

# An introduction to Critical Minerals and Rare Earth Elements

Victoria Bushan

Water Quality Standards Unit Chief

# What are Critical Minerals?

- Defined annually by the Department of the Interior, through the U.S. Geological Survey
  - 60 included on the 2025 list
  - vital to the U.S. economy and national security
  - may face potential risks from disrupted supply chains
  - critical mineral lists include things like copper, lithium, nickel, cobalt, graphite and rare earth elements (REEs)

# PERIODIC TABLE OF CRITICAL MINERALS

<b>H</b> Hydrogen																	<b>He</b> Helium					
<b>Li</b> Lithium	<b>Be</b> Beryllium	<p><i>Wait. Aren't these elements?</i> The Energy Act of 2020 describes "critical minerals" as minerals, elements, substances, or materials that (1) are essential to the economic or national security of the United States, (2) have supply chains at risk of disruption, and (3) are vital for making a product without which the United States would suffer<sup>[1]</sup>.</p>														<b>B</b> Boron	<b>C</b> Carbon	<b>N</b> Nitrogen	<b>O</b> Oxygen	<b>F</b> Fluorine	<b>Ne</b> Neon	
<b>Na</b> Sodium	<b>Mg</b> Magnesium	<b>Nb</b> Niobium	<p><b>Elements in RED</b> are listed as critical minerals in the 2025 USGS critical mineral list<sup>[2]</sup>. Graphite (C), barite (BaSO<sub>4</sub>), metallurgical coal, phosphate rock, potash, and fluorspar (CaF<sub>2</sub>) are also listed as critical minerals in the 2025 USGS critical mineral list<sup>[2]</sup>.</p>														<b>Al</b> Aluminum	<b>Si</b> Silicon	<b>P</b> Phosphorus	<b>S</b> Sulfur	<b>Cl</b> Chlorine	<b>Ar</b> Argon
<b>K</b> Potassium	<b>Ca</b> Calcium	<b>Sc</b> Scandium	<b>Ti</b> Titanium	<b>V</b> Vanadium	<b>Cr</b> Chromium	<b>Mn</b> Manganese	<b>Fe</b> Iron	<b>Co</b> Cobalt	<b>Ni</b> Nickel	<b>Cu</b> Copper	<b>Zn</b> Zinc	<b>Ga</b> Gallium	<b>Ge</b> Germanium	<b>As</b> Arsenic	<b>Se</b> Selenium	<b>Br</b> Bromine	<b>Kr</b> Krypton					
<b>Rb</b> Rubidium	<b>Sr</b> Strontium	<b>Y</b> Yttrium	<b>Zr</b> Zirconium	<b>Nb</b> Niobium	<b>Mo</b> Molybdenum	<b>Tc</b> Technetium	<b>Ru</b> Ruthenium	<b>Rh</b> Rhodium	<b>Pd</b> Palladium	<b>Ag</b> Silver	<b>Cd</b> Cadmium	<b>In</b> Indium	<b>Sn</b> Tin	<b>Sb</b> Antimony	<b>Te</b> Tellurium	<b>I</b> Iodine	<b>Xe</b> Xenon					
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Lanthanides			<b>La</b> Lanthanum	<b>Ce</b> Cerium	<b>Pr</b> Praseodymium	<b>Nd</b> Neodymium	<b>Pm</b> Promethium	<b>Sm</b> Samarium	<b>Eu</b> Europium	<b>Gd</b> Gadolinium	<b>Tb</b> Terbium	<b>Dy</b> Dysprosium	<b>Ho</b> Holmium	<b>Er</b> Erbium	<b>Tm</b> Thulium	<b>Yb</b> Ytterbium	<b>Lu</b> Lutetium					
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U.S. Department of the Interior  
U.S. Geological Survey

[1] Nassar, N.T., Pineault, D., Allen, S.M., McCaffrey, D.M., Padilla, A.J., Brainard, J.L., Bayani, M., Shojaeddini, E., Ryter, J.W., Lincoln, S., and Alonso, E., 2025, Methodology and technical input for the 2025 U.S. List of Critical Minerals—Assessing the potential effects of mineral commodity supply chain disruptions on the U.S. economy: U.S. Geological Survey Open-File Report 2025–1047, 32 p., <https://doi.org/10.3133/ofr20251047>.  
[2] <https://www.usgs.gov/programs/mineral-resources-program/science/about-2025-list-critical-minerals>

# What are Rare Earth Elements?

- Subset of critical minerals
- A relatively abundant group of 17 elements composed of scandium, yttrium, and the lanthanides
- Necessary components of more than 200 products across a wide range of applications



57  
**La**  
Lanthanum

# Critical Minerals and General Applications



## MAGNETICS

Computer Hard Drives  
Disk Drive Motors  
Anti-Lock Brakes  
Automotive Parts  
Frictionless Bearings  
Magnetic Refrigeration  
Microwave Power Tubes  
Power Generation  
Microphones & Speakers  
Communication Systems  
MRI

Nd Tb Dy Pr



## METAL ALLOYS

NiMH Batteries  
Fuel Cells  
Steel  
Super Alloys  
Aluminum/Magnesium

Nd Y La Ce Pr



## DEFENSE

Satellite Communications  
Guidance Systems  
Aircraft Structures  
Fly-by-Wire  
Smart Missiles

