the Vidalia capacity, plus Graphite One's proposed Graphite Creek mine in Alaska and associated graphite anode materials refinery, as well as Canadian projects such as the graphite anode material supply chain Nouveau Monde Graphite Inc. is developing in Ontario.

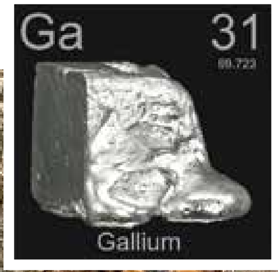
For now, the active anode material being produced at Vidalia offers an alternative to China for the largest ingredient in EV batteries while also bringing new clean energy jobs to Louisiana.

"Syrah looks forward to positively contributing to the communities around Vidalia and the company's stakeholders in the U.S. for many years to come," said Syrah Resources Managing Director Shaun Verner.

In addition to the loan guarantee from DOE, Syrah is evaluating commercial bank loans, partnerships, and other options to fund the planned expansions of its graphite processing plant in Louisiana.


TESLA INC.

**Tesla has agreed to buy roughly 70% of the graphite anode material produced during the first phase of operations at Syrah's Vidalia plant.**




Sampling of carbonatite rocks at Sheep Creek returned high-grade gallium, rare earths and other minerals critical to the U.S.

US CRITICAL MATERIALS CORP.

# US looks for domestic gallium sources

## China dominates global supplies of future-leaning tech metal

By **SHANE LASLEY**
DATA MINE NORTH

**WITH A GROWING RANGE** of unique properties that are being leveraged in next-generation smartphones, shape-shifting robots, and catalysts that scrub carbon dioxide from the atmosphere, gallium is an uncanny tech metal that teeters on the edge of science fiction and science fact.

Gallium's unusual properties begin with its 85.6-degree Fahrenheit melting point, which means it is a solid at normal room temperatures but will melt into a pool of silvery liquid metal in the palm of your hand. While this mirror-like pool of metal is reminiscent of mercury, gallium is not toxic and is much safer to handle.

While gallium's low melting point, coupled with its ability to readily alloy with most metals, offers some intriguing possibilities for the future, the most popular current use for this metal is in semiconductors for high-tech applications.

"The development of gallium arsenide as a direct band-gap semiconductor in the 1960s led to what are now some of the most well-known uses of gallium – in feature-rich, application-intensive, third- and fourth-generation smartphones and in data-centric networks," the U.S. Geological Survey penned in a report on minerals and metals considered critical to the United States.

Gallium arsenide and gallium nitride, which is a wide bandgap semiconductor, are used in next-generation smartphones, telecommunication networks, light-emitting diodes (LEDs), thin-film solar cells, quantum dots, and medical devices.

The high-tech liquid metal also demonstrates a surprising ability

MICHAEL HUSON/THE OHIO STATE UNIVERSITY

**Oak Ridge National Laboratory researcher Kyle Reed led a team testing an ORNL-made transistor in the reactor pool at The Ohio State University Nuclear Reactor laboratory.**

to greatly enhance the properties of other metals it is alloyed with, which is being leveraged by scientists to create self-cleaning "super catalysts" capable of scrubbing carbon dioxide out of the atmosphere and from industrial emissions.

Despite gallium's importance to today's and future technologies, the United States is reliant on imports for 100% of its supply of this avant-garde tech metal. Most of these supplies come from China, which produced roughly 98% of the world's gallium in 2023.

About a year ago, China put in place state-controlled restrictions on its exports of gallium, raising serious government and industry concerns about the impacts a shortage of gallium could have on America's high-tech and automotive sectors.

"Owing to China's 2023 gallium export controls, the United States and other countries began considering the start or restart of domestic primary gallium production," USGS penned in its 2024 Mineral Commodity Summaries report.

## New avenues for gallium nitride

Roughly 74% of the gallium imported into the U.S. during 2023 was used in integrated circuits by the high-tech, automotive, aerospace, healthcare, telecommunications, and other sectors of the economy, according to the USGS. At around 25%, most of the rest of this tech metal went into optoelectronic devices such as laser diodes, LEDs, photodetectors, and solar cells.

While gallium arsenide is the older and more popular semiconductor compound made from this critical metal, gallium nitride offers some superior properties that make it increasingly important for the integrated circuits going into faster and more reliable telecommunications devices, servers, laptop adapters, and even onboard chargers for electric vehicles.

Gallium nitride semiconductors boast superior power density and heat resistance, which has traditionally been used primarily for military applications. Today, this semiconductor is finding more uses in 5G networks, commercial wireless infrastructure, power electronics, satellites, EVs, and consumer electronics.

"GaN offers higher power density, more reliable operation and improved efficiency over traditional silicon-only based solutions," Texas Instruments wrote about its portfolio of integrated circuits using gallium nitride power transistor technology.

In a quest to build more durable monitoring equipment for conventional nuclear reactors and next-generation microreactors, scientists at Oak Ridge National Laboratory have been testing the limits of gallium nitride's resistance to heat and radiation.

To accomplish this, ORNL researchers placed gallium nitride transistors next to a research reactor core at Ohio State University. These transistors withstood high heat and radiation for three consecutive days, including seven hours, with the reactor running at 90% power.

The gallium nitride transistors stood up to 100 times higher accumulated dose of radiation than standard silicon devices at a sustained temperature of 125 degrees Celsius (257 degrees Fahrenheit) – far exceeding the team's expectations.

"We fully expected to kill the transistors on the third day, and they survived," said lead researcher Kyle Reed, a member of the Sensors and Electronics group at ORNL.

He hopes the ORNL research into gallium nitride for nuclear reactor electronics and other applications will create new markets for this wide bandgap semiconductor.

"We're opening up different side avenues for using gallium nitride, so we can start to create a more reasonable market demand for investment, research, and workforce development for subclasses of electronics beyond consumer-grade," Reed said.

## Liquid metal super catalysts

While gallium's superior semiconductor properties keep this metal at the very vanguard of technological innovation, its ability to take on the catalytic properties of other metals it is alloyed with to create liquid metal "super catalysts" is pushing the bounds of science.

Though this research is still in its infancy, early results by Australian scientists seem to indicate that the properties of traditional catalysts such as platinum or nickel are multiplied many times over when suspended in liquid gallium.

Gallium-enhanced catalysts could be used to scrub CO2 from industrial emissions or the atmosphere, as well as improve industrial catalytic processes that are responsible for a significant portion of global greenhouse gas emissions.

In 2021, a team of Australian and U.S. researchers led by Professor Kourosh Kalantar-Zadeh at the University of New South Wales School of Chemical Engineering mixed nano-sized silver rods into gallium to create a catalyst able to break atmospheric CO2 down to its constituent parts – oxygen and carbon.

This process could be used to greatly reduce CO2 emissions from vehicles and industrial sites.

"We are very hopeful that this technology will emerge as the cornerstone of processes that will be internationally employed for mitigating the impact of greenhouse emissions," Kalantar-Zadeh said at the time.

In a paper detailing this technology, the researchers estimated it would cost about $100 per metric ton to convert CO2 into oxygen and a saleable carbon flake product that could be used in batteries or carbon fiber materials for high-performance products like aircraft, racing cars, and luxury vehicles.

The Australian research team created yet another liquid-metal catalyst in 2022 that is thousands of times better at scrubbing CO2 from industrial exhaust than solid-state platinum.

"To keep the single atoms separated from each other, the conventional systems require solid matrices to stabilize them. I thought, why not use a liquid matrix instead and see what happens," said Arifur Rahim, a postdoctoral research fellow at the University of New South Wales.

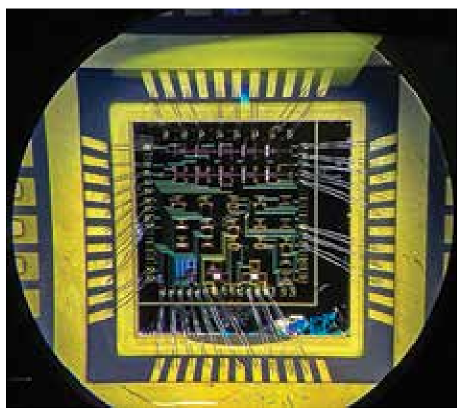
This pondering led to the discovery of a process to create a metal that enjoyed the liquidity of gallium and the catalytic properties of platinum.

Even more remarkably, at a ratio of less than 0.0001 parts platinum to one part gallium, this new liquid metal alloy is 1,000 times more efficient than a solid-state catalyst with around 10% platinum.

The liquidity of the gallium-platinum alloy offers yet one more advantage – it is

FOOBAR PHOTOGRAPHY

**A silver metal with a melting temperature of 85.6 degrees Fahrenheit, gallium is a critical mineral that is increasingly being used in a wide array of high-tech, green energy, and military applications.**



KYLE REED/ORNL, U.S. DEPT. OF ENERGY

**Electronic devices with gallium nitride transistors could be used in nuclear sensing equipment due to their high resistance to radiation.**

self-cleaning.

Like a water fountain, the liquid mechanism constantly refreshes itself, self-regulating its effectiveness over time and avoiding the catalytic equivalent of pond scum building up on the surface.

As it turns out, platinum lends its catalytic abilities to gallium, a driving force behind the reaction.

"The platinum is actually a little bit below the surface and it's activating the gallium atoms around it," said Andrew Christofferson, an Exciton Science associate investigator who worked on the project. "So, the magic is happening on the gallium under the influence of the platinum. But without the platinum there, it doesn't happen."

In 2023, the Australian scientists came up with yet another gallium-based catalyst, this time for the chemical manufacturing side of the equation.

While the chemical sector and the catalysts that support it are largely unseen, they are an essential part of modern life. Paper, plastic, fertilizers, rubber, fuels, and laundry detergent are just a small sampling of the products that depend on the catalytic process.

While much of the global focus on reducing CO2 going into the atmosphere has been on obvious emitters such as vehicles and the generation of electricity, the production of chemicals accounts for nearly 15% of global CO2 emissions and climbing.

"It's expected that the chemical sector will account for more than 20% of emissions by 2050," said Kalantar-Zadeh. "But chemical manufacturing is much less visible than other sectors – a paradigm shift is vital."

Working on the same principles as the silver rod and platinum catalysts, the liquid gallium-nickel catalyst developed by Kalantar-Zadeh's team could substantially lower the energy required for chemical processes and, thus, the CO2 emitted by them.

"By dissolving nickel in liquid gallium, we gained access to liquid nickel at very low temperatures – acting as a 'super' catalyst," said Junma Tang, a postdoctoral researcher at the University of New South Wales.

The researchers said their formula could also be used for other chemical reactions by mixing metals using low-temperature processes.

"It requires such low temperature to catalyze that we could even theoretically do it in the kitchen with the gas cooktop – but don't try that at home," Tang said.

### Idaho gallium deposit emerges

With China's hand on the gallium spigot, American tech manufacturers and the Pentagon are looking for alternative sources of this future-leaning tech metal.

Following China's 2023 announcement that all exports of this tech metal would require government authorization, a Pentagon spokesperson said, "The (Defense) Department is proactively taking steps using Defense Production Act Title III authorities to increase domestic mining and processing of critical materials for the microelectronics and space supply chain, including gallium and germanium."

Like many other critical minerals and metals, gallium is typically recovered as a byproduct of mining more common metals – primarily aluminum, zinc, and sometimes copper.

A recent report by the USGS, however, indicates that potential for domestic gallium production as a byproduct of base metal refining is low. US Critical Materials Corp.'s Sheep Creek project in southwestern Montana, however, may host high enough concentrations of gallium, alongside high-grade rare earth elements and other critical minerals, that it could offer a domestic tech metals source that does not rely on other metals.

Analysis completed at Idaho National Lab earlier this year highlights Sheep Creek's potential as an extraordinarily high-grade domestic source of both rare earths and gallium.

Highlights from the samples analyzed by Idaho National Lab include:

- 13.45% total rare earth elements (TREE) and approximately 250 parts per million gallium.
- 13.82% TREE and approximately 300 ppm gallium.
- 17.78% TREE and approximately 350 ppm gallium.

> *>> "By dissolving nickel in liquid gallium, we gained access to liquid nickel at very low temperatures – acting as a 'super' catalyst"*
>
> *–Junma Tang, a postdoctoral researcher at the University of New South Wales*

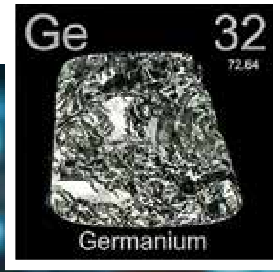
"The gallium and rare earth grades, calculated and verified by Idaho National Laboratory, are higher than any that we are aware of in the United States," said US Critical Materials President Jim Hedrick.

Idaho National Lab is also developing a process to efficiently and sustainably recover and separate the rare earths, gallium, and other critical minerals found at Sheep Creek.

"Not only is our gallium high grade, but we are also confident that working together with Idaho National Laboratory, we will be able to create a proprietary separation process that will be environmentally respectful," said Hedrick.

Sheep Creek, however, is an early staged project that requires more exploration before it is ready for permitting and development into a potential future source of domestic gallium.

In the meantime, the USGS reports that "One company in New York recovered and refined high-purity gallium from imported primary low-purity gallium metal and new scrap" during 2023.




Larger data transfers due to AI and other digital technologies are pushing up the demand for germanium used to minimize signal loss in fiber optic cables.

RAMON AT ADOBE.STOCK.COM

# Germanium: the OG Digital Age metalloid

## Original computer semiconductor now energizes space ambitions

By SHANE LASLEY

DATA MINE NORTH

**GERMANIUM IS A VERSATILE** and powerful semiconductor that traces its technology roots back to the dawn of the Digital Age and continues to lend its superlative semiconducting and optical properties to enhancing computers, smartphones, solar panels, fiber optics, and other devices 80 years later.

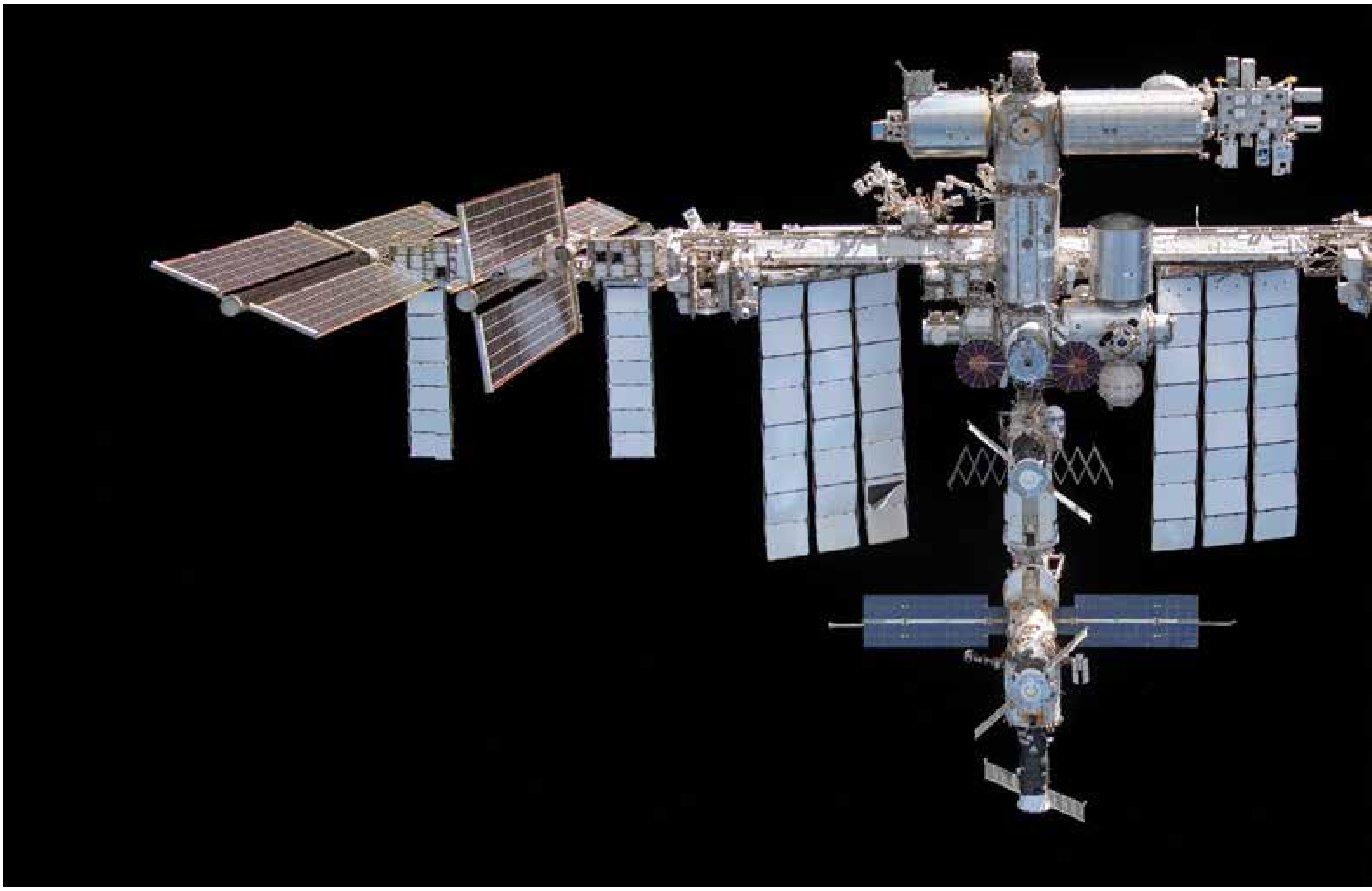
In 1945, Sylvania introduced the first germanium diode to enhance the vacuum tube computers that launched the Digital Age, and by the 1950s, both Sylvania and General Electric had developed germanium transistors to replace the vacuum tubes in the enormous mainframes of the day.

These first steps into packing more computing power into a smaller space have evolved into the smartphones we now carry in our pockets that are hundreds of thousands of times more powerful than the Apollo-era computers that guided Man's first flight to the Moon.

Despite being the original and more powerful semiconductor for the transistors that kickstarted the age of modern computing, germanium was supplanted by silicon, a more abundant and less expensive material that is now the namesake for the global capital of computer technology and the Digital Age.

While today's global headquarters for technology and innovation may not be known as Germanium Valley, the Digital Age's original semiconductor still boasts superior semiconductive and optical qualities that make it a critical ingredient in some of the most advanced technologies of the 21st century – from quantum

NASA



Above: Germanium-based multi-junction solar panels generate electricity to meet the increased energy demands of the International Space Station.

computers here on Earth to solar panels powering space exploration.

"The extensive use of germanium for military and commercial applications has made it a critical material in the United States and the rest of the world," the U.S. Geological Survey penned in a 2018 report on critical minerals.

This criticality rose sharply upon China's 2023 emplacement of state-controlled restrictions on the exports of this historic and future-leaning element of innovation.

### Energizing space exploration

Germanium is one of six elements classified as metalloids, which have characteristics of both metals and non-metals. – the other five are boron, silicon, arsenic, antimony, and tellurium. These six metalloids are used as semiconductors for high-tech and green energy applications.

Germanium's particularly powerful semiconductive properties are now being used to energize human exploration of the Moon, Mars, and beyond.

The metalloid's ability to power space exploration begins aboard the International Space Station, which recently received a power upgrade that involved the installation of germanium-based multi-junction solar panels to generate the electricity to meet increased energy demands of the space lab that is serving as a springboard for NASA's Artemis missions to the Moon.

"The main difference is that the solar cells are now germanium-based instead of silicon-based," explains Bendix De Meulemeester, director of marketing and business development at Umicore. "Whereas silicon is optimized to convert one specific part of the light spectrum into electricity, germanium allows for triple-junction cells. Each junction converts a different portion of the light spectrum into electricity, so overall conversion efficiency is a lot higher."

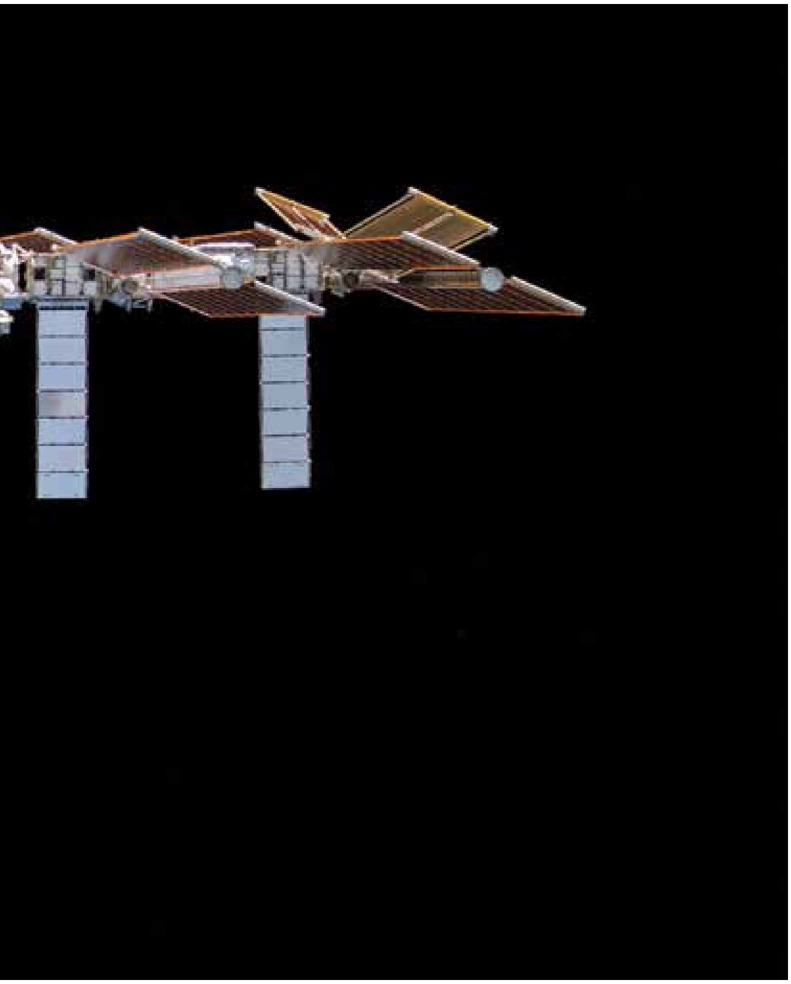
The more durable and higher efficiency germanium-based solar panels are also expected to power the Lunar Orbital Platform-Gateway, a lunar orbiter that is pivotal to NASA's Artemis missions to establish a base on the Moon that will serve as a scientific outpost on humanity's path to Mars and beyond.

In the meantime, germanium is already energizing the robotic pioneers that are exploring the Red Planet ahead of human arrival by helping to generate power in different ways aboard each of the rovers – converting sunlight into electricity with the solar panels aboard Curiosity and converting heat into electricity to power Perseverance.

"We're very proud to be a part of these exploration missions and look forward to contributing to a better understanding of our solar system," De Meulemeester said of the germanium-based materials Umicore is contributing to NASA missions.

### Down to Earth optical properties

While germanium's technological roots are firmly planted in its



semiconductive abilities, the growth in demand for this critical material stems from unique optical properties that are enhancing infrared technologies and fiber optics.

"The major use of germanium worldwide is for fiber optic systems, whereby germanium is added to the pure silica glass core of fiber optic cables to increase their refractive index, minimizing signal loss over long distances," USGS penned in a fact sheet on germanium's criticality.

In addition to increasing the refractive index, the addition of germanium to fiber optic cables improves the quality of data traveling over long distances by reducing chromatic dispersion or the flattening of the initially sharply defined binary pulses of information.

"This degradation makes the signals (ones and zeros) more difficult to distinguish from each other at the far end of the fiber," said Kevin Miller, CEO of M2 Optics, a company that specializes in customized fiber optic communications testing and networking platforms.

The need for highly reliable fiber optics is growing rapidly as more people are sharing ever larger files over the internet, and AI applications are placing enormous new demands on bandwidth.

"Germanium's ability to minimize signal loss over long distances in fiber optics has become increasingly important given the expanding demand for high performance data networking," Matthew Blackwood and Catherine DeFilippo from the U.S. International Trade Commission penned in a March 2024 report on Chinese export controls on germanium and gallium.

Precedence Research forecasts that the fiber optics market will expand from $8.1 billion in 2023 to $13.3 billion in 2033, a more than 60% increase over the coming decade.

This is helping to drive similar growth in the global demand for germanium, which is expected to increase from 120,000 metric tons in 2023 to 190,000 metric tons in 2034, a 60% climb, according to ChemAnalyst.

Infrared imaging devices used by the military, law enforcement agencies, and increasingly in the private sector are another major driver of demand for the optical qualities offered by germanium.

