IDENTIFYING CRITICAL MINERAL RESOURCES

Virginia T. McLemore

New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM

Society for Mining, Metallurgy, & Exploration

- Critical and Strategic Minerals Importance to the U.S. Economy
  - https://www.smenet.org/What-We-Do/Technical-Briefings/Critical-and-Strategic-Minerals-Importance-to-the
- Rare earth elements
  - https://www.smenet.org/What-We-Do/Technical-Briefings/Rare-Earth-Elements

What are critical minerals?

Presidential Executive Order No. 13817 define critical minerals as

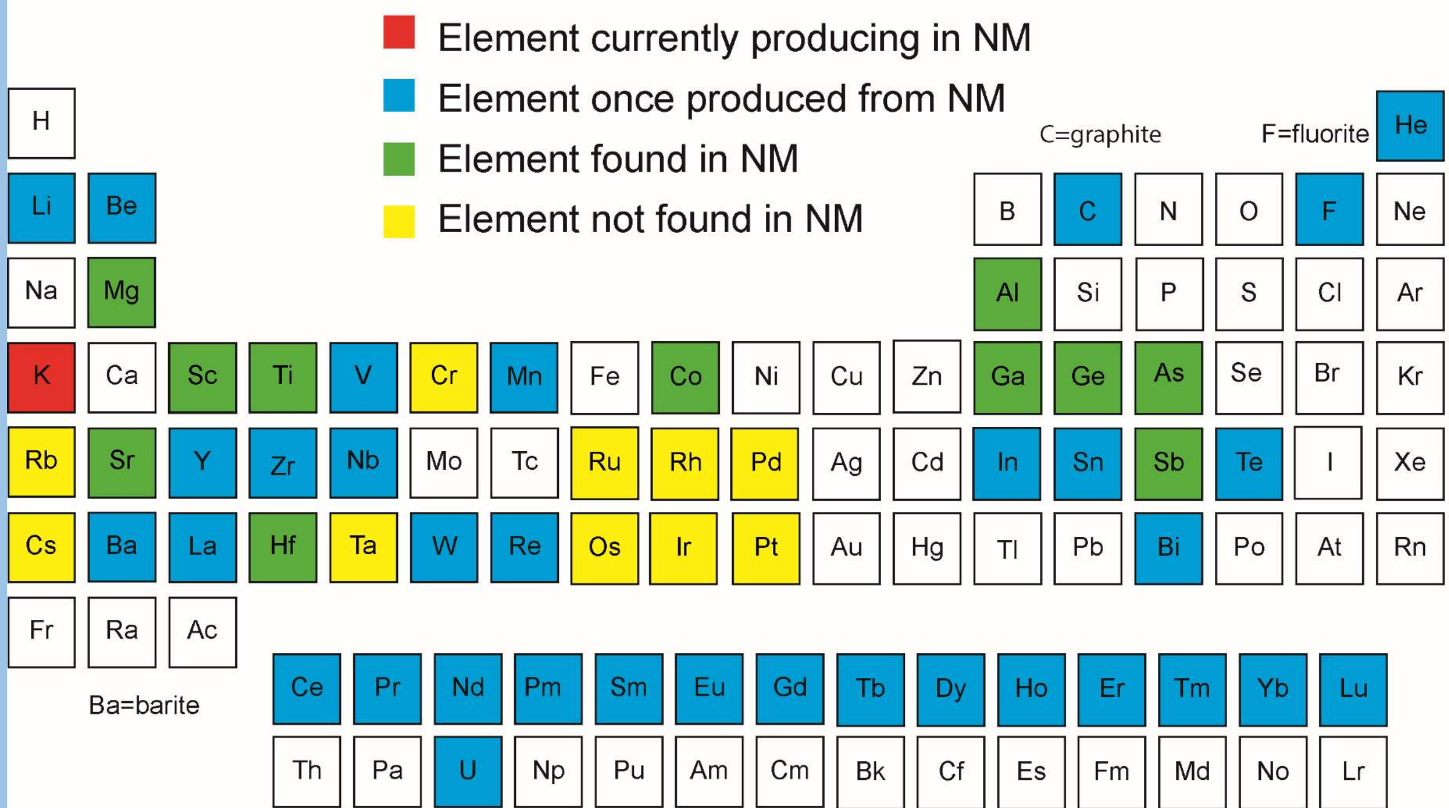
"*a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security*"

Critical Minerals

- Minerals needed for military, industrial or commercial purposes that are essential to renewable energy, national defense equipment, medical devices, electronics, agricultural production and common household items
- Minerals that are essential for use but subject to potential supply disruptions
- Minerals that perform an essential function for which few or no satisfactory substitutes exist
- The absence of which would cause economic, national security, or social consequences
- 33-50% minerals are classified as such