Nd Eu Tb Dy Y Lu Sm Pr La



## CATALYSTS

Petroleum Refining  
Catalytic Converter  
Fuel Additives  
Chemical Processing  
Air Pollution Controls

Nd La Ce Pr



## CERAMICS

Capacitors  
Sensors  
Colorants  
Scintillators  
Refractories

Nd Y Eu Dy Lu Gd La Ce Pr



## PHOSPHORS

Display phosphors-  
CRT,LPD,LCD  
Fluorescents  
Medical Imaging  
Lasers  
Fiber Optics

Nd Eu Tb Y Er Gd Ce Pr



## GLASS & POLISHING

Polishing Compounds  
Pigments & Coatings  
UV Resistant Glass  
Photo-Optical Glass  
X-Ray Imaging

Nd Gd Er Ho La Ce Pr

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# Why are critical minerals an emerging contaminant?

1. Changing supply
2. Increasing demand
3. Market uncertainty



65  
**Tb**  
Terbium

# REE Background

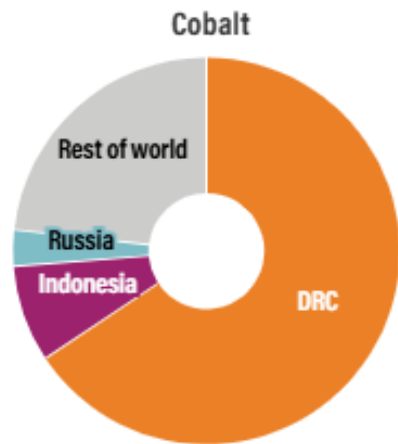
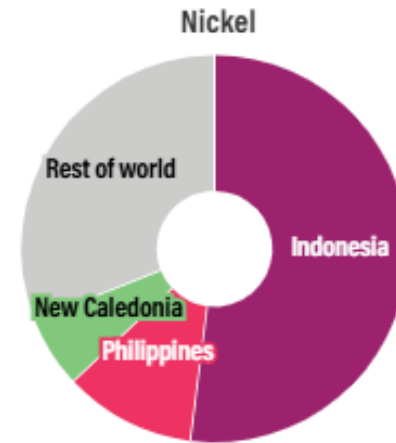
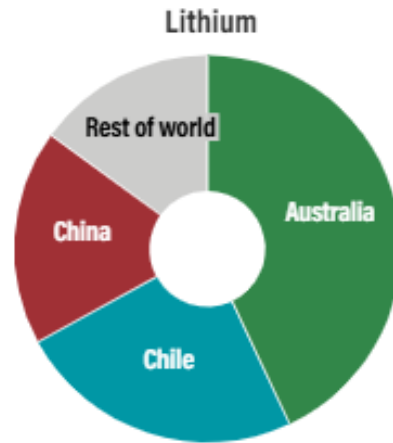
- 1993
  - China - 38 % world production
  - United States - 33 %
  - Australia - 12 %
  - Malaysia and India - 5%
  - Brazil, Canada, South Africa, Sri Lanka, and Thailand
- 2008
  - China - >90 % world production
- 2011
  - China - 97 % world production



60  
**Nd**  
Neodymium

# Where minerals were mined and processed in 2023

Share of mined minerals    Share of processed minerals

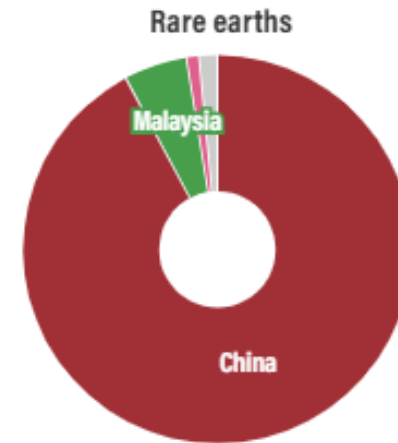
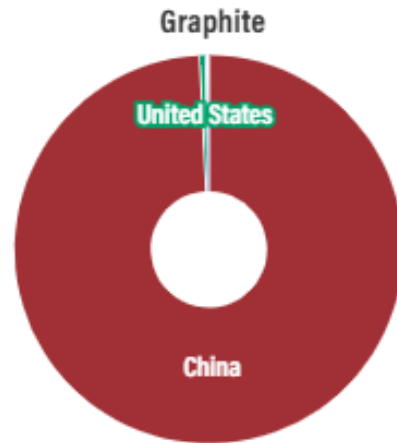
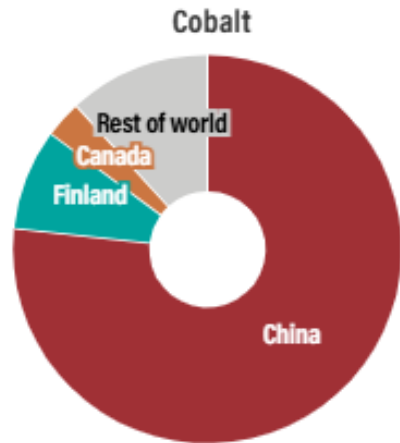
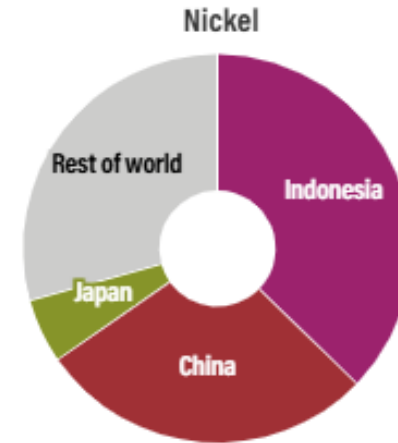
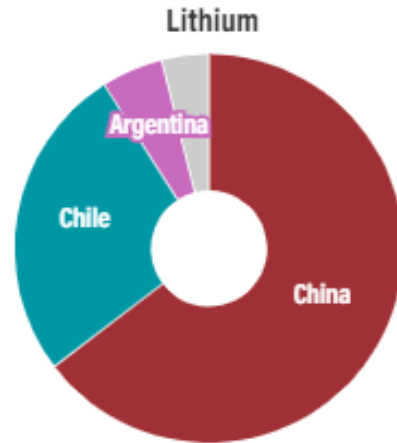
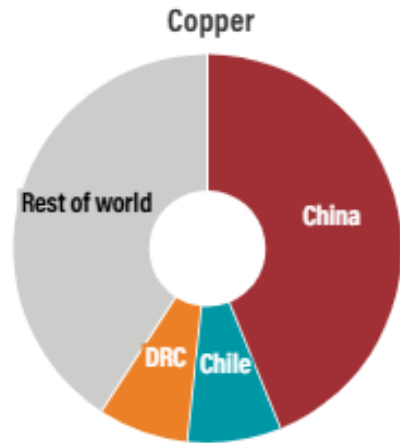