"Infrared optical devices improve a soldier's ability to operate weapon systems in harsh conditions effectively, and they are increasingly used in remotely operated unmanned weapons and aircraft," the USGS inked in its germanium report.

This technology is also increasingly being used for border patrol and search-and-rescue operations.

## China restrictions increase criticality

Germanium's longstanding role as superior superconductor for the electronics sector, along with its increasingly crucial role in forward-leaning clean energy, aerospace, telecommunication, and military technologies, firmly places this metalloid on America's critical minerals list.

Germanium also happens to be high on the list of mined materials on which China is placing export controls.

In July of last year, China's Ministry of Commerce announced that government authorizations would be required for exports of various gallium and germanium products.

The export restrictions on this pair of technology metals, which went into effect last August, were emplaced to "safeguard national security interests," according to the ministry.

China produces around 60% of the world's germanium, and the communist nation's export controls are expected to result in significant changes in global supply chains, according to the U.S. International Trade Commission report penned by Blackwood and DeFillippo earlier this year.

Over the first three months of restrictions, China exported a total of 591 kilograms of germanium metal, compared to the 7,965 kilograms exported in July, the month before export restrictions began.

At the same time, the U.S. imported 38,000 kg of germanium metal and dioxide in 2023, a 20% increase over 2022. China was the largest source of the germanium imported into the U.S. last year.

## Germane domestic alternatives

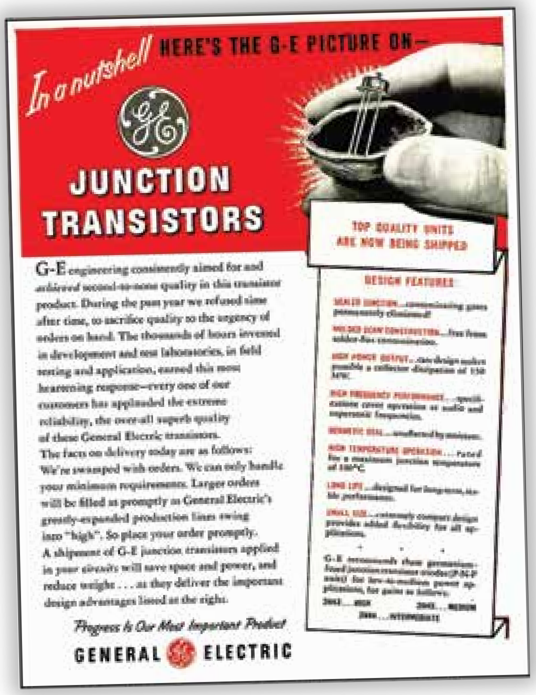
While the U.S. leans on imports from China and others to supplement its germanium needs, a fair amount of the technology metalloid is produced domestically. This includes the production of germanium as a byproduct of zinc mining in Alaska and Tennessee.

"As a byproduct metal, the supply of germanium is heavily reliant on zinc production," according to the USGS.

Teck Resources Ltd.'s Red Dog Mine in Alaska, the second-largest producer of zinc on Earth, is also a globally significant source of germanium.

As operator of both Red Dog and Trail Operations – a refinery in southern British Columbia that processes the concentrates from Red Dog and other zinc mines – Teck is the largest germanium producer in North America.

The high-quality germanium products produced at Trail are used




A 1954 advertisement for General Electric's high-performance germanium-infused transistors.

in fiber optic cables, high-speed computer chips, quantum computer transistors, solar cells, light-emitting diodes (LEDs), and night vision goggles, to name a few.

Germanium was also recovered as a byproduct of zinc mining and refining in Tennessee, as well as recycled from industry-generated scrap at a refinery in Oklahoma.

The germanium from Tennessee, however, was taken offline last November due to a pause in production of Nyrstar's Middle Tennessee Mines. The company attributes the temporary shutdown to weak zinc prices coupled with rising costs due to inflation.

During the downtime, however, Nystar is investigating the potential of investing roughly $150 million to build a state-of-the-art germanium and gallium recovery and processing facility at its Clarksville zinc smelter in Tennessee.

The company says it is in talks with the government on the possibility of building this facility that would be capable of producing enough germanium and gallium to supply roughly 80% of America's current demand for the pair of technology minerals.

The U.S. Department of Defense may be interested in investing in a major germanium and gallium recovery plant on American soil.

"The (Defense) Department is proactively taking steps using Defense Production Act Title III authorities to increase domestic mining and processing of critical materials for the microelectronics and space supply chain, including gallium and germanium," a Pentagon spokesperson said in the wake of China's export restrictions.

DOD is also stockpiling germanium recycled from outdated military hardware.

Under the Strategic Materials Recovery and Reuse Program, which operates under the Strategic and Critical Materials Stock Piling Act of 1939, DOD recovered 3,000 kilograms of germanium in 2022 from discarded night vision lenses and Bradley Fighting Vehicle turret windows and was placed in the National Defense Stockpile.

While 3,000 kilograms will not break America's reliance on China, the program underscores germanium's use in military hardware and the importance of the original Digital Age semiconductor to the Pentagon.

A 3D rendering showcases NASA's vision for using robotic building technologies to construct critical infrastructure on the Moon, including landing pads, roads, and blast walls, leveraging local resources to support sustainable extraterrestrial bases.

NASA

# Click print to build a future in the stars

## From rocket engines to lunar habitats, 3D printing is revolutionizing aerospace, turning dreams into reality

By A. J. ROAN
DATA MINE NORTH

**IN THE NOT-SO-DISTANT** past, the idea of constructing a rocket engine or spacecraft components with just the click of a button seemed like pure science fiction. Yet today, 3D printing is rapidly transforming the aerospace industry, turning once-impossible designs into tangible reality, and bringing us closer to the stars than ever before.

Aerospace has always been on the cutting edge of technology, but with the advent of 3D printing, it is entering a new era of innovation.

This groundbreaking technology is revolutionizing the way aircraft and spacecraft components are designed, manufactured, and maintained. From the creation of complex geometries that were once impossible to conceive, let alone produce, to the reduction of weight and material waste, 3D printing is enabling engineers to push the boundaries of what is possible.

It is not just about making things faster or cheaper – though it does both – but about unlocking new levels of creativity and efficiency in aerospace engineering.

With the advent of 3D printing, various new methods of design, production, innovation, and even solutions to problems not even dreamed of have begun to open up for the amateur and professional alike.

In aerospace, this means complex components, like entire rocket engines, can be produced in a single piece, drastically reducing assembly time and potential failure points. This capability not only streamlines production but also introduces a level of precision and integrity that traditional methods struggle to achieve.

Supplementing this, new alloys and materials, specifically tailored for additive manufacturing, are being developed to further enhance performance and durability, ensuring these printed components can withstand the extreme conditions of space.

Beyond these advancements, 3D printing is revolutionizing maintenance by enabling on-demand production of replacement parts, minimizing downtime, and extending the lifespan of critical systems.

Moreover, this innovation also inspires designs not even borne of Earth. Engineers are now capable of exploring the potential of in-space or in-situ manufacturing, where components can be printed directly in orbit or on other planets, paving the way for sustained human presence in space.

With each new advancement, 3D printing is transforming the world, turning once-implausible dreams into a tangible future.

### The aid of 3D printing

While the aerospace industry thrives on pushing the boundaries of innovation, and 3D printing has quickly found itself at the forefront of this endeavor, what exactly is it about this technology that enables such broad-sweeping improvements?

• Rapid prototyping and iteration: One of the most significant advantages of 3D printing is the ability to rapidly produce prototypes. In aerospace, where precision and performance are critical, the ability to quickly iterate on designs allows engineers to test and refine parts in a fraction of the time required by traditional manufacturing methods. This not only accelerates the research and development process but also fosters innovation by allowing more room for experimentation.

• Complex geometries and lightweight structures: 3D printing excels in creating complex geometries (like crisscrossing patterns or hollow shapes) that are difficult, if not impossible, to achieve with conventional manufacturing techniques. In aerospace, this means the production of lightweight yet strong components that reduce overall aircraft weight, leading to improved fuel efficiency and performance. These complex structures, such as intricate lattice frameworks, can now be designed with material distribution optimized for strength and minimal weight.

• Cost-effective custom tooling: The ability to produce custom tooling on-demand is another game-changer. 3D printing enables the creation of specialized tools and jigs that are tailored to specific manufacturing needs, significantly reducing lead times and costs. This is especially beneficial in aerospace, where production runs are often small and highly customized.



AMCM GMBH

**3D-printed combustion chamber highlights the advanced capabilities of metal additive manufacturing in aerospace, showcasing intricate and complex geometries that enhance engine performance and efficiency.**

• On-demand manufacturing and maintenance: In an industry where downtime can be incredibly costly, the ability to produce replacement parts on-demand with 3D printing is invaluable. Whether on Earth or in space, this capability ensures that critical components can be replaced quickly, reducing aircraft downtime and extending the operational life of key systems.

• Component consolidation and increased durability: 3D printing allows for the consolidation of multiple parts into a single, unified component. This not only simplifies the assembly process but also reduces potential failure points, improving the overall reliability of aerospace components. Furthermore, the integration of advanced materials through additive manufacturing enhances the durability and performance of these parts under extreme conditions.

• Applications beyond earth: Perhaps the most forward-thinking application of 3D printing is its potential for space exploration. This allows for the creation of parts and tools in space, reducing the need for extensive resupply missions. In-situ resource utilization, where materials found on other planets or moons are used in manufacturing, could become a reality, making the dream of space habitation a reality.

These applications highlight just how transformative 3D printing is for the aerospace industry. By enabling rapid innovation, reducing costs, and allowing for the creation of components that were once thought impossible, 3D printing is helping to usher in a new era of aerospace engineering.

### A different angle

What was once a simple recipe of base element proportions – like the combination of copper (88%) and tin (12%) that left its mark on an entire age of human civilization with the discovery of bronze – has become a sophisticated form of metallurgical alchemy.

These new alloys are not just stronger and more durable; they are tailored at the molecular level to enhance performance in ways traditional materials never could.

This is now one of the most remarkable aspects of 3D printing, particularly benefiting the aerospace industry through the development of specialized alloys and metals designed to meet exacting specifications.

For decades, metals like aluminum and titanium have been aerospace staples. However, the advent of 3D printing has empowered engineers to design alloys with unparalleled precision, optimizing properties such as weight, strength, and heat resistance.

By incorporating nanoscale particles into metals, scientists have created something they call superalloys.

One such superalloy is NASA's GRX-810, which can withstand higher temperatures and stress than conventional alloys and offers up to 2,500 times longer service life.

"It took us a while to convince ourselves that these results were real. We understood then that, you know, something had changed, and we made an alloy that we were very excited about," NASA Research Materials Engineer Tim Smith said in an interview with Inverse. "You even have better irradiation properties. So, applications that are higher radiation environments, fission or fusion reactors, things like that, will all benefit by having these oxides dispersed in it."

Owing to the harsh and unforgiving nature of space, NASA's materials research and development efforts aimed to enable enhanced mechanical properties for all conditions.

GRX-810 is the purported epitome of this, as it boasts "remarkable performance improvements" over many of today's leading alloys, such as Inconel – a nickel-chromium superalloy.


NASA/JORDAN SALKIN

NASA's insignia is 3D printed with GRX-810, a superalloy designed for extreme durability.

### 3D printing multiple materials

While some components can be printed entirely from a single material, 3D printing also allows for the engineering of multiple materials within a single part, combining different metals or incorporating non-metallic composites to optimize specific properties in targeted regions of the print.

With the ability to combine multiple materials, 3D printing has opened up new frontiers in aerospace manufacturing. Engineers can now tailor parts with a level of specificity that was once unimaginable.

By embedding different materials within a single component, they can create structures that are both lightweight and incredibly strong, which is particularly useful in aerospace, where the balance between weight and durability is crucial.

For example, a component might have a rigid metallic core to withstand stress, while the outer layers could be made from a lighter composite material that offers flexibility or heat resistance. This multi-material approach allows for the design of parts that can perform optimally under different conditions, whether it is the extreme temperatures of space or the mechanical stresses of atmospheric re-entry.

In addition, the flexibility of 3D printing enables the integration of complex features such as forming internal cooling channels directly into parts as they are built layer by layer.

These cooling channels, often made from advanced composites or ceramics, can drastically improve the efficiency and lifespan of aerospace components, making them ideal for engines and high-performance systems.

The ability to customize the composition and structure of materials does not just enhance performance—it also contributes to sustainability.

By only using the necessary amount of each material and optimizing designs for weight and durability, 3D printing reduces waste and energy consumption during production. This is particularly important in the aerospace industry, where every gram counts, and where the reduction of material waste can significantly lower costs and environmental impact.

### Earthly applications

While 3D printing's potential in space exploration captures the imagination, its impact on Earth is no less transformative. This technology is reshaping the aerospace industry by streamlining the manufacturing of aircraft components; reducing costs and enhancing environmental sustainability.

It is now well understood that the impact of 3D printing in aerospace lies in its ability to produce intricate components with unmatched precision and efficiency that conventional casting or machining cannot match, this technology has become a wellspring of potential, leaving engineers asking, "what can't we do?"

From engine parts to air ducts, 3D printing allows for the reimagining of nearly all aspects of manufacturing. Although it still suffers from slower production speeds, has the possibility of micro-failures during the printing process, and struggles with limitations in the size of parts that can be printed in a single piece, the fact remains – everything that has ever been engineered has the potential to one day be remade through the lens of additive manufacturing.

This technological revolution is not just theoretical; it is already bearing fruit in various aerospace applications. Defense and space contractors like Boeing and Lockheed Martin are utilizing 3D printing to create components that are lighter, more efficient, and capable of withstanding extreme conditions.

Boeing, for instance, has incorporated over 60,000 3D-printed parts across its fleet of commercial and military aircraft, significantly reducing production times and costs. Meanwhile, Lockheed Martin uses 3D printing for parts in the F-35 fighter jet, including complex fuel nozzles and structural components, improving performance and reducing weight.

Additionally, Airbus is leveraging 3D printing to manufacture cabin and structural components for its aircraft, leading to significant weight savings and fuel efficiency. The company's A350 XWB, for example, contains over 1,000 3D-printed parts. Similarly, GE Aviation uses 3D printing to produce fuel nozzles for its LEAP engines, reducing the number of parts in each nozzle from 20 to one and improving durability while cutting production time.

These advancements not only demonstrate the industry's growing reliance on 3D printing but also highlight the limitless potential of this technology to continually redefine what is possible in aerospace engineering. And if these kinds of improvements are being made here on solid ground, what does it mean for a future in the stars?

ADOBE STOCK

**Metal 3D printing enables the precise creation of complex and durable components, reducing material waste and allowing for innovative designs that were previously impossible.**

## Space applications

The challenges of space exploration demand many things: resilience, ingenuity, and perhaps a touch of crazy. To aid these qualities, 3D printing has emerged as a critical support system that has transformed the way we approach the final frontier.

While advancements in 3D printing have already begun to revolutionize spacecraft development on Earth, with organizations like SpaceX and NASA leading the charge, the true transformative potential of this technology becomes even more apparent in its role within the broader space exploration sector.

Creating critical components like the SuperDraco engine, which serves as both the main propulsion and the launch escape system for the Dragon 2 spacecraft, and other key elements such as combustion chambers and nozzle extensions for the Falcon 9, SpaceX leverages 3D printing to enhance the efficiency and safety of its spacecraft.

NASA is similarly harnessing the power of 3D printing to advance its ambitious missions. From developing intricate parts for their next-generation rockets to creating tools and components on the International Space Station (ISS), NASA is exploring the full potential of additive manufacturing in space. For example, with the Artemis program, NASA has successfully 3D printed components like the RS-25 injector for the Space Launch System, which powers the Artemis missions to the Moon. This innovation significantly reduces production time and allows for more resilient designs.

Moreover, the refabricator on the ISS exemplifies NASA's innovative approach, allowing astronauts to recycle plastic waste into new tools and parts, showcasing how 3D printing can sustain long-duration missions.

## Printing in space

Despite the successes so far, the true test lies in a future where 3D printing harnesses resources found in space, for space.

NASA envisions a scenario where astronauts can 3D print habitats and tools on the Moon or Mars, using local materials to construct shelters and infrastructure – a concept known as in-situ resource utilization (ISRU). By reducing the need to transport heavy materials from Earth, ISRU could be the key to a sustainable human presence on other planets, making long-term space exploration more feasible and cost-effective.

This vision extends beyond mere survival; it is about thriving in space. Imagine astronauts on Mars using 3D printers to turn the planet's regolith into protective habitats, radiation shields, or even components for vehicles and scientific instruments. This approach not only conserves resources but also enables rapid adaptation to unforeseen challenges. If a critical part breaks, rather than waiting for a resupply mission, astronauts could print a replacement on-site, ensuring mission continuity.

ISRU also aligns with the broader goals of sustainability and resource efficiency, principles that are increasingly vital as humanity pushes the boundaries of exploration.

By utilizing local materials, the utilization of local resources reduces the financial and environmental costs of space missions and paves the way for a new era of space architecture, where structures are designed with the environment in mind, whether that environment is Earth, the Moon, or Mars.

This vision, while still in its infancy, is a testament to the power of 3D printing to not only help solve immediate challenges but also to inspire a new way of thinking about what is possible in the uncharted territories of space.

As we stand on the cusp of a new era in exploration, 3D printing offers a bridge between imagination and reality, turning the dreams of space colonies, interplanetary travel, and sustainable living among the stars into tangible possibilities.

The once fantastical idea of printing habitats on the Moon or crafting tools from Martian soil is no longer just a page out of science fiction; it is the blueprint for the future. With each layer of material laid down, we are also laying down the foundations of humanity's next great adventure.

So, as we continue to push the boundaries of what is possible, the question is no longer just about where we'll go next, but how we'll build the future once we get there. With 3D printing as our guide, the answer may be simpler than we ever imagined—just click "print."


Aluminum smelting is a complex process that requires large-scale industrial operations like this smelter in Kazakhstan, where alumina is refined and electrolyzed in high-temperature cells to extract aluminum, a process demanding precision and significant energy input.

WIKIMEDIA COMMONS

# Transforming aluminum to transform the world

## Cutting-edge innovations turn aluminum into a cornerstone of the green transition, reshaping technology and the future

By A.J. ROAN
DATA MINE NORTH

**IMAGINE A METAL** that's as light as it is strong, capable of taking cars further on a single charge and helping planes soar higher with less fuel. Enter aluminum – the unsung hero of the green revolution.

This year, aluminum isn't just playing a supporting role in the shift to sustainability; it's stealing the spotlight, driving innovations that are making our world lighter, faster, and a whole lot greener.

From electric vehicles pushing the limits of range and efficiency, to the high-capacity batteries driving them farther, and the aerospace industry's relentless pursuit of lighter, more fuel-efficient aircraft, aluminum is at the core of these technological leaps. It is proving to be a game-changer, powering innovations that are shaping a sustainable future.

This versatile metal has evolved far beyond recycled soda cans, now sitting at the heart of innovations driving advancements in energy storage, transportation, and beyond. Aluminum is enabling technologies crucial for a sustainable future.

Its unique combination of strength, lightness, and recyclability makes aluminum indispensable in the race to cut carbon emissions and build a sustainable future. However, achieving a truly green aluminum industry comes with its own set of challenges.

Traditional aluminum production is energy-intensive, with smelting processes historically responsible for significant greenhouse gas emissions – a challenge central to the green paradox. Balancing the demand for this versatile metal with the need to reduce its environmental footprint is a complex dilemma that the industry is only beginning to unravel.

However, recent technological advancements are beginning to shift this narrative. Innovations like carbon-free smelting, advanced batteries, cutting-edge alloys, and more are redefining aluminum's role across various industries.

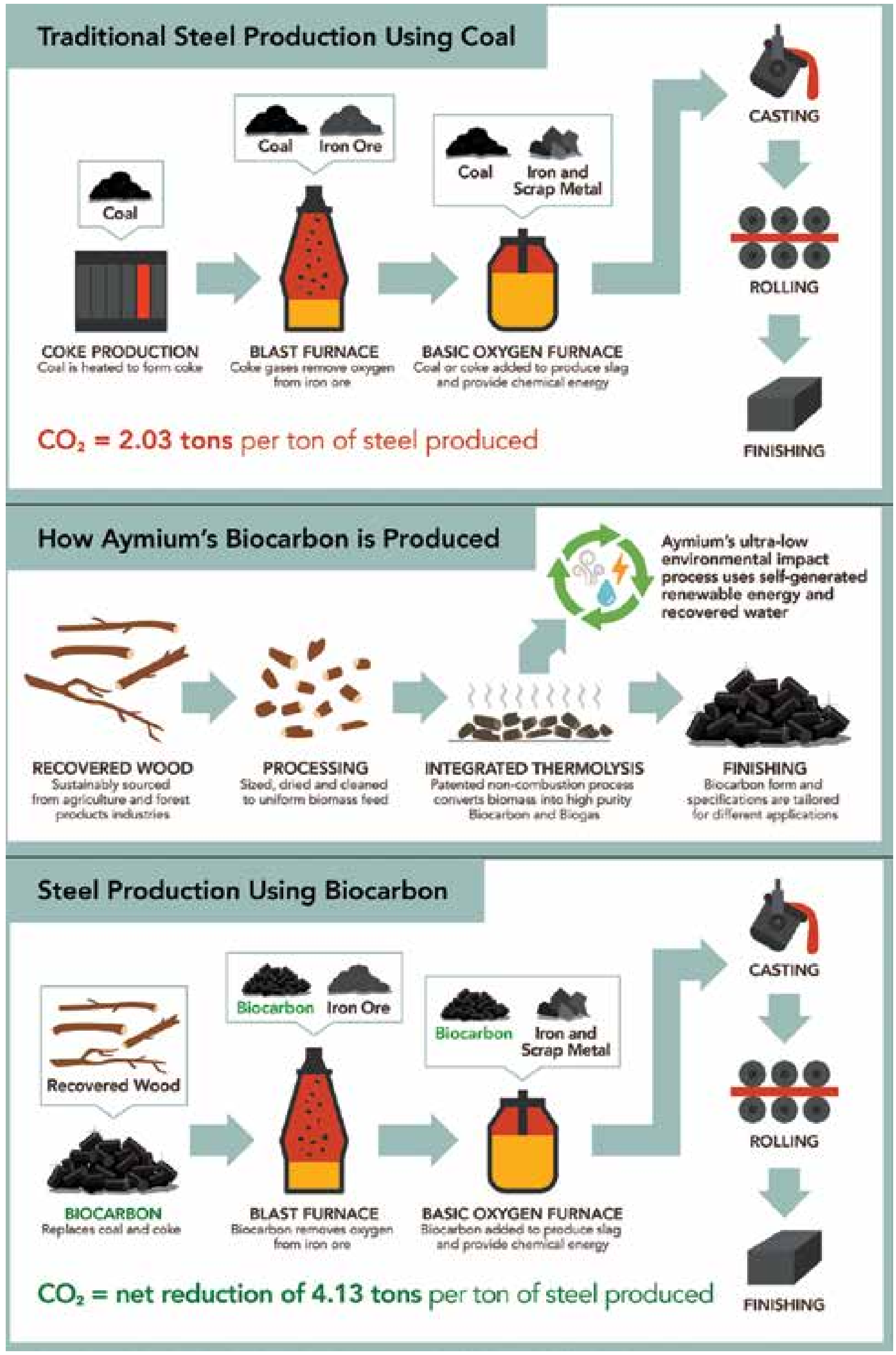
Aluminum's influence spans multiple industries, particularly in automotive, where its weight-reducing properties enhance both electric and internal combustion vehicles.

By lightening the load, aluminum directly contributes to increased range for EVs and improved fuel efficiency for traditional vehicles. This is especially critical as automakers strive to meet stringent emissions targets while also catering to the growing demand for more efficient and longer-range vehicles.

Similarly in the aerospace industry, where every pound spared can result in substantial fuel savings, aluminum is an essential material.

Modern aircraft are increasingly incorporating aluminum alloys that offer a superior strength-to-weight ratio, enhancing both performance and fuel efficiency. The development of aluminum-scandium alloys, for example, is pushing the boundaries of what's possible, offering stronger, lighter components that are critical for next-generation aircraft.

As the world accelerates toward a greener future, aluminum stands out as a material that's not only adaptable and resilient but also central to the technologies driving this change. Its versatility, combined with ongoing innovations in production and application, ensures that aluminum will continue to play a pivotal role in shaping a sustainable future—whether it's in the air, on the road, or beyond.




