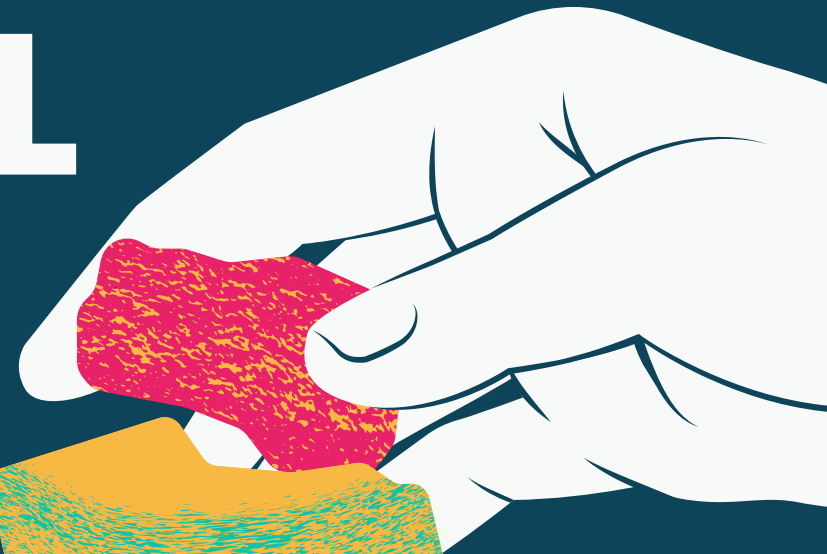
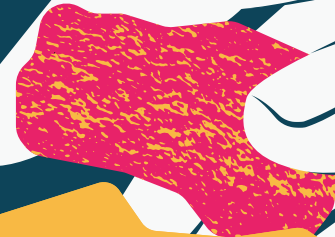
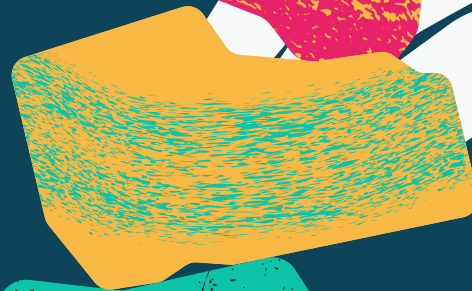
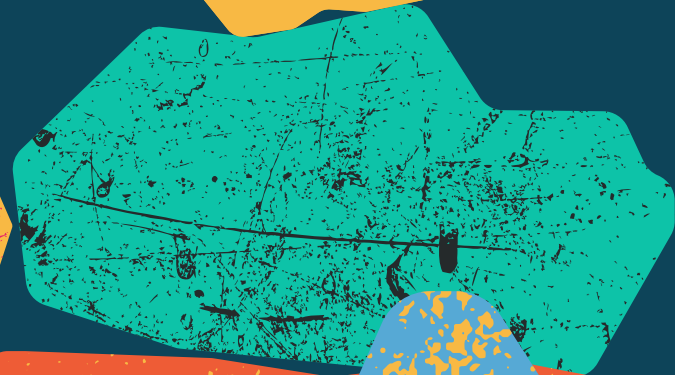
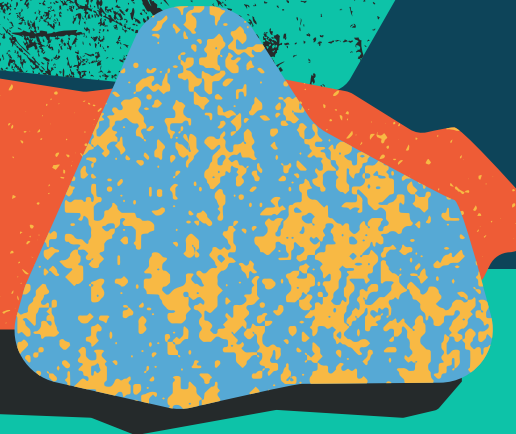
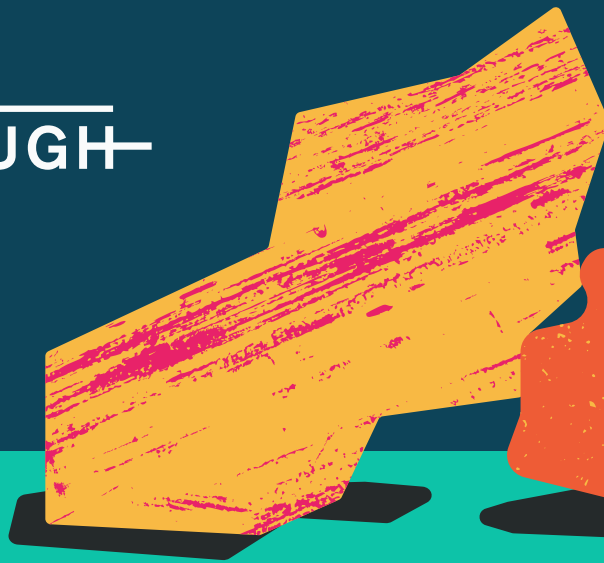
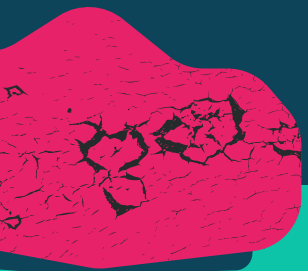
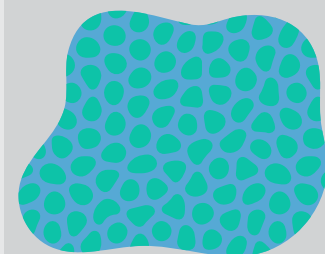
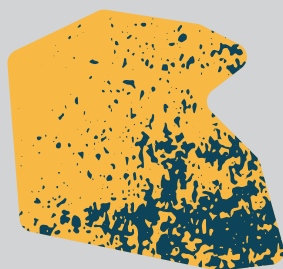
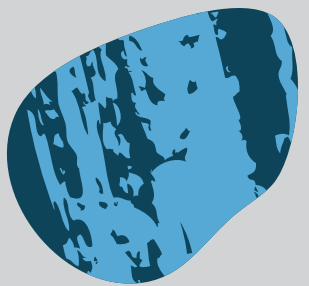
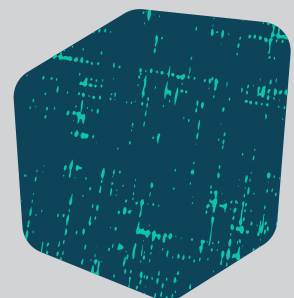
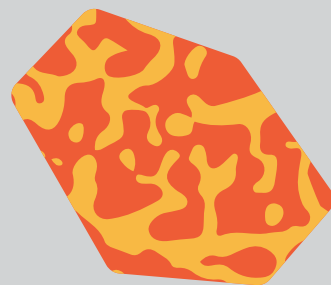
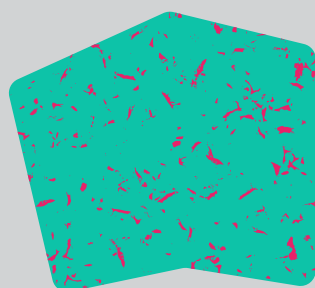
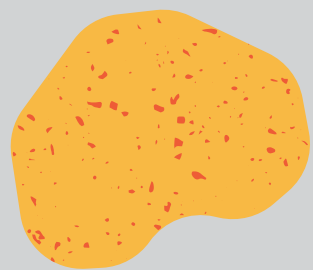
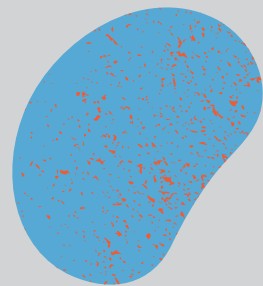
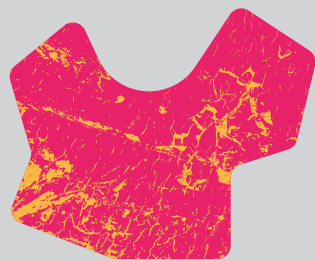
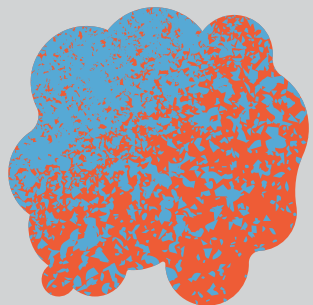
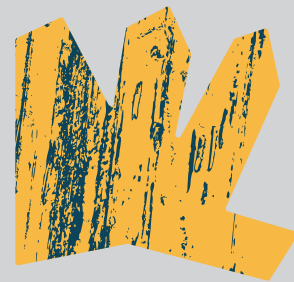
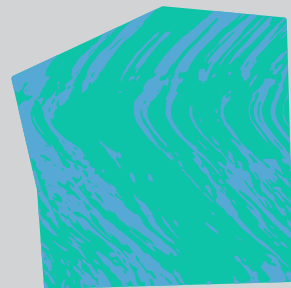
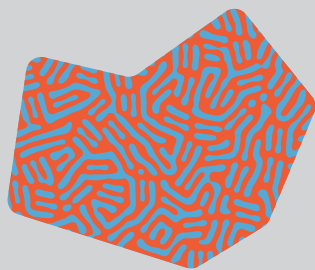
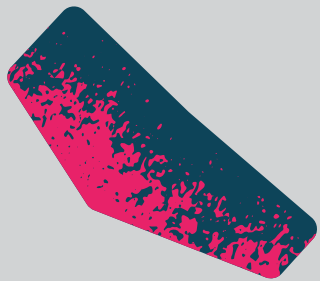
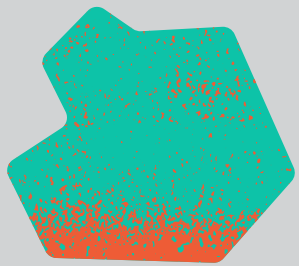


# THE CRITICAL MINERALS PICTURE BOOK

**BREAKTHROUGH**  
INSTITUTE



Seaver Wang, Peter Cook, Ryan Alimento



# WHO WE ARE

The Breakthrough Institute is an environmental think tank that is pro-growth, pro-technology, and pro-development. We are bipartisan and advance durable solutions grounded in empirical and cutting-edge research.



## Seaver Wang

is Director of the Climate and Energy program at the Breakthrough Institute. He holds a PhD in Earth and Ocean Sciences from Duke University and a BA in Earth Sciences from the University of Pennsylvania. Seaver's work on energy systems and mineral supply chains has been published in the journals *Joule*, *Applied Energy*, and *Nature Communications*. He contributed a chapter on *Mining the Deep Sea: A New Minerals Frontier* to the book volume *Critical Minerals and the Future of the U.S. Economy* published by the Center for Strategic & International Studies and has testified before the U.S.-China Economic and Security Review Commission on seafloor minerals. His research has been cited by members of Congress and by the *Washington Post*, *Associated Press*, *Bloomberg*, *Axios*, *Business Insider*, *Financial Times*, and *S&P Global*.



## Peter Cook

is an analyst on the Climate and Energy program at the Breakthrough Institute. He holds an MS and BS in Earth Sciences from the University of Michigan. Before joining the Breakthrough Institute, Peter worked on drilling rigs and as an exploration geologist for the mining industry. Peter's work on critical minerals and industrial supply chains has been published in the journals *Minerals*, *Environmental Science and Technology*, and *Nature Communications*. His work has also been cited by members of Congress and by *Grist*, *Our World in Data*, and *MIT Technology Review*.



## Ryan Alimento

is an analyst on the Climate and Energy program at the Breakthrough Institute. He holds a BS in chemical engineering and MS in green technologies engineering from the University of Southern California. He works on energy innovation and industrial policy and has been quoted in the *Heatmap News* and *Reuters*, and has had his research presented to the board of the Fusion Industry Association.

# FOREWORD

To effectively develop a national critical minerals policy agenda, policymakers can no longer afford to think about mining and metals in broad and general terms.