Critical Minerals in New Mexico

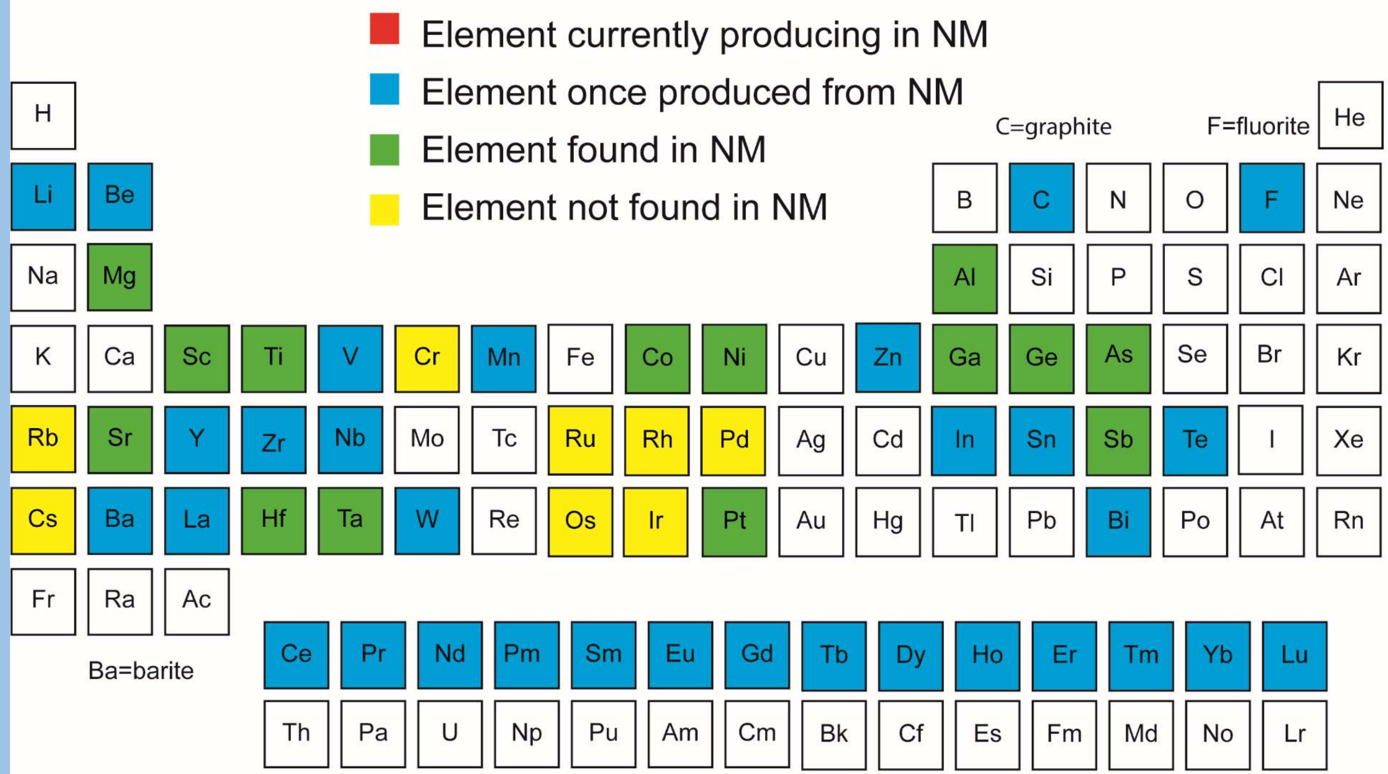
2020



Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

Critical Minerals in New Mexico

2022

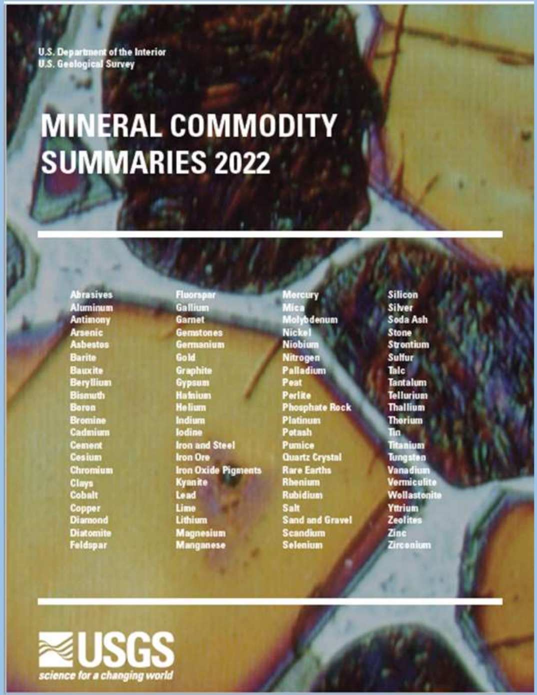


Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

U, Re, He, and K (potash) were removed from the critical minerals list in 2022 and Zn and Ni were added.

Figure 2.—2021 U.S. Net Import Reliance[1]

Commodity	Net import reliance as a percentage of apparent consumption	Major import sources (2017–20)[2]
ARSENIC, all forms	100	China, Morocco, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Germany, China
FLUORSPAR	100	Mexico, Vietnam, South Africa, Canada
GALLIUM	100	China, United Kingdom, Germany, Ukraine
GRAPHITE (NATURAL)	100	China, Mexico, Canada, India
INDIUM	100	China, Canada, Republic of Korea, France
MANGANESE	100	Gabon, South Africa, Australia, Georgia
MICA (NATURAL), sheet	100	China, Brazil, Belgium, India
NEPHELINE SYENITE	100	Canada
NIOBIUM (COLUMBIUM)	100	Brazil, Canada
RUBIDIUM	100	Germany
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	China, Germany, Australia, Indonesia
VANADIUM	100	Canada, China, Brazil, South Africa
YTTRIUM	100	China, Republic of Korea, Japan
GEMSTONES	99	India, Israel, Belgium, South Africa
TELLURIUM	>95	Canada, Germany, China, Philippines
POTASH	93	Canada, Russia, Belarus
IRON OXIDE PIGMENTS, natural and synthetic	91	China, Germany, Brazil
RARE EARTHS,[3] compounds and metals	>90	China, Estonia, Malaysia, Japan
TITANIUM, sponge	>90	Japan, Kazakhstan, Ukraine
BISMUTH	90	China, Republic of Korea, Mexico, Belgium
TITANIUM MINERAL CONCENTRATES	90	South Africa, Australia, Madagascar, Mozambique
ANTIMONY, metal and oxide	84	China, Belgium, India
STONE (DIMENSION)	84	China, Brazil, Italy, India
CHROMIUM	80	South Africa, Kazakhstan, Russia, Mexico
PEAT	80	Canada
SILVER	79	Mexico, Canada, Chile, Poland
TIN, refined	78	Indonesia, Peru, Malaysia, Bolivia
COBALT	76	Norway, Canada, Japan, Finland
DIAMOND (INDUSTRIAL), stones	76	South Africa, India, Congo (Kinshasa), Botswana
ZINC, refined	76	Canada, Mexico, Peru, Spain
ABRASIVES, crude fused aluminum oxide	>75	China, France, Bahrain, Russia
BARITE	>75	China, India, Morocco, Mexico
BAUXITE	>75	Jamaica, Brazil, Guyana, Australia
SELENIUM	>75	Philippines, China, Mexico, Germany
RHENIUM	72	Chile, Canada, Kazakhstan, Japan
PLATINUM	70	South Africa, Germany, Switzerland, Italy
ALUMINA	58	Brazil, Australia, Jamaica, Canada
GARNET (INDUSTRIAL)	56	South Africa, China, India, Australia
MAGNESIUM COMPOUNDS	55	China, Brazil, Israel, Canada
ABRASIVES, crude silicon carbide	>50	China, Netherlands, South Africa
GERMANIUM	>50	China, Belgium, Germany, Russia
IODINE	>50	Chile, Japan
TUNGSTEN	>50	China, Bolivia, Germany, Canada
CADMIUM	<50	Australia, China, Germany, Peru
MAGNESIUM METAL	<50	Canada, Israel, Mexico
NICKEL	48	Canada, Norway, Finland, Australia



https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

Critical minerals change with time and country

- Salt was once a critical mineral, but is now abundant with low supply disruptions
- Copper is considered critical mineral by Japan


minerals
MDPI

Article

Environmental Implications of Resource Security Strategies for Critical Minerals: A Case Study of Copper in Japan