**Infographic of steel production compared to using Aymium's biocarbon.**

AYMIUM

## Domestic shortcomings

In 2024, aluminum continues to be one of the most critical materials in the global push toward sustainability. With its unique properties, this metal is integral not only to automotive and aerospace industries but also to construction, consumer goods, as well as future renewables, making it a cornerstone of modern technology and infrastructure.

Feeding enough aluminum to meet the demand of these diverse industries requires a substantial supply of this increasingly critical metal. In 2023, the apparent domestic consumption of aluminum in the U.S. was around 4 million metric tons. However, this figure doesn't fully capture the total aluminum brought into the country.

According to the U.S. Geological Survey's Mineral Commodity Summaries 2024, the U.S. imported approximately 4.8 million metric tons of crude and semi-manufactured aluminum. With the country being 44% reliant on these imports, this data suggests that actual consumption may be higher than reported, or that a portion of the imported aluminum is being stockpiled, exported, or otherwise allocated for future use.

Regardless of the actual number, the U.S. currently operates only five primary aluminum smelters, and from those, produced around 19% of the apparent consumption last year, approximately 750,000 metric tons.

Although not as reliant as some of the other critical minerals, this limited domestic production highlights another possible vulnerability in the supply chain. As global demand for aluminum continues to grow, this dependence poses risks not only to national security but also to the broader goal of reducing carbon emissions.

### Green paradox

In the world of materials science and industrial production, a complex issue known as the "green paradox" has long been recognized.

The green paradox refers to the irony that materials essential for advancing green technologies often come with significant environmental and social costs in their production – negating at least some of their potential benefits.

This concept is a recurring theme not just for aluminum, but for numerous critical materials like lithium, cobalt, rare earth elements, copper, and nickel.

Things like EVs, solar panels, wind turbines, advanced batteries, and even the electrical grids that support renewable energy infrastructure all rely heavily on these critical minerals. Without them, the transition to a sustainable, low-carbon future simply wouldn't be possible.

Despite the undeniable benefits they offer, the extraction and processing of these materials often comes at a steep environmental cost. Aluminum and copper mining are energy-intensive and contribute to greenhouse gas emissions, while lithium and cobalt extraction can lead to water depletion and are strongly tinged with ethical concerns.

Hence, a paradox: they are essential for a greener future, yet their production methods are often anything but green.

### The fire

With a mix of cutting-edge technology and bold ambition, global mining company Rio Tinto is rewriting the rules of aluminum production, turning what was once an environmental risk into an opportunity for innovation by attacking aluminum

WIKIMEDIA COMMONS

**Aluminum does not occur naturally in a pure form due to its reactivity. Instead, it is extracted from bauxite ore, refined into alumina, and then smelted through electrolysis.**

production from two fronts – by revolutionizing the smelting process itself and the fuel that powers it.

Joining forces with industry leader Alcoa, Rio Tinto is addressing the challenge of carbon emissions from aluminum smelting using an innovative new technology.

Described as the most significant advancement in the aluminum industry in over a century, this technology, known as ELYSIS, replaces the traditional carbon anodes in the electrolytic cells of electric furnaces with proprietary inert anodes.

Instead of producing CO2 as a byproduct, these inert anodes release pure oxygen.

This climate-saving technology is expected to lower production costs by 15% and increase output by the same percentage. Additionally, it can be retrofitted to existing smelters or used to construct new facilities, making it versatile and scalable.

"ELYSIS is a truly disruptive technology for the industry, and it's thanks to Québec expertise that we are the first in the world to produce GHG-free aluminium," said Pierre Fitzgibbon, Québec Minister of Economy, Innovation and Energy. "This is a technological innovation with unprecedented benefits for our aluminium sector, which remains an undisputed world leader."

As proof of concept, the first deployment of this technology will be built adjacent to the existing Arvida smelter, allowing the use of the current aluminum supply and casting facilities.

Supported by the governments of Canada and Québec, as well as tech giant Apple, this innovative approach to aluminum manufacturing has already been successfully demonstrated at the ELYSIS Industrial Research and Development Center in Saguenay–Lac-St-Jean.

This joint venture between Rio Tinto and Alcoa will continue its research and development program to scale up the ELYSIS technology and has already completed the construction of larger prototype cells designed to be integrated at the end of an existing production line at Rio Tinto's Alma smelter.

### Fueling lower CO2 emissions

While revolutionizing the smelting process itself with ELYSIS is a major step forward, Rio Tinto is also addressing the environmental impact of the fuels used in aluminum production.

In 2022, Rio Tinto, Steel Dynamics, and Nippon Steel Trading formed a strategic partnership with Aymium – a pioneer in renewable energy solutions – investing over $200 million in its innovative biocarbon technology.

This collaboration aimed to replace fossil fuel inputs in metals production with Aymium's carbon-negative products, reducing CO2 emissions and advancing their sustainability goals.

Partnering with Aymium, Rio Tinto has formed Évolys Québec Inc., a joint venture focused on producing this biocarbon

from sustainably sourced biomass using Aymium's proprietary technology. Its product line includes biocarbon for

> “This is a technological innovation with unprecedented benefits for our aluminium sector, which remains an undisputed world leader.”
>
> –Québec Minister of Economy, Innovation and Energy Pierre Fitzgibbon

metallurgical purposes, bioenergy, agricultural, biohydrogen, and activated carbon.

Unlike traditional fuels, which contribute significantly to carbon emissions, Aymium’s biocarbon not only reduces the carbon footprint of aluminum production but actually removes more carbon from the atmosphere than it emits.

The biocarbon can be used directly in existing smelting operations, making it a versatile and immediately impactful solution.

“Our mission is to accelerate the transition away from fossil fuels and reduce the impact on the environment,” said Aymium CEO James Mennell at the time of the investment. “Aymium’s products allow immediate replacement of fossil fuels with renewable, carbon negative inputs without any changes to existing manufacturing processes or equipment. This investment and partnership will further advance our mission of improving the environment with our new partners on a global scale.”

This collaboration will see the development of a biocarbon production facility designed to support Rio Tinto’s decarbonization efforts and further the global miner’s commitment to sustainable aluminum production.

### Aluminum-scandium alloy

As it stands, aluminum production is responsible for an estimated 1.1 billion metric tons of carbon emissions each year. Even as one of the world’s largest aluminum producers working to reduce that number, the demand for aluminum in new and emerging technologies continues to rise.

NioCorp Developments Ltd., a company focused on producing critical minerals for high-tech industries, is at the forefront of developing aluminum-scandium alloy – a material that could redefine performance in automotive and defense applications, as only a small dose of scandium is needed to bolster the strength and toughness of aluminum.

Operating the Elk Creek critical minerals project in Nebraska, NioCorp has access to one of the richest scandium deposits in the U.S., alongside niobium, titanium, and rare earth elements.

Recognizing the potential of scandium for high-performance applications in the early 2010s, NioCorp has steadily developed the infrastructure and technology needed to produce an alloy that joins together the lightweight, strength, and corrosion resistance of aluminum with the exceptional durability and heat resistance of scandium. Building on this foundation, NioCorp has laid out a three-phase development strategy for the aluminum-scandium master alloy more concretely around 2022. This plan set the stage for pilot-scale production to begin shortly thereafter.

Collaborating closely with its development partner, Nanoscale Powders LLC, NioCorp has been refining the production process, with an eye toward reaching full-scale commercial production.

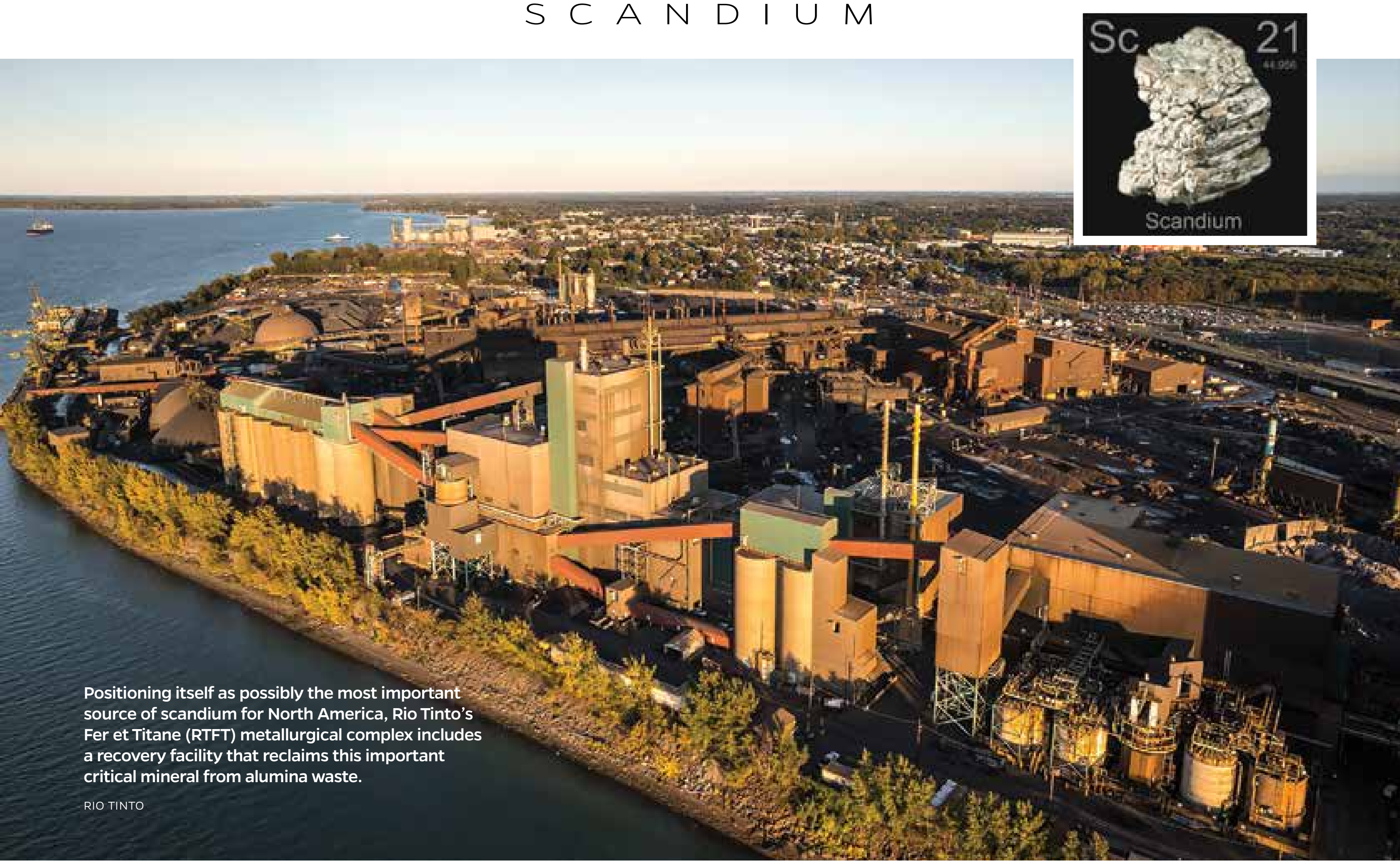
By late 2024, the company’s effort finally bore fruit as it successfully produced scandium metal at a pilot-scale facility in Pennsylvania. This milestone not only demonstrated the feasibility of the production process but also paved the way for the creation of kilogram-sized samples of aluminum-scandium master alloy – later sent to its “unnamed automaker partners” for testing.

“The progress being made in this phased commercialization effort is important given the rapidly growing interest in scandium alloys across both the commercial transportation sector and in the national defense community,” said NioCorp Developments Executive Chairman and CEO Mark Smith. “This successful test demonstrates that we can make scandium metal at a high-enough purity level to proceed directly to the pilot-scale production of kilogram-sized samples of aluminum-scandium master alloy.”

From that success, the company remains focused on scaling production, aiming to move from 10-kilogram (22-pound) ingots to 100 kg (220 lb) ingots, ultimately targeting full-scale commercial production.

NioCorp’s advancements in aluminum-scandium alloys not only exemplify the cutting-edge innovation driving the aluminum industry forward but also underscore the critical role that such materials will play in shaping the future of transportation and defense.

As the global demand for aluminum continues to surge, these innovations, alongside those from industry leaders like Rio Tinto, highlight a pivotal shift toward a more sustainable and resilient aluminum industry—one that is essential to powering the technologies of tomorrow while addressing the environmental challenges of today.




Positioning itself as possibly the most important source of scandium for North America, Rio Tinto's Fer et Titane (RTFT) metallurgical complex includes a recovery facility that reclaims this important critical mineral from alumina waste.

RIO TINTO

# North America fortifies scandium supply

## Projects, initiatives, and technology expand scandium supply chain security

By A.J. ROAN
DATA MINE NORTH

**WHILE IT MAY NOT HAVE** quite as strong a chemical bond to its adopted lanthanide siblings as they do each other, scandium does possess similar enough characteristics and is almost always found at the same geological gatherings (deposits) as the rest of its rare earth family.

Named for the Latin word for Scandinavia, "Scandia," – as the mineral was thought to only dwell off the Nordic peninsula – scandium was theoretically predicted to exist after Russian chemist Dmitri Mendeleev devised the periodic table of elements in 1869.

10 years later, Mendeleev's postulate would come true as Lars Frederick Nilson, a Swedish chemist, discovered the element in 1879, adding the 21st element to the periodic table.

Scandium is not considered rare in Earth's crust, with estimates varying between 18 to 25 parts per million, comparable in abundance to cobalt. However, scandium is distributed sparsely and occurs in trace amounts in many minerals, including alongside rare earth elements.

Beyond its close chemical and geological ties to rare earths, scandium is considered a critical mineral in its own right due to its traditional alloying qualities and emerging high-tech properties.

Scandium's primary and most enduring use is in lightweight and strong aluminum-scandium alloys, widely used in aerospace components and sports equipment. In recent years, solid oxide fuel cells (SOFCs) have become another major application area for scandium due to their ability to improve the efficiency and longevity of these cells.

Additionally, scandium is finding increasing use in ceramics, electronics, lasers, lighting, and metal 3D printing, reflecting its versatility and growing demand across various high-tech industries.

According to the U.S. Geological Survey's 2024 Mineral Commodity Summaries, the United States remains 100% reliant on imports for its scandium supplies.

These imports primarily come from Europe, China, Japan, and Russia. Like many critical elements, scandium imports are difficult to track due to proprietary restrictions and national security concerns, making it challenging to fully understand the supply chain.

Nevertheless, the geopolitical risks are evident, particularly with the ongoing Russia-Ukraine conflict, which underlies the vulnerability of relying on Russian imports, a significant global supplier of this critical mineral.

Given the growing critical role it will play in high-tech and defense applications, securing a stable and domestic supply of scandium is of paramount importance. This urgency has spurred various initiatives to explore and develop scandium resources within North America.

One notable effort is the advancement of aluminum-scandium alloy production by Rio Tinto, positioning North America as a potential key player in the global scandium market.

ALERIS

A technician applies a coating to aluminum-magnesium-scandium alloy – called AA5028 – developed by Aleris in collaboration with Airbus, highlighting the advancements in this critical mineral for aerospace and high-tech industries.

## Scandium from aluminum

Though scandium is often associated with rare earths, most of the global supply of this alloying metal is recovered as a byproduct of titanium, zirconium, cobalt, nickel, and aluminum production.

As it so happens, the largest aluminum producer in North America and fourth largest in the world, Rio Tinto, has chosen to capitalize on its vast alumina capabilities by developing a scandium recovery facility at its Fer et Titane metallurgical complex in Sorel-Tracy, Quebec.

Completing the complex in 2021, this C$6 million (US$4.8 million) project, supported by a C$650,000 (US$520,000) contribution from the government of Quebec, positioned Rio Tinto as the first North American producer of high-purity scandium oxide, capable of supplying approximately 20% of the global market.

Running at full capacity, the facility produces roughly three metric tons of scandium oxide per year – global demand for scandium is estimated to be between 30 and 40 metric tons annually. With 99.99% scandium prices fluctuating between US$4,000 and US$20,000 per kilogram (2.2 pounds), this market has presented a significant opportunity for Rio Tinto.

The plant extracts high-purity scandium oxide from the waste streams of titanium dioxide production at its Lac Tio mine near Havre-Saint-Pierre, Quebec. This strategic alignment allows the scandium recovered from the plant to integrate seamlessly with Rio Tinto's aluminum operations in the Saguenay–Lac-Saint-Jean region of Quebec.

"With the support of Rio Tinto's aluminium business, we are uniquely positioned to deliver aluminium-scandium master alloys and develop synergies with North America's manufacturing supply chain," said Rio Tinto Iron and Titanium managing director Stéphane Leblanc.

In 2022, Rio Tinto announced plans to quadruple its scandium oxide production capacity from three to twelve metric tons per year by 2024. This expansion, part of a C$30-35 million (US$22-26 million) project, aims to meet over 50% of the estimated global demand for scandium.

"With this breakthrough process creating value from waste, Rio Tinto et Titane's ambition is to become a key supplier in the global scandium market," said Leblanc. "I want to congratulate our employees who brought this project from the drawing board to commercial demonstration in less than two years."

To fully realize the potential of its future scandium business, Rio Tinto formed Element North 21, a business to commercialize its scandium products.

Deriving its name from scandium's number on the periodic table and the business' Canadian headquarters, Element North 21 initially offers three scandium products – 99.9% pure scandium oxide, a standard aluminum-scandium alloy, and specialized aluminum-scandium alloys for aerospace and 3D printing applications.

Furthermore, the company said it would be able to scale up scandium production to meet market demands by adding additional modules to its scandium recovery plant in Quebec.

By expanding its scandium production capabilities, Rio Tinto's efforts have strengthened North America's supply chain for this critical material, thereby reducing dependency on imports.

Unlike Rio Tinto's approach of producing scandium as a byproduct of aluminum production, other North American operations are advancing scandium production and recovery through both recycling of rare earth elements and straightforward mining methods.

## Scandium production initiatives

Presently, several projects in North America, as well as allied nations, are

*>> "I want to congratulate our employees who brought this project from the drawing board to commercial demonstration in less than two years."*

*–Rio Tinto Iron and Titanium managing director Stéphane Leblanc*

advancing scandium production and recovery through various methods, either directly or indirectly.

To aid in the future establishment of a stable scandium supply, a diverse group of companies is spearheading efforts in scandium mining and processing, leading the way through innovative projects and strategic collaborations. These companies include:

• USA Rare Earth LLC and Texas Mineral Resources Corp.'s Round Top project in Texas offers a potential significant supply of scandium. The vast deposit at this project would also provide a domestic source of rare earths and lithium, further bolstering its importance to the U.S. economy.

• NioCorp Developments Ltd. is advancing the Elk Creek project in Nebraska, which focuses on niobium alongside titanium and scandium. NioCorp is collaborating with automakers to develop aluminum-scandium vehicle parts, highlighting scandium's strategic role in enhancing vehicle performance and sustainability.

• Energy Fuels Inc. is expanding into rare earth element production with a new separation facility at their White Mesa Mill in Utah, expected to be operational by early 2024. This facility aims to produce up to 15,000 tons of rare earth oxides annually, which should include scandium as a byproduct.

• Ucore Rare Metals Inc.'s Bokan-Dotson Ridge rare earths project in Alaska is enriched in scandium. They are also advancing the RapidSX rare earths separation technology to be installed at their Louisiana Strategic Metals Complex, which is expected to recover scandium alongside the rare earths.

• Scandium Canada Ltd. is advancing the Crater Lake project in Quebec, conducting fieldwork and metallurgical pilot tests with a goal of completing a prefeasibility study by 2025. They have also been developing aluminum-scandium powders for 3D printing since 2021.

Outside of North America, Australian companies have begun seeing the value and strategic importance of mining this critical resource. These include:

• Scandium International Mining Corp. is developing the Nyngan project in southeastern Australia, which is one of the few primary scandium projects globally. This project aims to produce scandium oxide and integrate it into the global supply chain.

• Sunrise Energy Metals Ltd. is advancing the Sunrise project in southeastern Australia, aiming to become a major supplier of high-purity scandium oxide in the coming years.

While many companies are working on developing deposits to retrieve raw sources of scandium, others are advancing rare earth element separation technology, which, while not specifically targeting scandium, likely includes its recovery given its presence among the suite of REEs.

• American Resources Corp., through its ReElement Technologies subsidiary, is developing its proprietary ligand assisted displacement (LAD) chromatography REE separation technology. This method allows scalable production volumes to process multiple feedstocks, likely including scandium.

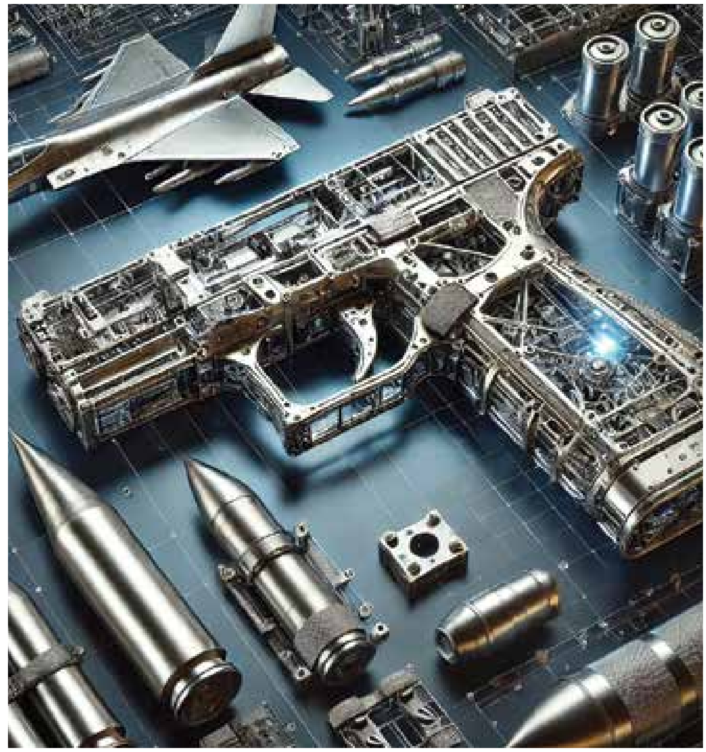


IMAGE GENERATED USING DALL-E BY OPENAI

Scandium-aluminum alloys play a critical role in high-tech military applications, including lightweight pistol frames and aerospace components.

• US Critical Materials Corp. is collaborating with Idaho National Laboratory (INL) to develop advanced separation methods for rare earth elements. This collaboration focuses on creating environmentally sound techniques to extract rare earths and critical minerals from carbonatite ores at its Sheep Creek project in Montana, which includes high-grade rare earths and scandium, aiming to contribute to a stable supply of critical minerals.

• Rare Earth Salts Separations and Refining LLC has developed its proprietary electrochemical process for high-purity separation and refining of rare earth elements from various feedstocks, including both ore-based and recycled materials. The company's environmentally friendly technology at its Nebraska facility focuses on producing critical rare earth oxides like neodymium, praseodymium, and terbium and will most likely include scandium.

• Phoenix Tailings, Inc., is operating the first rare earth metal refinery in the U.S., using proprietary processes to produce elements like neodymium and dysprosium with zero toxic byproducts and zero direct carbon emissions. This technology potentially includes scandium recovery, contributing to a sustainable domestic supply chain for critical minerals.

The expansion of scandium production in North America marks a significant step toward securing a stable supply of this critical mineral. By leveraging innovative technologies and strategic collaborations, companies across the continent are not only addressing current demand but also preparing for future needs.

These efforts ensure that North America can reduce its reliance on imports, mitigate geopolitical risks, and support high-tech and defense industries with future reliable sources of scandium. As these projects continue to develop, the United States has begun the shift for one commodity out of reliance and into independence.


Titanium's versatility shines in many consumer products such as milk, cheese, paper, and paint, but it's also used to give the brilliance and a silvery color to fireworks.

WIKIMEDIA COMMONS

# Critical titanium is on our doorstep

## Reliance on imports for this white metal could darken days

By A.J. ROAN

DATA MINE NORTH

**WHEN PEOPLE SEE SOMETHING** pristine white, they often think of it as pure or clean – this imagery is plastered everywhere, from unblemished lab coats to sterilized hospitals. Yet, it may be surprising to know that the rich whiteness seen in many consumer products actually comes from a critical metal, titanium.

From the whiteness of milk to the foundation used in makeup, if it is used to lighten or brighten, it most likely contains titanium.

According to the United States Geological Survey's Mineral Commodity Summaries 2024, a significant portion – an estimated 90% -- of the titanium mined each year is used to impart a stark whiteness to a wide variety of consumer goods we use every day.

"Titanium is different than most other metallic elements in that it is mined primarily to satisfy demands for a chemical product – titanium dioxide for pigment – rather than for the metal itself," the U.S. Geological Survey penned in a 2018 report on the luminous metal.