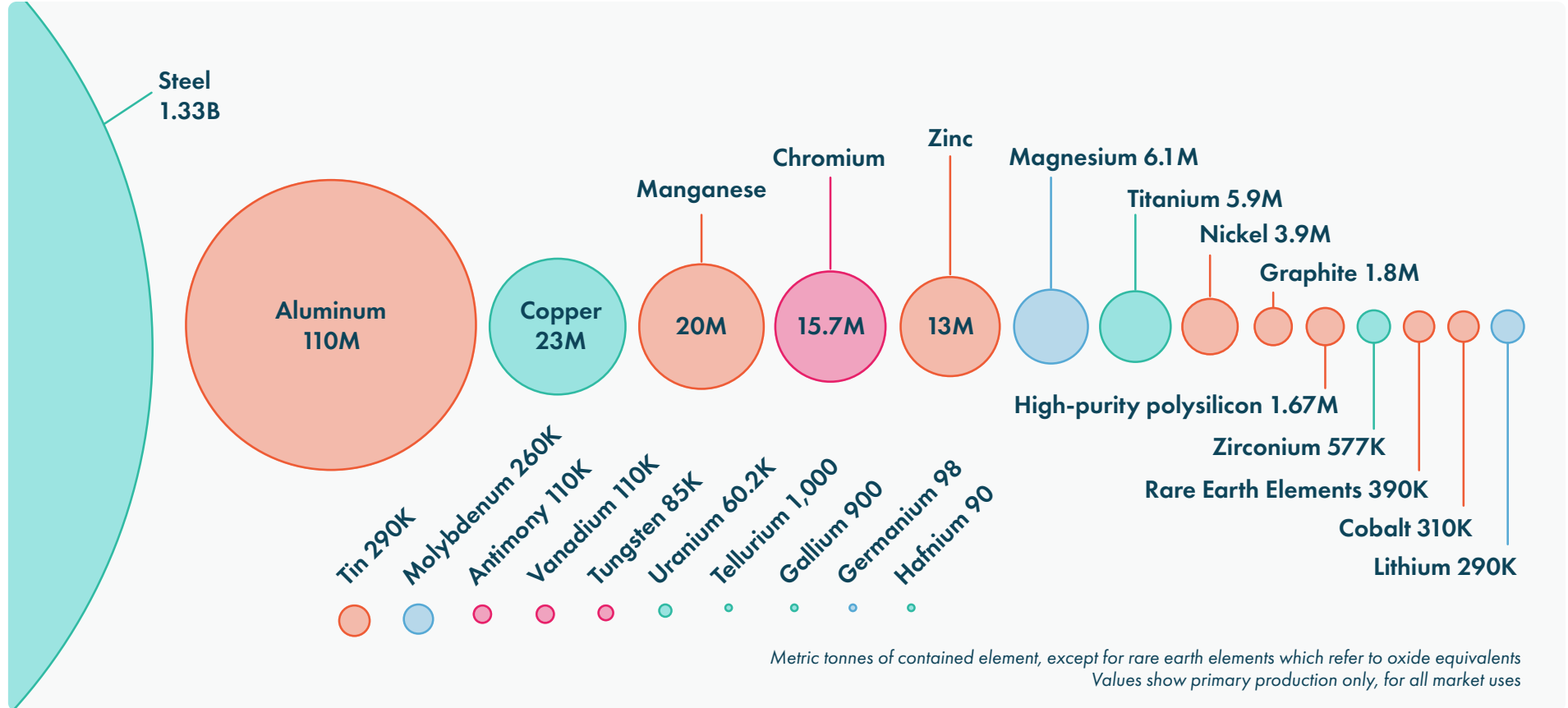
With no less than 60 minerals now listed by the Department of the Interior's U.S. Geological Survey as critical minerals, policymakers and staff must start considering what America's objective should be for each given supply chain. The overarching goal of the federal government over the next ten to fifteen years should be to remove as many minerals from the critical minerals list as possible, rather than continue adding to it.

For each commodity, strategies should account for current U.S. strengths and weaknesses along that supply chain, understand shared links between certain minerals whose production may be intertwined, and group minerals into categories based on similar goals or characteristics.

This booklet seeks to provide a first-order national strategy outline for each of 22 different critical minerals including rare earths, together with high-purity polysilicon, steel, and molybdenum. In total, our overview covers 38 USGS-designated critical minerals, more than half of the 60 entries on the 2026 USGS list.

We hope this publication can serve as a valuable resource for policymakers, researchers, and business leaders contemplating the path towards greater American critical mineral supply chain security. Success will equip our nation with powerful technologies that can unlock energy abundance, economic power, and a brighter future for the environment and for the American people.

# Critical Minerals: Markets Both Big and Small



Inside the bin of “mineral commodities” are a wide assortment of ores, metals, and chemicals of different qualities and market volumes. A producer of fiber optic cable will use a micrometer-thick coating of germanium, and computer chip fabs make semiconductors by layering one atom of hafnium at a time. Meanwhile, in just two weeks, the U.S. makes enough aluminum cans to stretch to the Moon and beyond.

The most appropriate policy tools for bolstering U.S. supply security will change based on commodity market size. Each total market in turn reflects various geologic resources, industrial processes, end-use technologies, and market dynamics, many of them crucial for national strategic needs and to the livelihoods of American businesses and workers.

# Setting Specific Goals for Specific Minerals

America's potential to seize global mineral leadership depends on many factors including the quantity of domestic deposits, the presence of key downstream industries, and the mineral's overall strategic value. The nation requires some minerals that it is not sufficiently endowed in to produce at scale, while abundant geologic resources for other minerals could allow the U.S. to not only become self-sufficient but also to recapture shares of global markets.

We divide the 25 minerals covered in this booklet into four categories based on domestic prospects and national importance. Accompanying each category is a simple goal statement that we hope can better orient a U.S. critical minerals strategy towards a set of clear, well-defined visions.

## Dominance minerals

(become or remain a major world producer)

- Germanium
- Lithium
- Magnesium
- Molybdenum

## Independence minerals

(secure American strategic needs)

- Copper
- Gallium
- Manganese (seafloor)
- Rare earth elements
- Steel
- Tellurium
- Titanium
- Uranium
- Zirconium & Hafnium

## Revitalization minerals

(filling capability gaps and stimulating growth)

- Aluminum
- Cobalt
- Graphite
- High-purity polysilicon
- Manganese (conventional)
- Nickel
- Tin
- Zinc

## Stockpiling minerals

(supporting key industries during major crisis)

- Antimony
- Chromium
- Vanadium
- Tungsten

# POLICY LEVERS

A number of repeated patterns emerge from our analysis that highlight needs shared across multiple critical mineral supply chains.



## Resilient markets

Price volatility and market manipulation dissuades investments needed to fill many supply chain gaps. Even commodities subject to Chinese export controls require assurance against the possibility of China resuming exports to undercut projects under development.



## Demand pull policies

Manufacturers need reasons to buy non-Chinese materials. Vital specialty materials like transformer electrical steel, superalloys, or high-assay low-enriched uranium fuel require clear demand signals to drive necessary investment.



## Mineral exploration

For some minerals, promising resources in the United States could unlock competitive new production or commercialize new unconventional resources like geothermal brines, solution mining, legacy mine tailings, or recovered byproducts.



## Permitting improvements

Arbitrary federal land management decisions and legal technicalities obstruct a number of promising mine projects. Procedural reforms can alleviate bureaucratic hurdles without any changes to performance-based environmental standards.



## Research & Development

Innovation policies can help develop new approaches to processing, metallurgy, manufacturing, and materials substitution. R&D efforts in recycling can also produce considerable critical minerals from feedstocks like electric arc furnace dust and recycled batteries.



## International cooperation

In many cases, the United States can supplement if not secure supplies of critical minerals or metals by partnering with allied and partner nations to develop promising overseas projects.



## Strategic stockpiling

For a select few minerals like chromium, vanadium, antimony, and tungsten, U.S. domestic prospects are highly limited and downstream needs are amenable to stockpiling as a primary solution to mitigate supply chain disruptions.



## Build key projects

Some supply chain vulnerabilities require targeted attention at a particular step to fill a specific bottleneck or to maximally leverage domestic opportunities. Projects may utilize mature technologies or need to demonstrate and commercialize new approaches.



12 Aluminum



20 Lithium



28 Tellurium



13 Antimony



21 Magnesium



29 Tin



14 Chromium



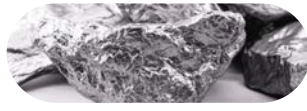
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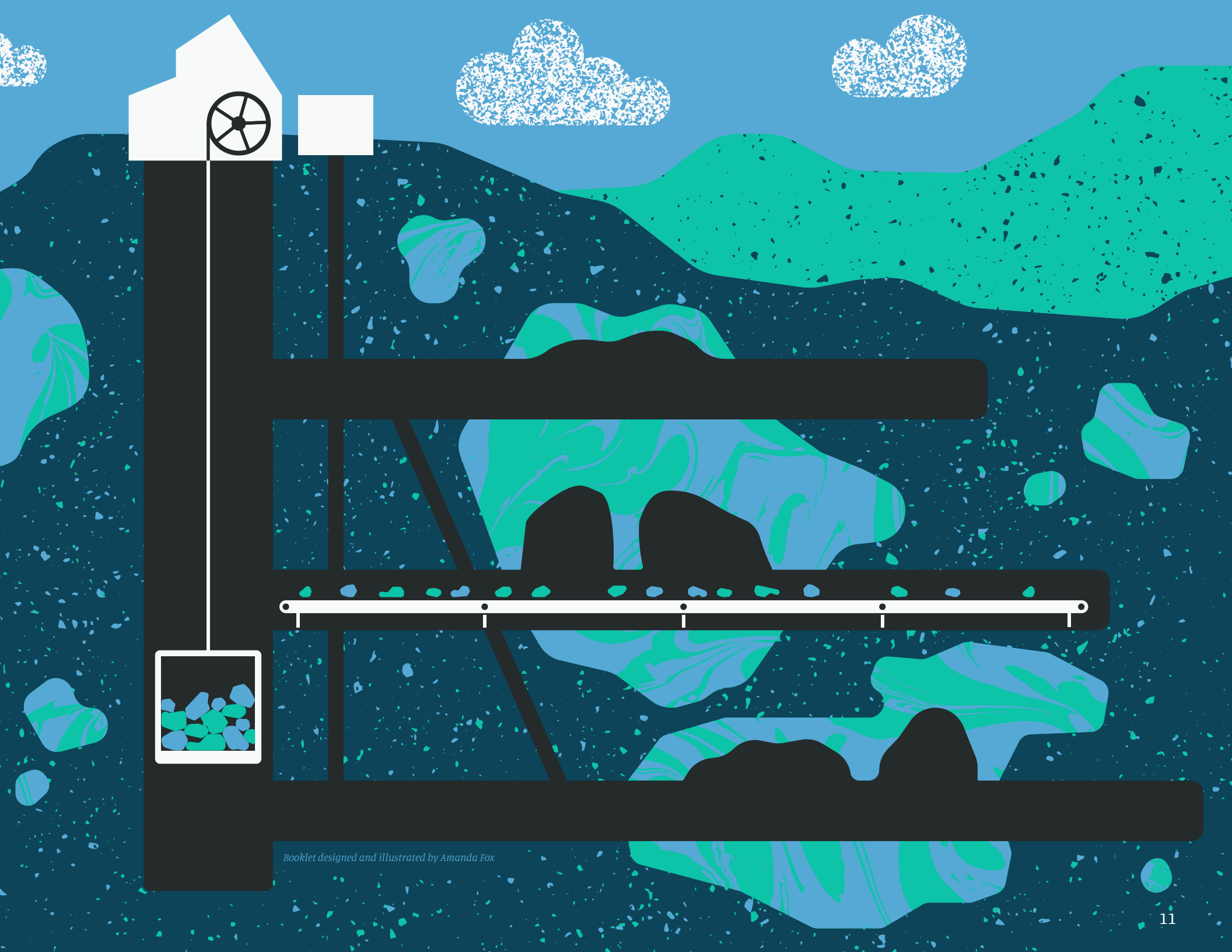
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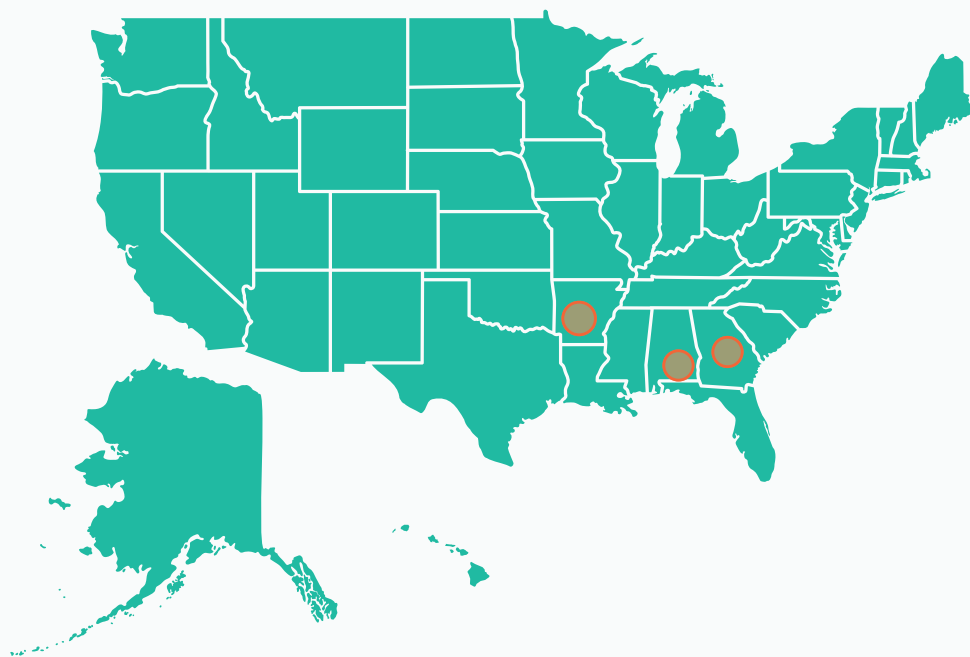


