Defining Critical Minerals & Their Uses

What are "Critical Minerals?"

Why are they "Critical?"

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Illinois State Geological Survey

Brief Introduction

ILLINOIS
Illinois State Geological Survey
PRAIRIE RESEARCH INSTITUTE

Prairie Research Institute
Critical Minerals Research and Development Center

Illinois Basin CORE-CM

IRENES
Illinois Rare Earth Novel Extraction and Supply

Please Get Out your Smart Phone

I know you have one, get it out ☺

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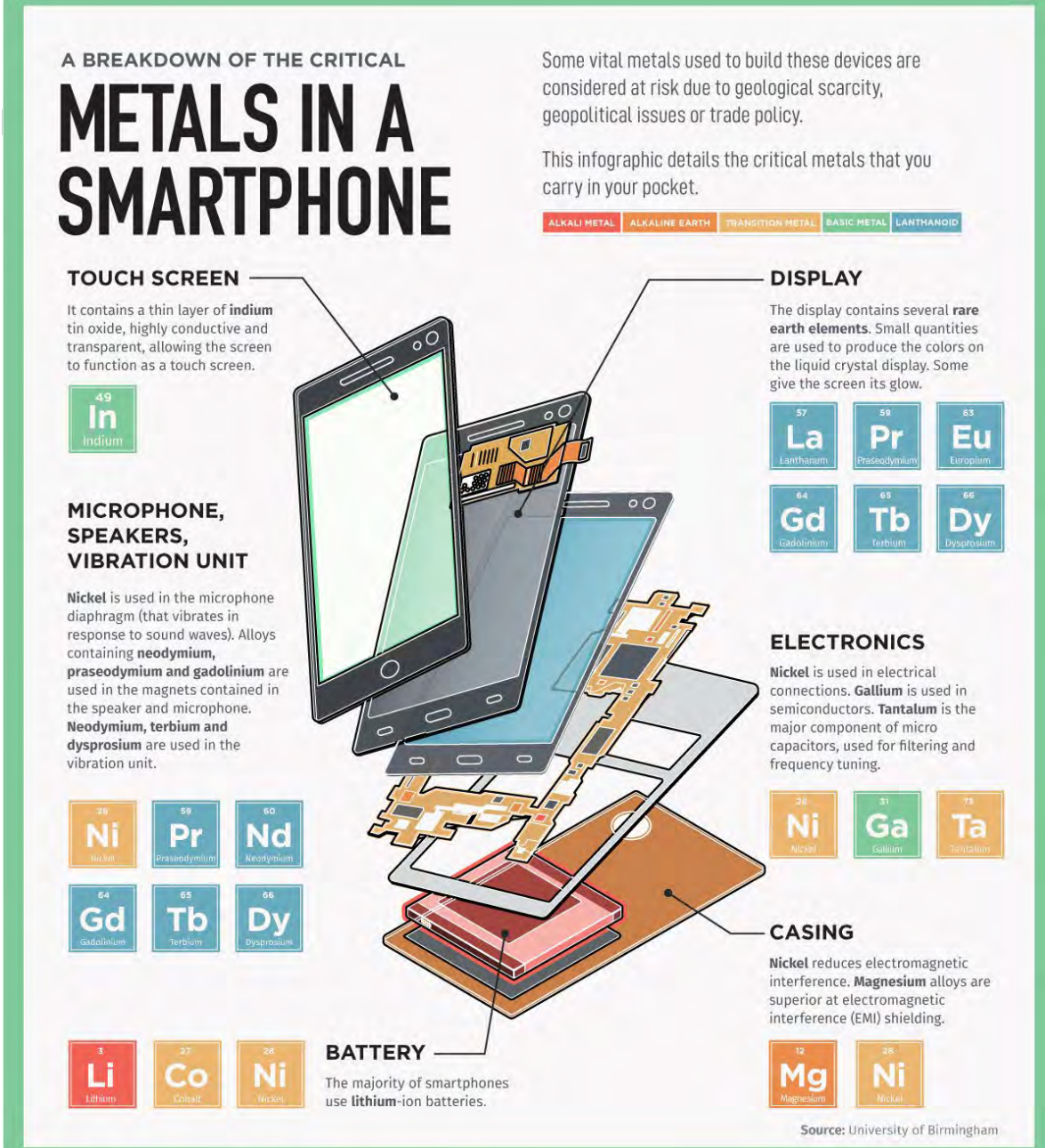
- In 2023: Apple sold approximately 231 million iPhones
- *Apple consumed just shy of 11,000 tons CM just for iPhones, in just 1 year*
- In 2024: Approximately 8 billion smart + feature phones w/ active subscriptions
- *375,000 short tons CM just in phones!*

Values from: Statista.com



Graphic from Visual Capitalist: https://www.visualcapitalist.com/visualizing-the-critical-metals-in-a-smartphone/

What is “Critical Mineral?”