Source: IEA 2024.



# Where minerals were mined and processed in 2023

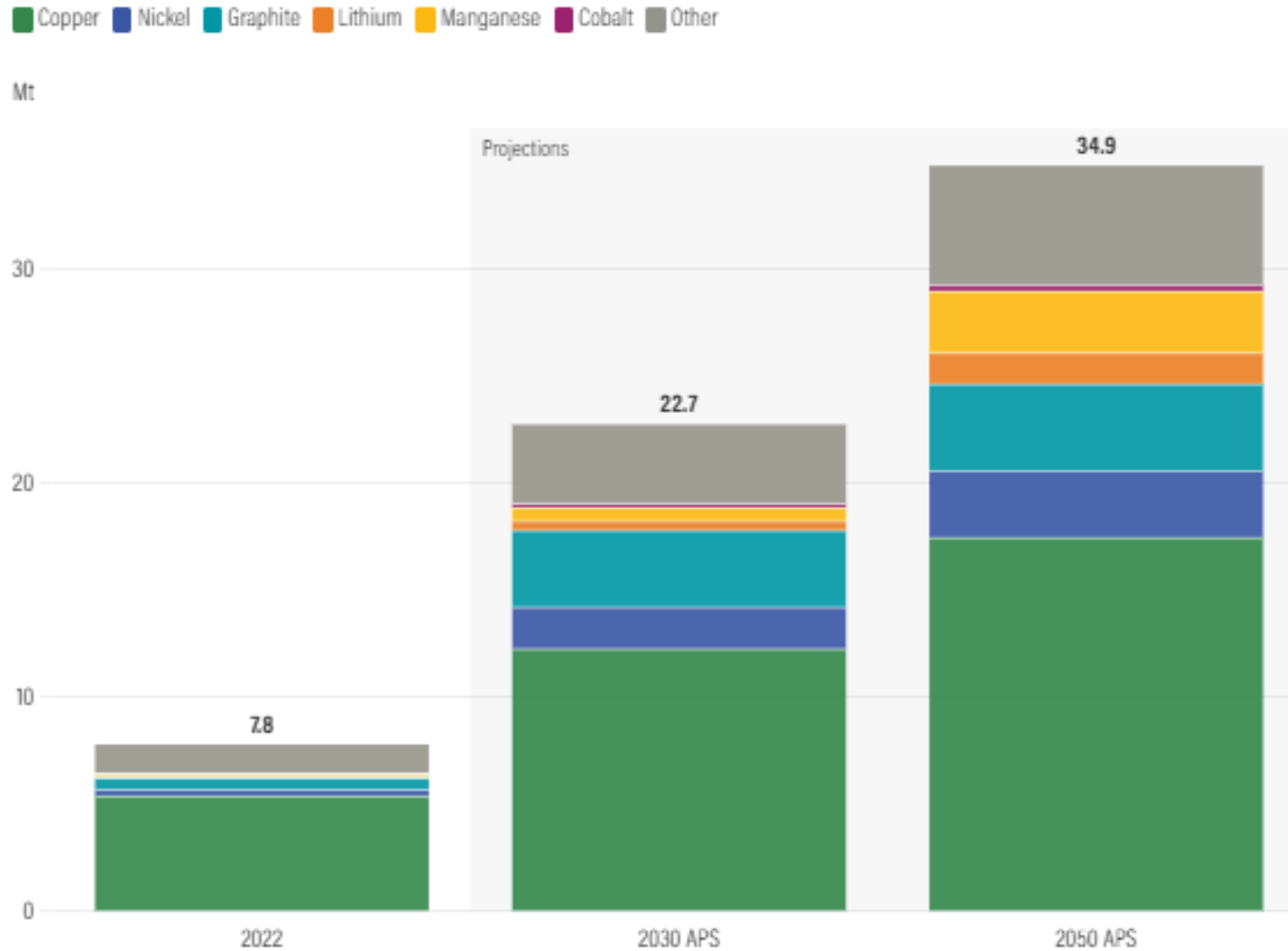
Share of mined minerals    Share of processed minerals



Source: IEA 2024.