Ran Motoori *, Benjamin C. McLellan and Tetsuo Tezuka

Graduate School of Energy Science, Kyoto University, Kyoto 606-8501, Japan; b-mclellan@energy.kyoto-u.ac.jp (B.C.M.); tezuka@energy.kyoto-u.ac.jp (T.T.)
* Correspondence: motoori.ran.45m@st.kyoto-u.ac.jp; Tel.: +81-75-753-3300

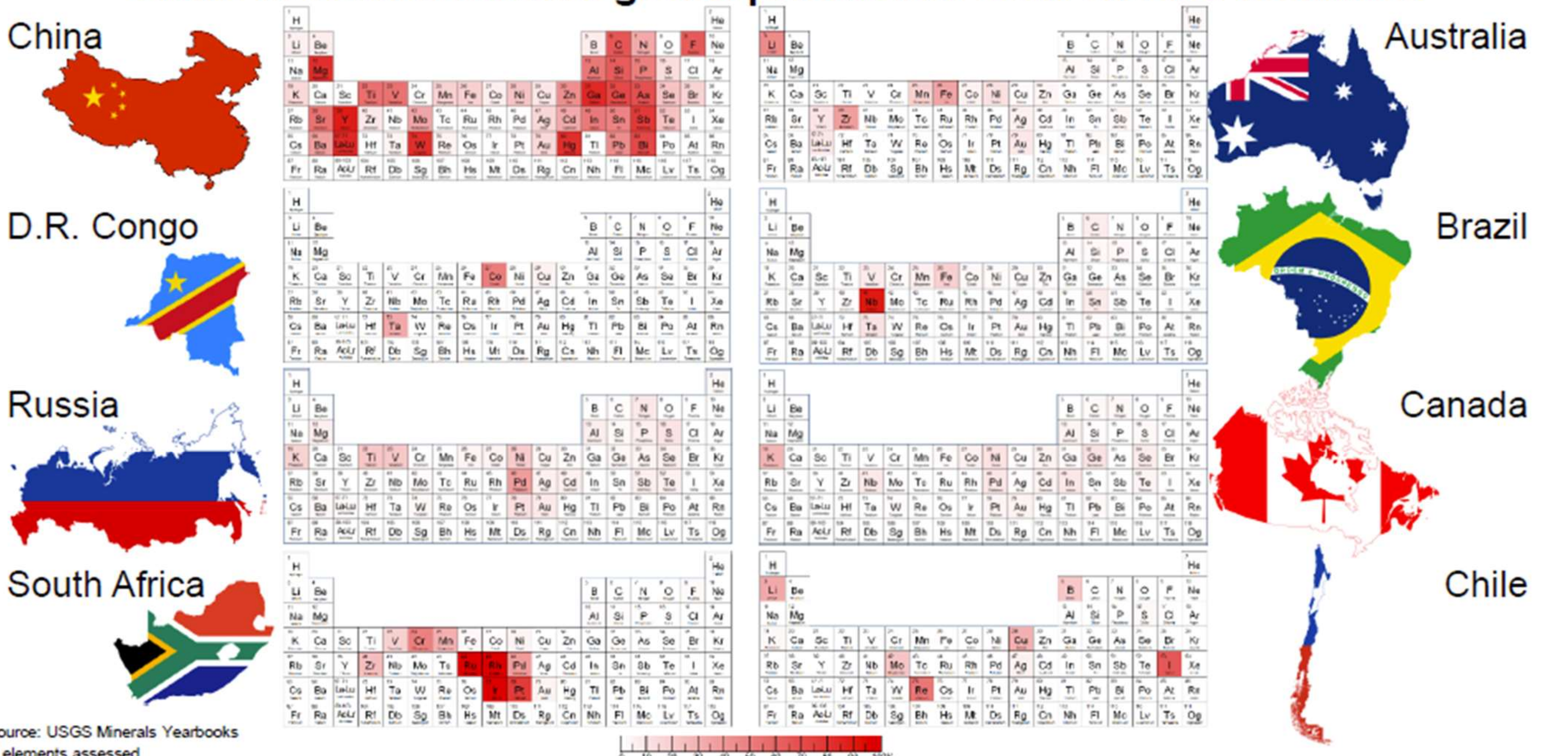
check for updates
Received: 9 October 2018; Accepted: 26 November 2018; Published: 1 December 2018

Abstract: In the assessment of critical minerals, environmental impacts have been a focus of a number of methodologies. In the case of resource security for critical minerals, there are a variety of potential strategies that might be used to reduce criticality from the supply risk perspective, but

Why are critical minerals so important?

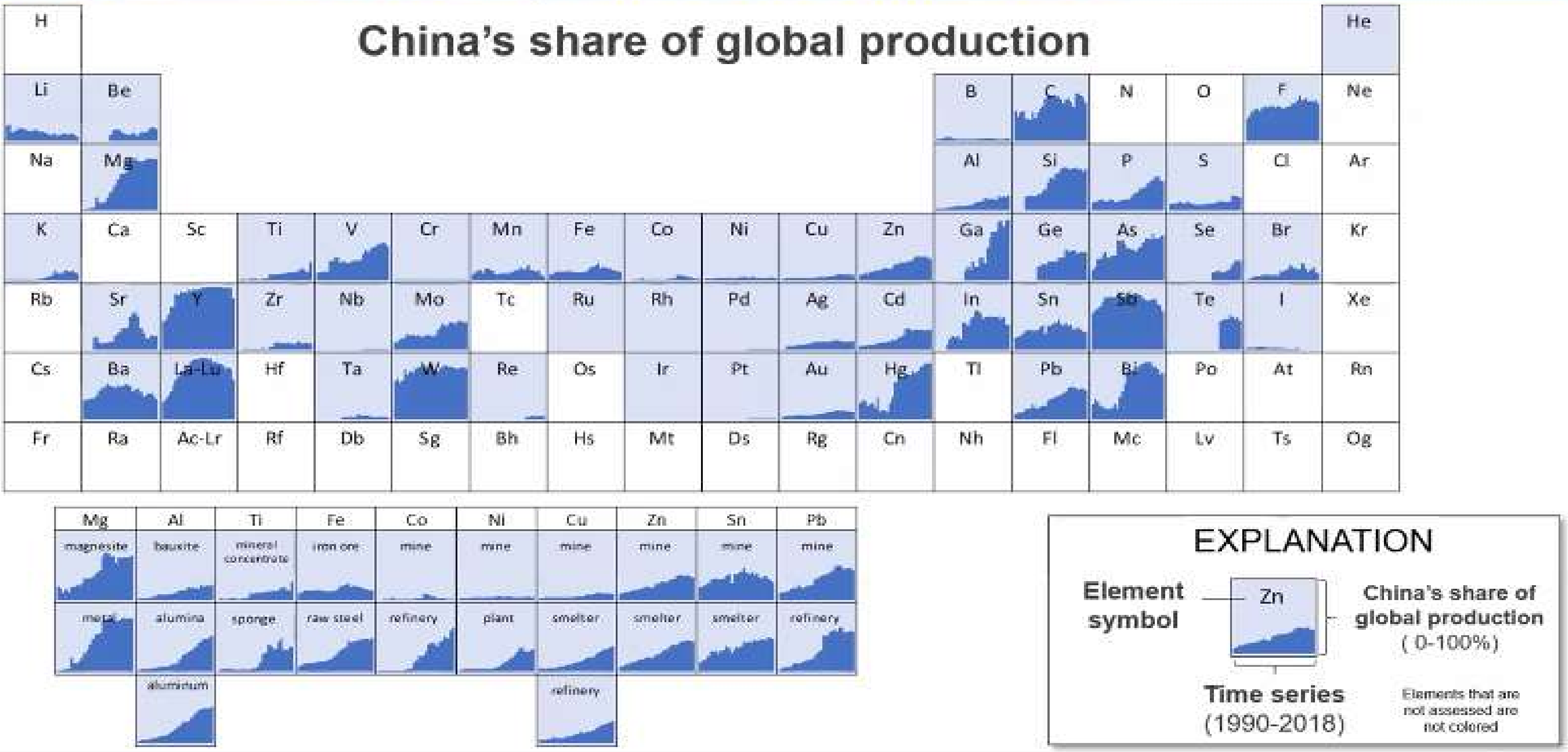
Production of many mineral commodities is highly concentrated in a few countries.