*Booklet designed and illustrated by Amanda Fox*

# Aluminum

- Support aerospace, electric grid, auto making, defense, and construction sector needs
- Build electrolytic metals knowledge for magnesium, rare earths, steel, and beyond

Notable aluminum deposits



## Recommendations



### Research & Development

Maintain strong recycled metal production



### Build key projects

Build new lines with high-purity sections



### Research & Development

Expand electrolytic magnesium as an aluminum alternative



### Resilient markets

Ensure affordable industrial power

## Critical Links

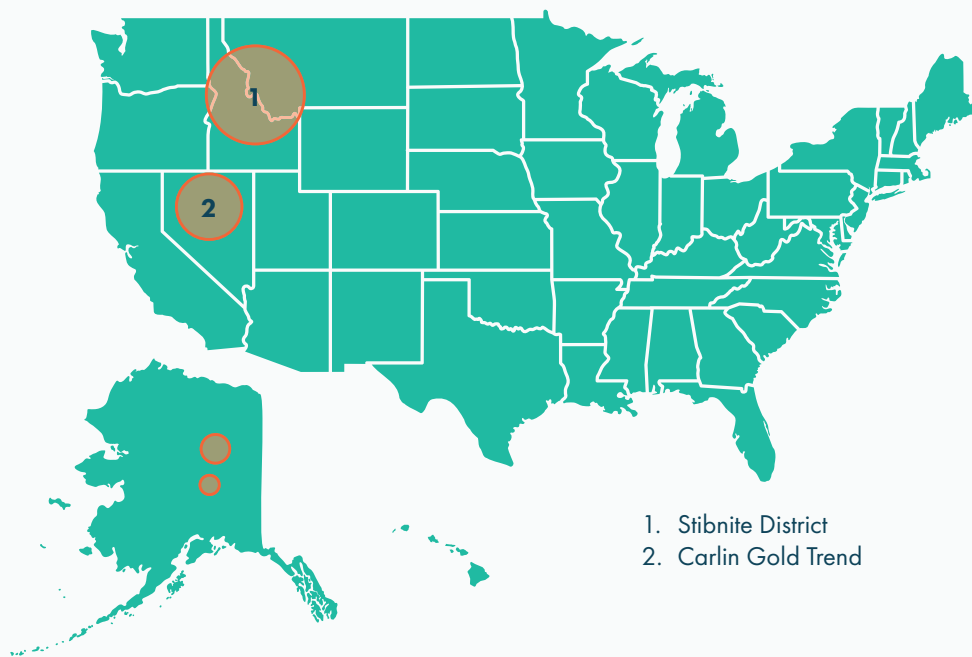
- Gallium can be recovered as a byproduct of alumina production
- Magnesium, copper, silicon needed for Al alloys
- Aluminum may be recoverable from non-bauxite ores via novel techniques

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
100% (metallurgical bauxite) 71% (alumina) 60% (aluminum)	Low	No	Yes	20% (bauxite) 62% (alumina) 61% (aluminum)

# Antimony

- Support military munitions, lead-acid batteries, consumer goods, semiconductors
- Strategically stockpile antimony and make plans to scale production during times of conflict

Notable antimony deposits



1. Stibnite District
2. Carlin Gold Trend

## Recommendations



### Mineral exploration

Explore resources in Alaska, Idaho, Montana, Nevada



### Build key projects

Expand midstream production of oxides, metals, military-grade trisulfide



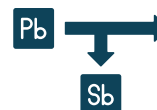
### Permitting improvements

Develop plans to scale production in times of national conflict



### Strategic stockpiling

Fill ammunition depots and national defense stockpile with help of domestic production



### Build key projects

Equip secondary lead smelters with antimony recovery capabilities

## Critical Links

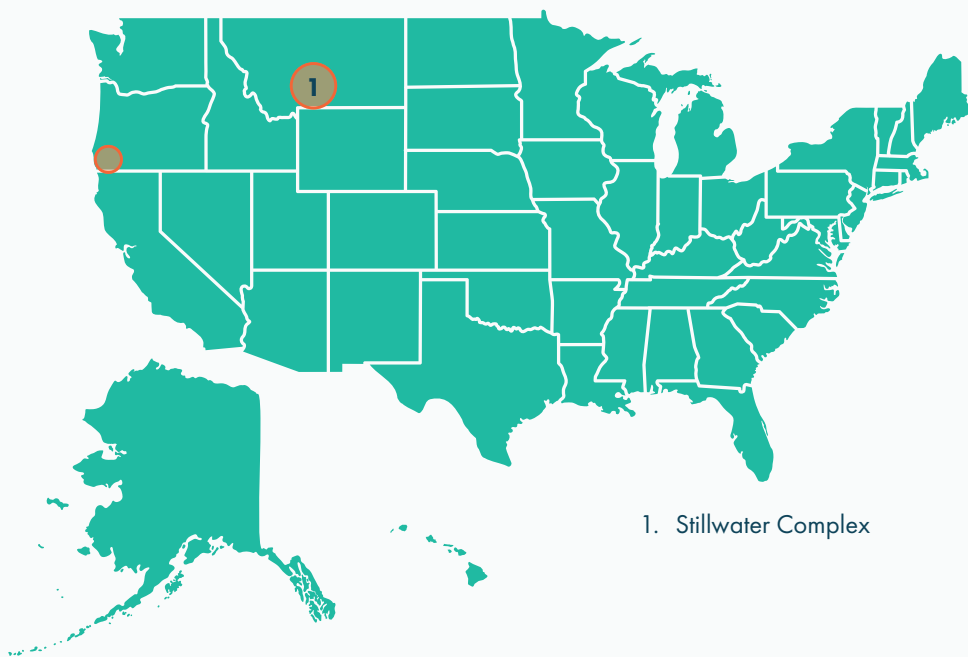
- Can be recovered alongside gold and lead

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
91%	Medium	Yes	Yes	36% (mining)

# Chromium

- Stockpile for steel and defense sector needs during times of national crisis
- With few deposits and no mine, ferrochromium, or metal production, U.S. prospects limited

Notable chromium deposits



1. Stillwater Complex

## Recommendations



### Strategic stockpiling

Maintain strategic stockpiles



### International cooperation

Co-develop secure overseas mining and processing



### Mineral exploration

Prioritize exploration of western Montana



### Research & Development

Improve recycling rates and techniques

## Critical Links

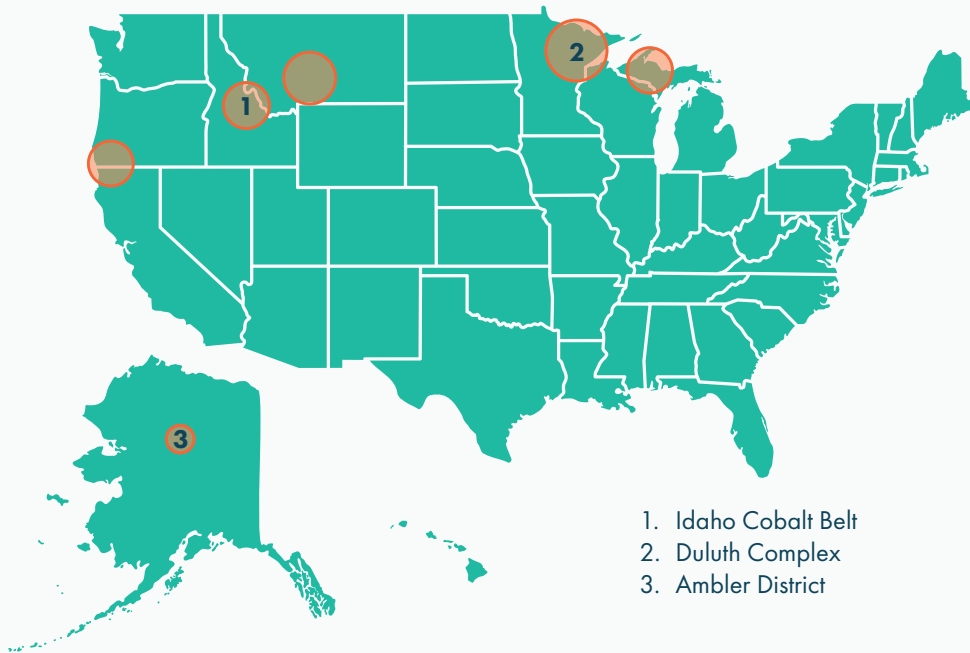
- Used in superalloys with cobalt, manganese, nickel
- Used in stainless steels with nickel and manganese

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
77%	Low	No	No	<1% (mining) 49% (processing)

# Cobalt

- Support batteries, military, gas turbines, advanced nuclear, high-temperature cobalt samarium permanent magnets
- Fill midstream supply chain gaps in processing and battery chemicals

Notable cobalt deposits



- Idaho Cobalt Belt
- Duluth Complex
- Ambler District

## Recommendations



### Resilient markets

Build markets resilient to Chinese price volatility



### Build key projects

Develop secure hydroxide, metal, and battery-grade sulfate midstream projects



### Build key projects

Develop deposits in Minnesota, Michigan, Montana, Idaho



### Permitting improvements

Two seafloor nodule recovery operations could deliver U.S. cobalt independence

## Critical Links

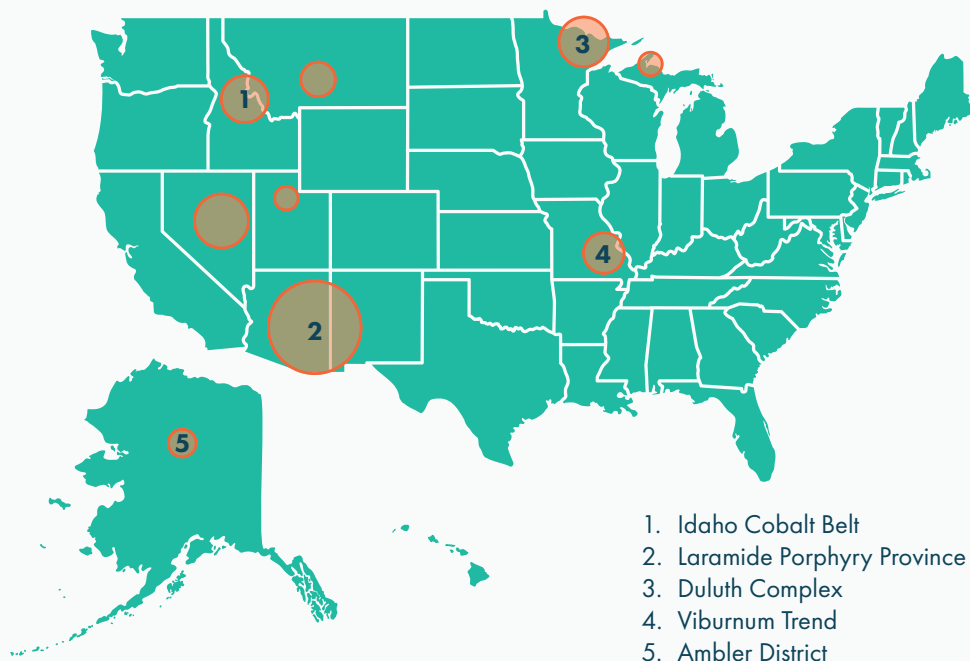
- Often co-occurs with copper and nickel
- Molybdenum, tungsten, yttrium, and others in superalloys and specialty steels
- Seafloor nodule resources

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
79%	Medium to High	Yes	No	<1% (mining) 82% (processing)

# Copper

- Improve competitiveness to remain a significant global copper ore and metal producer
- Avoid tariff-induced diversion of allied and partner copper ore and metal exports to China