# Critical mineral demand could more than double by 2030 and quadruple by 2050



Note: APS = Announced Policies Scenario (countries' climate and energy goals are met in full and on time); Mt = Million tons.  
Source: [IEA 2023](#)



# Supply Uncertainty

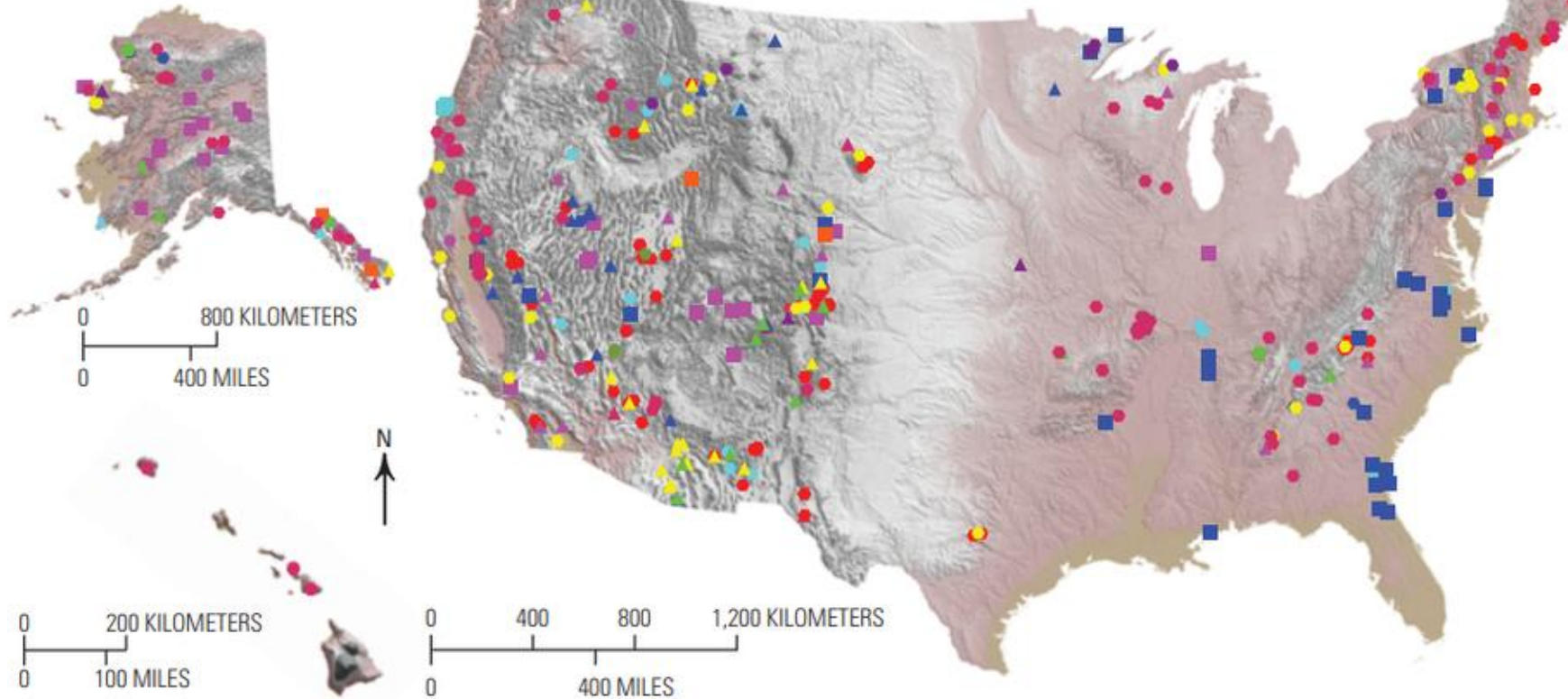
- Some countries with healthy mineral supplies are implementing export restrictions
  - China restricting exports for 7 of 17 REEs
  - Democratic Republic of Congo temporarily halted exports of cobalt for 10 months in 2025
- Changing tariff policies