Share of each element's global production from various countries



Data source: USGS Minerals Yearbooks
Not all elements assessed

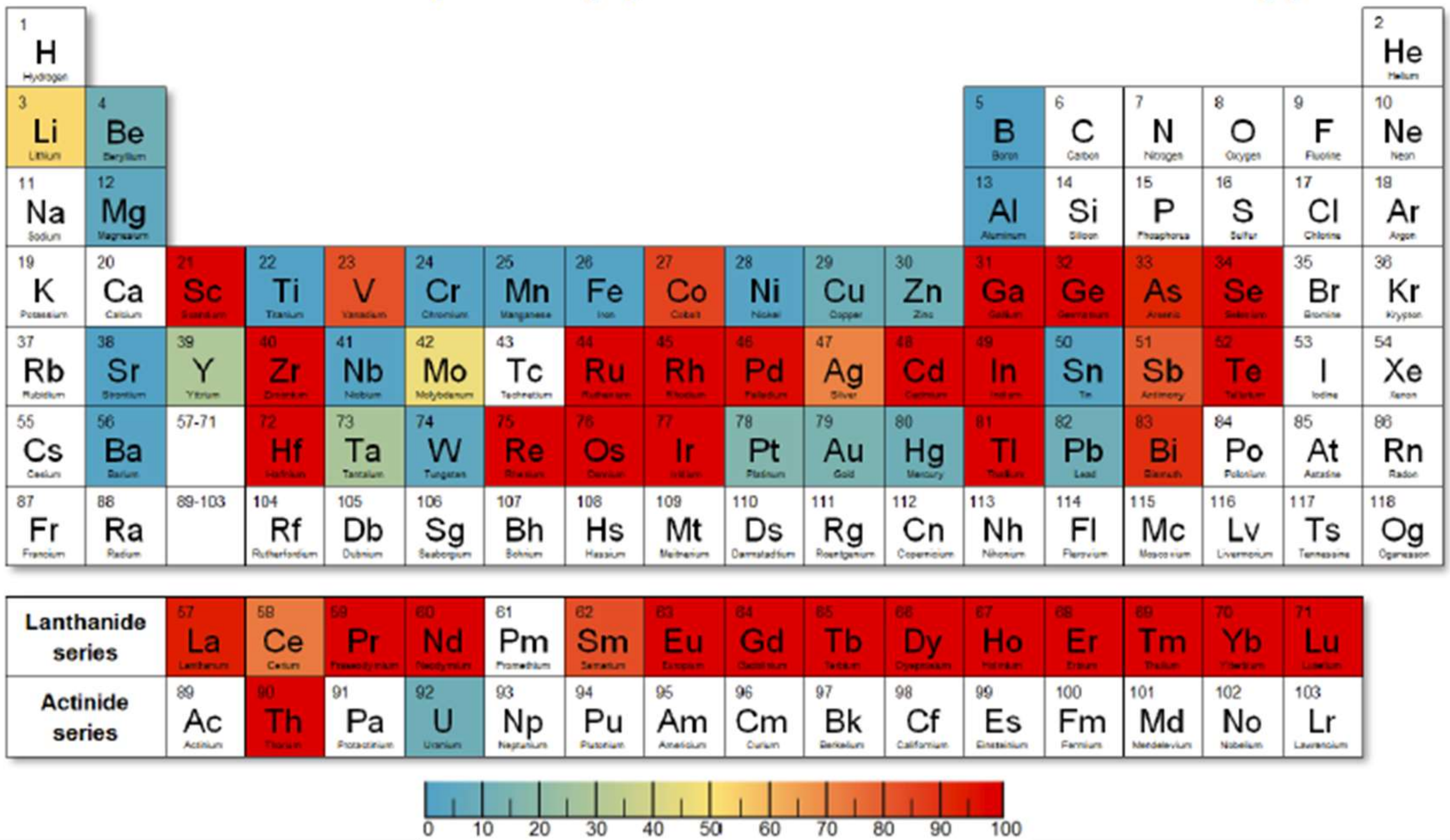
China's share of global production has increased markedly over the past three decades for many mineral commodities.



Nassar, N.T., Alonso, E., and Brainard, J.L., 2020, Investigation of U.S. Foreign Reliance on Critical Minerals—U.S. Geological Survey Technical Input Document in Response to Executive Order No. 13953 Signed September 30, 2020 (Ver. 1.1, December 7, 2020): U.S. Geological Survey Open-File Report 2020–1127, 37 p., https://doi.org/10.3133/ofr20201127.

Many of the mineral commodities required for advanced technologies are recovered only as byproducts during the processing of other minerals.