Despite its widespread use in consumer products, the importance of titanium extends far beyond just its whitening properties. This metal also plays a crucial role in various high-tech and strategic applications that stress its classification as a critical mineral.

## Titanium's critical role

Titanium's unique properties, such as a high strength-to-weight ratio, corrosion resistance, biocompatibility, and high-temperature stability, make it indispensable in multiple high-tech and strategic applications.

The aerospace industry heavily relies on titanium for aircraft structures and engines. The metal's intrinsic functions enable the production of aircraft that are both lightweight and strong, significantly improving fuel efficiency and overall performance.

In the defense sector, titanium is crucial for manufacturing similarly lightweight, strong, and corrosion-resistant components for military aircraft, naval vessels, missiles, and armor plating. This durable metal enhances the performance and longevity of basically all military equipment, making it a strategic material for national security.

Furthermore, titanium is vital in the energy sector, particularly in power generation, where its resistance to corrosion and ability to withstand high temperatures are essential for constructing power plants, offshore oil rigs, and pipelines.

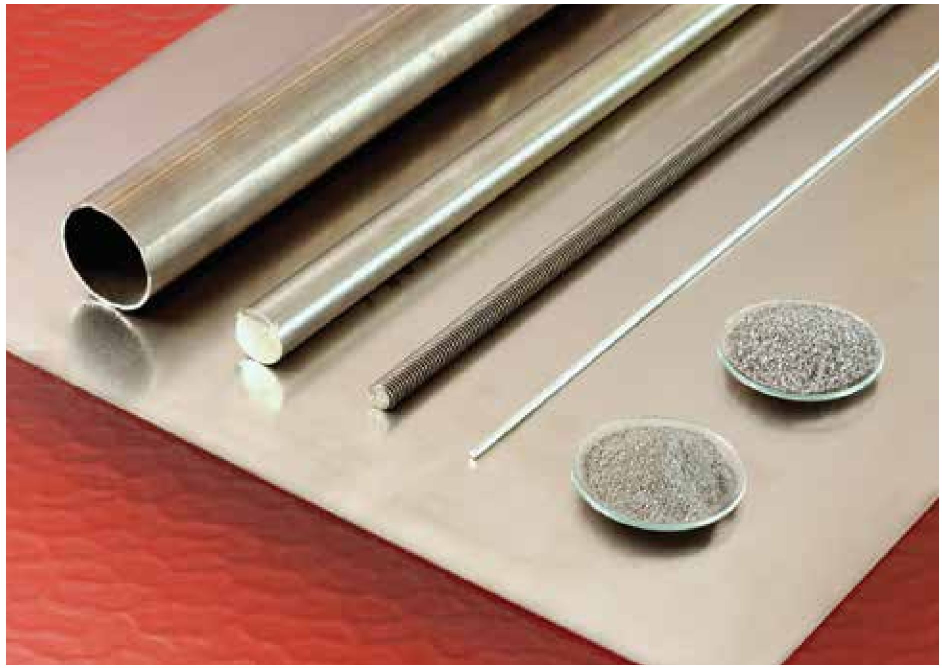
The durable metal's biocompatibility also makes it a preferred material for medical implants, such as joint replacements and dental fixtures.

To appreciate titanium's critical role, it is essential to understand its journey from raw mineral to the versatile material used across various industries.

## Not just a metal

While most immediately think of solid titanium in high-performance sports equipment or large armor plating, it is actually its powdered form, known as sponge titanium, that comprises the basis of the entire titanium industry.

Sponge titanium, used to produce titanium ingots, is transformed into slab, billet, pipe, bar, plate, sheet, and other mill products. This highly volatile form of pure titanium is also used to create the beautiful flashes of white light in fireworks.



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Titanium isused in many industrial applications like plates, tubes, rods, and powder.

Titanium dioxide (TiO2) is what delivers exceptional whiteness to a wide variety of household goods and foods. It has three qualities that make it ideal for creating whiter whites – it is white, safe for human consumption, and scatters light extremely well.

"Titanium dioxide has properties for whiteness, opacity, and chemical inertness that make it especially suitable for use as a pigment to impart a durable white color to paints, paper, plastic, sunscreen, toothpaste, and wallboard," the USGS wrote in its 2018 titanium report.

Most high-quality white paints available today contain "titanium white," a pigment made from titanium dioxide. In addition to imparting a reflectiveness and whiteness that makes rooms appear brighter, titanium dioxide increases paint's opacity, assisting in the "one-coat cover" touted by many manufacturers.

It is also used to make foods such as skim milk and cottage cheese whiter and creamier looking, and even to enhance the whiteness of paper.

There are very few replacements for titanium dioxide when it comes to pigments. Lead, once the ingredient of choice for white paint for nearly 2,000 years, has similar whitening qualities but is seldom used today because of its toxicity.

According to the USGS, more than 95% of titanium mineral concentrates in 2023 were consumed by domestic pigment producers.

Because it is used in such a wide variety of products, most U.S. consumers use a product containing titanium dioxide every day. However, the production and supply of titanium face significant challenges, impacting its availability and cost. Even with the high demand for titanium dioxide in consumer products and its importance in strategic applications, domestic titanium production in the United States has faced a downturn.

## Current landscape

According to USGS, titanium sponge metal was produced by only one operation in the U.S. last year.

This facility, operated by ATI Titanium LLC (a subsidiary of Allegheny Technologies Inc.) in Salt Lake City, Utah, has an estimated capacity of 500 tons per year and produces titanium that is further refined for use in electronics.

To give perspective, 500 tons of titanium sponge is roughly enough to manufacture the components for around 50 Boeing 787 Dreamliner aircraft, which each use approximately 10 tons of titanium.

However, the U.S. requires much more titanium annually, with estimated consumption around 40,000 tons, primarily for aerospace, defense, and industrial applications. In 2023 alone, the U.S. imported approximately 42,000 tons of titanium sponge to meet this demand, highlighting the significant reliance on foreign sources despite the high domestic need.


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**Rutile, a titanium-rich mineral, is essential for producing titanium dioxide, widely used in paints, plastics, and paper.**

At one point, two other facilities held a combined capacity of roughly 23,500 tons, enough to support more than half of the country's needs, but these facilities have since been in an idled status since 2016 and 2020, respectively.

The idling of these facilities, operated by TIMET (Titanium Metals Corporation) in Henderson, Nevada, and another in Rowley, Utah, by ATI Titanium, reflects the broader challenges faced by the domestic titanium industry, including fluctuating market conditions, high operational costs, and competition from foreign producers.

Recognizing the strategic importance of titanium, the U.S. government has taken steps to support the domestic industry. The Department of Defense, for example, has invested in several projects to ensure a reliable supply of titanium for military applications.

In recent years, the Defense Production Act Title III has been invoked to bolster domestic production of critical minerals, including titanium. This act provides funding for the development of new extraction and processing technologies and offers incentives for companies to expand their production capabilities.

Additionally, the National Defense Stockpile (NDS) program has been leveraged to maintain reserves of titanium sponge and other critical materials to mitigate supply chain disruptions.

While these initiatives are vital for addressing immediate supply chain vulnerabilities, long-term sustainability of the titanium supply also hinges on expanding domestic mining and production capabilities.

Efforts are underway to develop new titanium mines and production facilities across North America, aiming to reduce dependency on foreign sources and enhance the resilience of the supply chain.

## North America has titanium

From the western reaches of Alaska to the far east of Quebec in Canada, numerous locations of possible iron-rich deposits have been recorded, and where there is iron, there is a good chance there is the titanium mineral ilmenite. Additionally, the continental U.S., including regions in Florida, Georgia, and the Carolinas, hosts significant potential titanium stores, with heavy mineral sand deposits rich in titanium.

Titanium mining involves extracting the two primary titanium-bearing minerals ilmenite and rutile, which are typically found in heavy mineral sand deposits along coastlines or in hard rock deposits inland.

Mining operations generally use surface techniques like open-pit mining and dredging to excavate these minerals, which are then processed through gravity and magnetic separation methods to isolate the titanium minerals from other materials. The resulting

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**A puck of titanium sponge, the porous form of titanium created during the initial processing of the ilmenite or rutile, crucial for producing aerospace components and consumer goods.**

titanium concentrate is further refined to produce titanium dioxide or titanium sponge.

A 2016 report by the Alaska Division of Geological & Geophysical Surveys (DGGS) identified the potential for critical minerals-enriched marine placers approximately 100 miles northwest of Nome, at the western tip of the Seward Peninsula. The report concludes that sedimentary processes in the Bering Strait could create heavy-mineral placers containing titanium, zirconium, rare earth elements, and minor quantities of tin, tungsten, niobium, and precious metals.

"We conclude that sedimentary processes in the Bering Strait are present that could create heavy-mineral placers containing minerals with titanium, zirconium, and rare earth elements plus minor tin, tungsten, niobium, and precious metals," DGGS penned in its report.

The beaches of Nome are not the only Alaskan sites rich in titanium. The Kemuk prospect, located further south, is believed to contain a vast lode of titanium. Initial work by Humble Oil Company estimated that Kemuk holds 2.4 billion tons of material averaging 15 to 17% iron, alongside significant titanium and silicon deposits.

Millrock Resources Inc. revisited the Kemuk project in 2010 but focused less on titanium and iron and more on the potentially larger copper deposit indicated by the area's mineralization.

As for America's northern neighbor, Canada produced approximately 500,000 metric tons of titanium mineral concentrates in 2023. This represents a decrease from previous years, attributed to a decline in global demand and reduced production capacity in some mines. Despite this decline, Canada continues to play a significant role as a leading producer of titanium in North America, reflecting its importance in the global titanium supply chain.

Most of the titanium comes from Rio Tinto's Lac Tio mine near Havre-Saint-Pierre, Quebec, home to the largest ilmenite deposit in the world, positioning Canada to be well-equipped to circumvent national security issues and provide a North American supply chain.

Alongside its impressive titanium capability, Rio Tinto is also addressing scandium supply risks by extracting high-purity scandium from the waste streams of its aluminum production at the Sorel-Tracy plant in Quebec.

America's southeastern states of Florida and Georgia host rich coastal heavy mineral sand deposits that could help reduce foreign reliance.

In 2020, Chemours Titanium Technologies, one of the world's largest producers of titanium dioxide, invested approximately $86 million into a heavy mineral sand project in Georgia. This project is currently producing titanium, zircon, and rare earth elements, marking a significant step toward enhancing domestic titanium production.

Other players that are contributing to a future titanium supply include IperionX, which is developing the Titan Project in Tennessee and aims to become a leading supplier of low-carbon titanium.

While a potential ally in Greenland, Bluejay Mining plc, is advancing the Dundas Ilmenite Project, considered the one of the world's highest-grade ilmenite projects, could also become a vital source for North America.

With these developments, despite the current challenges, there are promising solutions on the horizon to mitigate the risk associated with this critical white metal. This progress highlights a step toward reducing reliance on foreign sources, although that still leaves 49 other critical minerals and metals to address.

This large storage facility in Brazil exemplifies the scale of tailings sites globally. Such sites represent unconventional sources of critical minerals that could bolster domestic supply.

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# Turning waste into wealth in novel ways

## Federal, private, academic, and public sectors collaborate to find critical minerals through unexpected methods

By A.J. ROAN
DATA MINE NORTH

**IN THE QUEST FOR A SUSTAINABLE** and secure supply of critical minerals, North America is turning to unconventional sources that promise to redefine the landscape of resource extraction.

As the drive toward a green economy intensifies, innovative methods are emerging to harvest essential minerals through atypical means. These efforts, bolstered by significant investments and collaborative ventures among allied nations, are paving the way for a resilient and environmentally responsible supply chain crucial for the technologies of tomorrow.

The importance of critical minerals in today's technology-driven world cannot be overstated. These essential elements, such as rare earths, lithium, cobalt, nickel, and many others, are integral to the production of clean energy technologies, advanced electronics, and military equipment, directly correlating to national defense in its most literal sense.

However, the traditional supply chains for these minerals are fraught with geopolitical risks, environmental concerns, and growing demand that outstrips supply. This has led to a heightened focus on alternative, unconventional sources that can provide a more stable and sustainable supply of critical minerals.

This approach is gaining attention due to its potential to diversify supply chains, mitigate the environmental impacts of traditional mining, provide incentives to clean up old sites, and – perhaps most critically – offer a workaround to the slow timelines associated with developing new conventional mines.

These sources include mining waste, coal ash, acid mine drainage, pyrite in shale, and byproducts of oil and gas production, to name a few.

Additionally, more exploratory sources such as deep-sea mining, marine-derived minerals, space mining, and phytomining are being investigated.

By tapping into these overlooked critical mineral sources, we can potentially reduce reliance on geopolitically sensitive regions, while simultaneously transforming environmental liabilities into economic opportunities. For instance, recovering rare earth elements from coal ash not only provides a new supply of these essential minerals but also helps in remediating long-standing environmental hazards.

The vast potential of unconventional sources remains largely untapped, presenting a unique opportunity to harness valuable minerals from materials previously deemed as waste. Among these sources, the waste from decades of mining stands out as particularly promising.

## The potential of waste

Mining waste, which consists of tailings and other residues left over from the extraction of metals like aluminum, copper, and gold, contains small amounts of critical minerals that were previously considered uneconomical to recover.

Recent advancements in extraction technologies have made it feasible to reclaim these valuable elements from what was once disregarded. This process not only provides a new supply of essential minerals but also addresses environmental concerns by reducing the need for new mining operations and mitigating the impact of existing waste sites.

A prime example of this potential can be found in the vast quantities of tailings stored at mining sites around the world.

Tailings, the remnants of crushed ore after the extraction of valuable metals, are often stored in large containment facilities. These facilities hold an estimated four billion tons of material globally, which were previously viewed as a byproduct with little to no value.

Another promising unconventional source could come from coal waste. The United States produces approximately 129 million tons of coal ash annually, a byproduct of coal combustion in power plants.

Over more than a century of coal usage, at least 5 billion tons of residual waste strewn over 1,000 storage sites have accumulated across the country, with this ash being rich in rare earth elements at concentrations comparable to some natural ore deposits.

To capitalize on this abundant resource, the U.S. Department of Energy (DOE) has launched several initiatives to fund the recovery of rare earth elements from coal waste. In recent years, DOE has invested significant resources into research and development projects aimed at transforming this environmental liability into an economic opportunity.

These efforts include funding for pilot projects and advanced extraction technologies designed to efficiently recover critical minerals from coal ash. By leveraging these innovative approaches, DOE aims to establish a sustainable domestic supply chain for


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**DOE is funding research into recovering critical minerals from oil and gas well wastewater while also creating clean water.**

these essential materials, reducing reliance on foreign imports and supporting the clean energy transition.

In addition to coal waste, acid mine drainage (AMD) presents another promising unconventional source of critical minerals.

This environmental hazard arises when sulfide minerals in exposed rock react with water and air, forming sulfuric acid that leaches metals from the surrounding material. In the United States, AMD affects over 12,000 miles of streams and pollutes significant volumes of surface and groundwater. Of note, this can occur either naturally or from mining activities.

One of the technologies that may help mitigate the residual damages from AMD comes out of Penn State University through an innovative two-stage treatment process with the ability to recover up to 70% of rare earth elements from AMD while significantly reducing its environmental impact.

By injecting carbon dioxide into the drainage, the process produces carbonatites that facilitate the extraction of rare earth elements. This method not only recovers valuable minerals but also restores polluted water bodies, showcasing the dual benefits of environmental remediation and resource recovery.

Byproducts of oil and gas production present another unconventional source of critical minerals. This includes the vast amounts of wastewater generated during the extraction and processing of fossil fuels. Traditionally considered a pollutant, this wastewater contains significant concentrations of valuable minerals such as lithium, cobalt, and rare earth elements.

Similarly, recent investigations into shale formations have found them to contain significant lithium concentrations, particularly in pyrite minerals.

With the sword of Damocles hanging over the U.S. in the form of critical mineral shortages, innovation and necessity have driven efforts toward multiple facets to bolster supplies. This urgent need has spurred advancements in various areas, aiming to secure a stable and sustainable supply chain for these essential materials.

## Research vanguard

To address the looming shortages of critical minerals, a diverse array of research institutions, universities, and initiatives have risen to the challenge, developing cutting-edge technologies and innovative methods for resource extraction and processing.

These collaborative efforts span the United States, leveraging the expertise and capabilities of academic and industrial partners to create sustainable and resilient supply chains.

Among these pioneers, Missouri University of Science and Technology (Missouri S&T) exemplifies the forefront of this movement with its groundbreaking work in critical mineral and sustainable technology research.

Among their initiatives is the extraction of gallium and germanium from copper waste streams, supported by an $875,000 grant from Rio Tinto.

This innovative chemical dissolution and purification method transforms waste into valuable resources, offering new sources of critical minerals while reducing the environmental impact of traditional mining.

Additionally, Missouri S&T has secured nearly $2 million in research grants, enabling a wide range of projects focused on sustainable resource extraction and advanced manufacturing.

Their collaborations also include a $7 million project with the U.S. Department of Defense (DOD) to develop a demonstration-scale hydrometallurgical plant for cobalt and nickel separation and partnerships with US Strategic Metals, LLC to advance lithium-ion battery precursor materials.

Continuing the trend of innovative research in critical mineral recovery, the University of Utah is also making notable advancements.

University of Utah researchers have focused on extracting rare earth elements (REEs) from unconventional sources, including coal and shale formations. Identifying high concentrations of REEs in coal-adjacent formations within the Uinta coal belt of Colorado and Utah, by analyzing samples from active and historic mines, the team has demonstrated the potential for these secondary resource streams to transform waste into valuable supplies of critical minerals.

These initiatives, part of DOE's Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) project, are supported by substantial funding aimed at producing high-purity rare earth oxides, salts, metals, and other critical minerals from coal byproducts using advanced separation technologies.

This work not only enhances the domestic supply of essential minerals but also contributes to environmental remediation by leveraging waste materials.

Expanding beyond academic research, federal initiatives and private-public partnerships are also playing a crucial role in this endeavor.

## The benefits of capitalization

DOE's CORE-CM project is focused on developing methods for extracting rare earth elements and other critical minerals from coal, coal byproducts, and other unconventional sources.

This program has also allocated substantial funding to support advanced research and pilot projects, committing millions to various institutions and private companies to advance this field.

For instance, some of the companies that have received grant money include Tetra Tech, Inc., a consulting and engineering services firm awarded $1.5 million to develop advanced separation technologies for coal byproducts, and Winner Water Services, Inc., which focuses on water treatment solutions, also secured $1.5 million to create technologies for recovering REEs from coal ash, preparing the ash for use in the concrete market.

To further bolster the development of unconventional sources of critical minerals, the U.S. DOD has leveraged the Defense Production Act (DPA), a law that grants the President powers to prioritize and allocate resources for national defense.

Through the DPA, the DOD has provided substantial support to domestic projects, including $7 million awarded to Doe Run Resources Corp. for developing a hydrometallurgical plant for cobalt and nickel separation in Missouri.

Beyond government initiatives, private sector companies and public-private partnerships are playing a crucial role in advancing the field of unconventional critical mineral sources –collaborations that are essential in driving technological advancements and ensuring a steady domestic supply of these vital materials.

One of the key players in this arena is US Strategic Metals, which has partnered with Missouri S&T to advance research on precursor cathode active material (pCAM) for lithium-ion batteries.

This collaboration aims to leverage Missouri's natural resources and the university's cutting-edge facilities to enhance domestic production of battery materials. Under the agreement, Strategic Metals provides training for Missouri S&T personnel and students on the use of state-of-the-art extraction facilities, facilitating the development of efficient recovery processes for critical elements such as cobalt and nickel.

Ramaco Resources Ltd. has been working on extracting rare earth elements from the Brook mine in Wyoming. The company, in partnership with the DOE's National Energy Technology Laboratory (NETL), discovered significant deposits of magnetic rare earth elements in coal seams.

This project not only provides a new source of critical minerals but also repurposes dormant coal mines, contributing to environmental remediation and economic revitalization in coal communities.

Another notable example is Phoenix Tailings Inc., a company dedicated to recovering critical minerals from mining byproducts, particularly tailings.

Using advanced metallurgical processes, Phoenix Tailings extracts valuable elements such as cobalt, nickel, and rare earths from the leftover slurry from mining operations. This approach not only provides a new source of these essential minerals but also mitigates the environmental impact associated with traditional mining waste.

Although closely related to mining, recent developments in seeking unconventional sources have led companies to explore alternative deposits, such as clay. One such company is ioneer Ltd., which focuses on extracting lithium and boron from lithium clay at their Rhyolite Ridge project in Nevada.

Partnering with Korea-based EcoPro Innovation, ioneer aims to commercialize this lithium clay into refined materials for the North American EV battery supply chain. EcoPro plans to build a commercial-scale refining plant to process the clay, significantly boosting domestic lithium production and sharing profits with ioneer.

While the list of companies, partnerships, programs, initiatives and the like could go on, all this highlights a great, ongoing movement to establish unconventional sources as future conventional ones. This endeavor not only works toward securing a stable supply of these resources, it can also be done here at home and in ways that benefit more than just economically.

An Allseas-designed deep-sea nodule collector undergoes trials.
THE METALS COMPANY

# The changing tides of deep-sea mining

## Incalculable riches, delicate ecosystem, and the green energy future

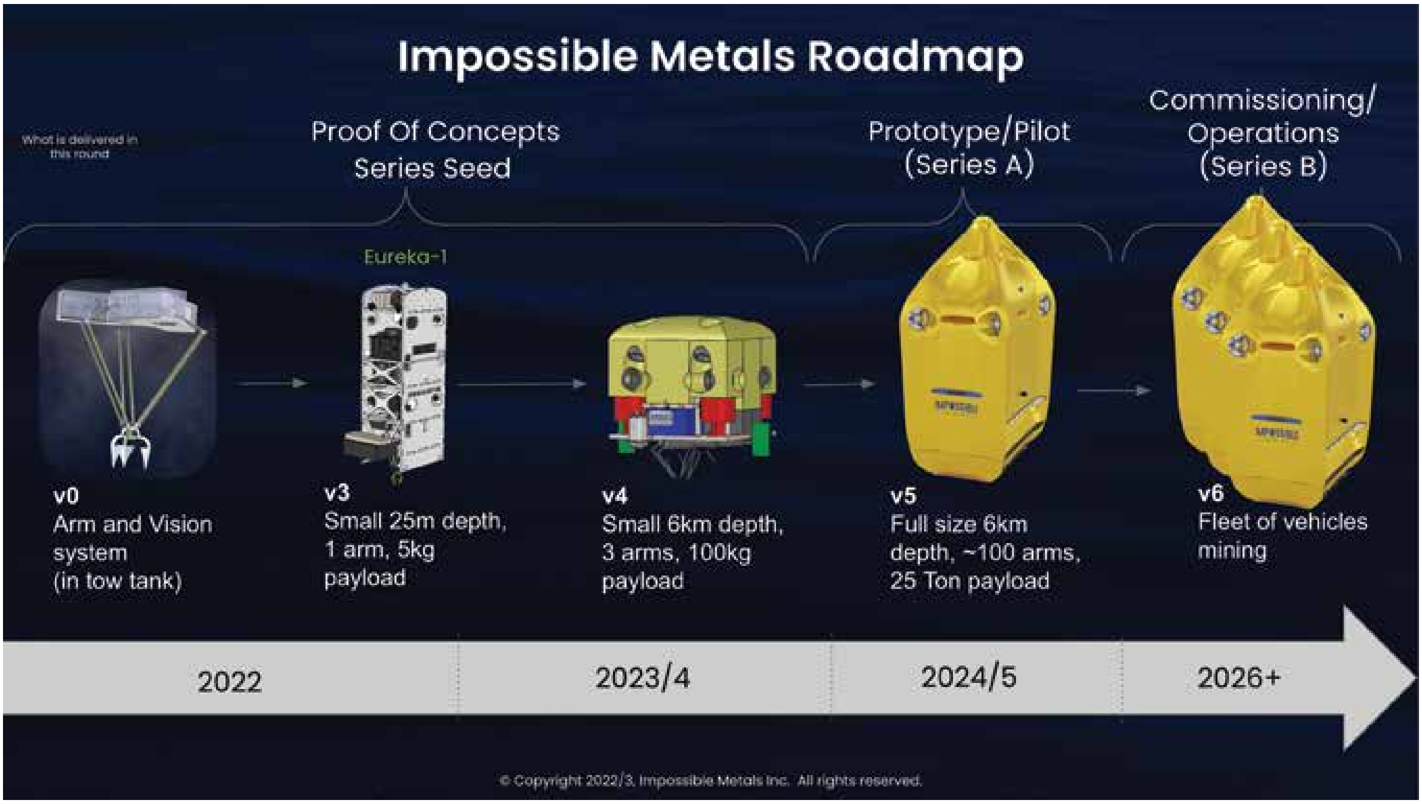
By K. WARNER
DATA MINE NORTH

**DEEP-SEA MINING HAS CAPTURED** the world's attention as a uniquely promising source of the metals needed for lithium-ion batteries powering the green energy future and a bitterly controversial topic of debate.