Notable copper deposits



## Recommendations



### Permitting improvements

Alleviate permitting barriers for promising domestic mines



### Research & Development

Support innovative copper processing routes to help enable new smelters



### Research & Development

Improve domestic scrap collection and recycling, attract scrap imports



### Mineral exploration

Explore unconventional production like in situ recovery or old tailings

## Critical Links

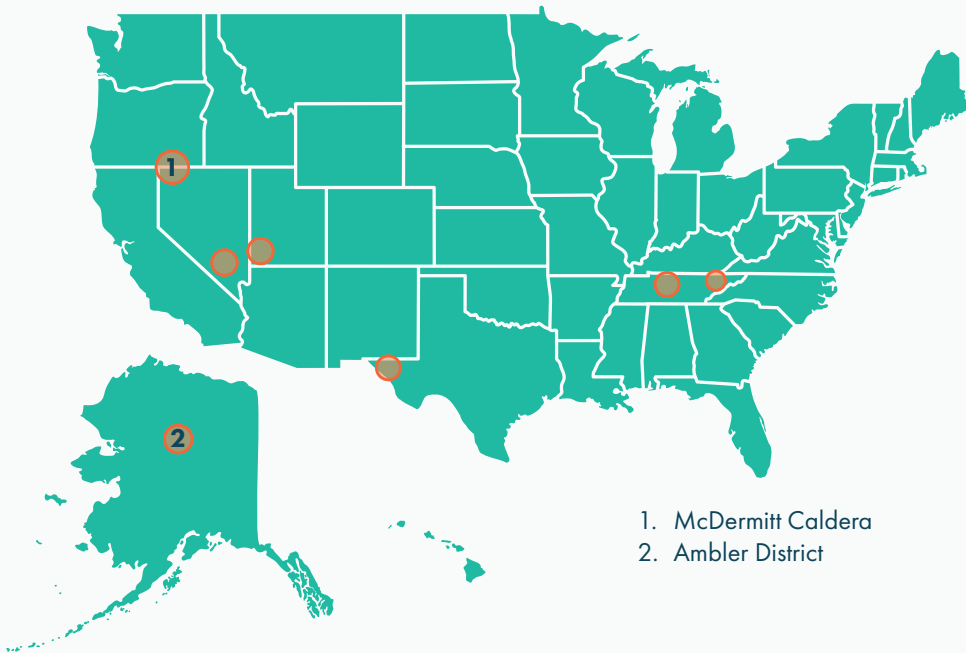
- Tellurium and selenium are byproducts of copper smelting
- Often co-occurs with nickel, cobalt, and molybdenum
- Likely co-produced from seafloor nodule resources

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
57%	Medium to High	Yes	Yes	8% (mining) 48% (processing)

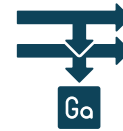
# Gallium

- Support materials for next-generation semiconductors, factory automation, data center power supplies
- Work with partners towards global mine-to-semiconductor supply chain diversification

## Notable mineral deposits with gallium byproduct potential



## Recommendations



### Build key projects

Develop gallium recovery at domestic and allied zinc smelters and alumina refineries



### Research & Development

Fund R&D to explore direct gallium extraction methods



### Demand pull policies

Expand domestic trimethyl gallium, high-purity gallium, and GaAs and GaN semiconductor wafer manufacturing



### Resilient markets

Use financial tools to secure investments against lifting of Chinese export controls

## Critical Links

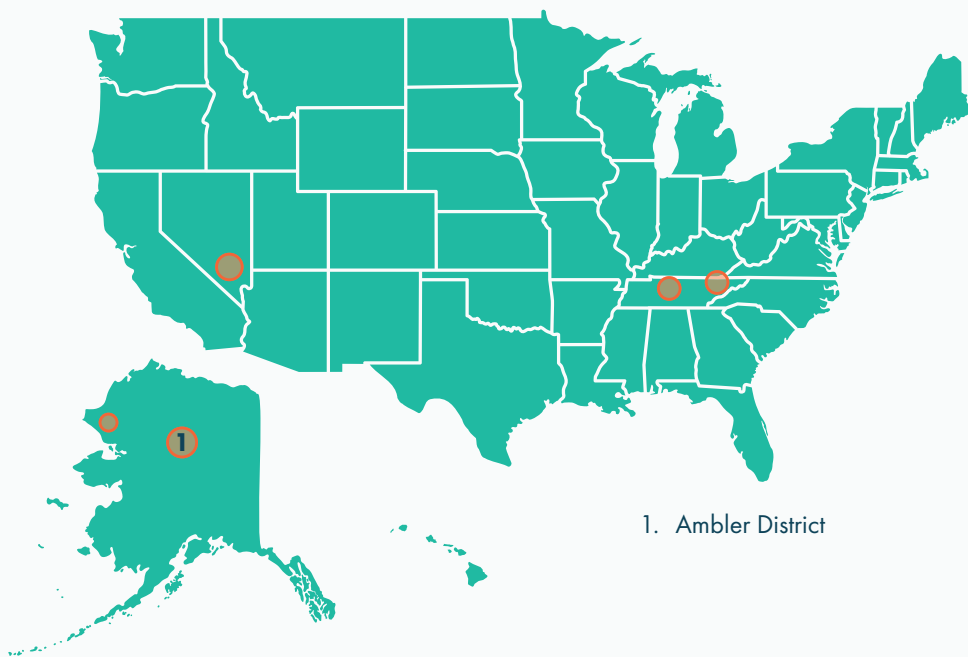
- Recovered as a byproduct of alumina processing
- Recovered as a byproduct of zinc processing
- Cadmium, indium, and germanium can also be recovered as zinc processing by-products

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
100%	Medium	No	No	99% (production from refineries)

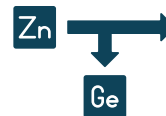
# Germanium

- Support fiber optics, night-vision lenses, satellite solar cells
- Fill upstream supply chain gaps and bolster domestic fiber optics industry

## Notable mineral deposits with germanium byproduct potential



## Recommendations



### Build key projects

Support allied and partner zinc smelter byproduct recovery and metal/oxide refining



### Research & Development

Continue and expand Defense Logistics Agency Germanium Recycling Program



### Research & Development

Boost yields from zinc processing and fiber optic and infrared lens recycling



### Build key projects

Establish a mine-to-fiber optic supply chain to serve data center demand

## Critical Links

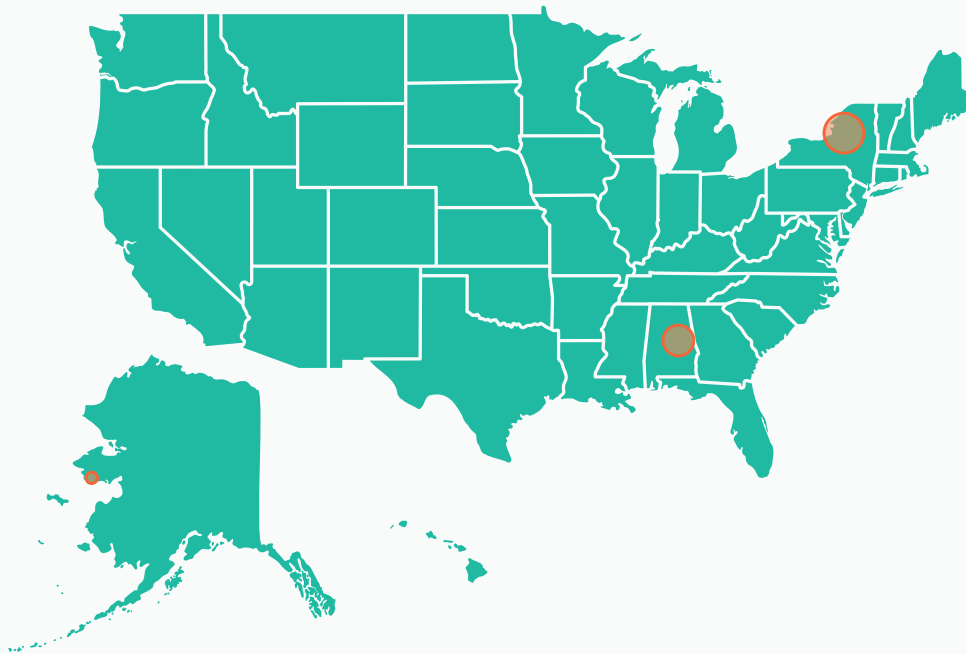
- Recovered as a byproduct of zinc processing
- Cadmium, indium, and gallium can also be recovered as zinc processing by-products

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
>50%	Medium	Yes (unrecovered from zinc ore)	No	68% (production from refineries)

# Graphite

- Diversify battery graphite material supplies
- Revitalize innovation and expertise in battery anode materials and processing

Notable graphite deposits



## Recommendations



**Build key projects**

Develop synthetic graphite capacity



**Build key projects**

Mine promising U.S. natural graphite deposits



**Resilient markets**

Ensure affordable industrial power



**Research & Development**

Pursue alternatives like graphite from biomass, graphene, silicon, and lithium metal



**Resilient markets**

Build markets resilient to Chinese price volatility

### 🔗 Critical Links

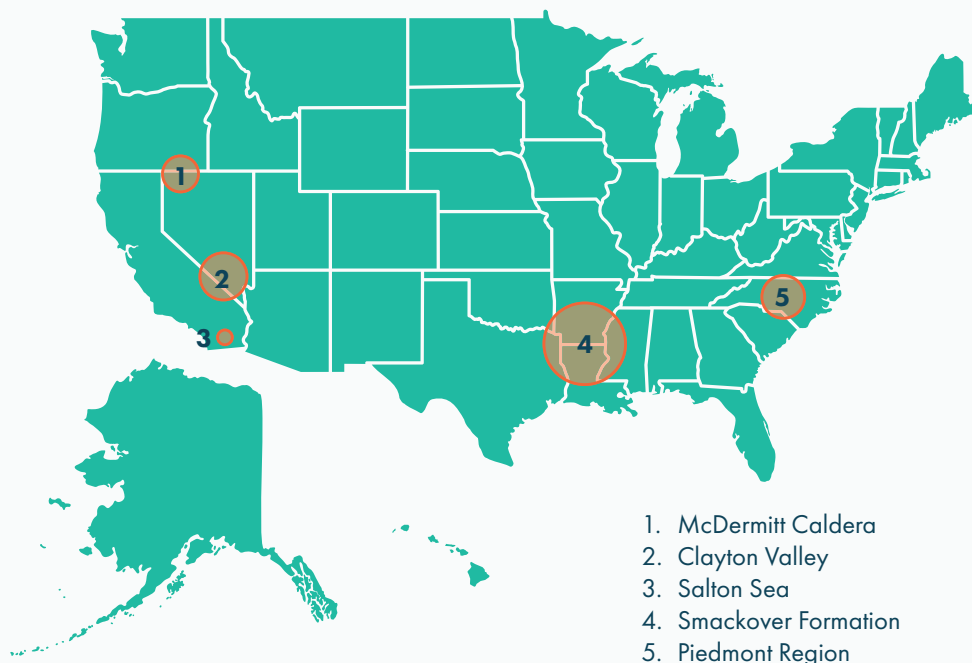
- Supports metallurgical graphite electrodes used for steel, aluminum, rare earths, nickel, silicon, magnesium, and more

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
100%	Low	No	Yes	78% (mining) 92% (synthetic battery-grade)

# Lithium

- Support domestic battery manufacturing sector
- Become a major global lithium producer and refiner

Notable lithium deposits, including brine resources



## Recommendations



**Build key projects**  
Support direct extraction from subsurface brines



**Research & Development**  
Proactively invest in recycling



**Mineral exploration**  
Support exploration for domestic spodumene ores



**Build key projects**  
Build refining with lithium carbonate <-> lithium hydroxide conversion ability



**Resilient markets**  
Build markets resilient to Chinese price volatility

## Critical Links

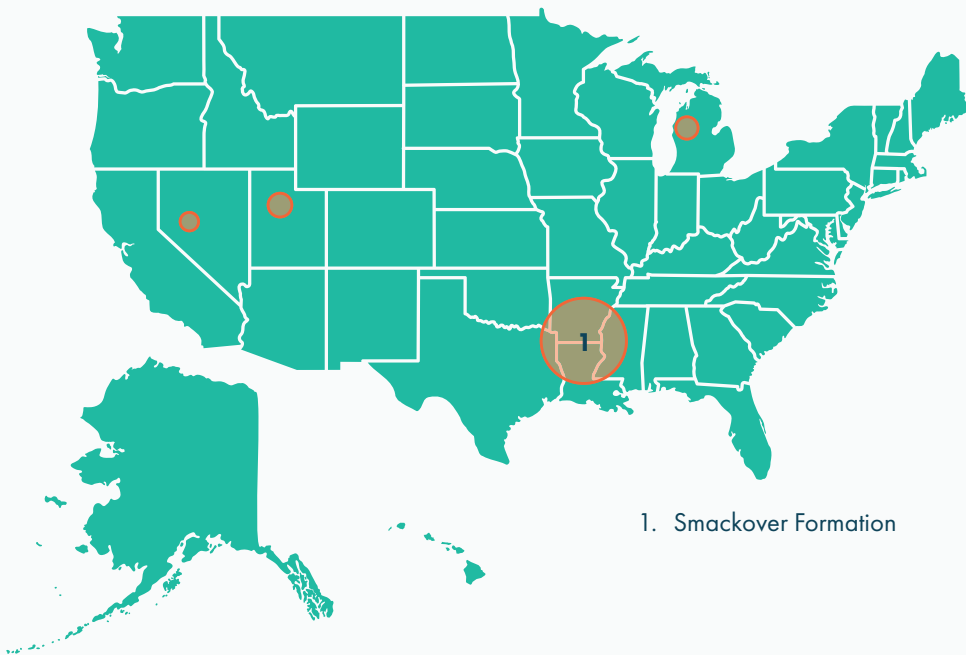
- Li-7 for some advanced nuclear reactors
- Li-6 to breed tritium for nuclear arsenal and for fusion