66  
**Dy**  
Dysprosium

# Domestic Supplies

UNITED STATES



## EXPLANATION Critical Minerals

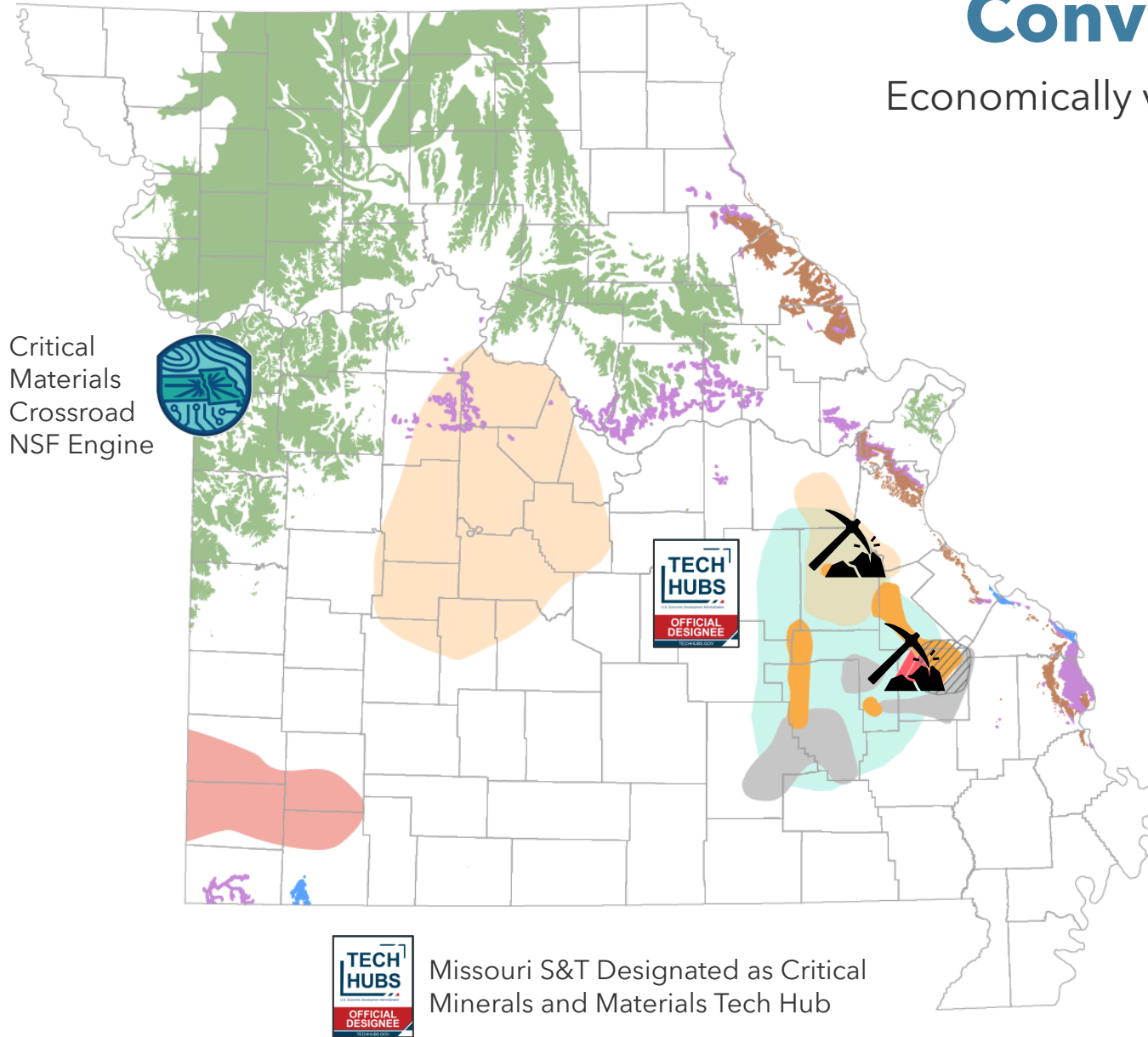
- |             |                           |
|-------------|---------------------------|
| ● Antimony  | ▲ Manganese               |
| ● Barite    | ▲ Niobium and Tantalum    |
| ● Beryllium | ▲ Platinum Group Elements |
| ● Cobalt    | ▲ Rare Earth Elements     |
| ● Fluorite  | ▲ Rhenium                 |
| ● Gallium   | ▲ Tellurium               |
| ● Germanium | ■ Tin                     |
| ● Graphite  | ■ Titanium                |
| ● Indium    | ■ Vanadium                |
| ▲ Lithium   | ■ Zirconium               |

**Figure 1.** Critical mineral resources in Australia, Canada, and the United States (Labay and others, 2017). Critical minerals support a broad range of industrial sectors and a diversity of high-tech industries important to global economies (see Primary Uses of Critical Minerals sidebar).

Base from National Oceanic and Atmospheric Administration ETOPO1 1 Arc-Minute Global Relief Model, 2017

# Conventional CM Reserves

Economically viable reserves for **36 of 60** critical minerals.



## Cobalt

*Largest known reserve in N. America*

## Lead

*Top global producer in 19<sup>th</sup>/20<sup>th</sup> centuries.*

## Gallium & Germanium

*Subject to Chinese export ban and controls*

## Heavy Rare Earths Pea Ridge Mine

*Viable reserves of terbium, dysprosium, ytterbium, & others*



MISSOURI  
DEPARTMENT OF  
NATURAL RESOURCES

# Missouri's Critical Mineral Resources

Missouri is home to a variety of critical mineral resources, including both known/verified occurrences and prospects:

## Southeast Missouri Lead District and Iron Metallogenic Province

- Viburnum Trend
- Mine La Motte
- Boss Iron-Copper Deposit
- Pea Ridge Iron Deposit\*
- Non-district occurrences

\*Designated a 'principle' REE deposit by US Geological Survey

### Cobalt-Bearing Minerals

Cobaltite	CoAsS
Siegenite	CoNi <sub>2</sub> S <sub>4</sub>
Bravoite	(Fe,Ni,Co)S <sub>2</sub>
Carrollite	Cu(CoNi) <sub>2</sub> S <sub>4</sub>
Fletcherite	Cu(Ni,Co) <sub>2</sub> S <sub>4</sub>
Millerite	NiS (+minor Co)