Undersea deposits contain quantities of nickel, cobalt, copper, and manganese sufficient to replace every U.S. car on the road today with an electric vehicle. They also host some of the most diverse, little-known, and least-understood ecosystems.

This young industry is up against the global warming time crunch, expensive engineering challenges, and projected mineral scarcities that have much more to do with how green a resource is than how much is available.

Energy transition industries in every nation are working to be able to access the material they need quickly and cheaply enough, all while laboring under dire cautions not to make the same




IMPOSSIBLE METALS

mistakes that got us here.

Soon, it will be time to decide what to do with the greatest untapped resource on Earth, nestled deep in the so-called lungs of the planet.

## Batteries in a rock

Much of the conventional terrestrial reserves of nickel, cobalt, and manganese are found in Russia, Indonesia, the Congo and South Africa, countries with insufficient protections for biodiversity, worker rights and population welfare.

The oceans of the world have three types of ore deposits – seafloor massive sulfides, polymetallic nodules, and cobalt crusts – with nodules dominating interest over the last couple of years.

- Cobalt-rich ferromanganese crusts occur between 400 and 5,000 meters in areas of significant volcanic activity. The crusts grow on hard-rock substrates of volcanic origin through precipitation of dissolved metals. Similar in general composition to polymetallic nodules, they are attracting investment in exploration for cobalt, platinum, rare earth elements, nickel, and manganese.
- Seafloor massive sulfides are hydrothermal mineral deposits (also known as black smokers) that form on and below the ocean floor. They are made up of sulfur compounds and base metals like copper, zinc, lead, iron, silver, and gold. More than 350 sites of high-temperature hydrothermal vents and about two hundred sites of significant massive sulfide accumulation have been identified since the 1970s.
- Polymetallic nodules contain layers of iron and manganese around a small core of ocean detritus, layered with a veritable wish list of critical minerals tailor-made for battery chemistry needs, including nickel, copper and cobalt, rare earth elements, and even lithium. The nodules are formed by the slow accretion of minerals from seawater, less than four millimeters per million years.

The abyssal plains where nodules develop are the relatively flat regions that cover more than 50% of the seafloor between 3,000 and 6,000 meters (1.86 to 3.72 miles) down, where polymetallic nodules reside under dark, corrosively salty, equipment-crushing pressures.

So far, their desirability and economic value outweigh the expense of their retrieval. Unlike ores on land, which rarely have metal yields above 20% and are often less than 2%, seabed nodules are 99% usable minerals and aren't toxic to excavate.

Viable deposits of nodules have been identified in the north-central Pacific Ocean, the Peruvian basin in the southeast Pacific, and the Indian Ocean – the most promising being the Clarion Clipperton Zone (CCZ), an abyssal plain in the equatorial Pacific Ocean between Central America and Hawaii, roughly half the size of Canada and potentially containing more nickel, manganese and cobalt than all the combined deposits on land to date.

## The lawless sea

Environmental concerns and vague legislation surrounding deep-sea mining have created a rift that has divided governments, electronics giants, vehicle manufacturers, banks, and scientists across unexpected lines.

So far, 31 contracts to explore and reserve specific zones of international waters for potential commercial mining have been granted by the International Seabed Authority (ISA), an autonomous UN-affiliated regulatory body with a history of ponderous deliberations.

After sufficient exploration, resource definition, and environmental baseline studies, commercial mining itself will require additional permitting. With mining contractors chomping at the bit, the ISA has slowly been developing its body of regulations in that regard, coined the Mining Code.

According to an article for the World Resources Institute, "after failing to reach an agreement in July 2023, the ISA now has until 2025 to finalize regulations that will dictate whether and how countries could pursue deep-sea mining in international waters."

Meanwhile, 19 of the ISA contracts issued so far permit the exploration of polymetallic nodules, seventeen of which are in the CCZ. Another seven contracts are for exploring polymetallic sulfides in the South West Indian, Central Indian, and Mid-Atlantic Ridges, and five are for cobalt-rich ferromanganese crusts, all in the Western Pacific Ocean. Each contractor is required to submit a contingency plan to respond effectively to incidents arising from its activities in the exploration area.

### Hurry up and wait

A surprising assortment of financial institutions, big industry names, and countries have joined in petitioning for a moratorium on deep-sea mining or distanced themselves by excluding subsea metals from procurement and investment policies.

Notable supporters of a pause include:

• Automotive manufacturers Ford, BMW, Volkswagen, and Volvo

• European Parliament, Germany, Chile, Spain, and several Pacific Island nations

• Tech giants Samsung SDI, Philips, Microsoft, and Google.

Tesla and General Motors have stayed out of it, remaining uncommitted. China, Japan, Russia, India, Mexico, Nauru, Norway, and the United Kingdom are some of the countries that support fast-tracking licenses for mining and are eager to get on with the long and complicated process of commercial extraction.

There are two types of DSM jurisdictions: A nation's Exclusive Economic Zone (EEZ) and the high seas, also known as Areas Beyond National Jurisdiction (ABNJ).

The ISA regulates the mining of ABNJ, which is roughly 58% of the planet's oceans. The 150 nations with EEZs are responsible for regulating the remaining 42% of the ocean, with over a dozen of them working to finalize their own DSM standards.

While international policy set by the ISA can set the tone for mining regulations, each of the 150 EEZ jurisdictions will establish its own policies.

India, Norway, and Japan have already begun exploring their EEZs.

• India's Ministry of Earth Sciences launched the five-year Deep Ocean Mission in 2021, an initiative to undertake deep ocean exploration focused on India's EEZs and continental shelf. The Matsya 6000 project vehicle is designed to get three personnel down 6,000 meters to the seabed to retrieve a sampling of polymetallic nodules.


DÖRKDESIGN

**The discovery of "dark oxygen" theoretically being generated by electrolysis of metals in polymetallic nodules might be playing an unexpected role in the abyssal ecosystem.**

• Norway's EEZ boasts massive sulfide deposits near inactive hydrothermal vents, not nodules. If all goes to plan, contractor permits for exploration should be obtainable by 2025, requiring data collection for up to eight years before starting to mine in 2032, assuming legislation to approve mining is approved.

• Analysis of Japan's nodule samples from this year indicates a rich resource, with the amount of cobalt alone estimated at about 610,000 tons, equivalent to 75 years of Japan's annual consumption, and nickel at some 740,000 tons, worth about 11 years. Researchers at the University of Tokyo and the Nippon Foundation announced further plans to launch a large-scale test project to harvest the nodules as early as next year, followed by a joint venture in 2026 with multiple Japanese companies for processing.

### Testing, testing

Technically, no one is mining yet – while more research is done to better understand what's at stake, data collection via exploration is the inevitable next step. In various countries' EEZs, commercial mining will likely be attempted in this decade, and the data will flow.

The seafloor hosts millions of square kilometers of metal ores. The nodules alone (with concentrations depending on location) demonstrably hold at least 38 different elements on the periodic table – fields of these knobby little potato-sized rocks containing everything needed for a smooth energy transition.

Their composition is so fortuitous Gerard Barron, CEO of The Metals Company (TMC), nicknamed them "batteries in a rock," and it stuck.

Through its subsidiaries, TMC holds exploration and commercial rights to three polymetallic nodule areas in the CCZ from the ISA. During pilot-scale nodule processing this year, TMC and SGS Canada produced the world's first nickel sulfate from nodules, verifying the resource's promise.

"The data collected will inform further engineering decisions to move this towards commercial scale, and TMC continues to expect that initial production will begin with a capital-light approach by leveraging the existing processing facilities of strategic partners, such as PAMCO. With the commencement of this new industry now being seen as imminent by countries and companies alike, this represents not just a major achievement for TMC but for the entire deep-seafloor minerals industry," said TMC Head of Onshore Development Jeffrey Donald.

Though they've been studied since at least the 1870s, the nodules' appeal for the green energy transition has inspired a new generation of investors and miners.

Author John L. Mero first raised the idea of marine mining in a 1960 article in Scientific American and later a book, The Mineral Resources of the Sea, which roused interest in marine mining. At the time, retrieval technology was unequal to the task.

Mero emphasized that marine mining could replace the great despoiler: on-land mineral extraction.

Barron is an outspoken advocate of this idea today, who has strongly influenced the forward momentum of investment and public awareness and taken swift and thorough advantage of exploration permissions.

In 2022, TMC's subsidiary Nauru Ocean Resources Inc. (NORI) and offshore partner Allseas successfully concluded the first integrated system test in the CCZ, driving a pilot collector vehicle across over 50 miles of the seafloor and bringing over 3,000 metric tons up a 2.7-mile riser system to the surface production vessel, Hidden Gem.

### Two sides of the same coin

The seas outside national jurisdictions have been the subject of a tug-of-war between commercial interests and environmentalists since the 1970s. While the worldwide debate for and against harvesting critical minerals from international waters rages on, exploration is already underway.

In the headlines are two camps, staunchly polarized opponents that remain unmovable in their ideals.

The first advocates for marine mining with tried-and-true methods of extraction with assurances that it is the lesser of two evils – it's better than mining on land. Proponents assert that extracting minerals from the deep sea would have fewer impacts on nature and human lives than land-based mining does.

The second team insists too little is known about the ocean and the role it plays in the health of the planet, the risk is too great, and what we don't know might come back to bite us – an indefinite moratorium is best.

On balance, there is a third, overlooked faction of practical visionaries and engineers that will not be swayed by the oversimplification of a complex issue. Both positions have good points, and innovators should diligently work to meet in the middle with solutions.

While TMC's online progress reports and charismatic CEO dominate the headlines, a lesser-known sea mining enterprise sailed onto TIME's inaugural list of 250 companies, reducing environmental impact this year.

That company, based out of California, is Impossible Metals – and its co-founders Renee Grogan and Oliver Gunasekara, tackling the problem with a common-sense approach that reflects the views of the deep-sea mining centrists – polymetallic nodules can be a saving grace in the planet's time of need, and the oceans deserve an extraction technology that creates the least disturbance possible.

"We are accelerating clean energy by harvesting critical battery metals from the seabed, while protecting the environment. We are building underwater robotic vehicles for harvesting, and have invented a new form of mineral processing that uses bacteria metal respiration," reads the company profile.

TMC

Polymetallic nodules have high concentrations of cobalt, manganese, and nickel.

Its innovative approach includes autonomous underwater vehicles (AUVs) equipped with a robotic collection system that hovers above the seafloor, using "pick and place" manipulator technology to harvest nodules individually, minimizing disturbance of the sediment and seafloor ecosystems. Image-sensing technology is designed to identify flora and fauna present and leave those nodules untouched.

While the commonly used decades-old dredging technology has high capital and operating expenditures, taking an average of nine years of payback time, Impossible Metals says its autonomous fleet can pay back capital in a third of the time, at the same rate of production.

A robotic fleet with no significant plume, no return water, no impact to sediment, low light, and noise pollution.

Rather than putting a new coat of paint on dredging – be it by bucket system, hydraulic suction, or mechanical – the practice of nodule harvesting needs a fresh-eyed engineering redesign.

But as Gunasekara points out, "It is difficult to course correct when you've invested millions of dollars in your technology."

### Other companies of note

Adepth is a Norwegian license holder that has developed a number of technical solutions around surveying and data analysis for deep-sea mining. They are well-positioned for operations in the Norwegian EEZ and contracting their services to operators in other jurisdictions.

Cobalt Seabed Resources holds licenses in the Cook Islands EEZ, with licenses of high abundance and grade. The Cook Islands was the first nation to award exploration licenses, and both the government and local population are highly supportive of deep-sea mining.

China Ocean Mineral Resources Research and Development Association is a state-backed entity that holds a wide variety of subsea mineral licenses in international waters. They are well-backed, have strong government support, and a variety of license options. Beijing is positioning itself for success in the industry by ramping up investment and shaping negotiations.

Global Sea Mineral Resources is a subsidiary of the Belgian dredging group DEME, with some excellent license areas secured in the CCZ, a talented and experienced team running their baseline surveying and collector testing, and they are backed by a large, experienced offshore operator.

Loke came onto the scene in 2019 via a joint venture with TechnipFMC, Wilhelmsen and Kongsberg. They are a Norwegian company that is well positioned to secure licenses in the EEZ, but crucially, they acquired licenses in the Clarion-Clipperton Zone in 2023.

A quiet player in the industry, Moana Minerals holds some of the highest-quality licenses in the Cook Islands EEZ. Their team is very experienced, with combined military, offshore diamond mining, and offshore oil and gas backgrounds. Their chairman, John Halkyard, worked for the Kennecott Consortium in the 1970s and is one of the few current miners to have previously run deep-sea operations.

Scandinavian Ocean Minerals has plans to harvest from a surprising density of polymetallic nodules in the Bothnian Bay and the Baltic Sea between Sweden and Finland. The Swedish Ministry of Climate and Enterprise granted Scandinavian Ocean Minerals an exploration permit in July 2023.

Transocean is the world's largest operator of deepwater drilling platforms. The American company has made several important joint ventures with key partners, including an investment in Global Sea Mineral Resources.

With countries and companies around the globe looking to the bottom of the oceans for the metals needed to build the clean energy future, and scientists and conservationists concerned that extracting these deepwater resources could create more problems than they solve, the deep-sea mining tides are sure to continue to ebb and flow.


As a critical battery metals with environmental challenges, ranging from excessive water use to high greenhouse gas emissions, nickel has a complex relationship with the energy transition.
SHUTTERSTOCK

# Nickel: bringing green tech home

## Nickel's continuing journey toward clean processes and domestic production

By K. WARNER
DATA MINE NORTH

**NICKEL HAS A COMPLEX** relationship with the ongoing energy transition: It provides relatively inexpensive energy density and greater capacity to the lithium-ion batteries powering electric vehicles and storing clean energy, helping to lower the cost of each kilowatt hour. Its properties have been instrumental in untethering the portable electronics we use every day and incorporating clean power produced by renewables such as wind and solar to industry and grids formerly reliant on fossil fuels.

Its drawbacks involve a long history of unsustainable extraction and refining processes.

Nickel's versatility has placed the silvery metal into nearly every aspect of daily life – from spoons to surgical tools, automobiles to bridges, jet engines to construction equipment, and construction itself. It has many advantages, including good catalytic activity, high mechanical strength, excellent corrosion resistance and thermal conductivity.

### Transition tech

Today, nickel also plays an increasingly significant role in the energy transition. In the coming years, expect its use to grow exponentially – an increase of around 65% by the end of the decade. Global demand for nickel is predicted to steadily grow to 3.47 million tons in 2024 from 3.2 million in 2023 due to its usage in fuel storage and EV batteries.

Nickel's leading use today is in steelmaking, the backbone of global industry, which accounts for about two million metric tons. The battery industry follows with 465,000 metric tons.

According to the United States Global Survey (USGS), "the leading uses for primary nickel are alloys and steels, electroplating, and other uses including catalysts and chemicals. Stainless and alloy steel and nickel-containing alloys typically account for more than 85% of domestic consumption."

Nickel became widely used in rechargeable batteries, most commonly in nickel-cadmium (NiCd) and in the longer-lasting nickel-metal-hydride (NiMH), which came to the fore in the 1980s, introducing the world to smaller, high-powered, and longer-lasting portable devices.

The mid-90s saw the first significant use of NiMH batteries in hybrid vehicles like the Toyota Prius. Around the same time, commercial lithium-ion batteries for personal electronics burst onto the scene.

To keep up with government- and industry-proposed climate goal trajectories, the total mineral requirements by clean energy technologies are forecast to rise significantly over the next decade. (The EV and energy storage markets are only the beginning – nickel is needed for high-performance alloys used in constructing massive wind turbines and solar panels as well.)

"The biggest source of demand variance comes from the uncertainty surrounding announced and expected climate ambitions," the International Energy Agency (IEA) inked in a report on critical minerals. "Governments have a key role to play in reducing uncertainty by sending strong and consistent signals about their climate ambitions and implementing specific policies to fulfill these long-term goals."

Batteries are set to overtake stainless steel by 2040 as the largest end-user of nickel.

The U.S.-proposed growth of hydrogen hubs, fuel and fuel cells also boosts nickel requirements for use in catalysts and electrolyzers; geothermal power is also a major employer of nickel.

"Of the total mineral demand from all low-carbon power sources in 2040, geothermal accounts for 80% of nickel demand, nearly half of the total chromium and molybdenum demand, and 40% of titanium demand," the IEA wrote.

According to a meta-analysis by the International Energy Forum (IEF), annual needs for nickel driven by energy transition technologies combined could increase from less than one million metric tons today to two to five million metric tons by 2050.

AI-GENERATED WITH ADOBE FIREFLY

**America sports only one nickel mine and no refinery – raw nickel concentrate is sent to a Canadian smelter, with most of the final product sent back to the United States primarily as stainless steel, adding to the overall carbon footprint.**

## Imports vs. domestic supply

America relies on imports for more than half of its annual nickel consumption, with about 45% supplied from Canada and the balance is covered mainly by Australia, Norway, and Finland. Canadian nickel imports to the U.S. have increased over the years from $527 million in 2022 to $1.04 billion in 2024.

Last year, the U.S. produced an estimated 17,000 metric tons of nickel, all from the Eagle Mine in Michigan (the only U.S. nickel mine in operation). This was a decrease of more than 10,000 metric tons from 2015. Global overproduction has kept prices low – sometimes too low to justify production.

Global surplus and low prices can make it difficult for mining companies to raise money for projects and stay profitable – leading to reduced output, suspended operations, or even abandoned projects – something the North American nickel industry can't afford, especially as the cost of going green (updating existing mines or opening new state-of-the-art projects) runs higher.

Streamlined permitting and government incentives geared to encouraging greener projects and byproduct and coproduct development at existing mines have been necessary to encourage a stable domestic product.

The last two years have shown a sea-change in international relations; the U.S. imported $19 million in refined nickel from Russia in 2023, a 93% drop from 2022.

A U.S. International Trade Commission briefing declared, "In response to Russia's invasion of Ukraine in February 2022, many trade partners that imported nickel from Russia, including many in Europe and the United States, imposed sanctions and trade actions that curtailed imports of nickel from Russia. This situation could present potential supply challenges as nickel demand is anticipated to grow in the future."

Russia and China are both categorized as Foreign Entities of Concern by the Department of the Treasury, potentially making batteries with nickel earmarked from those countries ineligible for credits under the Inflation Reduction Act. In coordination with the UK, the Treasury prohibited aluminum, copper, and nickel imports of Russian origin produced on or after April 13, 2024, and limited their usage on global metal exchanges.

Despite a contentious trade relationship, the U.S. imports from China. However, due to strong political differences, unsustainable practices, poor environmental, social and governance (ESG) ratings, and a history of seemingly dirty market dealings, North America and its allies are seeking ways to reduce extensive dependence on China's monopoly on critical minerals, including nickel products.

In the past decade, Indonesia's oil and gas production has diminished, and the country's nickel production has exploded onto the international scene. Now representing nearly half of global production, it has also been a problematic import, bought up by China and snubbed by the U.S. due to the country's reported deforestation, extensive pollution, and hazardous working conditions.

The flood of Indonesian nickel, most of which requires an energy-intensive process powered by coal to produce, has forced several western mining companies that produce cleaner nickel but at higher financial costs to shut down operations.

However, in its most recent impact report, Tesla Inc. (which snapped up a five-year, $5 billion nickel deal with the country early on) maintains that the transition to EVs "will not be possible by only relying on non-Indonesian nickel."

## Nickel in defense

Given inadequate mineral production at home, the U.S. – which also holds limited mineral inventories in its National Defense Stockpile – and other NATO militaries currently rely on vulnerable supply chains, driving the reality home that domestic mining and secure, friendly international imports are needed.

A shortage of green nickel would hurt far-reaching goals and economics in both the transportation and energy sectors, but when it comes to defense, the armed forces don't have the luxury of being picky about means.

Nickel is also used in military steel products, armor plating for tanks, anti-aircraft firearms and warships, as well as bullets and primers for small arms ammunition. Private and defense aerospace industries are a leading consumer of nickel-based superalloys in turbines and jet engine components. Tungsten nickel-iron alloy can attenuate and redirect electromagnetic waves to protect sensitive electronics.

The U.S. military also uses a lot of batteries, both in portable electronics carried by soldiers and in an increasing number of electric vehicles being deployed.

The Department of Defense (DOD) invested $20.6 million in developing the North American nickel supply chain by nearly doubling Canada's Talon Metals nickel exploration budget in Minnesota and Michigan. The partnership has funded nearly half of Talon's 2024 exploration plan.

The DOD also awarded $7 million to The Doe Run Resources Corporation this year under the Defense Production Act Investment program to facilitate the creation of a demonstration-scale hydrometallurgical plant in Viburnum, Missouri, to separate cobalt and nickel.

## Recycling nickel from steel, batteries

North America is a leader in nickel recycling, developed early on by the stainless-steel industry, which recognized the inherent economy of recycling compared to the cost of mine development, with over half of the nickel in circulation being recycled.

SHUTTERSTOCK

Nickel's leading use continues to be for steelmaking. This backbone of global industry accounts for 65% of nickel consumption, or about 2 million metric tons per year.

"Most secondary nickel was in the form of nickel content of stainless-steel scrap. Nickel in alloyed form was recovered from the processing of nickel-containing waste. Most recycled nickel was used to produce new alloys and stainless steel," USGS penned in its Mineral Commodity Summaries 2023 report.

The U.S. also produces nickel as a byproduct of smelting and refining platinum-group-metal ores in Montana and historic mine tailings in Missouri.

Across the critical mineral mining space, waste is being reassessed as a secondary mineral resource, a way to supplement primary mining. Genuine closed-loop practices are being developed, unlocking local sources closer to where they are needed, increasing overall resource independence, and notably reducing costs and energy use.

The Department of Energy (DOE) continues to promote an expanded battery recycling industry, focused on developing more refined processes capable of recovering critical minerals (each with its own policy initiatives, including nickel) to make a circular economy possible.

DOE's Battery Manufacturing and Recycling Grants program has a $3 billion budget to ensure "a viable domestic manufacturing and recycling capability to support a North American battery supply chain."

While chemical leaching, smelting and pyrometallurgy are in use today, next-generation battery recycling will be more exacting and efficient. To smelt and recover a metric ton of metal generates up to 2 metric tons of carbon dioxide. Following that, only 40%-60% of nickel and cobalt are recovered. Base metals also require further processing and refining before they can be reused.

As an example, with the support of Canadian grants, RecycLiCo's proprietary closed-loop hydrometallurgical process produces no greenhouse gas emissions, no landfill waste and low energy consumption when recycling lithium-ion battery scrap to be upcycled as high purity, battery-ready materials.

## The winding road to sustainable mining

Nickel is one of the most technically complex metals to process and refine, with every operation uniquely dependent on the category of ore deposit – sulfide, oxide, or laterite – and influencing later steps down the value chain. The industry is tackling a multitude of hidden costs by way of environmental challenges ranging from excessive water use to pollution and high emissions.

The current challenge is to markedly increase supply while meeting a new standard of ESG requirements.

Michigan and the Midwest are rich in nickel concentrations, where U.S. mining projects have been struggling to break ground due to local resistance and federal mining restrictions.

Green nickel mining has had to contend with a negative history, bringing to light decades of unresolved "not in my backyard" sentiment, which globalization had previously avoided. U.S. projects are now being put through their paces of red tape, protests, and long permitting timelines.

But there is a growing desire for greener nickel, with companies and investors eager to uphold advancing standards, now more than ever. And it will take time and a marathon mentality to bring to market.

Ensuring nickel can be produced more sustainably requires new industrial practices and standardization. Transparency and tracking throughout the production cycle are key in confirming green nickel as using renewable energy instead of fossil fuels, reducing and treating waste, remediating water usage, and keeping miners safe.

JONATHANFILSKOV-PHOTOGRAPHY FOR ISTOCK

**Batteries are set to overtake stainless steel as the largest end-user of nickel – but that's only the tip of the iceberg – nickel is needed for high-performance alloys used in constructing wind turbines and solar panels as well.**

"Technological advances could reduce nickel's environmental impact. For instance, there is increased interest in high-pressure acid leaching for nickel, which offers a less energy-intensive alternative to traditional extraction techniques. Research into bioleaching – which uses microorganisms to extract metals from ore, or even from e-waste – could even negate the need for high temperatures entirely," IEF analysts noted.