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
>50%	High	Yes	Yes	21% (mining) 73% (refining)

# Magnesium

- Break China's magnesium monopoly and leapfrog to new production techniques
- Secure supply needs for U.S. metals industries and defense

Notable magnesium deposits, including brine resources



## Recommendations



### Build key projects

Prioritize electrolytic production via seawater and geothermal brines



### Resilient markets

Ensure affordable industrial power



### Research & Development

Research magnesium recycling



### Resilient markets

Maintain magnesium tariffs on China



### Demand pull policies

Encourage downstream automotive and aerospace demand

## Critical Links

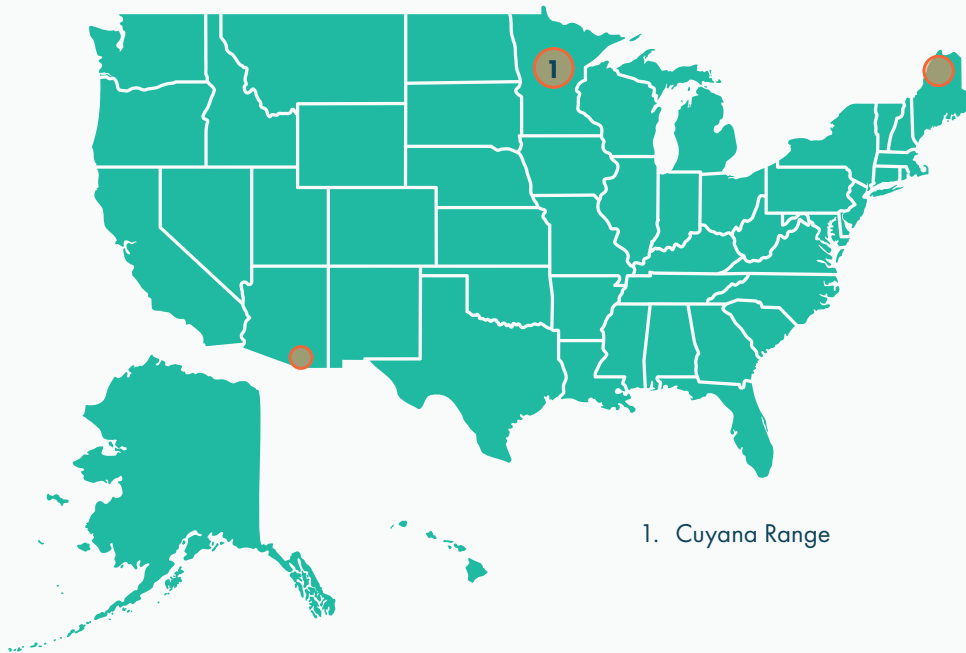
- Required for aluminum alloys, steelmaking, titanium smelting

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
>75%	Medium to High	Yes	Yes	61% (mining) 86% (processing)

# Manganese

- Support domestic steelmaking and maintain stockpiles for times of national crisis
- Ensure refined manganese metal supply for battery and other high-value applications

Notable manganese deposits



## Recommendations



### International cooperation

Prioritize partnerships with Australia, South Africa



### Build key projects

Develop secure electrolytic manganese metal production



### Mineral exploration

Explore recovery from unconventional resources, low grade ores, geothermal brines



### Permitting improvements

One seafloor nodule recovery operation could deliver U.S. manganese independence

## Critical Links

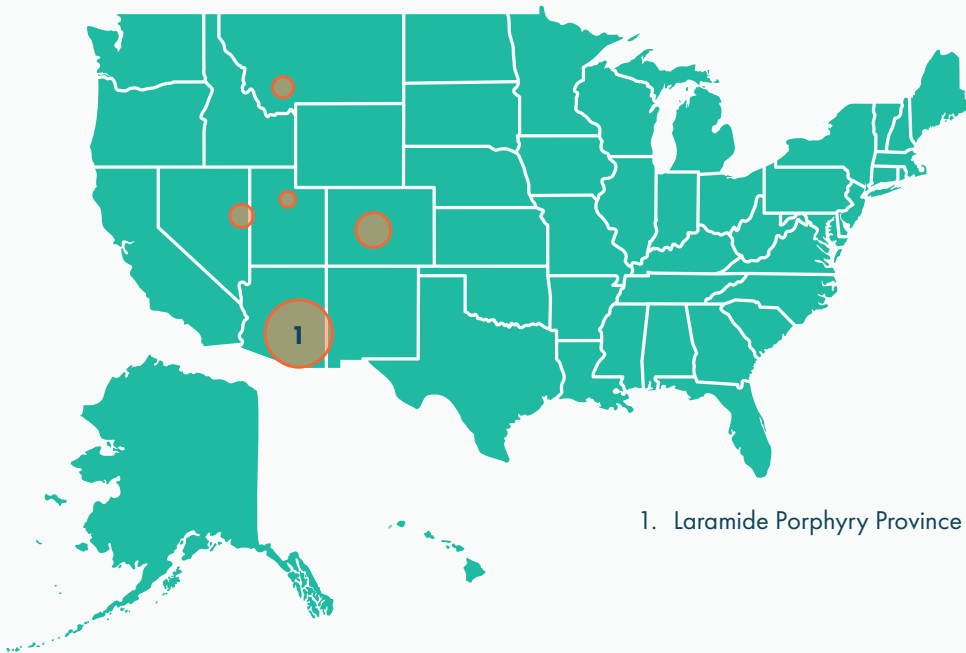
- Magnesium, vanadium, nickel, chromium, and zinc in common steels
- Seafloor nodule resources

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
100%	Low	No	Yes	4% (mining) 69% (processing)

# Molybdenum

- Support semiconductor, oil & gas, manufacturing, aerospace, nuclear sectors
- Fill downstream supply chain gap for increasingly important high-grade powder

## Notable molybdenum deposits



## Recommendations



### Build key projects

Fill supply chain gaps for purifying metal into high-grade powder, oxide



### Resilient markets

Keep existing mines and smelters resilient from global market volatility



### Research & Development

Support upgrades, expansions to producers of downstream products



### Strategic stockpiling

Stockpile select products needed for defense, semiconductor industries

## Critical Links

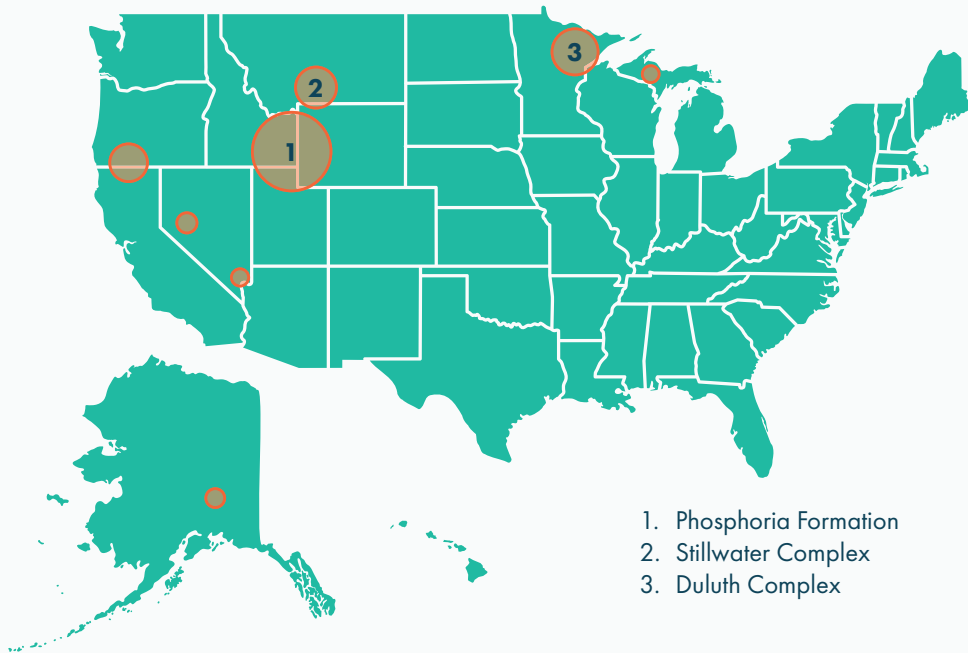
- Often co-produced with copper
- Cobalt, tungsten, yttrium, and others in superalloys and specialty steels

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
Net Exporter	High	Yes	Yes	37% (mining)

# Nickel

- Secure access for stainless steel, batteries, and superalloys
- Maximally leverage domestic resource opportunities

Notable nickel deposits



## Recommendations



**Build key projects**

Support new Michigan and Alaska mine projects



**Build key projects**

Fill downstream supply chain gaps, particularly battery-grade nickel sulfate



**Research & Development**

Pilot cheaper & cleaner processing techniques



**Research & Development**

Promote nickel-manganese-cobalt battery recycling



**Permitting improvements**

Facilitate permitting for in-progress and stalled Minnesota projects

### Critical Links

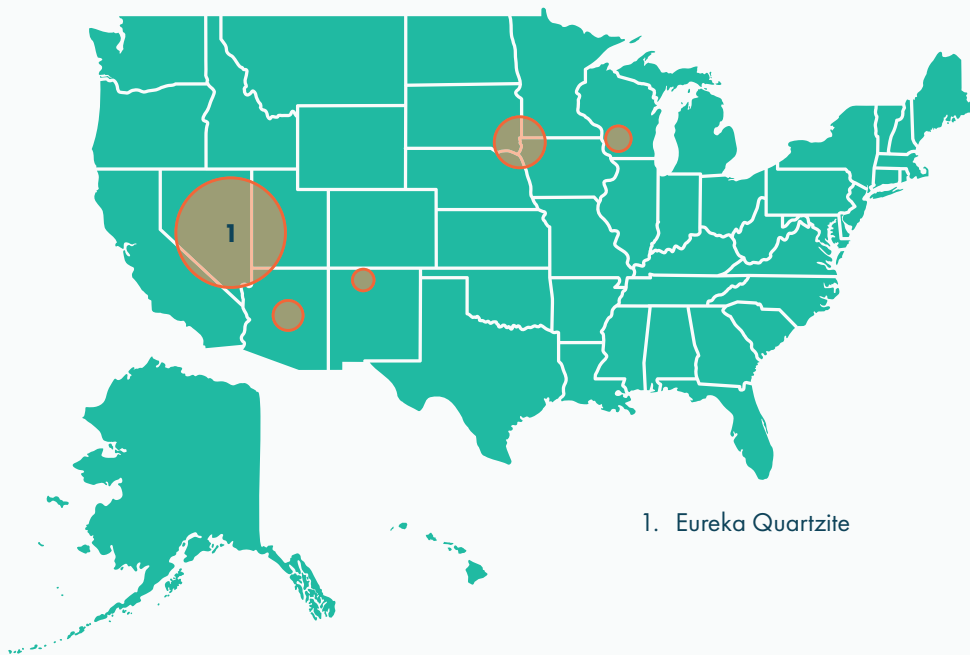
- Often co-occurs with copper and cobalt
- Magnesium, vanadium, manganese, chromium, and zinc in common steels.
- Seafloor nodule resources

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
41%	Low to Medium	Yes	No	3% (mining) 22% (processing)

# High-purity polysilicon

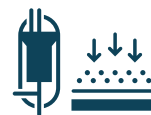
- Ensure secure supply for domestic semiconductor chip and solar cell manufacturing
- Work with allies and partners to diversify global metallurgical silicon, polysilicon, and silicon wafer capacity

Notable silica deposits for polysilicon production



1. Eureka Quartzite

## Recommendations



### Research & Development

Commercialize more efficient fluidized bed reactor and gas-to-wafer processes



### Resilient markets

Maintain tariffs on Chinese polysilicon and expand allied bans on Xinjiang polysilicon



### Resilient markets

Ensure affordable industrial power



### Resilient markets

Extend investment and production tax credits for polysilicon and ingot/wafer facilities