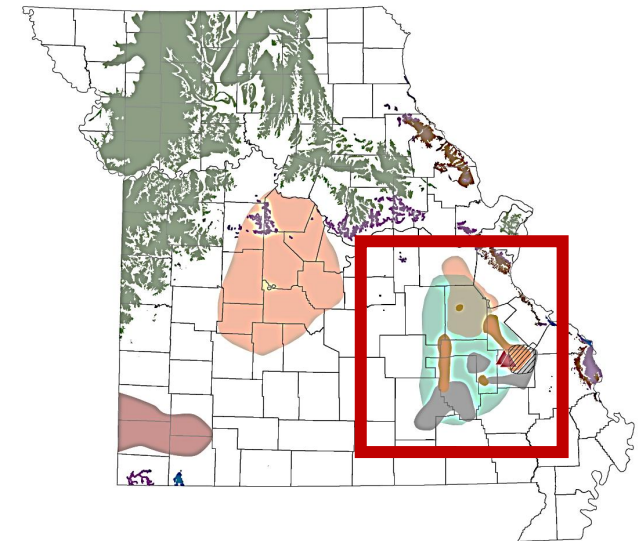
### REE-Bearing Minerals

Major:

Monazite	(Ce,La,Nd,Th)PO <sub>4</sub>
Xenotime	YPO <sub>4</sub>

Minor:

Bastnaesite	(Ce,La,Y,Nd)CO <sub>3</sub> (OH,F)
Britholite	(Ca,Ce,Y) <sub>5</sub> (SiO <sub>4</sub> ,PO <sub>4</sub> ) <sub>3</sub> (OH,F)
Allanite	(Ca,Ce,La,Y,Nd,Th) <sub>2</sub> (Fe <sup>2+</sup> ,Fe <sup>3+</sup> ,Ti)(Al,Fe <sup>3+</sup> ) <sub>2</sub> Si <sub>3</sub> O <sub>12</sub> (OH)
Tengerite	(Ca,Y <sup>3+</sup> ) <sub>2</sub> (CO <sub>3</sub> ) <sub>3</sub> -2-3(H <sub>2</sub> O)
Synchysite	Ca(Y,Ce,La)(CO <sub>3</sub> ) <sub>2</sub> F
Apatite	Ca <sub>5</sub> (F,Cl,OH)(PO <sub>4</sub> ) <sub>3</sub>



# Missouri's Critical Mineral Resources

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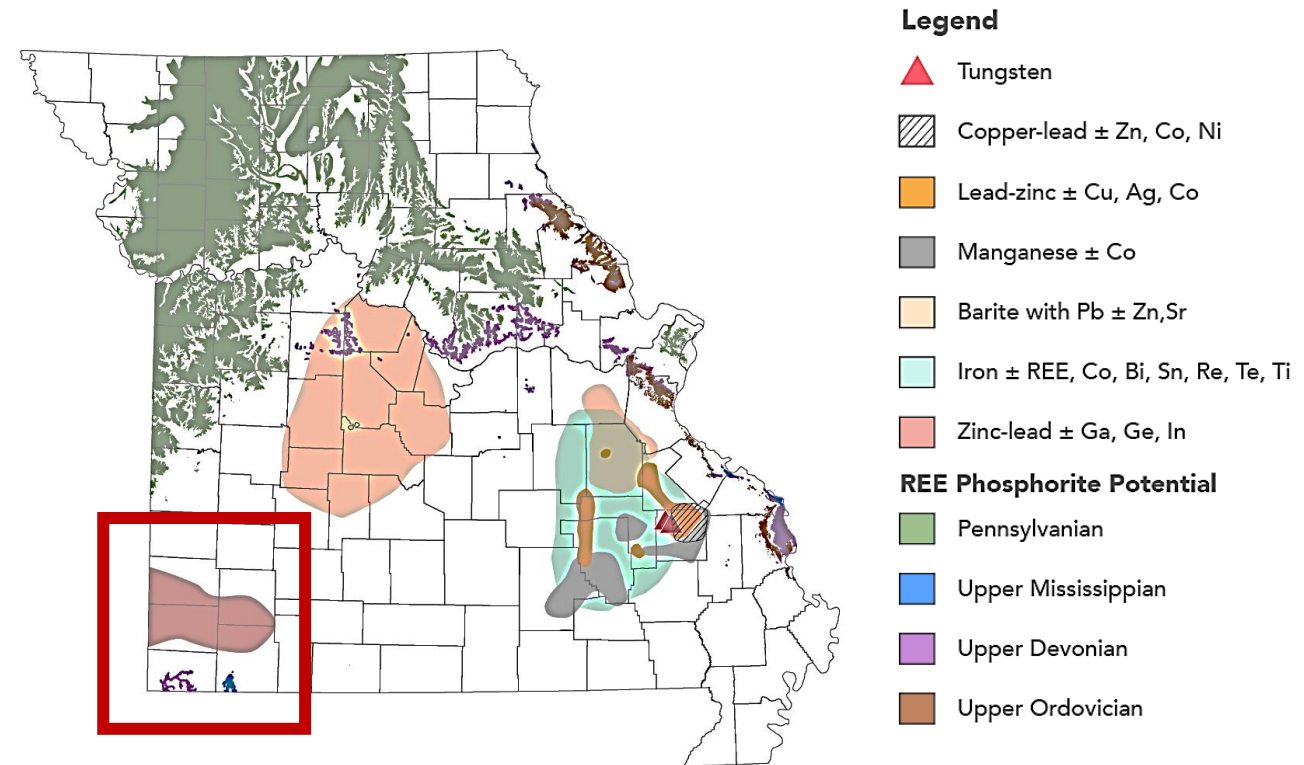
- Tri-State District