Statute definitions

What it means

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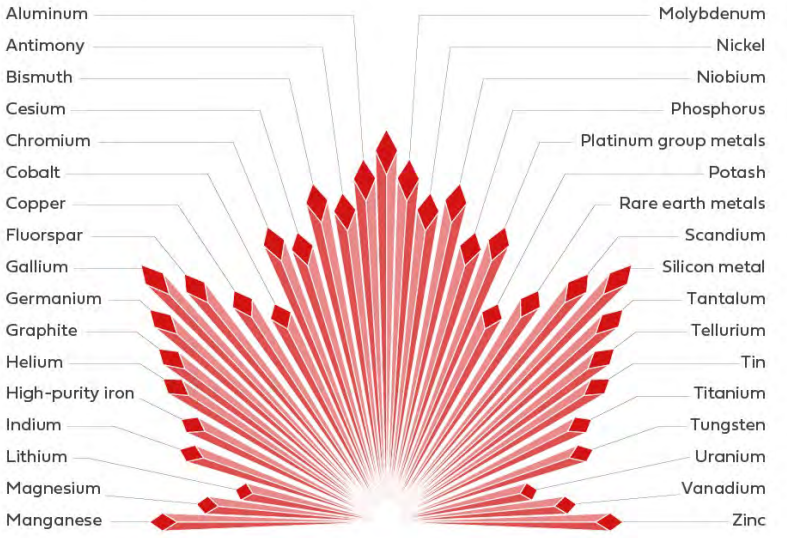
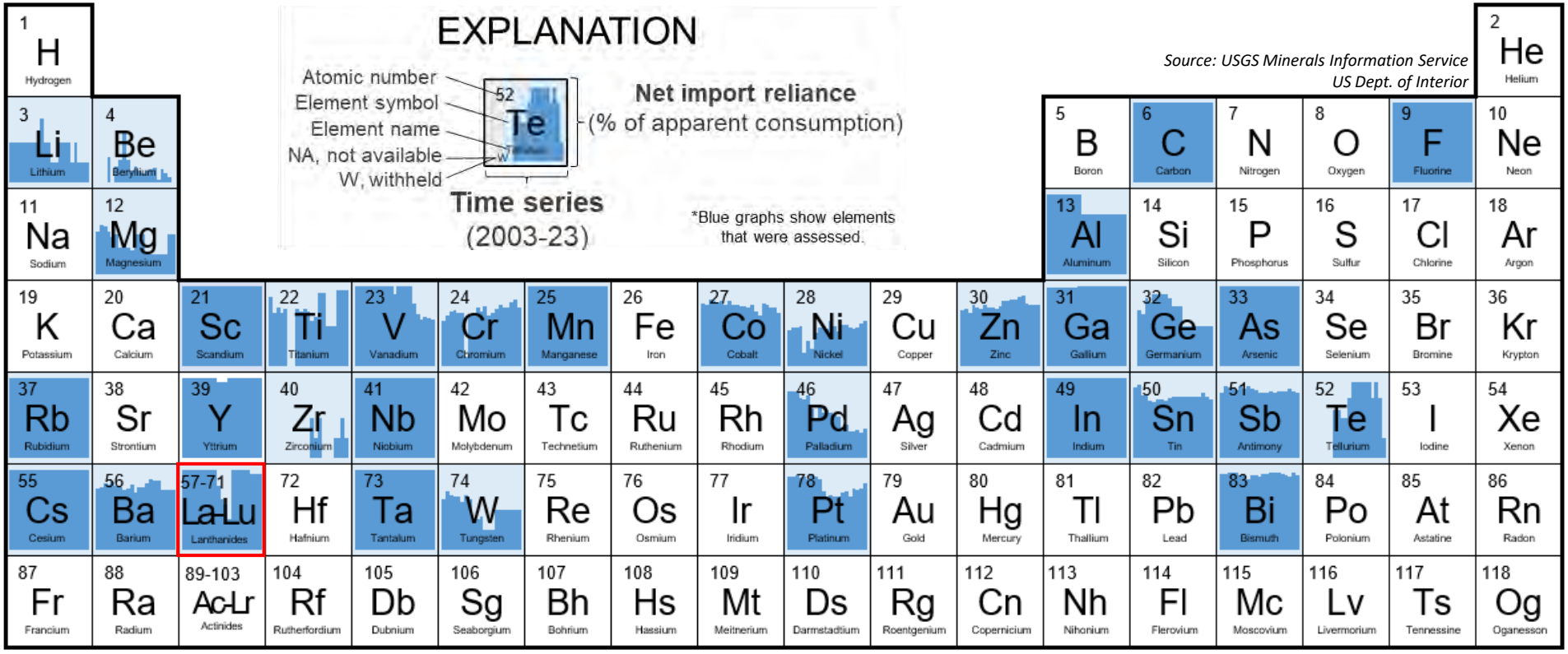
ILLINO
ENERGY & MINERAI

Statute Definitions

- Elements deemed vital to economic and national security by national government
- Significant overlap between US and Canada



Government of Canada



Source: USGS Minerals Information Service
US Dept. of Interior

What is a Critical Mineral (CM)?

CM are…

- Inputs into advanced technologies
  - Dy, Nd/Pr (magnets)
  - Li, Co, Ni (batteries)
  - REE (all sorts of things)
- Inputs into supply chains
  - Fluorspar (flux, acids)
  - Graphite (batteries)
- Small but mighty
  - PGE (catalysts, medicine)
  - Be (atomic applications)
  - Zn, Ti, Sc, Tin (metallurgy)

CM usually are **not**…

- Base metals
  - Iron, lead
  - Copper*
- Energy sources
  - Coal, Oil, Nat. Gas
  - Exception: U in Canada
- Precious metals
  - Gold, silver
  - Exception: PGE
- Aggregates (sand/gravel)
- Most important:

usually not widely available

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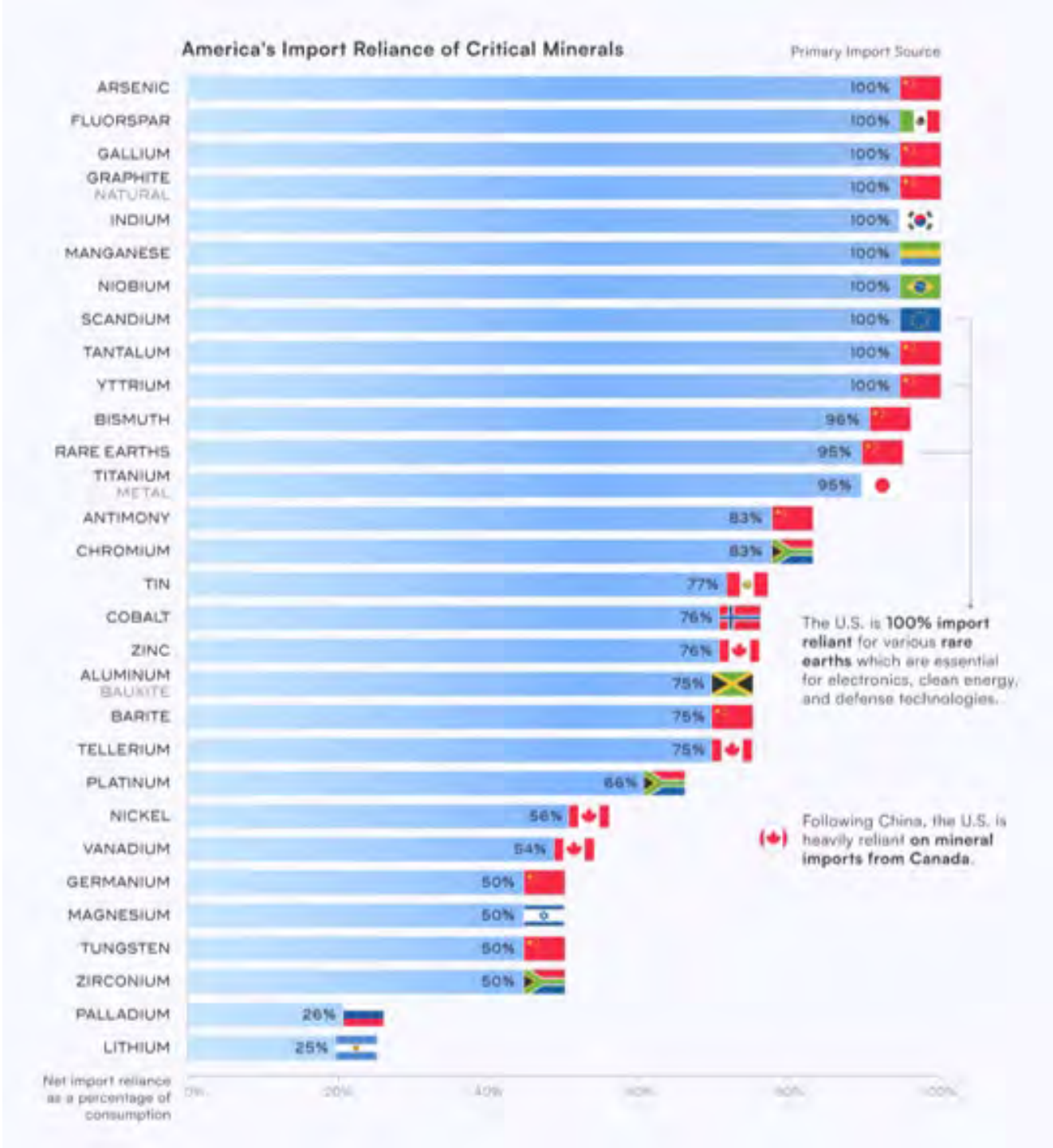
US CM Imports