## Critical Links

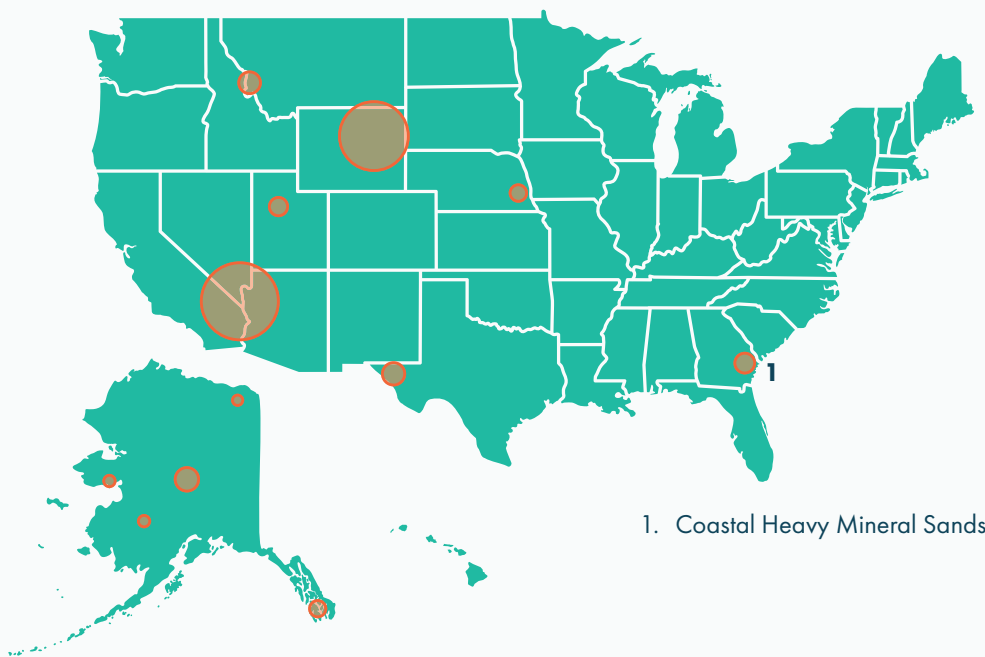
- Metallurgical silicon for aluminum alloys
- Ultrapure quartz required for ingot-pulling

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
>50%	Medium to High	Yes	Yes	87% (processing)

# Rare Earth Elements

- Diversify global rare earth supplies, magnet-making, related manufacturing
- Continue building domestic vertically-integrated supply chains to support U.S. auto, energy, telecoms, semiconductor, and defense needs

Notable rare earth element deposits



## Recommendations



### Build key projects

Develop ionic clay adsorption and heavy mineral sand deposits



### Resilient markets

Use financial tools to de-risk separation and oxide-to-magnet capacity



### Research & Development

Develop improved rare earth separation and metallization techniques



### Mineral exploration

Task DOE to assess unconventional resources: iron, coal deposits, bauxite, phosphates, geothermal brines



### International cooperation

Coordinate with allied manufacturers to build responsible ex-China supplier networks

## Critical Links

- Potentially co-produced from uranium mining
- Potentially co-produced with zirconium, hafnium, and titanium from heavy mineral sands

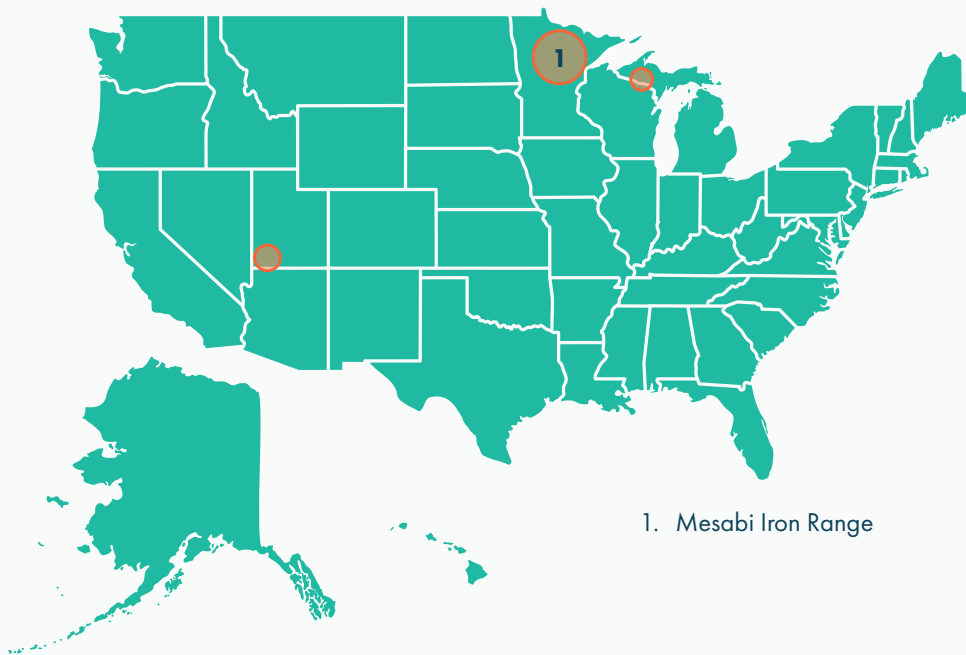
*\*Above assumes continued federal support for rare earth producer deals*

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
67% (100% for heavy rare earth elements)	Medium	Yes	Yes (light rare earth elements only)	69% (mining) 90% (processing)

# Steel

- ▶ Revitalize process knowledge for superalloys, specialty steels, precision metalworking, heavy forging
- ▶ Establish demand pull for critical minerals used mostly in steelmaking

Notable iron deposits for steelmaking



## Recommendations



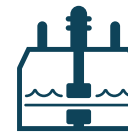
### Build key projects

Invest in electric arc furnaces for primary steel with upstream iron ore upgrading



### Demand pull policies

Leverage government procurement to signal demand for specialty steel and superalloy production



### Research & Development

Fund R&D, pilot projects for molten oxide electrolysis and other novel techniques



### Research & Development

Maximize steel production from recycled scrap

## Critical Links

- Magnesium, vanadium, nickel, manganese, chromium, and zinc in common steels
- Cobalt, molybdenum, tungsten, yttrium, and others in superalloys and specialty steels

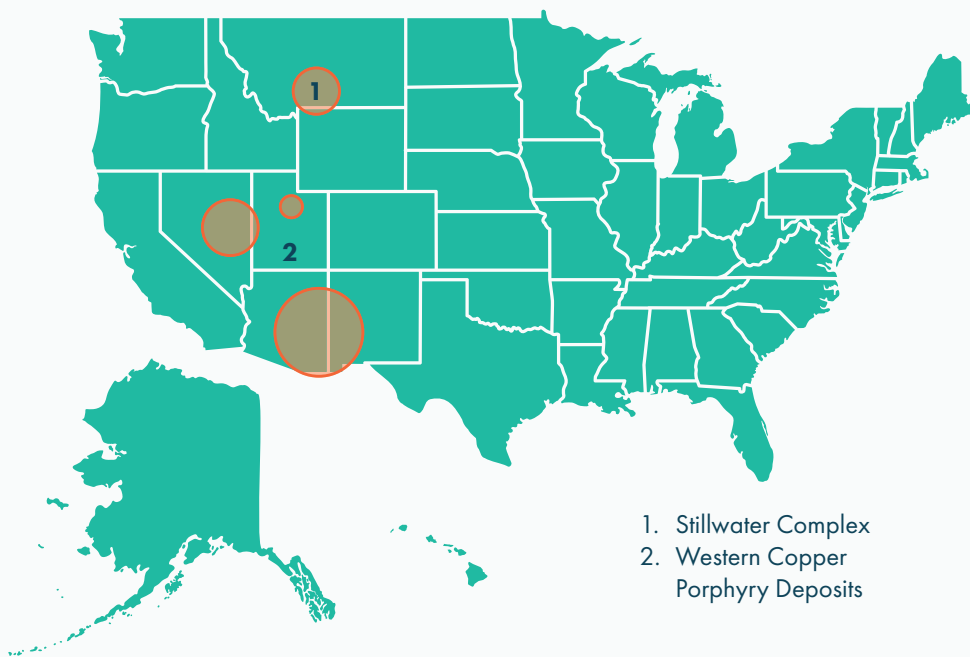
Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
13%	High	Yes (iron ore)	Yes	52%

# Tellurium

Courtesy of First Solar

- Support advanced thin-film solar technologies with strategic space and satellite applications
- Capture full domestic and allied byproduct recovery potential and expand midstream processing

Notable deposits with tellurium potential



1. Stillwater Complex
2. Western Copper Porphyry Deposits

## Recommendations



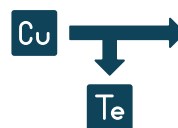
Build key projects

Support robust domestic copper production



Research & Development

Greatly improve tellurium recovery at mills and smelters



Build key projects

Develop domestic copper telluride processing and tellurium dioxide processing



Build key projects

Develop low-grade tellurium metal production

## Critical Links

- Recovered as byproduct of copper and lead smelting
- Significant domestic recycling expertise

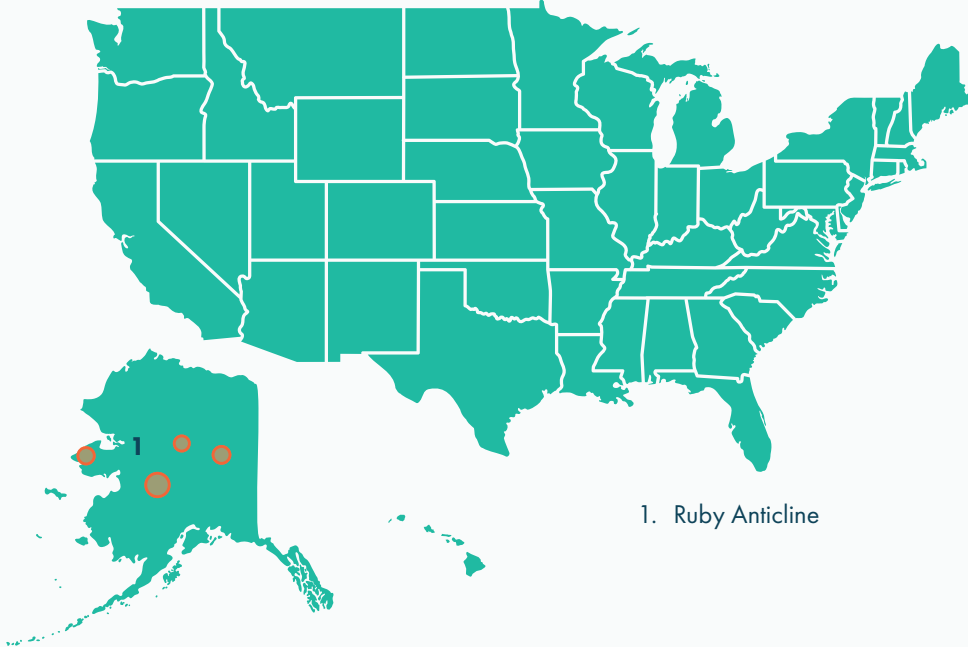
Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
>25%	Medium to High	Yes	Yes (high-purity refining only)	80% (production from refineries)



# Tin

- Support aerospace, automotive, construction, electronics, and manufacturing industries
- Diversify imports across refined tin, scrap, and ores to mitigate supply chain risks

## Notable tin deposits



1. Ruby Anticline

## Recommendations



### Mineral exploration

Prioritize exploring potential tin deposits in Alaska



### Research & Development

Proactively invest in recycling



### Research & Development

Develop economic substitutes for containers, solder, alloys, chemicals



### International cooperation

Secure feedstocks from allies and partners to support DPA-funded smelter

## Critical Links

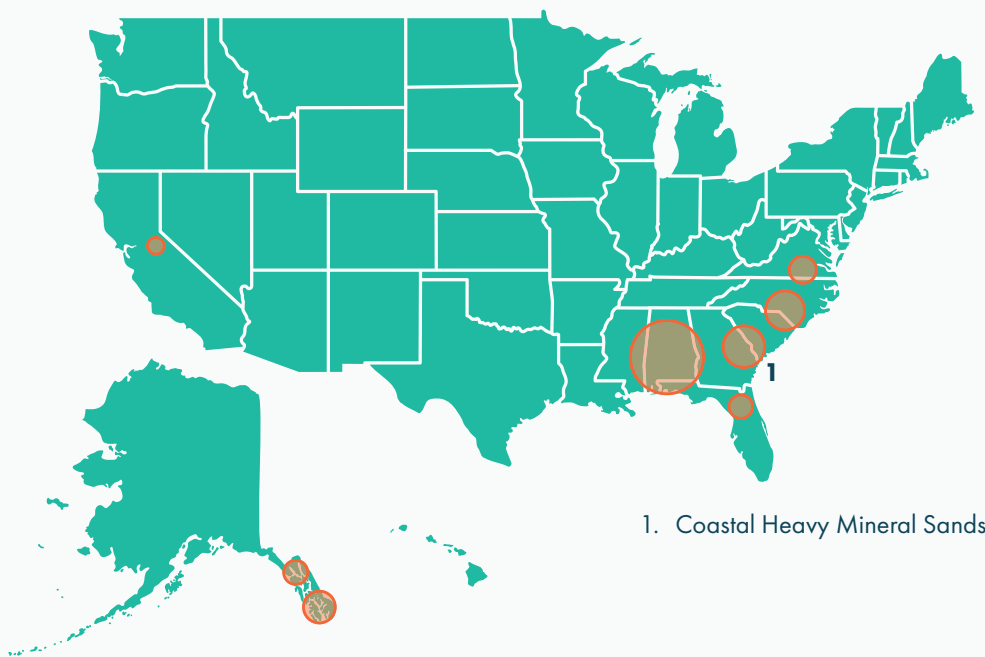
- Zinc for brass alloys
- Copper for bronze alloys