Specialized companies like Australia-based Queensland Pacific Metals also aim to refine and process nickel for EV batteries in a sustainable manner – with General Motors, LG Energy Solutions, and POSCO as investment partners. Nickel laterite ore will be processed using a proprietary method with no requirement for a tailings dam.

## Key growth drivers

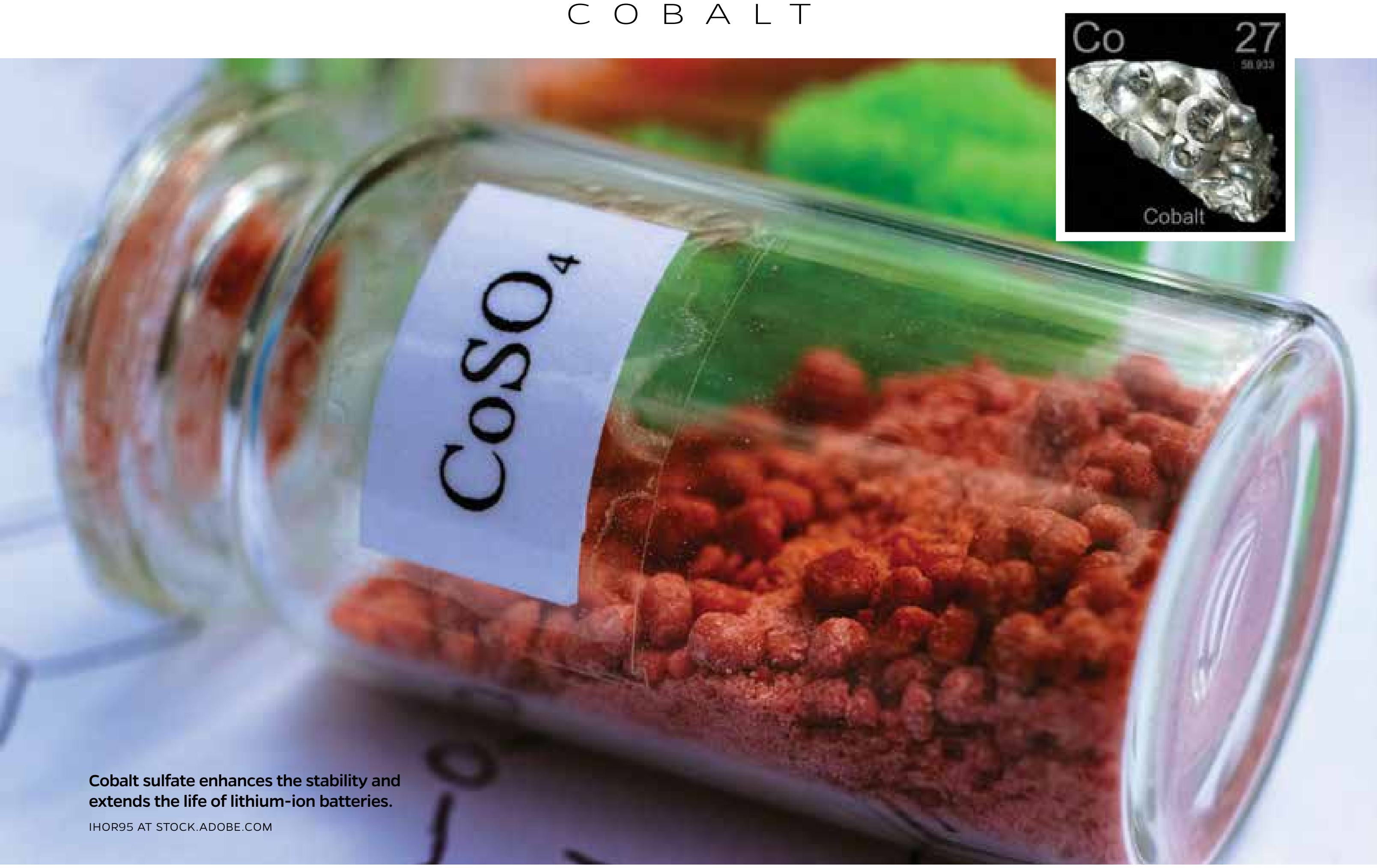
Innovative technological advancements are the revolutionizing force across the North American nickel market, from extraction to refining to recycling.

Innovations such as machine learning and automation are increasing mine safety and efficiency and improving performance while also enabling more sophisticated and effective recycling processes, driving overall costs down – a key factor in keeping mines in business and new projects inviting for investors.

The mining sector is also experiencing a rise in vertical integration – the expansion of a company into production stages normally handled by separate companies – upstream along critical minerals supply chains, with key players in manufacturing, retail, and transportation investing in anything from product offtake agreements to construction of neighboring refining and recycling hubs.

The development of more user-friendly recycling solutions is reducing the barrier to entry for consumers and companies alike. Accessibility, adaptability, and improved experiences bring a wider audience and increased adoption.

Government and private sustainability and collaboration initiatives are proving an increase in strategic partnerships and open data sharing with tech engineers, research institutions, and market leaders, enabling companies to leverage complementary strengths and accelerate sustainable innovation and commercialization.




**Cobalt sulfate enhances the stability and extends the life of lithium-ion batteries.**

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# The highs and lows of critical cobalt

## Will the controversial metal find its place in green tech?

**By K. WARNER**

DATA MINE NORTH

**ABOUT 30 YEARS AGO,** nobody thought much about cobalt.

Today, this metal, with myriads of uses, is one of those elements that gets dragged into the spotlight due to the role it plays in electric vehicle batteries, with critics citing the disparity between the environmental and social costs of producing cobalt and the green tech solutions this critical metal enables.

But we can't build a clean energy future without materials. How and where we get metals like cobalt in the greenest ways possible is the test of another renewable energy – human ingenuity.

Reinventing the way we power our world since the Industrial Revolution isn't fast or cheap. But it's getting easier.

Cobalt is used in critical industrial and military applications, including superalloys for parts in aircraft engines, gas turbines, high-speed steels, corrosion-resistant alloys, cemented carbides, and diamond tools, while cobalt catalysts play a strategically important role in the hydrogen and chemical industries.

"An estimated 50% of cobalt consumed in the United States was used in superalloys, mainly aircraft gas turbine engines" last year," according to the U.S. Geological Survey.

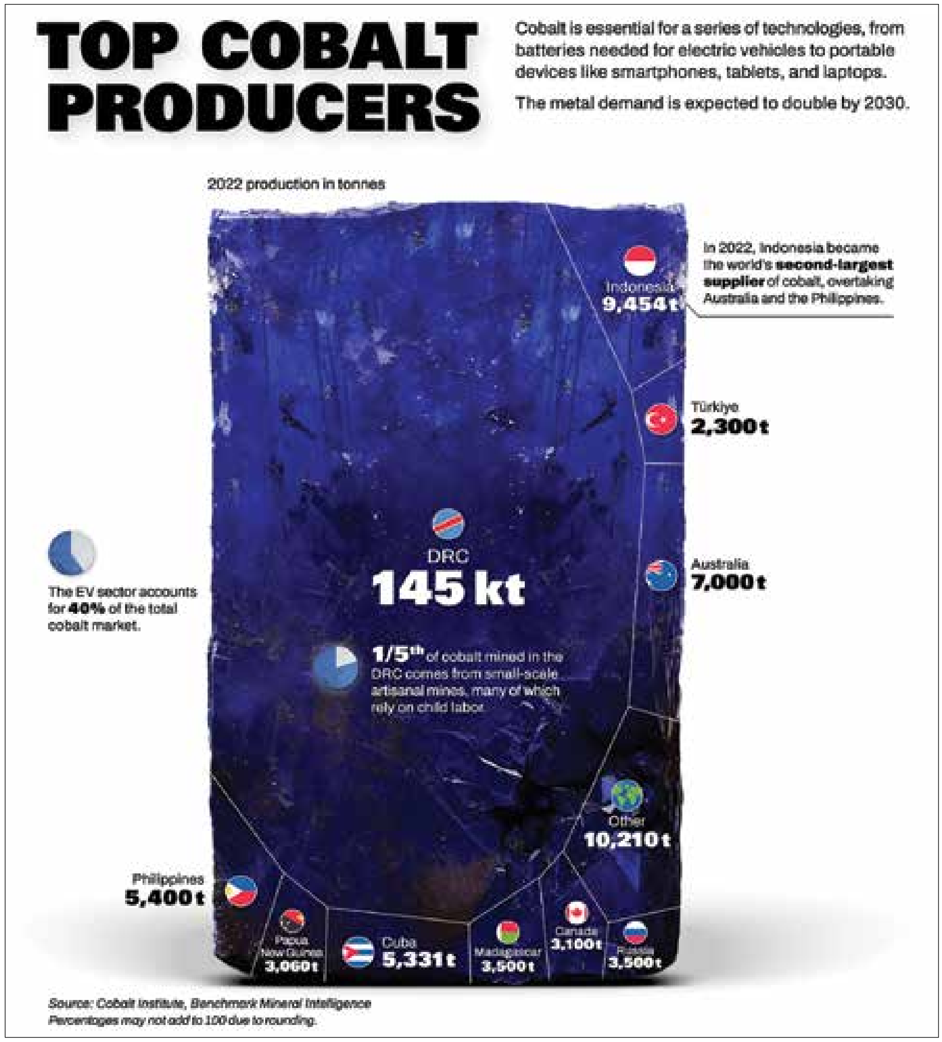
Cobalt's magnetic properties, when alloyed with aluminum and nickel, make it essential for powerful magnets used in wind turbines, hard disk drives, motors, sensors, and actuators, as well as in medical applications such as magnetic resonance imagery, radiotherapy, prosthetics, and implants.

Due to the growing need for cobalt in the lithium-ion batteries powering EVs and geopolitical issues related to its supply, this increasingly critical energy metal is considered at extreme risk of disruption.

According to S&P Global Commodity Insights research, a cobalt deficit in 2021 had mining companies increasing production in response to demand from the booming EV and battery markets. As demand unexpectedly cooled, the market was left with a surplus, exacerbated by increased production from Indonesia and the Democratic Republic of Congo (DRC), both of which have poor records of human rights and environmental regulation violations.

In 2023, cobalt used in energy storage drove 93% of total demand growth, with electric vehicles alone accounting for 45% of the global market. Cobalt's thermal stability, high melting point, and heat capacity prevent lithium-ion battery cathodes from overheating, while its good conductivity and high energy density enable batteries to store and transfer more energy, making them lighter and more efficient.

According to a report by the Cobalt Institute, "For the very first time in 2021, cobalt demand from electric vehicles overtook other battery applications to become the largest end use sector at 34% of demand. It is expected to account for half of the cobalt demand by 2026."



VISUAL CAPITALIST

## Problematic on land and sea

Potential solutions are twofold – push for less cobalt content in electronics and battery designs and steer clear of supply tainted by human rights issues. However, cobalt isn't going away, and keeping cobalt from artisanal mines in DRC out of the value stream is next to impossible due to the convoluted nature of the current supply chain.

"Global buyers engaging in a futile attempt to avoid cobalt associated with ASM (artisanal and small-scale mining) ignore the inconvenient truth that it is nearly impossible to separate the flow of ASM cobalt from the larger supply of industrially mined cobalt," said Dorothée Baumann-Pauly, director of the Geneva Center for Business and Human Rights.

With the top two cobalt-producing countries being the DRC and Indonesia, the choice is between environmental and social costs or a bigger price tag – safety and sustainability are expensive.

Deep-sea mining remains in its infancy, grappling with high costs and the immense pressures – both literal and figurative – of operating in poorly regulated international waters. While individual nations and member states of the International Seabed Authority are working to develop conventions that support industry and environmental security, the extreme wealth of oceanic battery metals remains tantalizingly out of reach.

The Western world's willingness to pay a premium for responsibly sourced cobalt may be the ultimate test of priorities.

## An embarrassment of riches

Cobalt is currently inexpensive and plentiful, but this isn't good news for the U.S. A collapse in price from over $40 to $17 per pound has hindered the development of domestic cobalt supplies, with the price dropping further to $11.72 as of August.

Oversupply has kept prices low. According to Bloomberg, hedge funds like Anchorage Capital Advisors and Squarepoint Capital are buying up cobalt at bargain-basement prices.

Similarly, during 2015-2016, when EVs were first promising demand, hedge funds physically hoarded enough of the global supply to create an artificial supply shock, which consequently led to a quadrupling of cobalt prices in 2017.

Meanwhile, China continues to build its stockpiles, staying ahead of the curve by buying up mines, constructing production facilities, and investing heavily across the spectrum of battery technologies, all while acquiring cobalt in record volumes. In response, the U.S. is seeking to reinvigorate its own stockpiling program, highlighting the metal's strategic value in defense.

While several countries are attempting to divorce themselves from a Chinese-dominated battery metals market, there is still risk that further geopolitical drama might send North America scrambling for supply in the future.

## Cobalt at home

Cobalt is predominantly a byproduct of nickel and copper mining, making its supply largely dependent on these other commodities. With new projects being slow and expensive to develop, U.S. domestic potential for cobalt remains in its early stages. Notably, Idaho is home to the largest cobalt belt in the U.S., with sediment-hosted copper-cobalt systems comparable to some of the DRC's largest deposits.

Despite this potential, the instability of demand and prices has created an on-again, off-again status for the only U.S. cobalt mine—the Idaho Cobalt Operation (ICO), built by Australian company Jervois Global in 2022.

Jervois wound up suspending the final construction stage due to costs higher than the price of cobalt could return. But, with the U.S. commitment to domestic production and emphasis on cobalt's importance to defense, the mine may yet reopen.

Several other North American sources of cobalt are in the pipeline. Among them, Electra Battery Materials is advancing the Iron Creek project in Idaho, which is home to one of the few primary cobalt-copper deposits in the U.S.

Additionally, Electra is expanding and upgrading The Ontario Cobalt Refinery about 300 miles north of Toronto – the only hydrometallurgical facility of its kind in North America. This strategic location positions Electra to supply key players like Ford, General Motors, and POSCO with essential battery materials.

Meanwhile, EVelution Energy has forged an alliance with Glencore to secure feedstock for its first commercial-scale cobalt processing facility in the U.S.

This facility, touted as the first green cobalt sulfate production site in the country, will generate its own power, deliver surplus clean electricity to nearby farmers, and recycle approximately 70% of the water it uses, minimizing its environmental impact. Construction is expected to begin this year, with full operation slated for 2026.

## DOD backs North American cobalt

Recognizing the strategic importance of cobalt, the U.S. Department of Defense (DOD) has provided grants to support several North American projects dedicated to processing, refining, and recycling this critical metal.

The largest such investment so far is a $20 million grant awarded to help complete the construction and commissioning of the Ontario Cobalt Refinery.

"This award will develop North American production of a key precursor material for large capacity batteries, helping to create a more robust industrial base capable of meeting growing demand across both the defense and commercial sectors," U.S. Assistant Secretary of Defense for Industrial Base Policy Laura Taylor-Kale said in August.

Electra, however, was not the Pentagon's first investment in Canadian cobalt. Earlier this year, DOD awarded $6.4 million to Fortune Minerals Ltd. to support development of the NICO cobalt-gold-bismuth-copper project, which includes a planned mine in the Northwest Territories and a hydrometallurgical refinery to be built in Alberta.

DOD has also invested in cobalt projects on U.S. soil, including a $15 million grant in 2023 to Jervois Mining USA to expand mining at its Idaho Cobalt Operations and potentially establish a refinery in the U.S. The Idaho investment was followed by a $7 million grant to The Doe Run Resources Corp. earlier this year to complete a demonstration-scale hydrometallurgical plant in Missouri that will focus on the separation of cobalt and nickel.

"This award is another important step towards decreasing reliance on unstable sources of cobalt and nickel, and ensuring a sustainable industrial base capable of meeting current and future demand," said Taylor-Kale.

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Electrolytically refined cobalt chips and a high-purity cobalt cube.

Another potential source of future cobalt in Missouri is drawing attention, as the Export-Import Bank of the United States (EXIM) has invited U.S. Strategic Metals to apply for a $400 million loan to fund the development of a battery materials processing facility and an associated cobalt-copper-nickel mine in the Show-Me State.

"The demand for domestic battery production and critical mineral exploration is on the rise, and this investment proves Missouri is well-positioned to capitalize on that opportunity and emerge as a national leader," said Missouri Gov. Mike Parson.

## Unconventional sources

In 2023, the Eagle Mine in Michigan made headlines by expanding its production to include cobalt-bearing nickel concentrate. This strategic move is part of a broader effort to tap into unconventional resources, with the potential to recover an additional 2 million pounds of cobalt from the mine's Humboldt Tailing Disposal Facility.

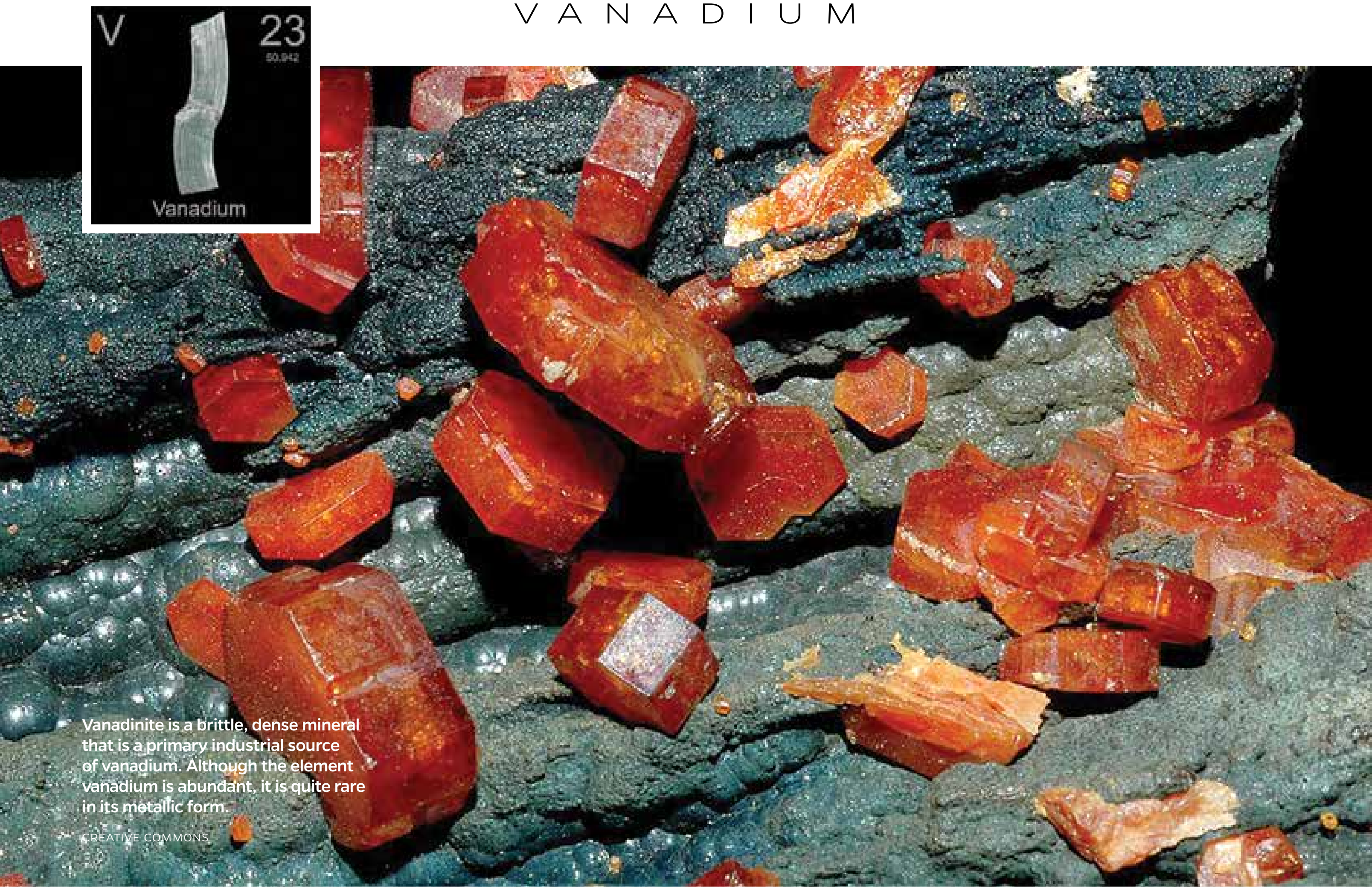
While Eagle Mine is pioneering new cobalt recovery methods, Missouri Cobalt has been steadily producing nickel-copper-cobalt concentrate from historic mine tailings at its Fredericktown facility since 2019. In addition to this, the company operates a pilot hydrometallurgical facility in Earth City, Missouri, which has been producing high-grade cobalt since 2020.

In a pinch, cobalt is infinitely recyclable, offering a sustainable solution regardless of the challenges surrounding its extraction and supply. With current techniques achieving efficiency rates between 89.7% and 99%, the secondary supply of cobalt from batteries, though small-scale now, is expected to grow as early generations of EV batteries reach the end of their life cycle.

According to the USGS, cobalt content from purchased scrap made up an estimated 25% of last year's consumption, with approximately 68% of recycled cobalt coming from batteries and another 24% sourced from hard metal scrap.

In a bid to further reduce dependency on imports, the U.S. Department of Energy released a national blueprint in June designed to guide investments in domestic lithium battery manufacturing while supporting research and development initiatives.

Central to this blueprint is the ambitious goal of eliminating cobalt from lithium batteries by 2030. To tackle the challenges associated with reducing or removing cobalt from EV batteries, the DOE's Vehicle Technologies Office has initiated a multi-year program dedicated to advancing these critical technologies and securing a more sustainable supply chain.




Vanadinite is a brittle, dense mineral that is a primary industrial source of vanadium. Although the element vanadium is abundant, it is quite rare in its metallic form.

CREATIVE COMMONS

# Vanadium is lightning in a very big bottle

## Redox flow batteries are just beginning to hit their stride

By K. WARNER
DATA MINE NORTH

**ALTHOUGH VANADIUM IS AN ABUNDANT** element, it is quite rare in its metallic form. That fact, combined with its position as a strategic metal for industry, national defense, and the green energy transition, has put it squarely on the list of critical minerals.

According to the United States Geological Survey (USGS), "Estimated U.S. apparent consumption of vanadium in 2023 increased by 27% from that in 2022. Metallurgical use, primarily as an alloying agent for iron and steel, accounted for about 94% of domestic reported vanadium consumption in 2023."

The most well-known and widespread use of vanadium is in the production of steel, rebar, and other building materials, where just one pound of ferro-vanadium added to a ton of steel almost doubles its strength, making it essential for construction projects.

By 2025, industry projections estimate that 85% of all cars will incorporate vanadium alloys, a shift expected to reduce vehicle weight, thereby increasing fuel efficiency in traditional internal combustion engine vehicles and extending the range of electric vehicles.

The demand for vanadium extends beyond steel production, with titanium-aluminum-vanadium alloy manufacturers emerging as the largest consumers in this space, driving significant growth in the marketplace.

Furthermore, vanadium alloys are indispensable for manufacturing fuel-efficient aircraft, as no substitutes can match their performance. These alloys also exhibit superconducting properties, such as vanadium-gallium tape, which is used in superconducting magnets.

As the need for efficient energy storage solutions grows, vanadium redox flow batteries are emerging as a key driver of future demand for this critical metal, particularly for grid-scale storage of renewable energy.

With the surging demand for lithium-ion batteries in consumer electronics and EVs, safer and longer-lasting alternatives like vanadium flow batteries are being sought. These batteries are nonflammable, compact, capable of discharging 100% of stored energy, and have a lifespan exceeding 20 years.

Additionally, vanadium recycling is mainly focused on reprocessing catalysts into new ones, further enhancing its value.

### An unfair weather battery

While solar and wind power generate clean and cost-effective electricity, their production is as unpredictable as the weather. To realize a future where grids rely entirely on renewable energy, vast amounts of battery storage are essential to prevent blackouts.

Vanadium flow batteries, which are powered by reduction-oxidation (redox) reactions, involve two different liquid electrolytes, both made from vanadium, that pass ions back and forth through a porous membrane. These batteries can store larger amounts of energy – as much as the size of the electrolyte cells can contain – and don't use flammable or polluting materials.

More than 20 flow battery chemistries, including iron-chromium, zinc-bromine, zinc-cerium, zinc-ion and magnesium-vanadium, have been studied, with vanadium redox standing out as the preferred technology, closest to wide commercial adoption.