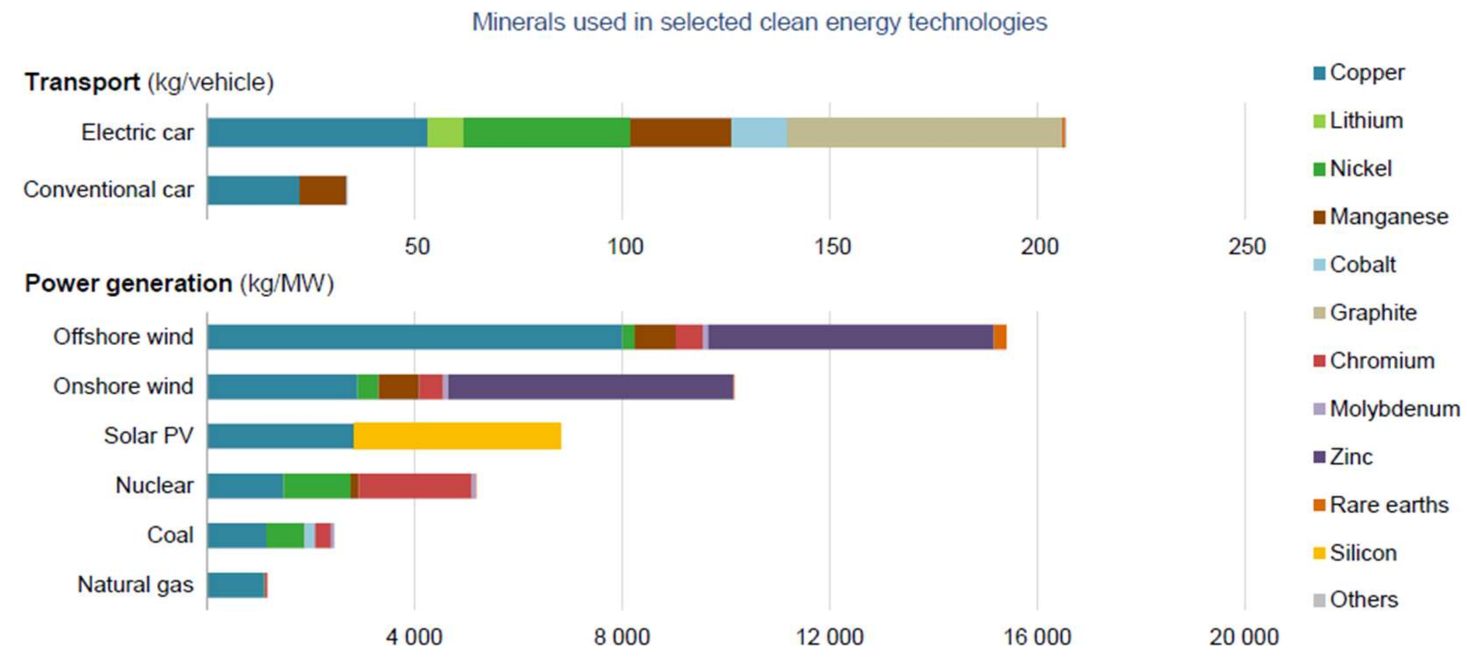
Share of element's primary production obtained as a byproduct



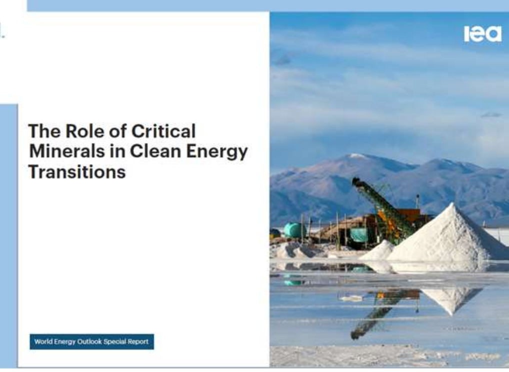
N. T. Nassar, T. E. Graedel, E. M. Harper, By-product metals are technologically essential but have problematic supply. *Science Advances* **1**, e1400180 (2015).

From Nassar and Fortier (2021)

The rapid deployment of clean energy technologies as part of energy transitions implies a significant increase in demand for minerals



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.



Mineral needs vary widely across clean energy technologies

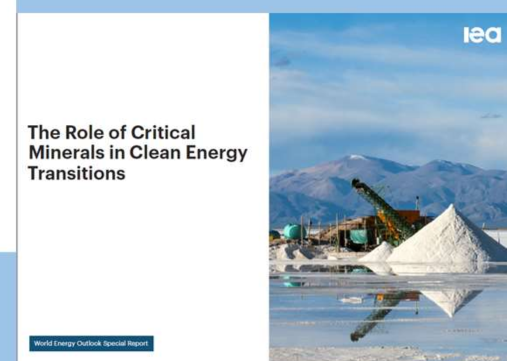
Critical mineral needs for clean energy technologies

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium*
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	◍	○	●	◍	●	○	◍
Hydro	◍	○	○	○	○	◍	◍	○	◍
CSP	◍	○	◍	○	○	●	◍	○	●
Bioenergy	●	○	○	○	○	○	◍	○	◍
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	◍	○	◍	○	○	◍	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	◍	○	○	●	◍

Notes: Shading indicates the relative importance of minerals for a particular clean energy technology (● = high; ◍ = moderate; ○ = low), which are discussed in their respective sections in this chapter. CSP = concentrating solar power; PGM = platinum group metals.

* In this report, aluminium demand is assessed for electricity networks only and is not included in the aggregate demand projections.

iea




How much raw material does a 30GWh NCM Li-ion Megafactory consume?
Graphite anode 33,000 tonnes
Cobalt 6,000 tonnes
Nickel 19,000 tonnes
Lithium 25,000 tonnes
© Benchmark Mineral Intelligence 2021

What are some of the programs being developed to address availability of critical minerals?

USGS Earth Mapping Resources Initiative (Earth MRI)

USGS's Response to EO 13817 and SO 3359:

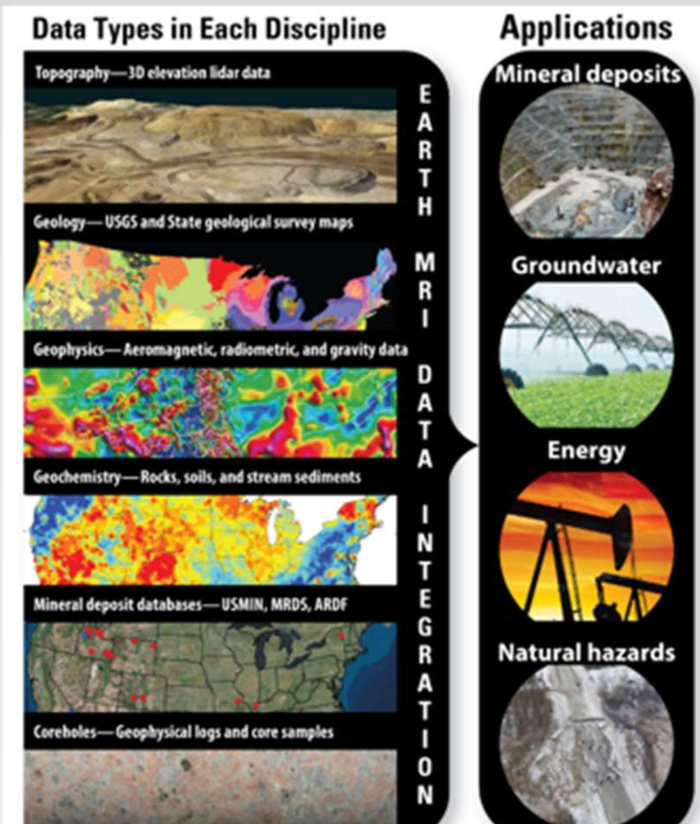
Earth MRI: Partnership between USGS and State Geological Surveys to generate state-of-the-art geologic mapping, geophysical surveys, and lidar data for the Nation in areas with critical mineral potential.