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
77%	Low	No	No	25% (mining) 49% (processing)

# Titanium

- Support aerospace industry
- Revitalize domestic titanium mines, smelters; fortify allied titanium production against Chinese dumping

Notable titanium deposits



1. Coastal Heavy Mineral Sands

## Recommendations



### Resilient markets

Restart idled mines and smelters with incentives like affordable industrial power



### Resilient markets

Protect Japanese and other allied titanium smelters against Chinese dumping



### Mineral exploration

Explore U.S. coastal heavy mineral sand resource development



### International cooperation

Pursue more efficient titanium smelting techniques in collaboration with Japan



### Research & Development

Continue to support titanium recycling

## 🔗 Critical Links

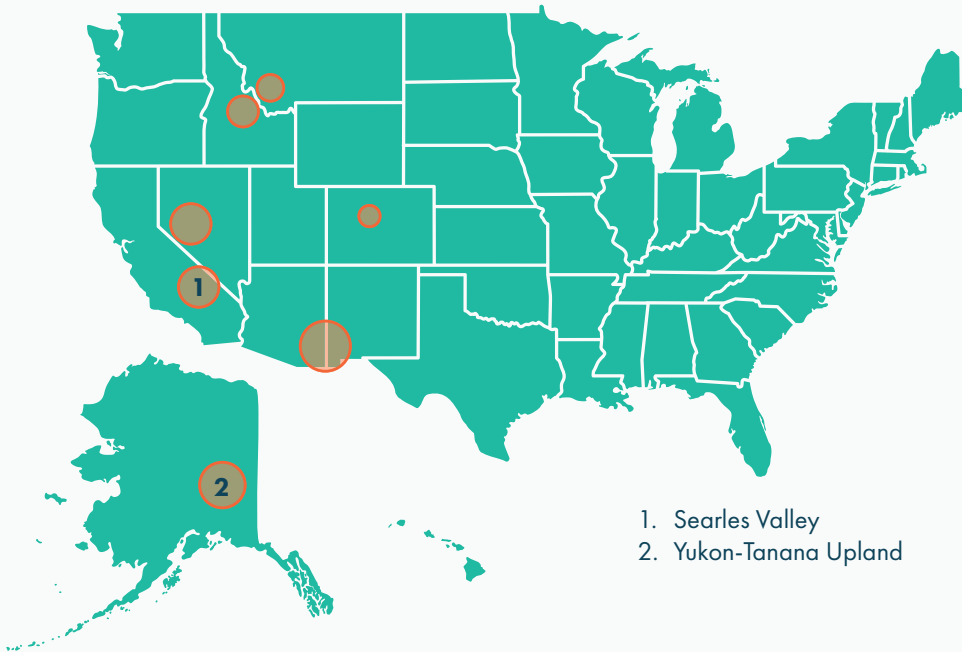
- Co-produced along with zirconium, hafnium, and rare earths from heavy mineral sands

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
100%	Low	Yes	No	39% (mining) 70% (processing)

# Tungsten

- Support military, aerospace, heavy industry, gas turbines, drilling equipment
- Diversify tungsten mining beyond China, Russia, and North Korea

Notable tungsten deposits



## Recommendations



### Resilient markets

Use financial tools to de-risk ongoing investments against lifting of Chinese export controls



### Demand pull policies

Fill ammunition depots and national defense stockpile as anchor customer for domestic production



### Resilient markets

Maintain tariffs on Chinese tungsten carbide powder



### Mineral exploration

Support exploration for promising domestic deposits

## Critical Links

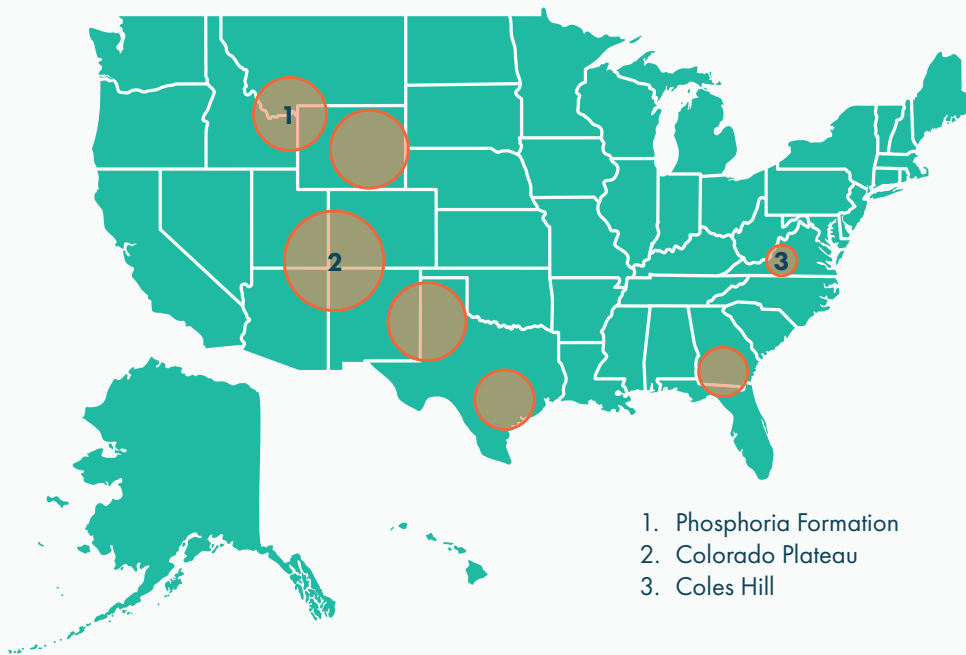
- Cobalt, molybdenum, yttrium, and others in superalloys and specialty steels

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
>50%	Medium	No	Yes	79% (mining)

# Uranium

- Significantly expand uranium enrichment and fabrication for domestic nuclear energy and defense needs
- Secure access to low-cost domestic deposits and foreign uranium ore

Notable uranium deposits



1. Phosphoria Formation
2. Colorado Plateau
3. Coles Hill

## Recommendations



### International cooperation

Partner to develop Australian and Canadian resources



### Mineral exploration

Explore for low cost deposits amenable to in situ recovery



### Resilient markets

Maintain bans on imported Russian enriched uranium and ore



### Build key projects

Develop midstream capacity, including through the establishment of a DOE-backed HALEU fuel bank



### Build key projects

Develop byproduct recovery capabilities from copper, rare earths, phosphate, and gold mining

## Critical Links

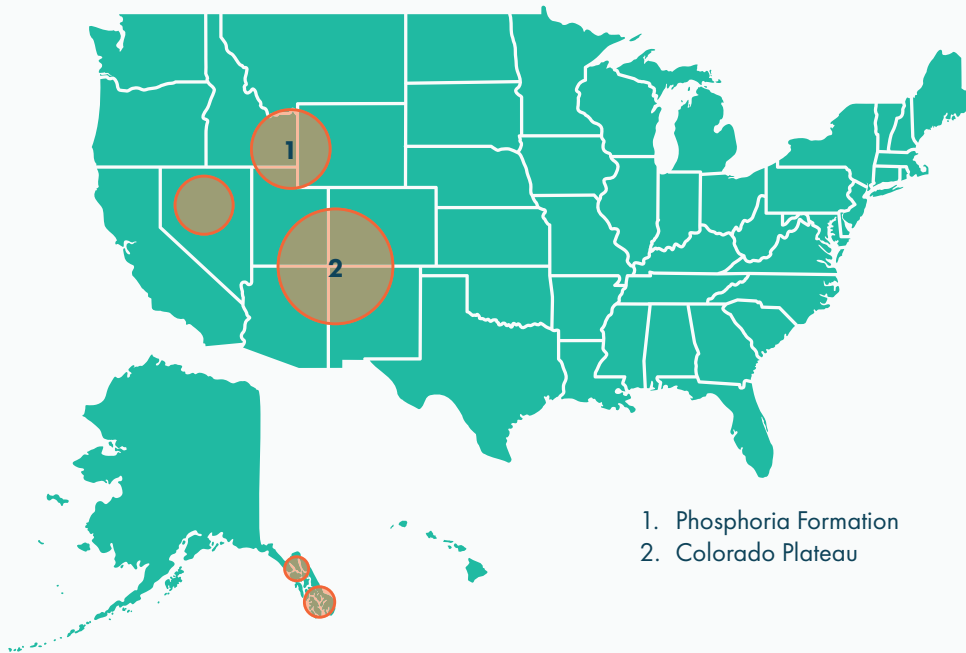
- Nuclear reactor fuel, nuclear weapons, depleted uranium materials
- Can be recovered from copper, rare earths, phosphate, and gold mining

Power Plant Purchases of Enriched Uranium	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
81% foreign origin	Medium	Yes	Yes	3% (mining)

# Vanadium

- Secure supplies for microalloying additions in domestic steelmaking
- Help shift supply chains away from China and Russia (91% of global mine production)

Notable vanadium deposits

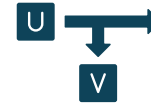


## Recommendations



### Resilient markets

Employ financial tools, defense stockpile procurement to restart shuttered U.S. mines



### Build key projects

Develop recovery capability using historic uranium mine tailings



### Research & Development

Increase recycling of ash, residues, spent catalysts



### International cooperation

Partner with Australia to develop Australian reserves

## Critical Links

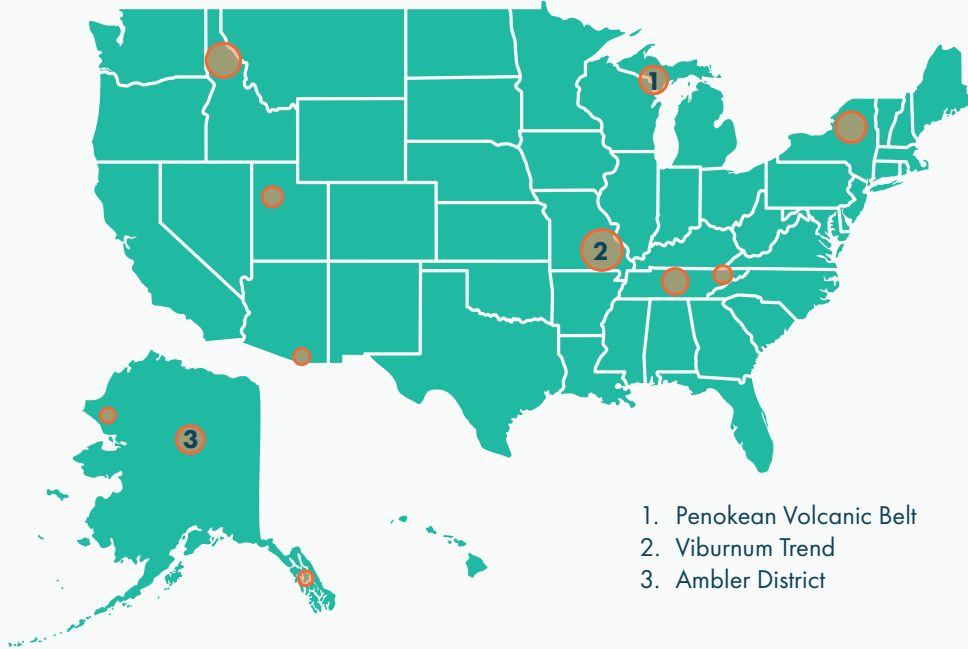
- Commonly mined as co-product with uranium
- Magnesium, vanadium, nickel, manganese, chromium, and zinc in common steels

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
41%	Low	No	No	75% (mining)

# Zinc

- Ensure supply security for galvanized steel coatings, brass, bronze, and zinc alloys
- Leverage zinc supply chain for production of gallium, germanium, cadmium, indium, and other byproducts