Vanadium, the dominant material cost in the electrolyte, is mined from Russia, China, Brazil and South Africa, although there are reserves in the U.S. and Canada.

Secondary vanadium is produced in Arkansas, Ohio, and Pennsylvania from waste materials such as petroleum residues, spent catalysts, and utility ash. These processed materials are then used to create vanadium pentoxide, vanadium-bearing chemicals, specialty alloys, and ferrovanadium.

Even the U.S. Army is getting in on flow batteries.

In partnership with Lockheed Martin, the U.S. Army Engineer Research and Development Center team at the Construction Engineering Research Laboratory Operational Energy broke ground in late 2022 on a redox flow battery featuring electrochemistry consisting of engineered electrolytes.

"Bottom line is, the Lockheed Martin flow battery will provide a feasible means of long-duration grid scale energy storage to Fort Carson and their mission-critical assets that no other Army installation currently possesses," Tom Decker, Army program manager, said. "This is a significant tool and has potential to make an impact on future military bases."

### Batteries to batteries comparison

Vanadium flow and lithium-ion batteries each excel in different areas, making them better suited for specific applications.

With proper maintenance, vanadium redox flow batteries can be charged and discharged indefinitely, lasting 15-25 years with minimal performance decline, and scaling up capacity is as simple as installing larger electrolyte tanks.

They are best suited for stationary industrial and utility applications, where capacity, safety, and lifespan are more important than energy density.

Vanadium flow batteries also have a more favorable environmental footprint, and the vanadium electrolyte can be reused when the battery needs to be replaced. However, vanadium batteries are generally more expensive.

DÖRKDESIGN

**Vanadium redox flow batteries are beginning to encroach on lithium-ion's territory for grid-scale electrical storage applications.**

Due to their high energy density and rapid charging capabilities, lithium-ion batteries are particularly well-suited for mobile devices and electric vehicles, providing the necessary output levels for these applications.

However, lithium-ion batteries have a shorter lifespan, with their energy storage capacity dropping over several years of usage. In stationary applications, they typically last for about 10,000 cycles or 15 years. Damaged lithium-ion batteries can also be fire hazards.

For grid-scale applications, lithium-ion batteries have further shortcomings. Battery packs capable of storing megawatt-hours require many thousands or even millions of cells, all requiring individual and collective monitoring.

### Domestic and global vanadium

Vanadium is typically produced as a byproduct or co-product of elements like iron, uranium, molybdenum, or phosphorus, with only about 20% of global vanadium output coming from primary production.

The rest is sourced from feedstocks such as Idaho ferrophosphorus slag, petroleum residues, spent catalysts, utility ash, and vanadium-bearing iron slag. While some vanadium is recovered through solution mining, this method remains economically marginal.

In the U.S., Energy Fuels produces high-purity vanadium at its White Mesa Mill in Utah, which also processes uranium and rare earths.

U.S. Vanadium manufactures high-purity vanadium pentoxide for various applications, including vanadium redox flow batteries, at its Hot Springs, Arkansas plant.

Additionally, AMG Vanadium recently completed a $300-million expansion of its Ohio facility, which focuses on recycling spent catalysts and vanadium-bearing residues into specialty metals.

Globally, over 200 vanadium redox flow battery projects have been deployed across North America, Europe, Australia, and Asia, with China's 100-megawatt Dalian system being the largest in the world, commissioned in 2022.

As vanadium flow batteries gain traction as a solution for grid-scale energy storage, the demand for vanadium and the companies producing these essential battery materials is expected to rise in the coming years.


President Biden signing the Prohibiting Russian Uranium Imports Act into law.
THE WHITE HOUSE

# US acts to secure domestic uranium supply

## Russian uranium import ban ripples through clean-energy sector

By A.J. ROAN
DATA MINE NORTH

**WITH THE CLOCK RUNNING DOWN** on uranium stockpiles, the U.S. faces an urgent need to secure its energy future. New legislation and significant investments are set to revive domestic production of this zero-carbon energy fuel, reduce reliance on foreign imports, and bolster national security –measures that aim to ensure a stable uranium supply for nuclear energy as the country races to meet its demands.

In May 2024, the U.S. enacted the Prohibiting Russian Uranium Imports Act, effectively banning the import of uranium from Russia. This bold move signaled a monumental shift for America's civil nuclear energy sector.

With shares of uranium companies tumbling earlier this year due to market uncertainties, the Senate's late approval of the Prohibiting Russian Uranium Imports Act immediately sent shockwaves through the energy markets.

"This is a national security priority as dependence on Russian sources of uranium creates risk to the U.S. economy and the civil nuclear industry that has been further strained by Russia's war in Ukraine," the White House said in a fact sheet. "Without action, Russia will continue its hold on the global uranium market to the detriment of U.S. allies and partners."

The legislation, which took effect on Aug. 11, aims to promote domestic production of advanced nuclear fuel by eliminating reliance on Russian-origin uranium imports, thereby stimulating the U.S. nuclear sector and fostering domestic competition.

The House bill was approved in December amid growing congressional support to cut off Russia in the wake of its invasion of

Ukraine, which had already banned imports of Russian oil by working with G7 (Group of Seven) allies to impose a price cap on seaborne exports of crude and petroleum products.

The ban prohibits the importation of unirradiated low-enriched uranium (LEU) produced in Russia or by a Russian entity. It also bans uranium that has been swapped or obtained to circumvent restrictions.

However, not all is dire straits, the legislation, which expires by the end of 2040, permits the Department of Energy (DOE) to issue waivers authorizing the entire volume of Russian uranium imports allowed under export limits set in an anti-dumping agreement between the Department of Commerce and Russia through 2027.

Without those waivers, the market could see a significant spike in enrichment costs, according to Jonathan Hinze, president of nuclear fuel market research firm UxC.

"But if there is an immediate ban it could be even more extreme," he said. "There are very limited supplies available."

## Far-reaching effects

The passing of the Prohibiting Russian Uranium Imports Act was met with strong support from some industry leaders, reflecting a broad consensus on the need to secure domestic energy sources.

Energy Fuels stands to significantly benefit from increased demand and diminished Russian imports.

"The U.S. should not rely on bad international actors to supply the fuel that powers our homes and workplaces with carbon-free nuclear energy," said Energy Fuels President and CEO Mark Chalmers. "As the country's leading producer of uranium, we are ready to safely and responsibly produce the uranium needed for nuclear energy—one of the best tools to reduce carbon emissions."

"It is critical to our national security and our energy security that we move immediately to revitalize our domestic uranium conversion and enrichment capabilities to ensure an uninterrupted supply of fuel," a spokesperson for U.S. utility Constellation Energy told Reuters.

Constellation Energy, the largest producer of carbon-free energy in the U.S., operates 21 nuclear reactors and provides energy to millions of homes and businesses.

To prevent immediate supply disruptions, the waiver system allows utilities to import

DEPARTMENT OF ENERGY; OFFICE OF NUCLEAR ENERGY

Uranium concentrate, called yellowcake, is used in the preparation of uranium fuel for reactors.

Russian uranium until January 2028, if no alternative sources are available or if imports are deemed in the national interest.

Despite this buffer, some analysts have highlighted the immediate risks that could arise even with this supply failsafe in place.

"The global markets are just not ready for a complete ban," said Nikko Collida, vice president, business development at ConverDyn, which provides uranium conversion services from the Metropolis Works conversion facility in Illinois. "It's not clear that the United States is ready to rapidly wean itself off Russian supply and, while waivers are expected to be the solution near- and mid-term, if Russia pulls the rug out from under this, it's going to be pretty catastrophic for the market."

Uranium Royalty Corp. CEO Scott Melbye also expressed concerns about the potential fallout.

"The increased isolationism of Russia from the West runs the risk of the fuel supply being divided along BRIC (Brazil, Russia, India, China) and Western lines," he said. "It's very important that the West develop its resources and nuclear fuel cycle in places like Canada, the United States, and Australia."

And their concerns aren't unfounded.

In May, Russia's state-owned uranium supplier Tenex notified its U.S. customers, including Constellation Energy Corp., Duke Energy Corp., and Dominion Energy Inc., that they had 60 days to secure a waiver exempting them from the import ban. Tenex-USA President Fletcher Newton told Bloomberg that the company "fully intends to honor all their contractual commitments in the U.S., but it has no control over what action the Kremlin might take."

Nonetheless, Melbye remained relatively optimistic.

"A number of U.S. utilities will sign on to the waiver, but we're just kicking the can down the road. The sooner we get off Russian supply, the sooner we won't be vulnerable to a cut off by Putin," he said.

Even as the U.S. seeks to reduce its reliance on Russian uranium, it must still contend with the current import landscape and consumption needs.

## Uranium market overview

DOE estimates that U.S. utilities have roughly three years of LEU available through existing inventory or pre-existing contracts to buffer the impending countdown.

Of particular note, the inventories include uranium at various stages of the nuclear fuel cycle, encompassing both triuranium octoxide (U3O8) and LEU.

This comprehensive inventory ensures availability of supply from raw material to reactor-ready fuel, but converting and enriching uranium remains a time-intensive and resource-heavy process, something that Russia has held a near-monopoly on for decades.

According to the Energy Information Administration's 2023 Uranium Marketing Annual Report, the largest source of uranium delivered last year was of foreign-origin with Canada the top source at 27%, followed closely by Australia and

Kazakhstan with 22% each. Russian-origin material accounted for 12% and Uzbekistan-origin material accounted for 10%, while domestic material made up only 5% in 2023, the same percentage as 2022.

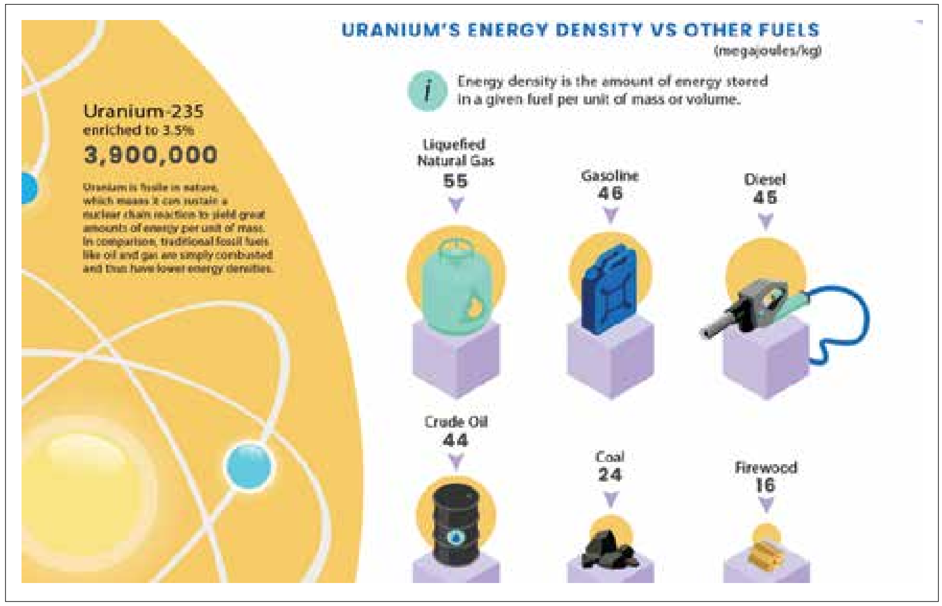
In total, this came out to roughly 49.2 million pounds of U3O8 – a compound of uranium used to make nuclear fuel.

During 2023, owners and operators of U.S. civilian nuclear power reactors purchased uranium deliveries equivalent to a total of 51.6 million pounds of U3O8.

Although not a large disparity, with the loss of nearly 10% from a major supplier, especially from a country that dominates the global market on enrichment capacity, it becomes an issue of establishing domestic sources to fill that gap.

The state of domestic production further underscores the hill to climb. In 2023, U.S. uranium mines produced only 50,000 pounds of U3O8 – a sharp decline from the 194,000 pounds produced in 2022.

It is estimated that U.S. reactors require approximately 32 million pounds of uranium annually to continue supplying roughly 20% of the country's electricity.



VISUAL CAPITALIST

### What led to this

Practically cornering the enrichment process, Russia has all but left the U.S. behind, hosting an estimated 44% of global enrichment capacity.

Historically, Russia's leadership in this sector has been facilitated by centralized control – a system in which all the primary processing is done at a single location rather than at multiple points throughout the system – by Rosatom, allowing it to become a major exporter of nuclear technologies and services.

This centralization, which enabled Russia to establish a significant presence in the global market, has long raised concerns about Moscow's ability to leverage its position for geopolitical purposes, especially emphasized by the ongoing war in Ukraine.

So, what exactly led to Russia's nuclear fuel dominance?

Russia's control in the enrichment sector can be traced back to after the end of the Cold War. In 1994, the U.S. and Russia signed a contract implementing the Megatons to Megawatts program, that saw highly enriched uranium from dismantled Russian nuclear weapons converted into low-enriched uranium for U.S. nuclear power plants.

These arrangements, along with cost advantages, led to the U.S. becoming heavily dependent on Russian enrichment services.

This dependency now poses a significant risk to U.S. energy security, as uranium in its natural form must be processed before it becomes a viable fuel source, a situation exacerbated by lack of domestic infrastructure over the last three decades.

Enriching natural uranium into nuclear fuel involves separating uranium-235 (U-235) from uranium-238 (U-238) to increase the concentration of U-235, making it a viable fuel source.

Currently, the U.S. largely uses LEU with U-235 concentrations of up to 5%, for its nuclear reactors. However, the future of nuclear energy, particularly with advanced reactors and small modular reactors (SMRs), lies in high-assay low-enriched uranium (HALEU).

HALEU, with U-235 concentrations between 5% and 20%, allows for more efficient and compact reactor designs, providing a higher energy density and improving the economics and safety of nuclear power.

To address this, the Department of Energy (DOE) has been advocating for the expansion of domestic HALEU production.

With the Prohibiting Russian Uranium Imports Act in place, the urgency to establish a robust domestic enrichment capability has only intensified, unlocking $2.7 billion in congressional funds earmarked for this very purpose, aiming to build the infrastructure necessary to produce HALEU domestically.

"A ban on Russian uranium imports is needed to release the USD$2.72 billion included in recent appropriations to revitalise a competitive domestic enrichment and conversion capability," said Maria Korsnick, president and CEO of the Nuclear Energy Institute. "It will take many years to build US capacity to serve the existing fleet and the deployment of next generation nuclear. The implementation of a meaningful programme to support capacity building is critical."

## Strengthening domestic supply

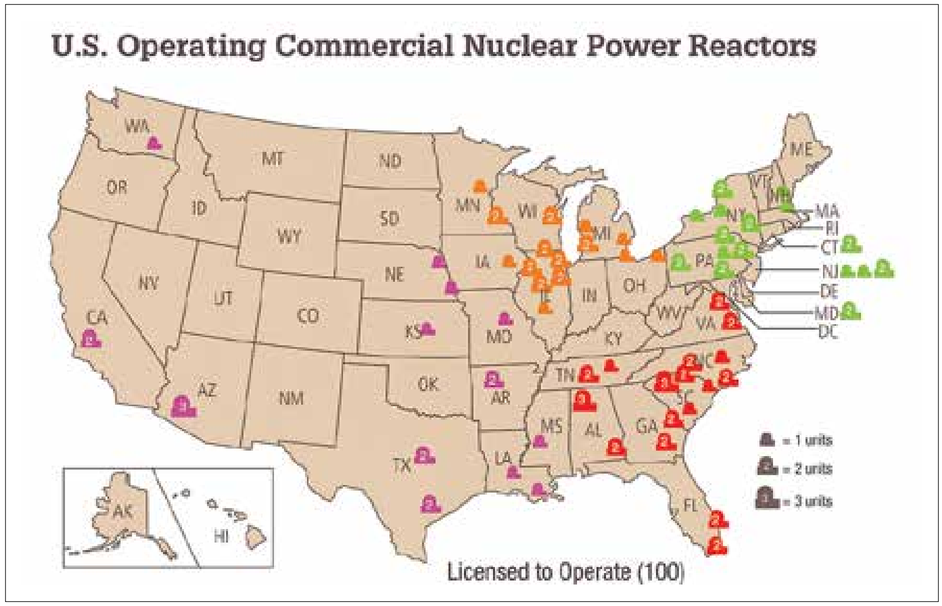
The congressional fund, initially set aside from previous nuclear energy appropriations in the Bipartisan Infrastructure Law for fiscal years 2022, 2023, and 2024, was contingent on the enactment of the Prohibiting Russian Uranium Imports Act.

With the bill now in place, DOE is set to use these funds to establish a robust domestic enrichment capability, particularly for HALEU.

Shortly after the signing, DOE's Office of Nuclear Energy put out a request for proposals that included the appropriated $2.7 billion for contracts to supply domestically produced low-enriched uranium, with a ceiling worth up to $3.4 billion for additional enrichment services and infrastructure development.

Encouraged by rising uranium prices and government support for nuclear energy, Energy Fuels has restarted production at three of its uranium mines in Arizona and Utah. Chalmers indicated that the company expects to produce between 150,000 to 500,000 pounds of U3O8 during 2024, with production anticipated to increase further in 2025 as they process uranium ore and alternate feed materials from their current stockpiles.

"The substantial increase in uranium prices, U.S. government support for nuclear energy, and a global focus on reducing carbon emissions have driven us to resume large-scale uranium production," the CEO




Map of all nuclear facilities located in the United States.

U.S. NUCLEAR REGULATORY COMMISSION

said. "We are uniquely positioned to take advantage of favorable policy and market conditions."

North of the border, with the market already feeling the effects of the import ban, Cameco, a Canadian uranium producer, reported a significant increase in its earnings due to rising uranium prices and long-term order growth.

Witnessing a 157% jump in its second quarter 2024 earnings report, Cameco is seeing first-hand the benefits of the ban being put in order.

"The need to replace retiring fossil fuel generation is clear, and nuclear energy is being recognized as a critical tool in the fight against climate change," said Cameco President and CEO Tim Gitzel.

Add this proof to the list of companies and projects shifting focus to this fuel commodity, and regardless of its designation as a critical mineral, uranium is seeing a rush not seen since the days of the Manhattan Project.

Though it took years of preparation, the U.S. is now poised to enhance its energy security, support its nuclear fleet, and contribute significantly to global efforts to combat climate change through the expanded use of nuclear power. While the journey ahead is fraught with challenges, the groundwork is being laid for a more resilient and sustainable nuclear energy future.

PGM-based lithium battery chemistries would extend their range per charge. With improved range, battery mass could be reduced, and a lighter vehicle begets more efficient operation, increasing range further.

SHUTTERSTOCK

# The clean energy future of platinum metals

## Indispensable, expensive, and rare – PGMs get a green upgrade

By K. WARNER
DATA MINE NORTH

**BACK IN 1950, THE FIRST** catalytic converter in the United States was a box bolted onto a car's undercarriage to reduce tailpipe emissions. It was patented by French mechanical engineer Eugene Houdry, who was concerned about the effects of automobile exhaust on the good people of Los Angeles.

And it would have worked if it had not been for the octane-boosting lead then being added to fuel, which could choke any catalyzer in short order. This would all change twenty years later with the Clean Air Act of 1970—Houdry was just too far ahead of his time. Today, the automotive industry is once again outpacing its own energy source. Hydrogen and electric vehicle batteries are beginning to replace gasoline, while modern catalytic converters are becoming valuable sources of platinum group metals (PGMs). As a result, the balance of demand is shifting away from fossil fuels and increasingly toward renewable energy solutions.

PGMs are vital as catalysts due to their excellent electrical conductivity, high melting points, and exceptional heat and corrosion resistance, making them indispensable in clean energy, military operations, and several key industries.

"To meet the nation's goal of net-zero carbon emissions by 2050, decarbonization of these energy and emissions intensive processes will be crucial. PGM catalysts, and the green hydrogen produced with them, can enable dramatic emissions reductions in these hard-to-decarbonize industrial sectors," Department of Energy's (DOE) Advanced Manufacturing Office PGM penned in a report on this group of hardworking precious metals.

### Small, but mighty

The World Platinum Investment Council reported that PGM-based lithium battery chemistries, including next-generation lithium-oxygen and lithium-sulfur, would extend the range per charge. With this improved range, battery mass could be reduced, leading to a lighter vehicle that operates more efficiently, further enhancing the vehicle's range.

This is a significant consideration in the world of EVs, where increased power often translates to increased weight, particularly for larger vehicles like trucks. For example, the 2023 GMC Hummer EV's battery alone weighs 2,900 pounds.

PGMs have the unusual distinction of being considered both industrial and precious metals, a designation that keeps them in high demand and a good investment. However, if PGM-reliant green technologies take off, even a small jump in demand will put devastating pressure on availability.

Major uses and mid-2024 prices for PGMs include:

• **Platinum** ($972/oz) – the group's namesake, and it is most recognized as a precious metal in jewelry, medical implants, and electronics, as well as a catalyst for scrubbing emissions and hydrogen technologies.

• **Palladium** ($904/oz) possesses the unique ability to absorb and release hydrogen, which is used in chemical processes that require hydrogen exchange, such as fuel cells, and as an excellent catalyst. Palladium is also used in capacitors and as a substitute for platinum.

• **Iridium** ($4,700/oz) – of which the U.S. is 100% dependent on imports, possesses notable chemical and thermal stability. Iridium-based catalysts are often used as anodes in proton exchange membrane (PEM) electrolyzers alongside platinum and palladium to boost vital chemical reactions and in the anode catalyst for hydrogen production.

• **Rhodium** ($4,650/oz) – and iridium are used as hardening agents for platinum palladium alloys. Rhodium is extremely corrosion-resistant and highly reflective, often used to add luster and strength to jewelry, mirrors, and headlight reflectors.

• **Ruthenium** ($400/oz) – another strengthening agent for PGM alloys. Due to its conductive properties and durability, it makes hard-wearing electrical contacts in electronics. Ruthenium is also used in highly efficient solar cells and as a catalyst.

## A family of critical catalysts

The PGM family (except for osmium) is on America's critical minerals list due to their invaluable industry applications, rarity, and supply chain risk.

As fossil fuels are phased out in private transport and heavy industry, the use of PGMs is now shifting to hydrogen production and as catalysts in hydrogen fuel cells, potentially doubling the demand for an already strained resource.

"PGM catalysts are important to maximizing the efficiency of emerging decarbonization technologies, specifically in proton exchange membrane electrolyzers for green hydrogen production from water and PEM fuel cells for transportation and stationary energy storage," DOE penned in a 2022 report on PGMs. "Under aggressive decarbonization scenarios, such as those striving toward net zero carbon emissions by 2050, demand for PGM catalysts is expected to grow rapidly, both domestically and globally."

Iridium, one of the rarest metals on Earth, is currently the catalyst of choice for electrolyzer stacks that split green hydrogen off water molecules. Without alternatives, its scarcity threatens to create a bottleneck that could stall the adoption of the technology entirely.

Platinum is the most common metal used as a catalyst for hydrogen fuel cells that generate electricity for transportation and stationary power, but other PGMs, such as palladium and ruthenium, can serve a similar purpose. It is estimated that a hydrogen vehicle fuel cell needs 30 to 60 grams of platinum, compared to only five grams in an automotive catalytic converter.

## Few and far between

In its PGM supply chain factsheet, DOE warns: "The six PGMs are among the least abundant elements on earth and occur in only a few countries worldwide, with the majority of production and reserves in South Africa and Russia. To secure the supply chains for these clean energy technologies, as well as green hydrogen and chemical manufacturing, the United States needs to invest in its domestic resources and in innovations in PGM substitutions, material efficiency, and recycling."

Key sources and projects in North American PGM production include:

• The Stillwater Complex deposit in Montana, mined since 1986, stands as the largest source of PGMs in the U.S. and boasts the highest ore grade globally. The Stillwater mine is projected to remain operational until 2053, while its neighboring East Boulder mine will continue until 2068. Sibanye-Stillwater also operates the Columbus Metallurgical Complex, which plays a crucial role in recycling catalytic converters to recover PGMs.

• Eagle Mine, operated by Lundin Mining in Michigan, produces platinum and palladium as byproducts of nickel and copper production, with small amounts of PGMs.

• Canada ranks among the top five global producers of PGMs, with its premier PGM mine located in western Ontario near Thunder Bay at the renowned Lac des Iles mine, a palladium-rich deposit also yielding gold, copper, and nickel byproducts. Approximately 73% of Canada's PGM production is concentrated in Ontario, Quebec, and Manitoba, while the remainder comes as byproducts from nickel and battery metals mining in regions like Sudbury, Quebec, Manitoba, Newfoundland, and Labrador.