Earth MRI Budget

- **FY 2019**: $9.598M
- **FY 2019 State Matching Funds:** ~$2.9M from 29 States
- **FY 2020:** $10.598M
- **FY 2020 State Matching Funds:** ~$2.2M from 27 States
- Seeking Other Agency Partnerships to leverage funds

Activities

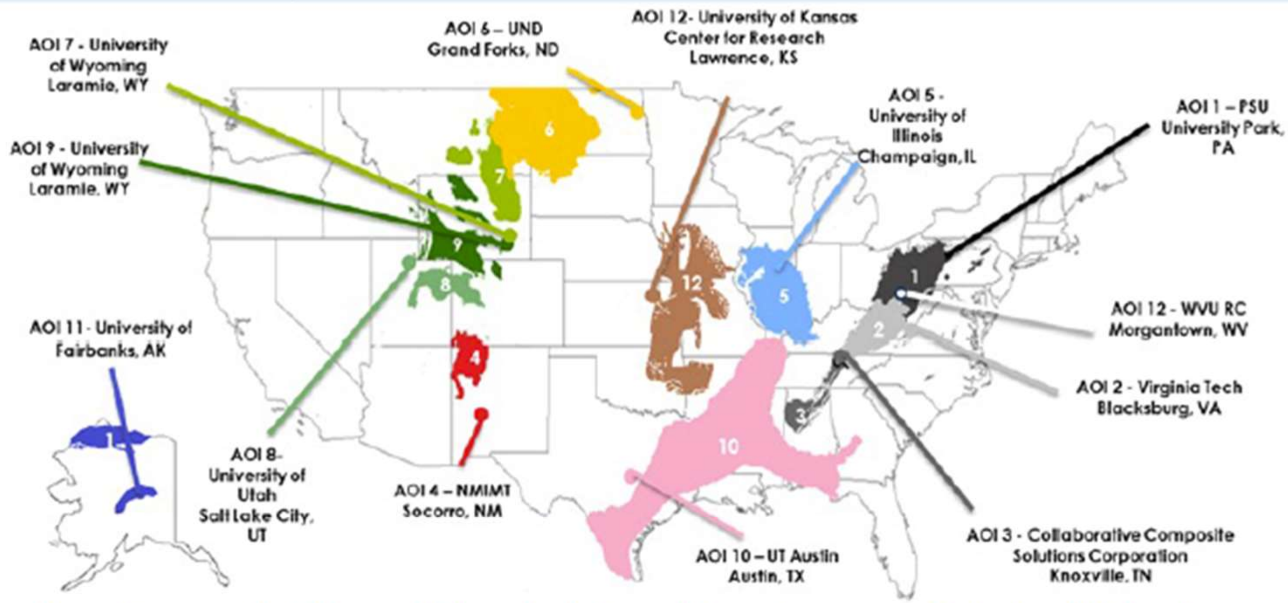
- **FY 2019:** Focused on rare earth elements
- **FY 2020:** Focused on rare earth elements and 10 more commodities: Al, Co, graphite, Li, Nb, PGEs, Ta, Sn, Ti, and W



CORE-CM Regional Challenges

U.S. DEPARTMENT OF ENERGY

Building coalitions to develop and implement strategies that accelerate and realize the full economic potential of carbon ore and critical minerals across the U.S.



- Address the upstream and midstream CM supply chain and downstream manufacturing of high-value, nonfuel, carbon-based products, ores and critical minerals
- Co-located with economically stressed communities in need of clean energy jobs and will provide the foundation for educating next generation technicians, skilled workers, and STEM professionals.

Small Scale Pilots: Proving Technical Feasibility

Quantity MREO Produced Annually				
	2018	**2019**	**2020**	**2021**
UKY (Refuse)	0.6 kg	1.5 kg	0.5 kg	Processing Begins in Fall
	80% purity	>90% purity	~98% purity	
WVU (AMD)	44 g		Field Pilot Construction (Facility Start Up January 2022	
	95 – 99% purity			
PSI (ASH)	0.01 kg MRES	0.149 kg MRES	1.06 kg MRES	1.76 kg MRES
	≤10% purity	≤14% purity	≤67% purity	≤91% purity
	0.004 kg MREO equivalent	0.057 kg MREO equivalent	0.41 kg MREO equivalent	0.67 kg MREO equivalent
UND (Lignite)	5-10 g	500 g	Pilot Construction (Facility Start – Up October 2021)	
		30 -85% purity		
	5 – 15% purity	4000 g		
		4 – 9 % purity		

Projects increased purity of MREOs being produced up to 99%

science for a changing world

Geological Survey of Canada
Natural Resources Canada

Queensland Government

Australian Government
Geoscience Australia

Prepared as part of a joint research program between the U.S. Geological Survey, Geological Survey of Canada, Geological Survey of Queensland, and Geoscience Australia

Deposit Classification Scheme for the Critical Minerals Mapping Initiative Global Geochemical Database

Open-File Report 2021–1049

U.S. Department of the Interior
U.S. Geological Survey

HOME
WHAT ARE MINERAL SYSTEMS?
- Find mineral systems by process
- Find mineral systems by commodity

Primary data layers
Structures
Tectonic units
Komatiite-hosted nickel
Iron formation
Rare-element pegmatite
Layered intrusion-hosted vanadium
DOCUMENTATION
CONTACT US