Galena      PbS  
Sphalerite      ZnS (+Ga,Ge,Cd,In,Ag)\*



- Phosphorites

- Phosphate-rich sedimentary rocks
- >15-20 percent P<sub>2</sub>O<sub>5</sub>
- Marine, non-detrital
- Uncharacterized in Missouri
- Lower cost, higher recovery of REEs

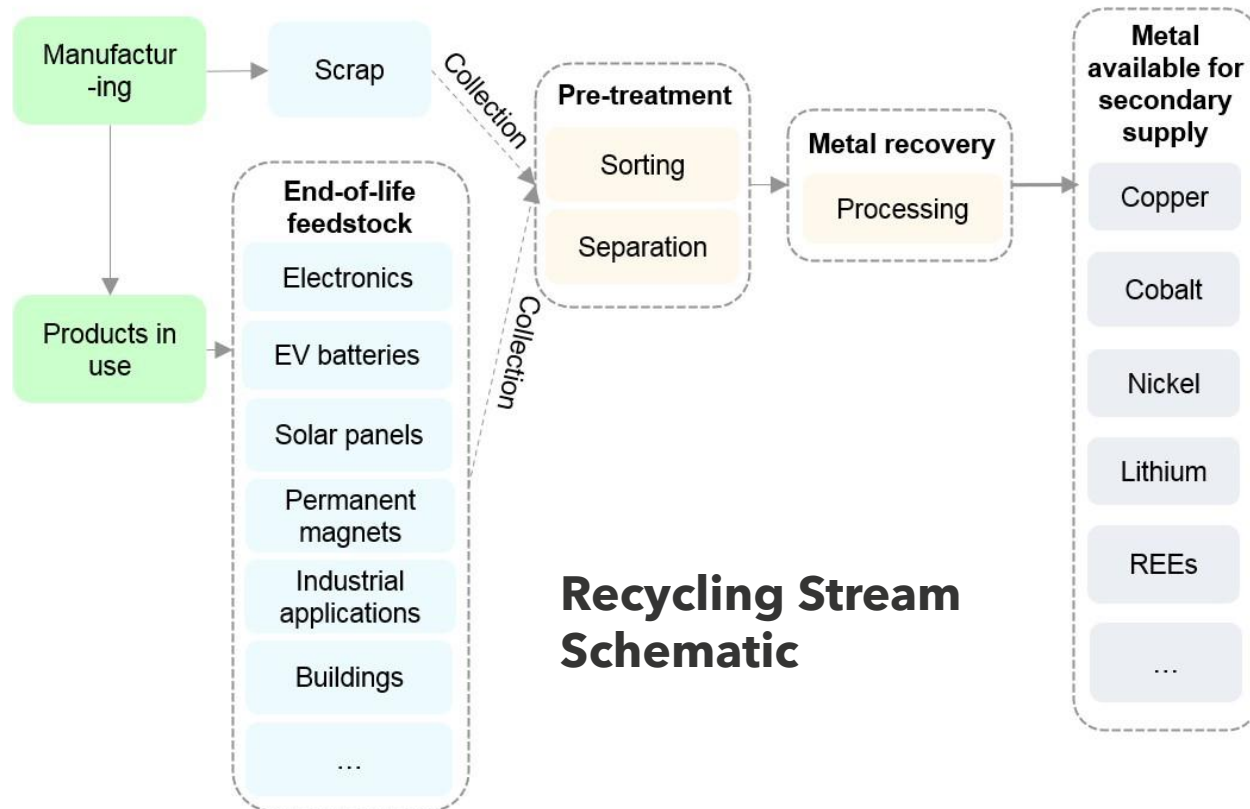


\*Export bans from China to the United States specifically include Gallium and Germanium

# Missouri's 'Unconventional' Critical Mineral Resources

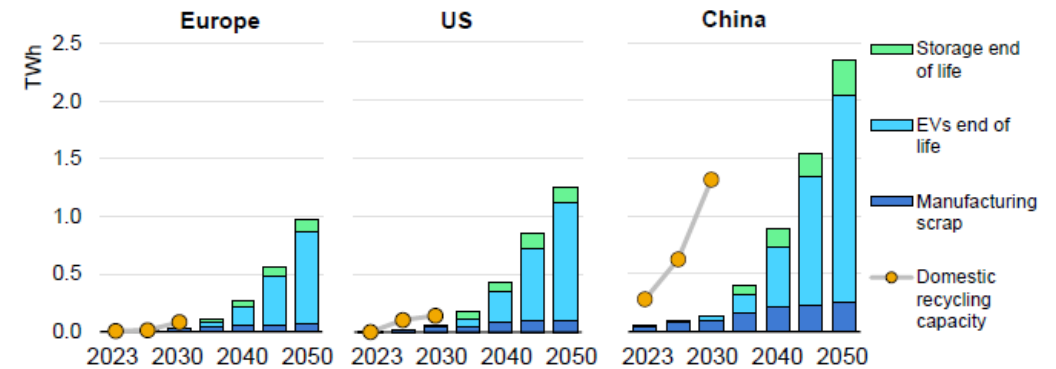
Electronic waste streams and recycling:

- Consumer/industrial electronics
- Battery energy storage systems (BESS) – rechargeable and non-rechargeable batteries and electric vehicle batteries



**Recycling Stream Schematic**

## EV Battery Recycling Capacity



IEA. CC BY 4.0.