• There are several junior polymetallic PGM projects in the United States, particularly in Alaska and Minnesota. In Canada, numerous additional PGM projects are also currently at the exploration stage.

## The critical role of recycling

In a sense, every country has access to a plentiful PGM source through recycling, which is ten times cheaper than extraction from the ground, where every ounce and dollar counts. Recycled PGMs can be reused indefinitely, with a process that reduces carbon intensity by up to 98% compared to initial mining, seamlessly integrating sustainability with economic efficiency.

Recycled PGMs, also known as secondary supply, will be crucial for maintaining a secure domestic supply and meeting market demand. Johnson Matthey, the world's largest recycler of PGMs with over 200 years of experience, exemplifies industry success by operating in more than 30 countries and achieving an impressive 99.95% purity in its recycling processes.

In its May 2024 PGM Market Report, Johnson Matthey explains: "PGM are used in a range of industrial applications which are fundamental for improving energy efficiency, reducing CO2 emissions, and safeguarding the environment. These include glass fibre (widely used for vehicle light-weighting, and renewable energy applications such as wind turbines and solar panels), biofuels and synthetic fuels (to partly replace conventional oil-based fuels in aviation, for example), copper foil manufacture ( for lithium-ion batteries), catalysts to control pollution from non-road and stationary engines, and hydrogen-related applications such as fuel cells and PEM electrolysis."

Industrialized recovery can reclaim significant amounts of PGMs, which are then reintroduced to the manufacturing supply chain, promoting circularity that benefits both the environment and economy.

PGM recycling is especially critical when exploring sustainable sourcing methods. Recovering PGMs from products such as e-waste, catalytic converters, and fuel cells is a given, while adding end-of-life solar panels and turbine blades offers an opportunity to further reduce the environmental impact of mining to meet the

PETER SCHREIBER FOR ISTOCK

**Platinum serves as a catalyst in fuel cells, facilitating the circular electrochemical reactions that convert water into hydrogen, then transform that hydrogen into electricity, with water as the only byproduct.**

rising demand for these metals.

"About 120,000 kilograms of palladium and platinum were recovered globally from new and old scrap in 2023, including about 42,000 kilograms of palladium and 9,000 kilograms of platinum recovered from automobile catalytic converters in the United States." the USGS report noted.

The high cost and scarcity of PGMs are also pushing research toward reducing their use. Exploring nanomaterials, unusual alloys and experimental polymers will expand into the space occupied by PGMs over time, but this suite of silvery metals holds sway over most applications for which they are uniquely suited.

## Catalyst for change

There is plenty of room for change in the field of catalysts and how they are applied to the energy transition.

Amidst the research on PGM-free alternative hydrogen catalyzers, metal and carbon nanomaterial combinations are promising candidates to help reduce or replace these rare metals in the future. Nanomaterials are being fabricated with graphene, incorporating various single-atom matrices of transition metals like iron, manganese, chromium or copper, even some simple organic compounds.

Nickel is also an abundant, cheap option under intense study. In addition to serving as a primary catalyst, nickel-based coatings offer a hard surface finish alternative to PGM-based coatings that are cost-effective, corrosion-resistant, and thermally stable – ideal for a wide range of industries and applications.

Carbon fabrics are also being embedded with minute amounts of highly functional catalysts using a conventional carbon fiber manufacturing process. These electrocatalysts boast a lifespan that is 100 times longer than conventional electrodes while maintaining optimal performance through trace amounts of ruthenium, resulting in significantly reduced manufacturing costs.

In addition to splitting hydrogen off water or hydrocarbons, researchers are investigating the potential of using PGMs, nickel, or other catalysts to produce geological hydrogen.

One such project is being conducted by a team of University of Texas at Austin scientists who are introducing nickel and PGM catalysts into iron-rich rock formations in the U.S. to produce geological hydrogen without emitting carbon dioxide, simulating the natural geologic process called serpentinization and coming full circle to learn from nature's original hydrogen production facility – planet Earth.

"If we could replace hydrogen that is sourced from fossil fuels with hydrogen sourced from iron-rich rocks, it will be a huge win," said Toti Larson, an associate professor at the University of Texas and the lead researcher on the project.


Primarily known for its use in soldering, tin's low melting point and corrosion resistance ensure dependable electrical connections in circuit boards.
ADOBE STOCK

# A quiet element that sustains modern tech

## Tin is indispensable today and shapes innovation of tomorrow

By A.J. ROAN
DATA MINE NORTH

**FROM $5 FLASHLIGHTS** to multi-million-dollar super computers, virtually all electronics rely on tin, primarily because of its use in soldering. If circuit boards are considered the backbone of technology, then tin-based solder could be seen as the connective tissue that holds the industry together. Despite its fundamental role in the Digital Age, tin is often overshadowed by other critical minerals and contends with growing supply challenges and inadequate investment.

In recent years, the tin market has navigated a gauntlet of obstacles, from volatile prices to geopolitical disruptions, all while dutifully holding together the technologies that power our modern world.

Newer technologies and devices are driving an ever-growing demand for tin, but meeting this demand is becoming more difficult. Supply chains are increasingly strained, pressured by environmental concerns, political unrest, and the reliance on a small number of producing countries.

Countries like China, Indonesia, and Myanmar dominate the global supply due to their substantial raw tin production capabilities, creating a precarious reliance on a few key players.

Political and economic volatility in these regions, coupled with a lack of environmental scrutiny, further strains the balance between supply and demand – uncertainties that have pushed the tin industry to a point where the supply chain teeters on a knife's edge, with minor disruptions potentially causing significant impacts on global markets.

For instance, in 2023, Myanmar's Wa State announced a halt in mining operations, which significantly disrupted the global supply chain and caused a sharp decrease in tin exports from the region. Similarly, Indonesia's recent shift in mining policies, including the controversial allocation of previously revoked mining permits to religious organizations, has added uncertainty to the tin market, further tightening supply and exacerbating concerns about long-term availability

Little need be said for the precarious relationship the West has with China.

Further complicating the situation is the stagnation of investment toward new tin mining projects. With no major new mines coming online and existing ones edging toward depletion, the industry's capacity to meet growing demand is becoming increasingly uncertain.

This shortfall is particularly alarming considering tin's irreplaceable role in emerging technologies.

With all these factors at play, tin remains overshadowed by more glamorous critical minerals like rare earths, lithium, and cobalt. While its diminished public perception could be speculated on, if it continues, this oversight will have significant repercussions.

As the world continues to advance towards a more digital and sustainable future, the demand for tin will only increase. Yet, without proactive measures to secure its supply chain, the industry risks facing a severe shortage that could undermine the very technologies that depend on this unassuming metal.

GRYBECK SLIDES, CONSORTIUM LIBRARY, UNIVERSITY OF ALASKA ANCHORAGE

**The Lost River Mine in Alaska was active intermittently from the early 1900s until 1955, producing over 687 tons of tin concentrate from approximately 51,000 tons of ore.**

## Too dependent

The United States is heavily dependent on imports to meet its tin needs, with 74% of the country's tin supply sourced from foreign producers.

While one of these suppliers includes Indonesia, the U.S. also relies heavily on Peru and Bolivia as well, two countries that present their own set of risks due to political instability and shifting environmental regulations.

Since domestic tin mining ceased in 1993 and smelting operations ended in 1989, the U.S. has increasingly relied on recycling and imports to fulfill its tin demand.

In 2023, the U.S. recovered around 17,000 metric tons of tin through recycling, which accounted for roughly 44% of the total 39,000 metric tons consumed. However, recycling alone will not meet predicted demand, leaving the U.S. vulnerable to potential supply disruptions.

This reliance not only highlights a strategic vulnerability but also raises questions about the long-term sustainability of the U.S. tin supply chain. With global demand for tin continuing to rise, especially in emerging technologies, the pressure on these supply chains is likely to intensify.

To mitigate these risks, there are ongoing efforts to enhance domestic recycling capabilities and explore potential alternative materials that could reduce dependency on tin. However, these initiatives are still in their nascent stages and face considerable challenges.

For now, the U.S. must continue to manage its existing supply chain, carefully balancing the reliance on imports with the uncertainties of the global market.

## Potential for tin

Historically, the United States was not always dependent on imports for its tin supply. Domestic tin production played a crucial role in meeting the nation's needs, especially during the 20th century. Notably, the Lost River mine on Alaska's Seward Peninsula was a significant producer of tin, particularly during the Korean War, before it ceased operations in 1955.

Various regions across the United States have a history of tin mining that contributed to the nation's supply. For instance, Temescal tin mine in California's San Bernardino County was notable for its production during the late 19th century.

Similarly, Alaska's York region was an important tin-producing area during World War II. Additionally, in North Carolina's Appalachian region, tin was mined alongside mica and feldspar, contributing to the area's mineral output, though tin was less prominent.

Beyond these somewhat-documented sites, other regions such as the Blue Mountains in Oregon, the Van Horn Mountains in Texas, and the Cornudas Mountains in New Mexico have been identified as containing tin, though they were never fully developed into large-scale operations.

With modern technological advancements and renewed interest in critical minerals, these areas, along with others, could be revisited as viable sources of tin, potentially reducing the nation's reliance on imports.

According to an assessment in 2018 by the U.S. Geological Survey (USGS), "In the United States, tin most commonly occurs in the mineral cassiterite. The majority of tin occurrences are located in the state of Alaska, but tin is known to occur in many other locations in the contiguous United States."

This assessment identified over 120 regions, mines, and mineral deposits that contain enrichments of tin, with efforts aimed at understanding the distribution and resource potential of these deposits for future supply considerations.

The findings from the USGS underscore the significant untapped potential for tin production within the United States. While these resources have yet to be fully exploited, the comprehensive mapping and analysis provided by the USGS offer a foundation for future exploration and development.

## Jack of all, master of none

While soldering remains the most recognized application of tin, this versatile metal is increasingly finding its way into a variety of advanced technologies, showcasing its importance far beyond traditional uses.

What makes tin irreplaceable is its unique combination of properties, which, while shared with other elements, are distinctly expressed due to its specific atomic structure and characteristics.

• Low melting point: Tin's low melting point, akin to gallium, enables its use in low-temperature processing applications, making it ideal for soldering and other temperature-sensitive technologies.

• High corrosion resistance: Comparable to zinc, tin's high corrosion resistance makes it valuable for coatings and protective layers, particularly in environments where oxidation is a concern.

• Excellent electrical conductivity: Much like copper, tin's excellent electrical conductivity ensures its critical role in electrical connections within circuit boards.

• Ductility and malleability: Reminiscent of gold and aluminum, tin's ductility and malleability allow it to be easily shaped into wires and sheets, facilitating its use in a range of manufacturing processes.

• Non-toxic nature: Similar to titanium, tin's non-toxic properties make it safe for use in consumer products, including food containers and medical devices.

Despite these remarkable properties, tin continues to fly under the radar in discussions about critical materials.

While its significance in emerging technologies is undeniable, the broader narrative often overlooks tin's contributions, leaving it to remain quietly indispensable in the advancement of modern industry.

This understated role highlights a curious disconnect between tin's essential functions and the recognition it truly deserves.

## Growing uses

Delving deeper into the properties that make tin one-of-a-kind, it becomes clear that this versatile metal is growing into an integral element of emerging technologies that are shaping the future across multiple industries.

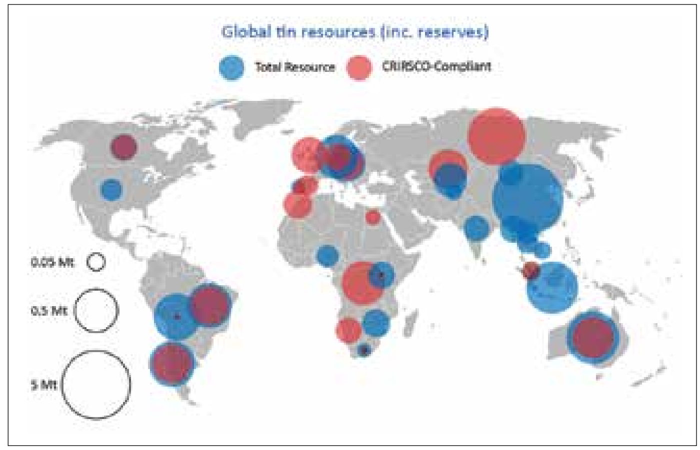
One of the most promising areas where tin is making an impact is in energy storage, particularly in lithium-ion batteries, where tin-based composites are being incorporated into the anodes. These composites enhance energy density and extend battery life, making them fundamental in the growing demand for EVs and renewable energy storage solutions.

This is crucial in the growing demand for electric vehicles and renewable energy storage solutions, where efficiency and longevity are paramount.

In the realm of solar energy, tin is finding its day in the sun through its role in developing next-generation photovoltaics, particularly in tin-based perovskite solar cells.

These cells provide a lead-free alternative to traditional perovskites, offering a more environmentally friendly option while maintaining high efficiency in converting sunlight into electricity.

Although still in the research phase, tin perovskite cells are seen as a potential breakthrough in solar technology, paving the way for greener energy production in the future.




INTERNATIONAL TIN ASSOCIATION

**Map of global distribution of tin resources in 2020, highlighting total reserves and CRIRSCO-compliant deposits across different regions.**

Tin also shines in its role as a transparent conducting oxide, particularly in the form of tin oxide. This material is vital for producing displays and solar cells, including LCD screens, touch screens, and OLED displays, where it provides both transparency and electrical conductivity.

The unique combination of these properties makes tin oxide a clear choice for modern electronics, especially as consumer demand for high-quality displays continues to grow.

Historically, tin was integral in the development of indium-tin oxide, a material that revolutionized the screens found in today's smartphones and tablets by enabling the creation of clear, electrically conductive films essential for responsive touch interfaces.

And while its contribution to that technology may not be widely recognized, tin has been instrumental in driving the screen-based innovations that have shaped the digital age, allowing us to literally see and interact with the world at the tips of our fingers.

Aside from energy storage, screens, and solar cells, there is another kind of cell that tin is found to be increasingly useful for: cell signal.

Tin alloys are now crucial in the production of high-frequency components essential for 5G networks, such as filters and antennas. These alloys enhance the performance and reliability of components which are necessary for meeting the high-speed, low latency demands of modern communication networks.

Finally, beyond electronic devices, tin's influence has also found its way into industrial processes where organotin compounds – tin atoms bonded to carbon-based organic molecules – are utilized as catalysts and biocides.

These compounds accelerate chemical reactions in the production of plastics and other materials while also preventing the growth of harmful organisms on marine coatings and agricultural products. The broad applicability of organotin compounds underscores tin's integral role across multiple sectors, from manufacturing to environmental management.

As tin continues to prove itself irreplaceable in a variety of advanced technologies and industrial processes, its necessity in the modern world cannot be overstated. Often disregarded, tin's versatility and unique properties position it as critical to sustaining and advancing key industries.

With its significance only set to grow, tin undoubtedly remains a fundamental component in today's technologies, while it drives innovation and supports the progress of tomorrow.


The drone industry is investigating new technologies that can extend flight times and expand drone applications.

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# The critical metal of clean energy dreams

## Tellurium devices transform sunlight and heat into electricity

By SHANE LASLEY

DATA MINE NORTH

**A HOT ENGINE AND A COOL BREEZE,** a cozy living room on a cold winter day, or the warmth of sunshine on your face and the coolness of the earth beneath your feet – there are temperature variations all around. Devices capable of efficiently transforming these thermal dichotomies into clean electricity 24 hours a day without any moving parts would forever change the energy dynamics on Earth. While such a miraculous technology seems like it belongs on the pages of a science fiction novel, a rare and remarkable element known as tellurium is bringing such perpetual clean energy dreams closer to reality than you may realize.

Setting aside any futuristic speculation, tellurium is already lending its unique and extraordinary properties to the production of American-made solar panels and thermoelectric generators that convert industrial waste heat into clean electricity and is being tested in solid-state batteries that could significantly extend the range of electric vehicles.

First Tellurium Corp., a British Columbia-based mineral exploration company that is rapidly evolving into a clean-tech firm, is pushing the cutting edge when it comes to applying tellurium's unique characteristics to futuristic clean energy technologies.

The tellurium-based solid-state batteries and thermoelectric devices being pioneered by First Tellurium and its partners have captured the attention of officials at the U.S. Department of Defense, National Science Foundation (NSF), and RESOLVE Inc., a Washington, DC-based non-governmental organization focused on sustainable solutions.

The reputational and funding support of DOD, NSF, and RESOLVE underscores the promise of future-leaning clean energy technologies that tellurium is enabling.

### Clean energy metalloid

With properties that fall somewhere between metals such as zinc and non-metals such as carbon, tellurium is one of a handful of elements on the periodic table classified as metalloids – antimony, arsenic, boron, germanium, and silicon are other members of this group of semimetals.

While tellurium does not often come up in conversation at the dinner table, this rare element with both metal and non-metal traits has quietly become an important ingredient to America's clean energy transition.

This is due to the metalloid's use in cadmium-telluride (CdTe) solar technology, which is less popular than traditional silicon panels internationally but represents the top photovoltaic solar technology in the U.S. According to the Department of Energy's 2023 Critical Materials Assessment, CdTe panels account for more than half of all new solar installations in the U.S.

This outsized popularity in the U.S. is due to the success of Ohio-based First Solar Inc., the world's largest manufacturer of CdTe solar panels. The company is on track to manufacture enough solar panels this year to generate roughly 16 gigawatts of electricity.

To help supply First Solar's growing demand, global metals and mining company Rio Tinto installed a circuit capable of recovering roughly 20 metric tons of tellurium per year at a Utah refinery that processes copper concentrates from its Kennecott Mine.

"We are proud to deliver a new domestic supply of tellurium to support the manufacturing of solar panels and other critical equipment here in the United States," Rio Tinto Copper CEO Clayton Walker said upon the mid-2022 start-up of this facility.

DOE, however, says that recovering tellurium as a byproduct of copper is "nearing saturation in every country other than China" and forecasts shortages of the rare metalloid if alternative supplies do not come online soon.

"Without significant expansion of the tellurium supply capacity, shortages of Te could occur in the short term (2025) and are likely in the medium term (2025-2035)," the Energy Department penned in its Critical Materials Assessment.

To help fill shortfalls, First Tellurium is exploring two tellurium-enriched projects – Klondike in Colorado and Deer Horn in British Columbia – that could offer North American supplies of this critical metalloid.

## Tellurium explorer and tech firm

While First Tellurium began as a mineral exploration company on the hunt for new sources of its namesake metalloid to meet solar demand, the company has come to realize that tellurium has more to offer the clean energy transition than previously realized.

This led the company to work with scientists at the University of British Columbia Okanagan to develop and test a solid-state lithium-tellurium battery that could solve the range and fire anxieties that have caused many drivers to be reluctant to buy an EV.

In 2023, the UBC Okanagan researchers published a study showing that the lithium-tellurium battery they are working on lasts longer, charges faster, stores more energy, and is safer than its lithium-ion counterparts.

"All-solid-state, lithium-tellurium batteries enable higher energy output with an improved safety rating inside a smaller form-factor, thereby expanding its possible applications," said Jian Liu, principal's research chair in energy storage technologies at UBC Okanagan.

Fenix Advanced Materials, a B.C.-based company that specializes in ultra-high purity metals for high-tech and clean energy applications, supplied the UBC research team with high-quality tellurium derived from First Tellurium's Deer Horn project.

"The high purity of the tellurium along with the mineral's overall attributes makes it ideal as a rechargeable battery material," said Liu.

Safer and longer-lasting batteries, as well as secure and reliable supply chains to support them, are high on the list of DOD priorities.

"Advanced batteries are the single-greatest cost and a bottleneck for electric platforms due to supply chain and integration issues," said Andrew Higier, director of the energy portfolio at the U.S. Defense Innovation Unit.

One of the primary issues is China's domination of supply chains for the batteries "essential to thousands of military systems," according to U.S. Deputy Secretary of Defense Kathleen Hicks.

"When it comes to batteries, America needs to lead the world," she said.

This is why DOD is interested in backing the tellurium-based technologies and supply chains being pioneered by First Tellurium and its partners.

"We had a very encouraging first meeting with the Department of Defense at this year's Energy Metals Conference in Washington, DC," said First Tellurium President and CEO Tyrone Docherty. "In subsequent meetings, they also expressed interest in our tellurium projects in Colorado and British Columbia and the thermoelectric device developed by our subsidiary PyroDelta Inc."

## PyroDelta explores thermoelectric future

The Pentagon has also expressed interest in tellurium-based thermoelectric devices being pioneered by PyroDelta that are shaping up to be a complete gamechanger in how clean energy is produced.

The PyroDelta thermoelectric generators were built upon a discovery made by German scientist Thomas Seebeck more than 200 years ago. At the time, Seebeck found that when one end of certain materials is heated and the other is cooled, a small amount of electricity is generated. The greater the temperature variation, the more electricity that can be generated.

These solid-state "Seebeck effect" generators are already being used to transform waste heat from industrial processes into low-cost and low-carbon electricity – simply attach these devices to a hot surface, and they generate electricity without any moving parts.

"This technology is projected to continue to grow quickly as an energy efficiency technology in industry, electronics, and transportation," DOE wrote in the tellurium section of its Critical Materials report.

The thermoelectric devices being developed by PyroDelta are demonstrating the potential to be significantly more efficient, withstanding far wider temperature extremes than traditional thermoelectric devices. The higher efficiency means more electricity generated from smaller heat variances, and the ability to withstand wider thermal extremes translates to wider thermoelectric applications.

Improving efficiency and lowering emissions from transportation is one area where PyroDelta sees its tellurium-based thermoelectric generators having an immediate impact.

As a first step, the company is testing the use of its devices to replace both the alternator and radiator in traditional internal combustion engine vehicles.

"A primary market for us currently is in automotive applications as a thermoelectric radiator, generating electricity from the heat differential of the hot liquid going through the thermoelectric pipe while air cools it from the outside," said Docherty.


## advertiser index



Eliminating the alternator, which is driven by the engine, is expected to result in significant fuel savings. There is the prospect that if this device generated enough electricity from engine heat, it could also charge batteries for more efficient hybrid vehicles.

Tellurium-based generators' ability to convert temperature variances to electricity is also showing the potential to improve the efficiency of EVs and solar panels.

PyroDelta is also developing a lightweight and compact thermoelectric generator that leverages the cooling effect of propellor downwash to generate electricity that extends the range of drones for civilian and military use.

UNIVERSITY OF BRITISH COLUMBIA OKANAGAN

**Lithium-tellurium battery cells being tested at UBC Okanagan's Advanced Materials for Energy Storage Lab.**

"Our research and development is aimed at producing a thermoelectric device that fits seamlessly into existing commercial drone systems, without modification," said Docherty. "We believe this feature offers a significant advantage for drone industry adoption and deployment."

The idea of temperature differences created by propellor downwash generating enough electricity to keep a drone flying longer speaks to the wide possibilities of tellurium-based thermoelectric devices.

It also raises the question, "Would a thermoelectric device with one side made from material that conducted heat and the other side made from material that deflects heat be a perpetual clean energy generator?"

So far, however, a tellurium-based perpetual thermoelectric generator has not made the leap from science fiction to science fact.

### Tellurium tech draws prestigious backers

The world-changing potential of the thermoelectric devices being pioneered by PyroDelta is attracting a lot of interest from organizations on a mission to push forward scientific progress in the U.S.

This includes RESOLVE Inc., a Washington, DC-based non-governmental organization focused on solutions that bridge the gap between people and the planet, which has entered into a partnership with PyroDelta to bring the thermoelectric device to market.

"RESOLVE's mission is to forge sustainable solutions to critical social, health, and environmental challenges by creating innovative partnerships," said Docherty. "This new venture aligns perfectly with that mission."

Under this partnership, RESOLVE is securing up to US$29 million to fund a three-phase strategy for manufacturing, marketing, and selling PyroDelta's generators.

Another exciting opportunity is an invitation for PyroDelta to submit a funding proposal to the National Science Foundation's Small Business Innovation Research and Small Business Technology Transfer program.

"The NSF grant would be of great value to us, not only for the dilution-free funding, but also because the NSF is highly respected in the U.S. for backing top-quality innovations," said Docherty. "Their seal of approval would open other doors for collaboration and partnerships."

The National Science Foundation grant being applied for by PyroDelta will support the advancement of its thermoelectric devices to enhance solar systems, especially where space is limited.

"As we've reported over the past six months, the device offers many potential applications for generating clean, renewable energy, particularly for solar, as well as conventional and electric vehicles and a range of industrial uses," said Doherty.

The interest from the National Science Foundation, RESOLVE, and DOD underscores the game-changing clean energy promise offered by the future-leaning technologies being pioneered by First Tellurium and its partners.






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