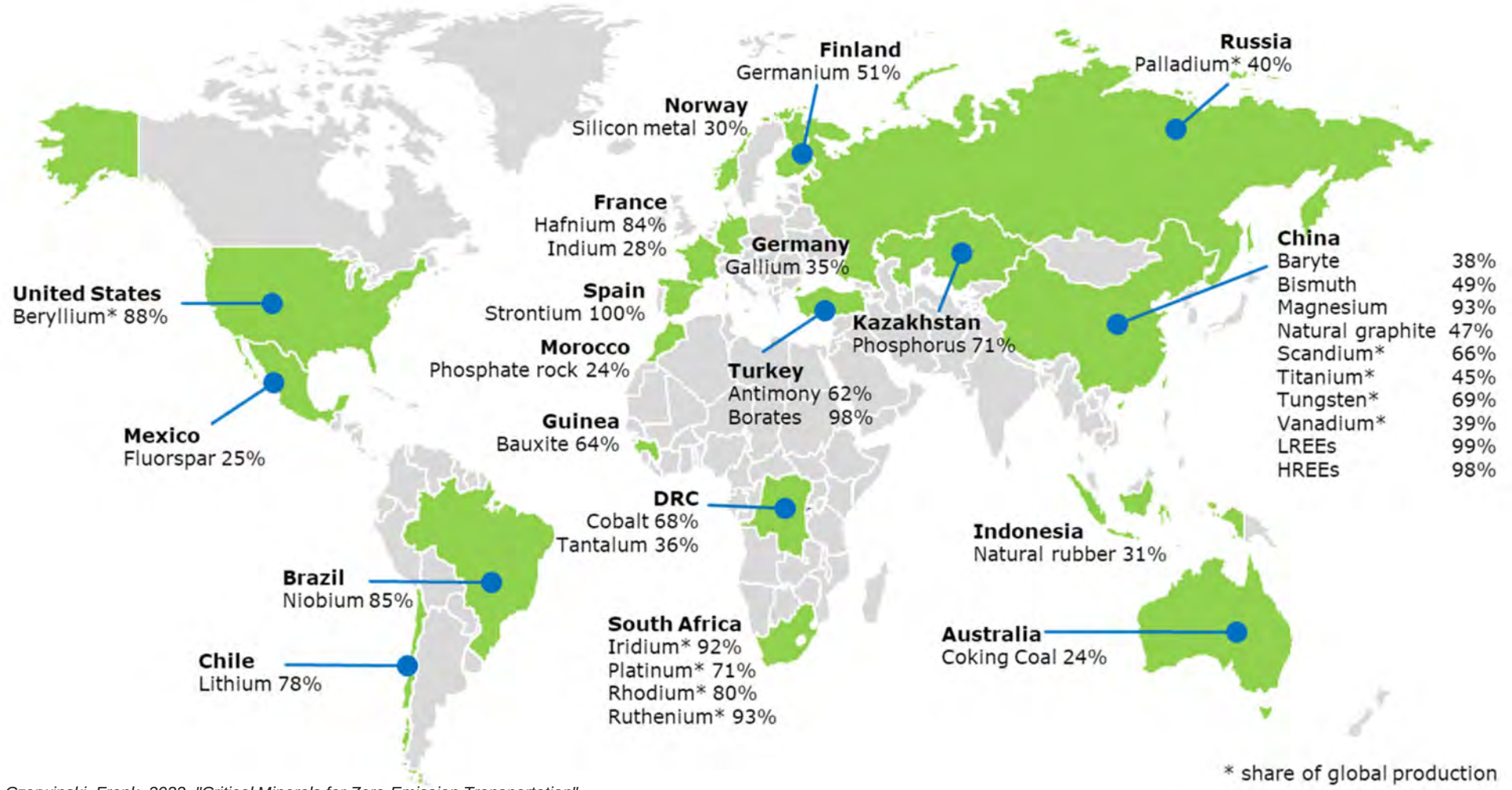
The US imports a large amount of the CM it depends on