Notable zinc deposits



1. Penokean Volcanic Belt
2. Viburnum Trend
3. Ambler District

## Recommendations



### Build key projects

Expand smelting capacity with byproduct recovery capabilities



### International cooperation

Partner with Australia to develop Australian reserves



### Research & Development

Ensure maximum recovery of zinc and byproducts from electric arc furnace waste



### Build key projects

Support development of zinc recovery from geothermal brines

## Critical Links

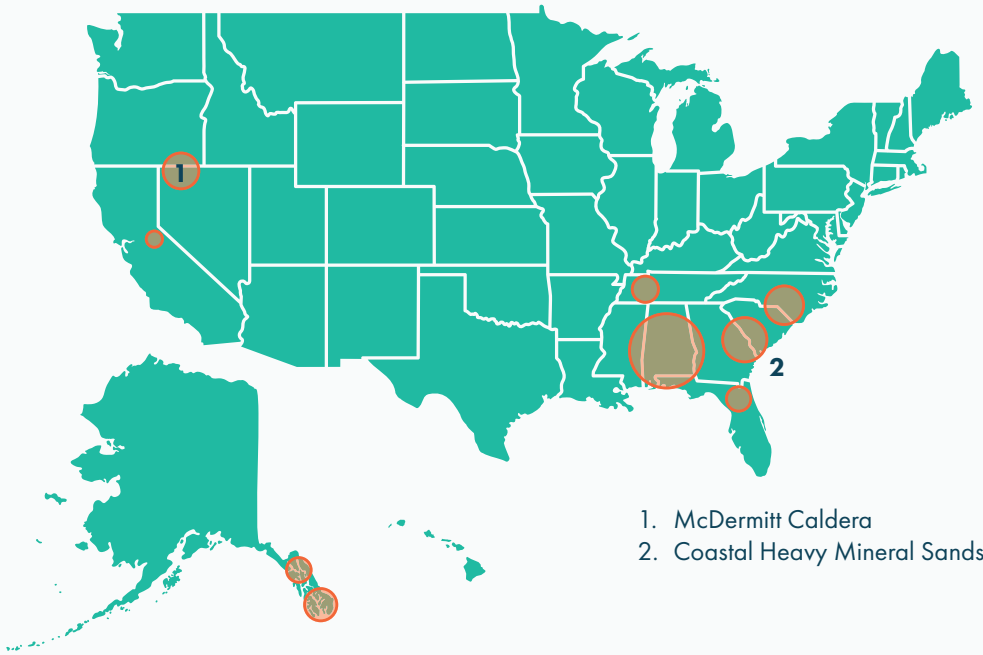
- Tin for brass alloys
- Galvanized steel, bronze, zinc alloys
- Zinc smelting allows cadmium, gallium, germanium, and indium recovery

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
73%	Medium	Yes	Yes	32% (mining) 49% (processing)

# Zirconium and Hafnium

- Support aerospace, power sector, nuclear, refractory, metallurgy needs
- Fill supply chain gaps in midstream processing

Notable zirconium and hafnium deposits



## Recommendations



### Build key projects

Fill midstream supply chain gaps for fused zirconia and oxychloride



### Build key projects

Explore co-production feasibility at rare earth and phosphate rock mines



### Mineral exploration

Explore U.S. coastal heavy mineral sand resource development



### International cooperation

Partner with Australia to develop Australian reserves

## Critical Links

- Often co-produced with titanium and rare earths from heavy mineral sands
- Hafnium recovered as a byproduct of zirconium production

Net Import Reliance	Ability to Meet Demand Domestically	Active Mining	Active Processing	Chinese Market Concentration
<25%	Medium	Yes	Yes	8% (mining)

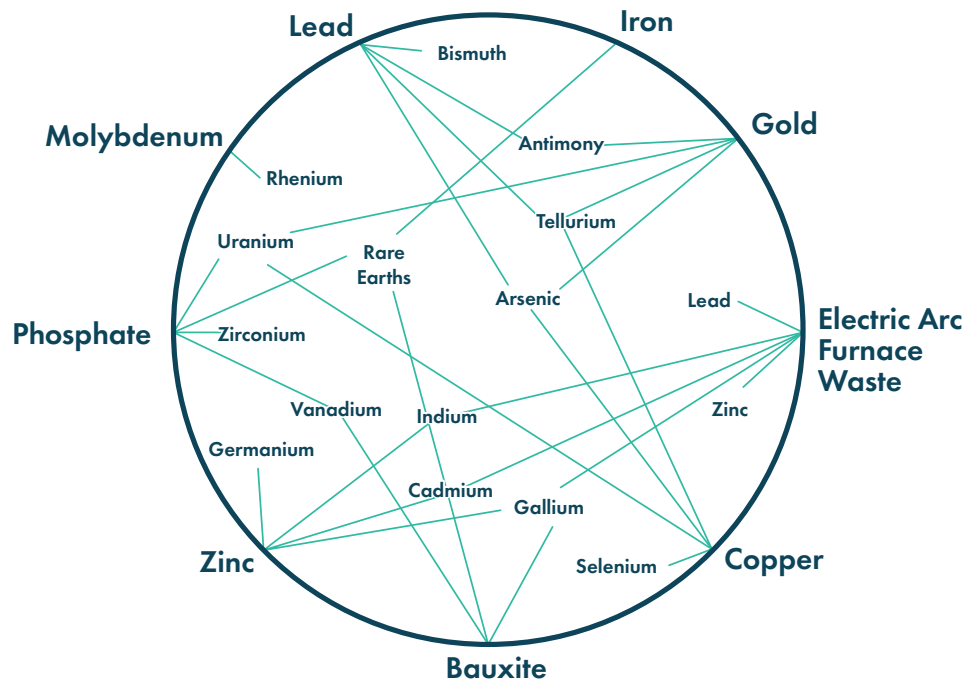
# Minerals and their End-Use Baskets

A helpful way to break down the list of around 60 USGS-designated critical minerals and other important strategic materials is to consider the broad categories of economic sectors that use them.

Some commodities are the primary component of major industrial metals and alloys. Others, including many in the previous category, are more minor constituents of common or specialized alloys. A number of minerals and materials play key roles in the function of lithium-ion and other batteries and of advanced semiconductor chips.

	Base metals Industrial metals	Alloy and superalloy constituents	Battery materials	Semiconductors
Aluminum				
Antimony				
Chromium				
Cobalt				
Copper				
Gallium				
Germanium				
Graphite				
High-purity polysilicon				
Lithium				
Magnesium				
Manganese				
Molybdenum				
Nickel				
Rare Earths				
Steel				
Tellurium				
Tin				
Titanium				
Tungsten				
Uranium				
Vanadium				
Zinc				
Zirconium and Hafnium				

# Byproduct Recovery and Unconventional Resource Opportunities



Many minerals occur in unconventional forms that the United States could tap into with the proper feasibility assessments, extraction technology, and processing expertise. In some cases, mines could recover minor amounts of minerals as byproducts of the ongoing production of major commodities like aluminum and zinc. In other cases, industry could access novel mineral resources like subsurface brines or seafloor nodules. Making use out of these opportunities can maximize production of some minerals while supplying other minerals the United States otherwise wouldn't be able to produce at all.

## Mineral recovery potential through low-impact in situ methods

- Copper
- Uranium

## Mineral recovery potential from seafloor resources

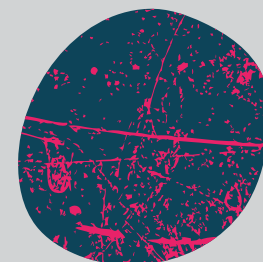
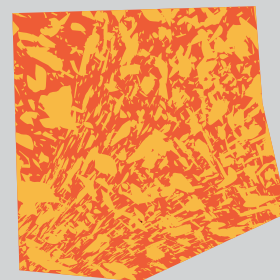
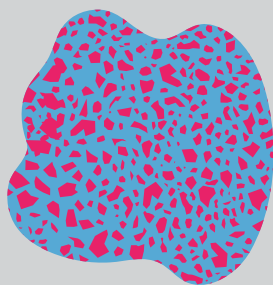
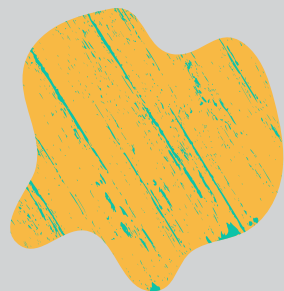
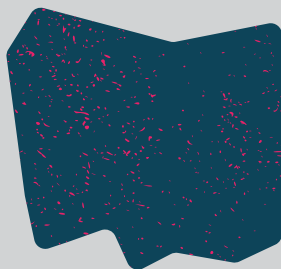
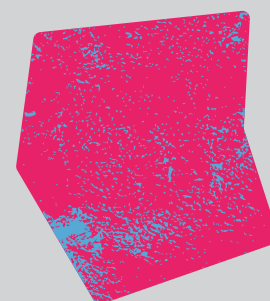
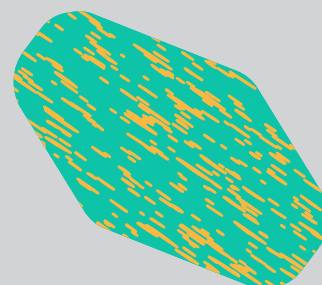
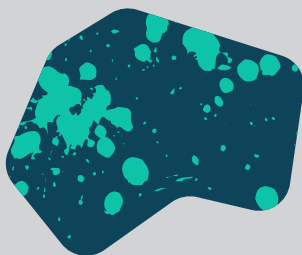
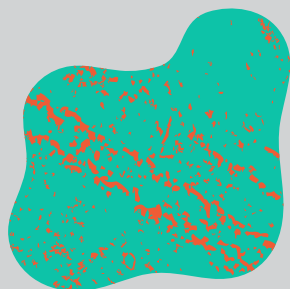
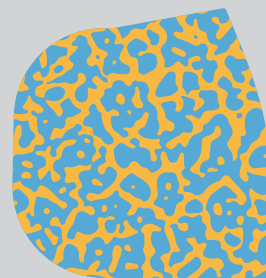
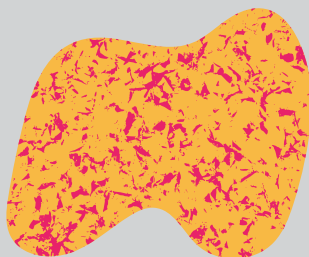
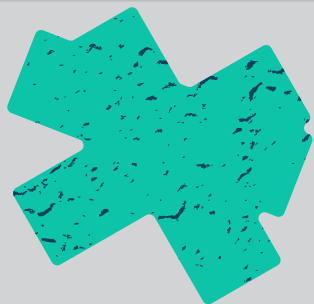
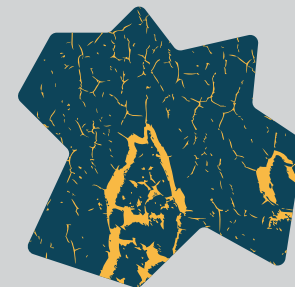
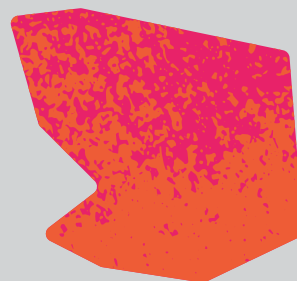
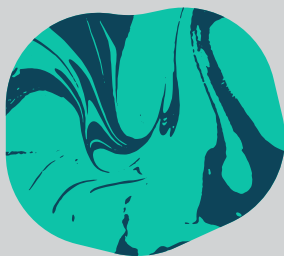
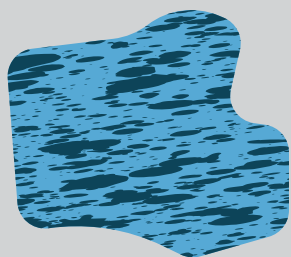
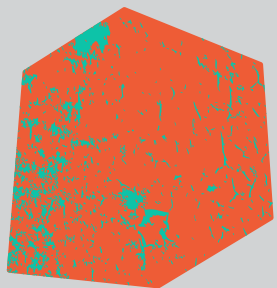
- Cobalt
- Copper
- Manganese
- Nickel
- Rare earth elements

## Mineral recovery potential from brines

- Antimony
- Lithium
- Magnesium
- Manganese
- Rare earth elements
- Zinc

# CON CLU SION

Steady efforts to bolster U.S. critical mineral supply vulnerabilities will remain a responsibility of not only the 119th Congress but the 120th Congress, the 121st Congress, and beyond. As this booklet's structure and organization emphasizes, policymakers will in many cases need to address the nation's critical mineral priorities piece by piece, process by process, and industry by industry. Even though mining and metals fundamentally support our modern technological civilization, the extraction and conversion of minerals into useful products is by no means simple. Failure to develop this know-how is now putting America at risk. To seize leadership in the energy, AI, aerospace, and advanced technologies of tomorrow requires hard work to rebuild supply chain capabilities today, starting with a mineral by mineral understanding of where the needs for action are greatest.



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