# Missouri's 'Unconventional' Critical Mineral Resources

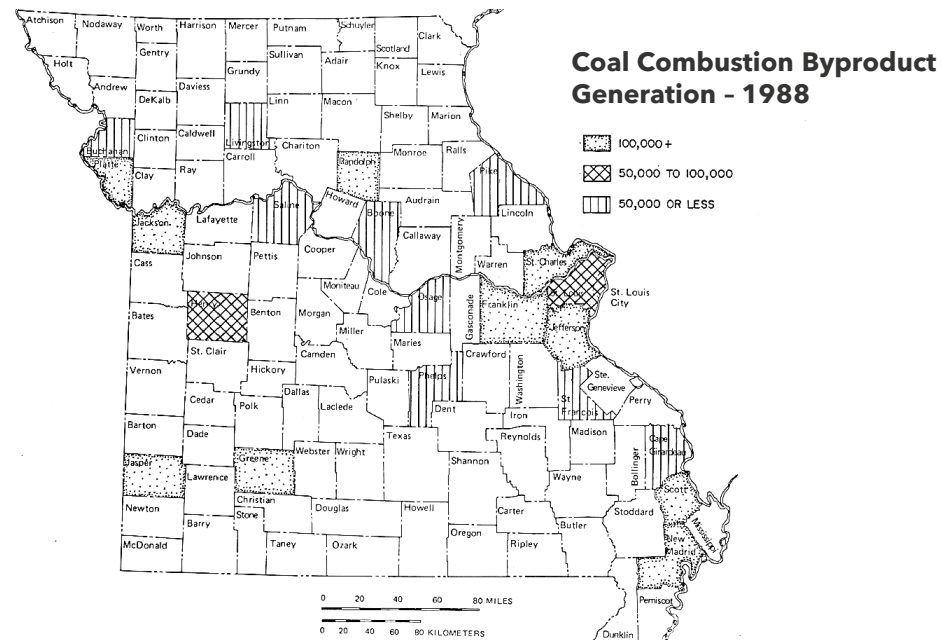
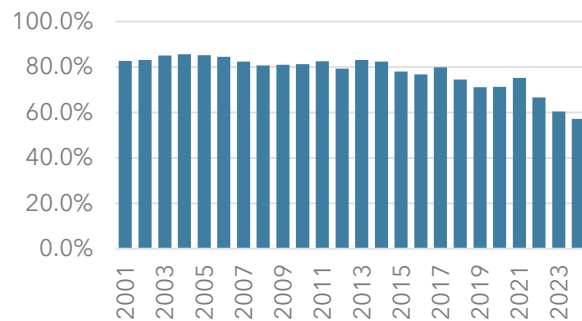
Historical mine waste, tailings, and chat:

- Pea Ridge mine, Mine La Motte, Tri-State district

Coal combustion byproducts (CCB):

- Coal bottom ash and fly ash
  - ~60 million tons landfilled/ponded *just* from 2001-2024
- Acid mine drainage (AMD)

Percent of Total Net Energy Generated from Coal: Missouri



# What does that mean for Missouri?

- Critical mineral extraction research funded at Missouri S&T
- Additional funding and investment for current mining projects
- Some closed mines considering reopening to mining tailings



58  
**Ce**  
Cerium

# Summary and Conclusions

It is possible, if not likely, that Missouri will see an increase in mining activity related to critical minerals

- Undeveloped deposits and prospects (including metallogenic deposits and phosphorites)
- Historic mines, waste, chat, and tailings (Pea Ridge, Mine LaMotte, Tri-state district)
- Coal combustion byproducts

Increase in mineral extraction likely to require infrastructure development (transportation, refining, processing) and other supply chain components

Current recycling capacity and infrastructure not currently well developed

- Fire safety, public health, and water quality concerns
- Retail/consumer Li-Ion battery packs already prolific
- Large volume of end-of-life EV batteries on the horizon

# How are we currently handling things?

- Site-Specific permitting
  - Other state criteria or permit limits
  - We have also relied on our definitions for acute/chronic toxicity in our water quality standards
    - Acute - "three-tenths (0.3) of the median lethal concentration, or the no observed acute effect concentration for representative species"
    - Chronic - "commonly used endpoints such as the no-observed effect concentration or inhibition concentration of representative species"

# What's happening so far?

Three sites have expressed an interesting in mining or reprocessing.

Parameters have been evaluated based on what is known to be present

- Cerium
- Cobalt
- Dysprosium
- Holmium
- Germanium
- Lithium
- Molybdenum
- Neodymium
- Praseodymium
- Strontium
- Terbium
- Tellurium

# Questions?

Victoria Bushan

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573-751-1419