- China
- The EU
- Canada

Canada exports significant raw & finished minerals to the US



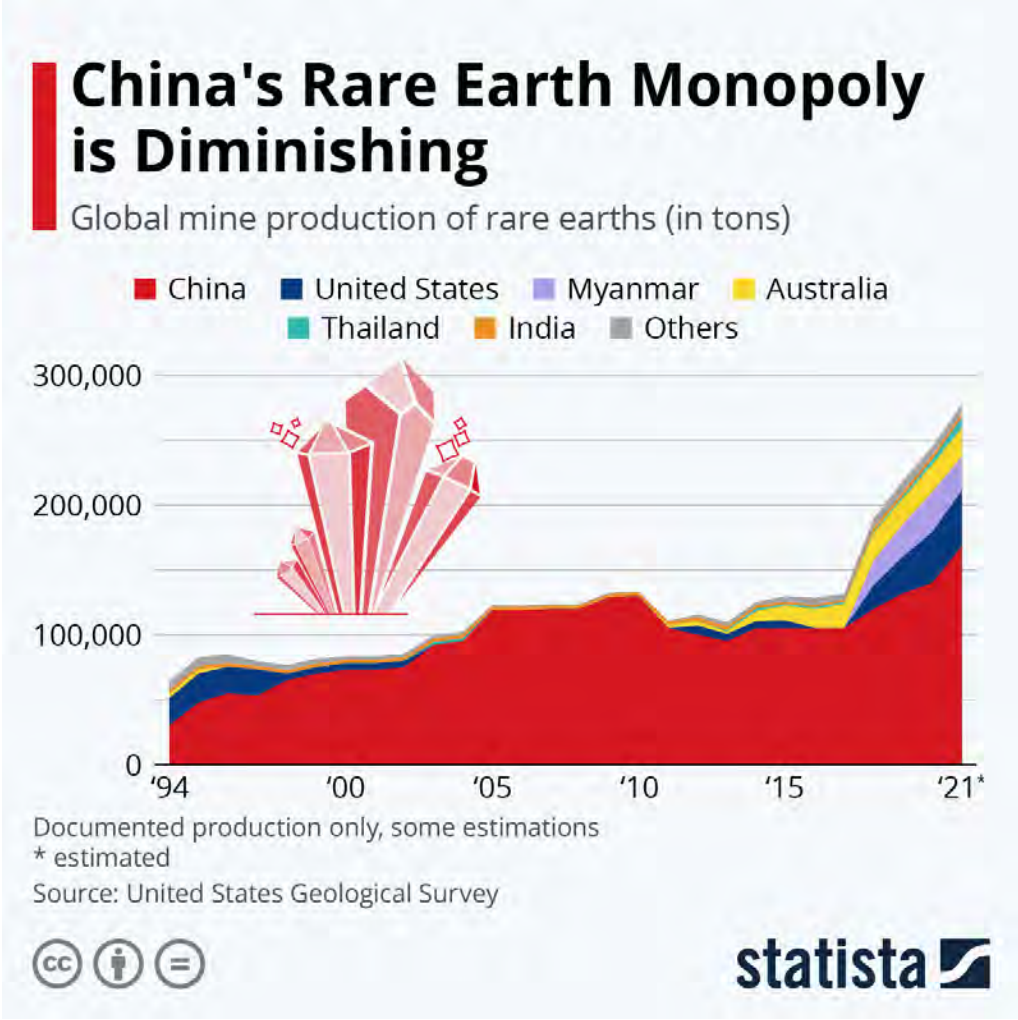
CM Industry: Production Worldwide



Czerwinski, Frank. 2022. "Critical Minerals for Zero-Emission Transportation" Materials 15, no. 16: 5539. https://doi.org/10.3390/ma15165539

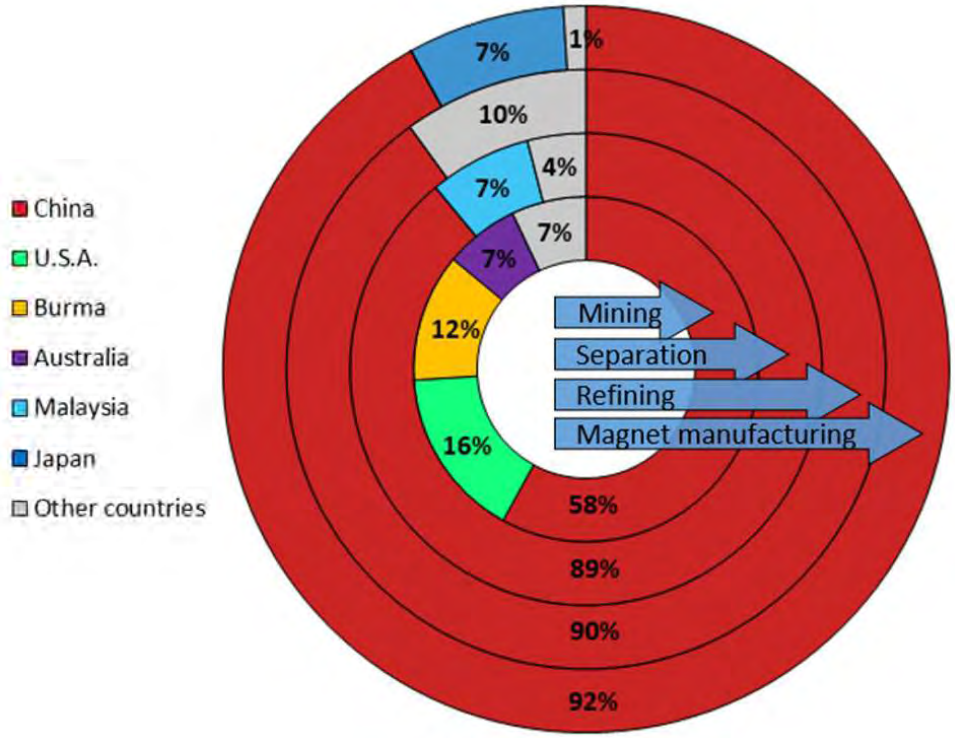
CM Mining is Diversifying …

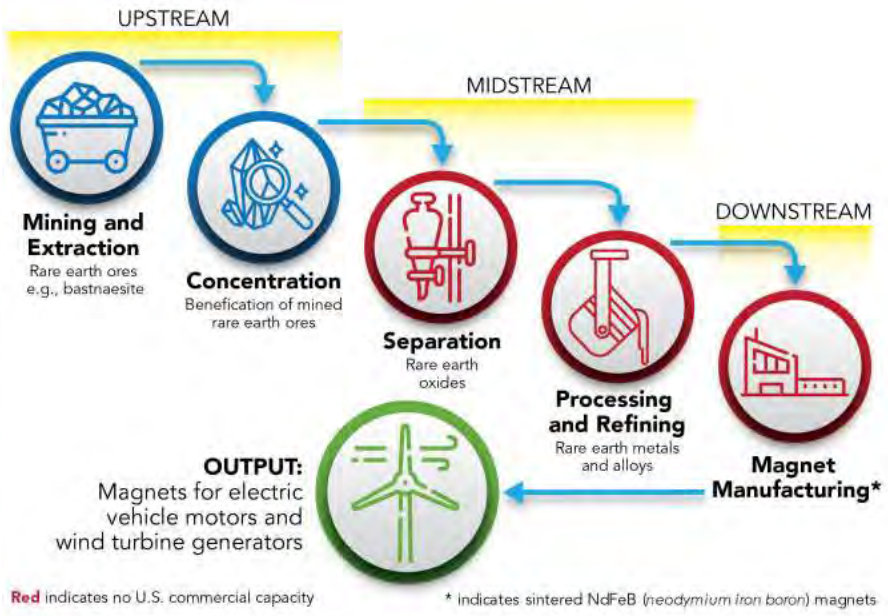
- Since the end of the cold war, China has dominated REE mining and production
- Since mid 2010's, supply has diversified
- 2021: 58% of REEs produced in China