MINERAL SYSTEMS ATLAS

Home / WHAT ARE MINERAL SYSTEMS? / Find mineral systems by process

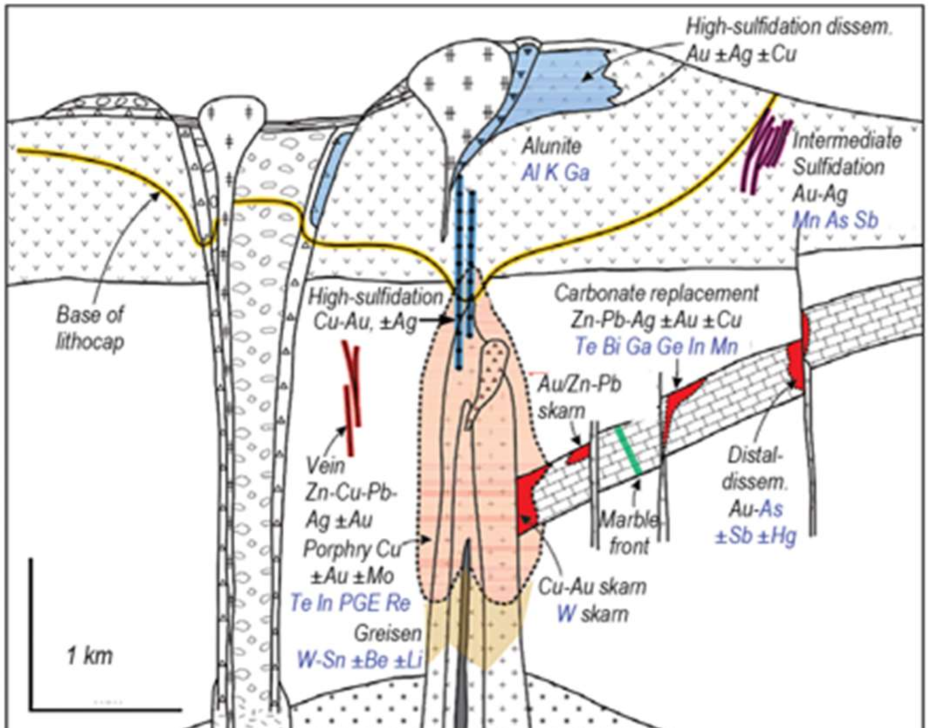
Find mineral systems by process

- Basin-related fluid flow
- Deformation and metamorphism
- Magmatic-related hydrothermal
- Orthomagmatic
- Sedimentary
- Weathering and regolith

The Minerals Systems Atlas groups known (Australian) mineral deposit types (mineral subsystems') within a mineral system context on the basis of perceived common, regional-scale metallogenic processes,following the scheme proposed by Geoscience Australia (Table 1; Fraser et al., 2007; GA Record 2007-16). These processes and resultant mineral deposits may have occurred in more than one geodynamic (tectonic) setting, but a knowledge of the specific setting is not required in order to select data.

Mineral Systems Approach

Example: Porphyry Copper-Molybdenum-Gold System



Hofstra and Kreiner (2020), USGS Open-File Report 2020-1042

System Name	Deposit types	Principal Commodities	Critical minerals
Porphyry Cu-Mo-Au	Pegmatite	Li, Cs, Ta	Li, Cs, Ta, Be
	Greisen	Mo, W, Sn	W, Sn
	S-R-V Tungsten	W	W, Bi, Mn
	Porphyry/Skarn Molybdenum	Mo, W, Sn	W, Re, Bi
	Porphyry/Skarn Copper	Cu, Ag, Au, Mo	PGE, Te, Re, Bi, U
	Polymetallic Sulfide S-R-V-IS	Cu, Zn, Pb, Ag, Au	Mn, Ge, Ga, In, Bi, Sb, As, W, Te
	Distal Disseminated Ag-Au	Ag, Au	Sb, As
	High sulfidation Au-Ag	Cu, Ag, Au	As, Sb, Te, Bi, Sn, Ga
	Lithocap Alunite	Al_2O_3, K_2SO_4, H_2SO_4	Al_2O_3, K_2SO_4, Ga
	Lithocap Kaolinite	Kaolin	Ga

Abbreviations: **S** skarn, **R** replacement, **V** vein, **IS** intermediate sulfidation.

Some of the challenges in producing critical minerals

5 Dimensions of Mineral Availability

WHAT *Questions Must We Ask?*

1. **Geologic** Availability

✓Does the mineral resource exist?

2. **Technical** Availability

✓Can we extract and process it?

3. **Environmental & Social** Availability

✓Can we produce it in environmentally and socially responsible and acceptable ways?

4. **Political** Availability

✓How do governments influence availability through their policy and actions?

5. **Economic** Availability

✓Can we produce it at a cost users are willing and able to pay?

Challenges

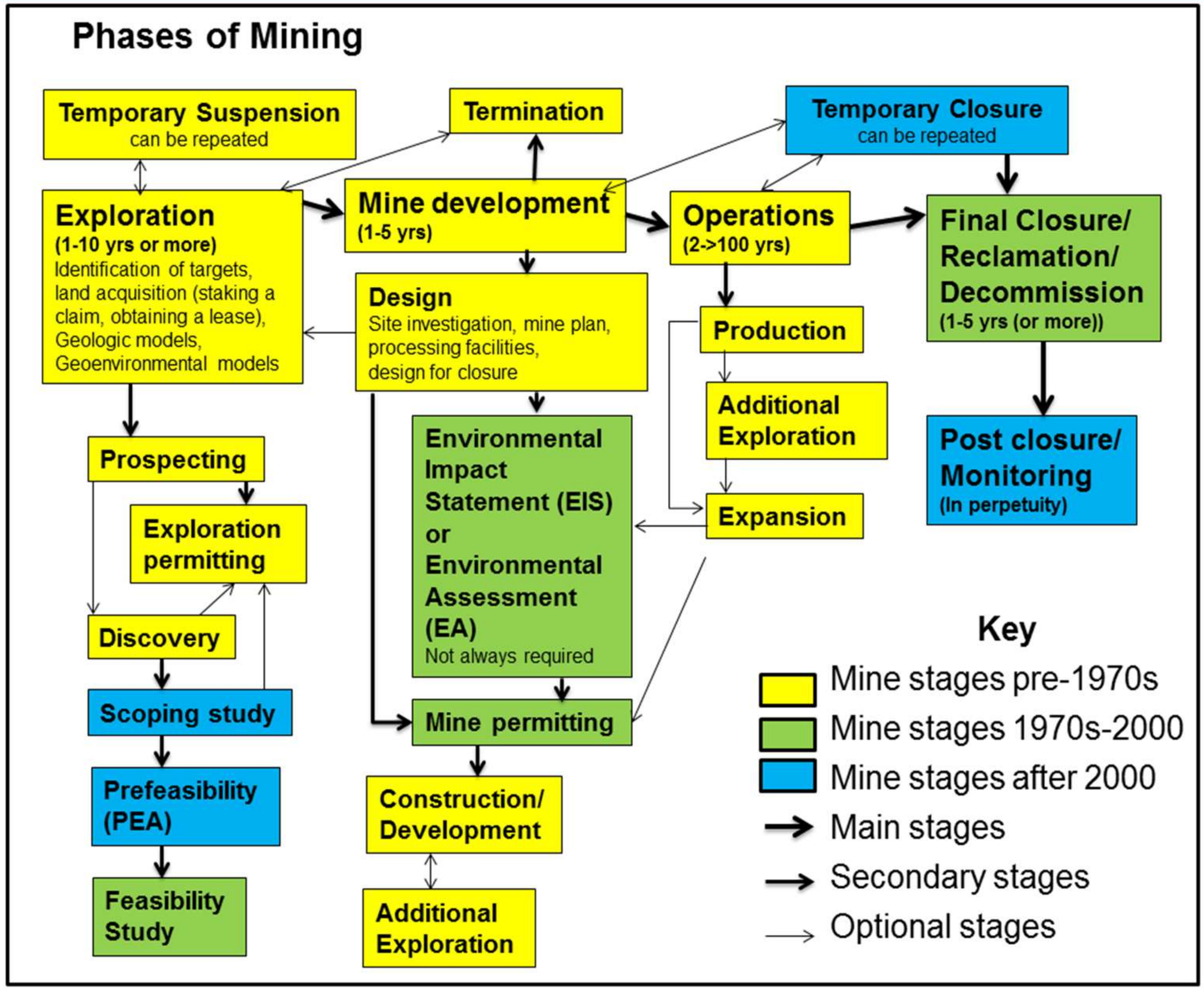
- How much of the minerals do we need?
- Are there enough materials in the pipeline to meet the demand for these technologies and other uses?
- Can any of these be recycled?
- Are there substitutions that can be used?
- Are these minerals environmental friendly—what are the reclamation challenges?
  - REE and Be are nearly always associated with U and Th and the wastes from mining REE and Be will have to accommodate radioactivity and radon