The Problem in Processing…

- While raw REE has diversified, processing into metals suitable for production has not

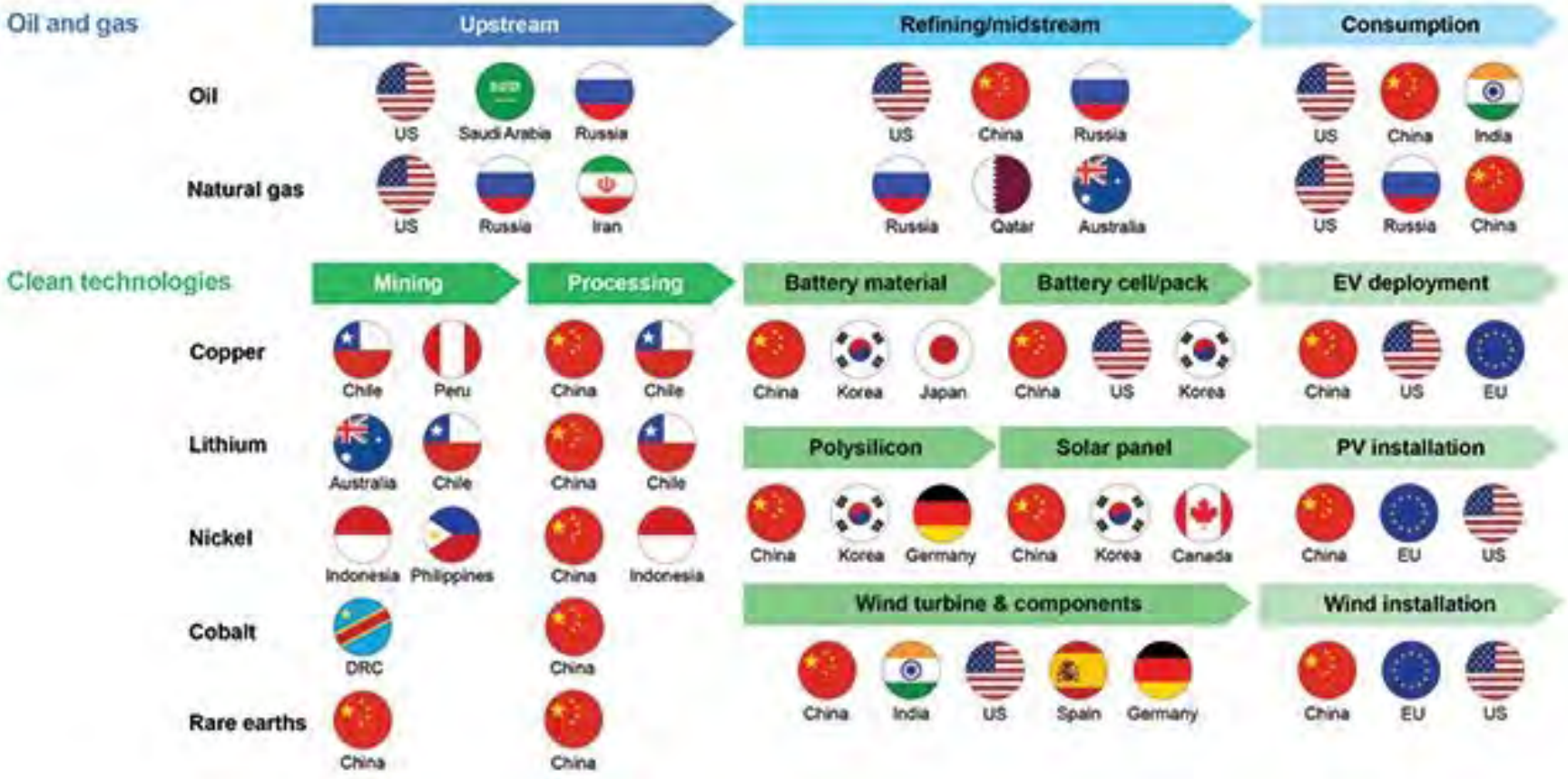




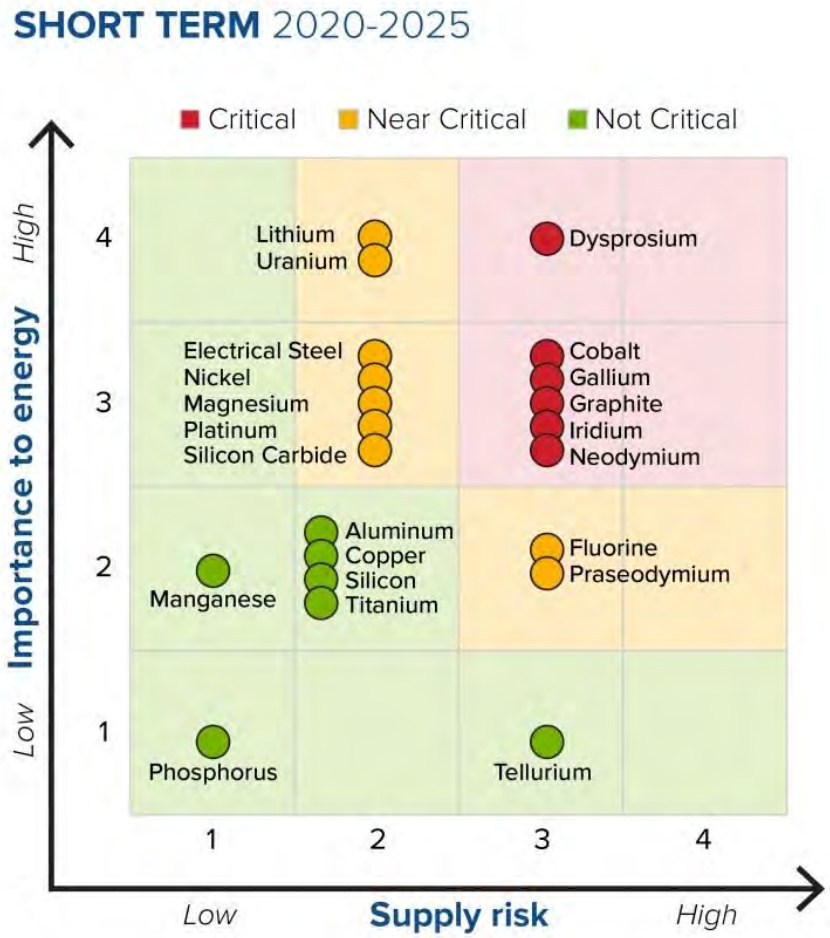
US DOE Presentations & Fact Sheets
https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

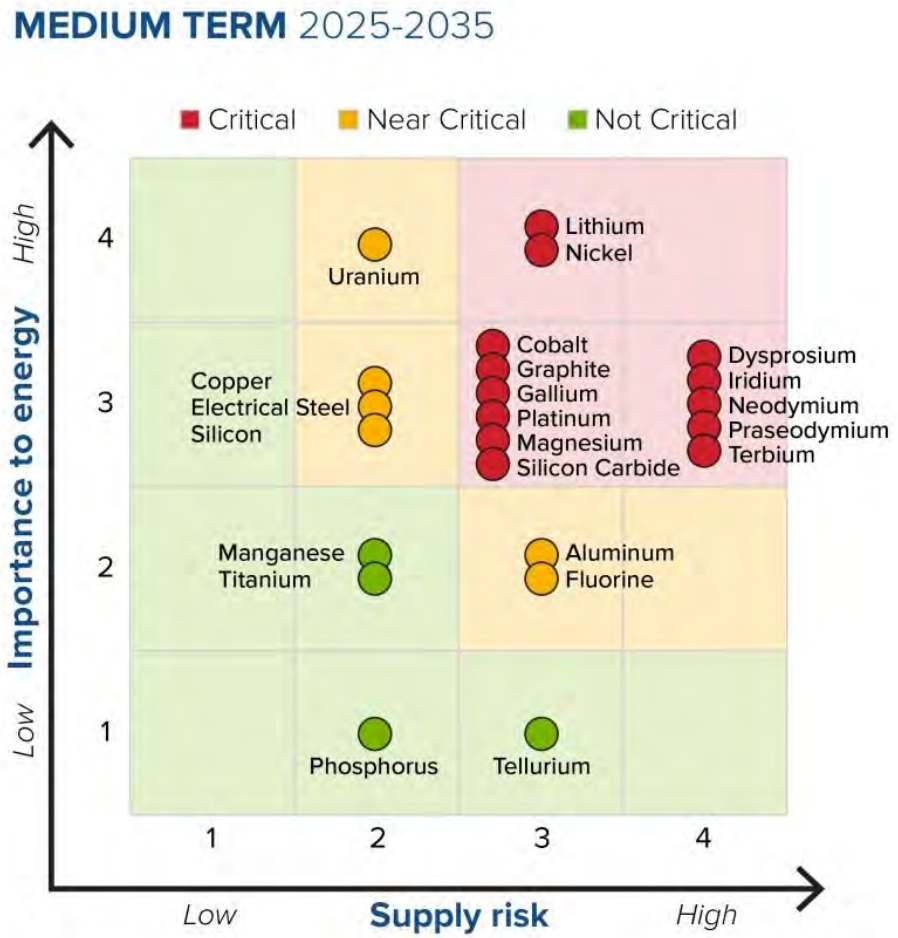
The Problem in Processing…

Many critical mineral supply chains are highly transnational: **Mining ≠ Independence**



US DOE: CM Supply Risk





Occurrence of Critical Mineral Resources

Occurrence of minerals and resources in general

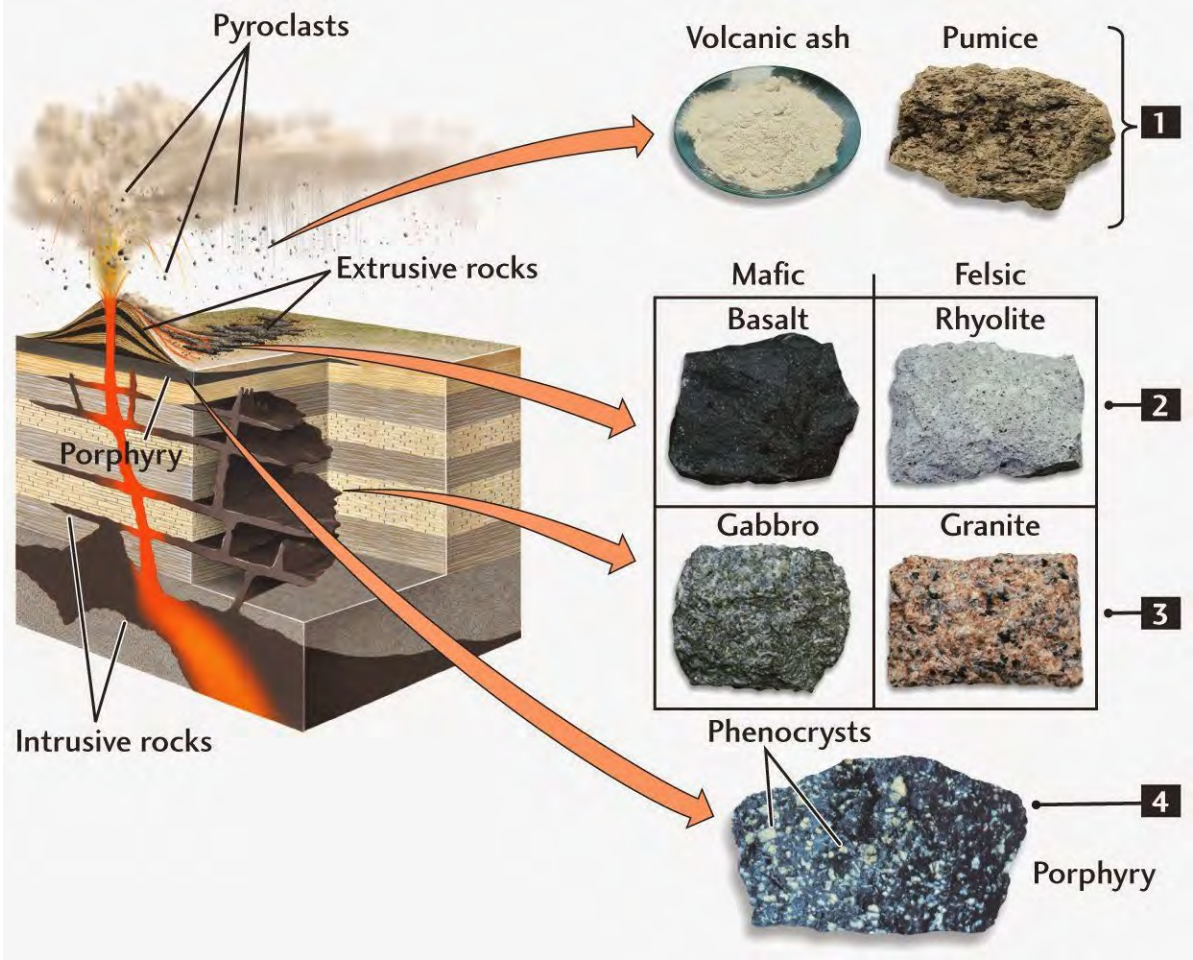
Why aren't critical minerals everywhere?