Challenges

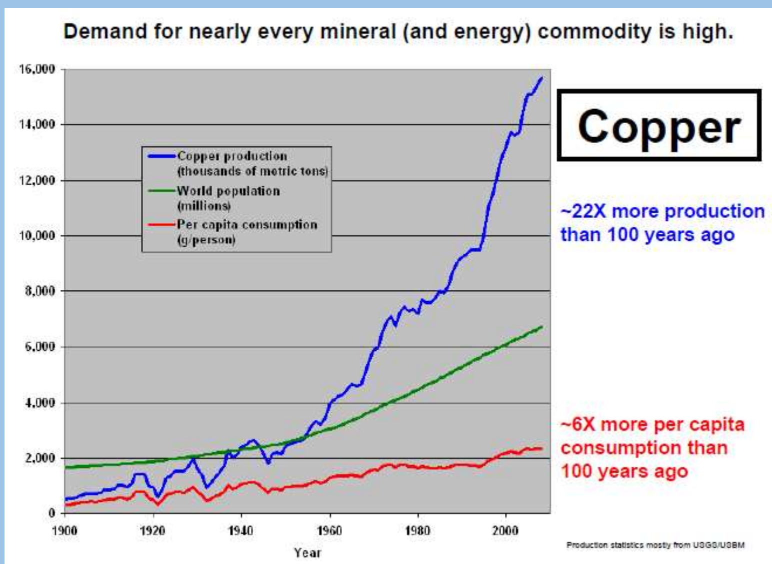
- The small volumes of strategic/critical minerals utilized makes them price sensitive
- New producers need a reliable, long-term buyer
- Long-term buyers require a fixed price, but operating costs are variable
- Monopolies/oligopolies can drive out marginal producers by over-supplying the market until the competition is eliminated
- Are any of these minerals "conflict minerals", i.e. minerals that fall under the Conflict Minerals Trade Act (H.R. 4128)
  - Minerals that provide major revenue to armed fractions for violence, such as that occurring in the Democratic Republic of Congo (GSA, Nov. 2010)

Life cycle of a mine

- Exploration takes years
- Permitting takes >10 yrs
- Operators are not going to jeopardize their primary commodity for a potential risky by-product



Why isn’t copper a critical mineral in the U.S.?



World Mine and Refinery Production and Reserves: Reserves for multiple countries were revised based on company and (or) Government information.

	Mine production		Refinery production		Reserves[6]
	2020	2021[e]	2020	2021[e]	
United States	1,200	1,200	918	1,000	48,000
Australia	885	900	427	450	[7]93,000
Canada	585	590	[e]290	300	9,800
Chile	5,730	5,600	2,330	2,200	200,000
China	1,720	1,800	10,000	10,000	26,000
Congo (Kinshasa)	1,600	1,800	1,350	1,500	31,000
Germany	—	—	643	630	—
Indonesia	505	810	269	270	24,000
Japan	—	—	1,580	1,500	—
Kazakhstan	552	520	515	470	20,000
Korea, Republic of	—	—	671	650	—
Mexico	733	720	492	470	53,000
Peru	2,150	2,200	324	350	77,000
Poland	393	390	560	590	31,000
Russia	[e]810	820	1,040	920	62,000
Zambia	853	830	378	350	21,000
Other countries	2,840	2,800	3,450	4,300	180,000
World total (rounded)	20,600	21,000	25,300	26,000	880,000

World Resources:[6] A U.S. Geological Survey study of global copper deposits indicated that, as of 2015, identified resources contained 2.1 billion tons of copper, and undiscovered resources contained an estimated 3.5 billion tons.[8]

thousand metric tons of contained copper

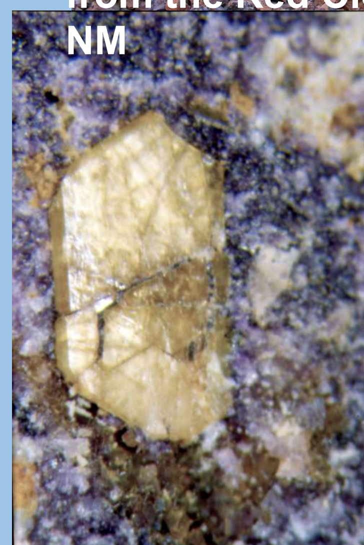
- Ready availability of copper
- Import only 45% of our consumption
- Abundant reserves

Summary

- Critical minerals are nonfuel minerals that are essential to the economy and defense of the U.S. that are subject to potential supply disruptions
- Both administrations (U.S.) have tasked the DOI (USGS), DOE, and DOD with critical minerals research
- Critical minerals are stand alone deposits, by-products or co-products, or trace amounts in known deposits
- Critical minerals are needed in order to move to a “green” CO_2-free economy
- Solving the shortage of critical minerals will involve more than exploration, mining, and processing (including recycling); but also changes in permitting but still protecting the affected environment and communities as well as the business models for financing some of these commodities

REE-bearing Eudialyte from Wind Mountain, Cornudas Mountains, southern NM

Bastnasite [(Ce,La)(CO_3)F] in purple fluorite breccia from the Red Cloud mine, Gallinas Mountains, central NM




QUESTIONS?