Why is China so good at this?

What is a Mine?

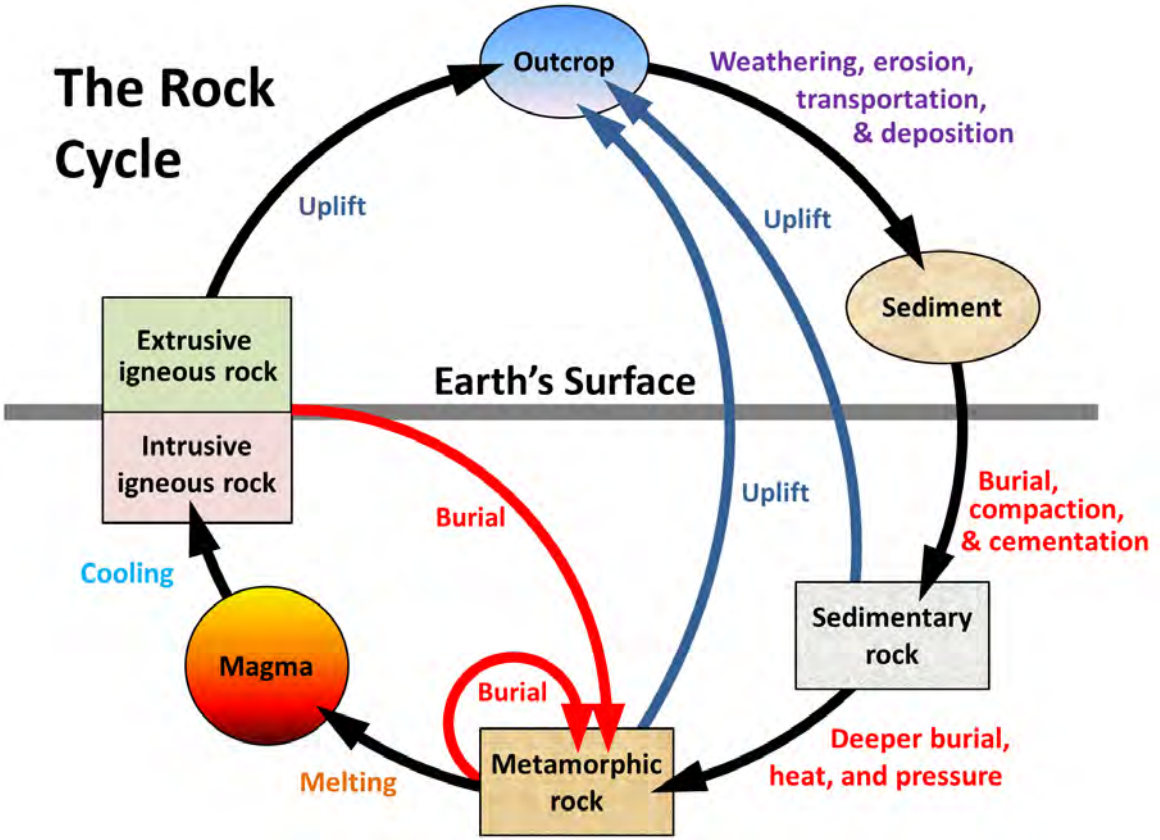
CM Geology 101: Igneous Rocks

- Igneous: “from fire”
- Magma/lava cools to form various igneous rocks
- Major source of many different minerals and ores
- Can be directly mined, or can support nearby mineral formation



CM Geology 101: Rock Cycle

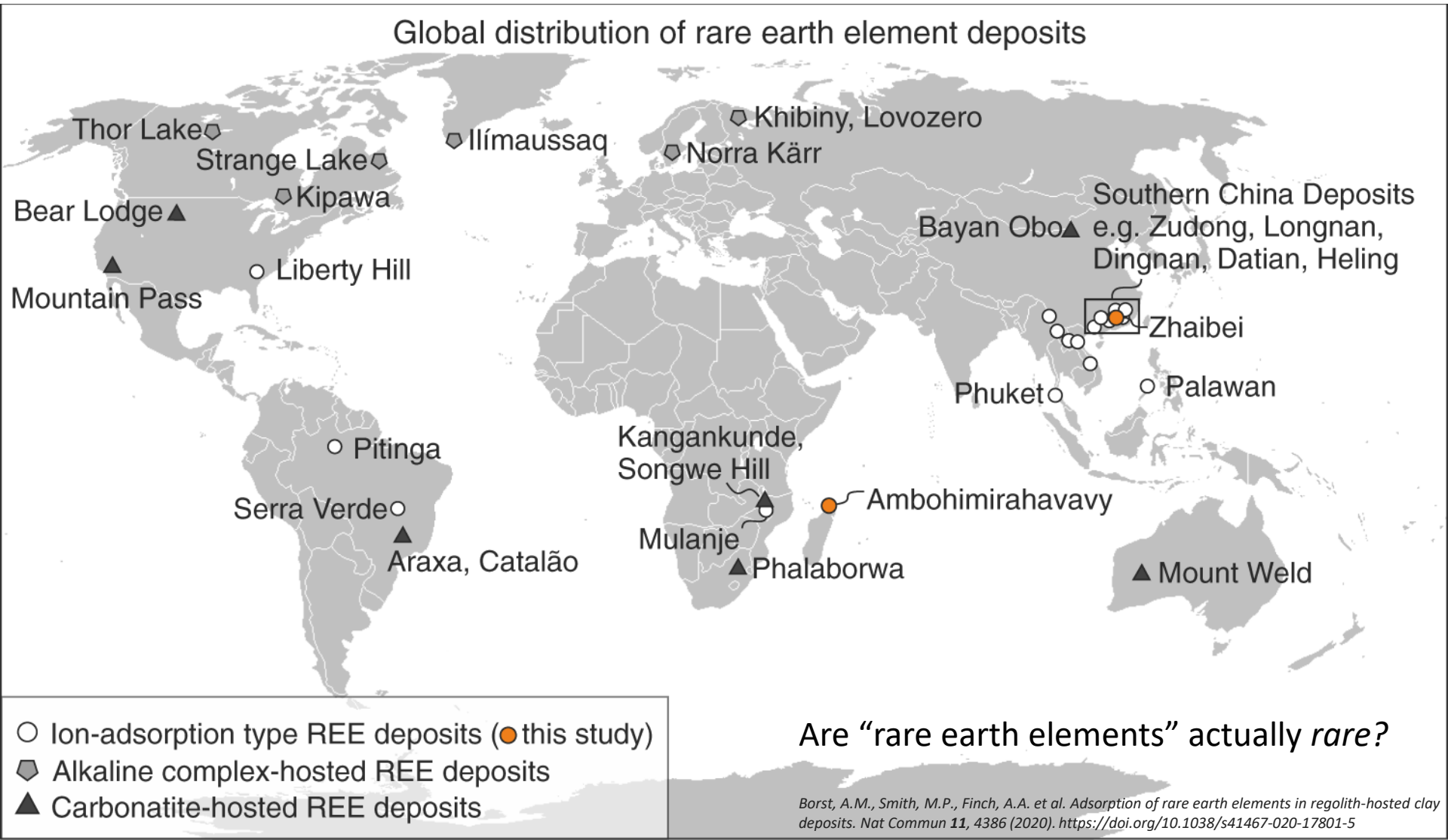
- Once formed, igneous rocks are changed into other kinds of rocks
- Physical changes
- Compositional changes
- Geographic changes



CM Geology 101: Where is CM?

- Original igneous CM-enriched rocks are relatively rare
- Rock cycle reorganizes minerals, chemistry, and geography of CM
- Result 1: *some places have original igneous CM and REE deposits*
  - Western US, China, sub-Saharan Africa
- Result 2: *some places have secondary REE deposits in other kinds of rocks*
  - Mainly China

CM Geology 101: REE Deposits

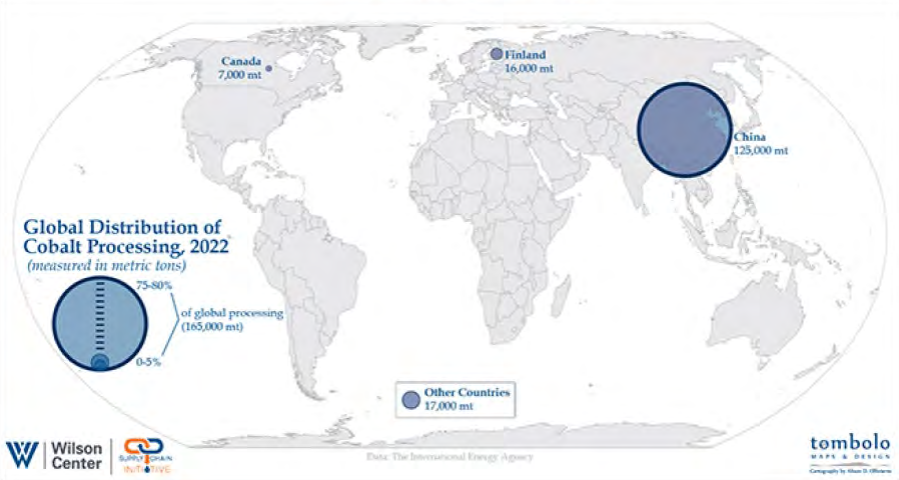


Are “rare earth elements” actually *rare?*

*Borst, A.M., Smith, M.P., Finch, A.A. et al. Adsorption of rare earth elements in regolith-hosted clay deposits. Nat Commun **11**, 4386 (2020). https://doi.org/10.1038/s41467-020-17801-5*

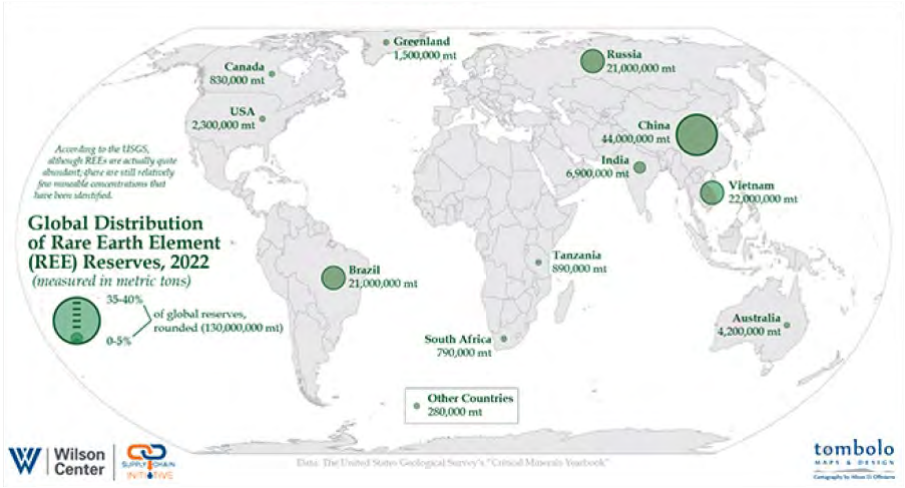
CM Geology 101: CM Reserves

Cobalt Processing

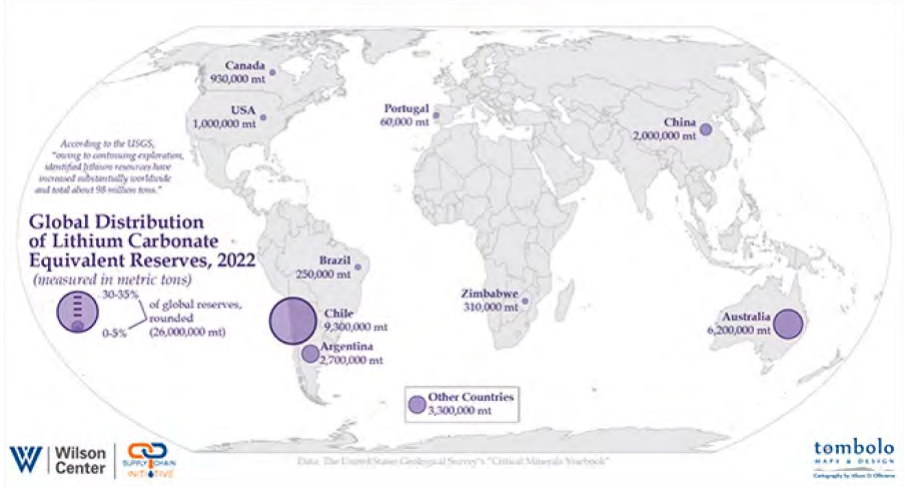


- Ongoing geologic processes reorganize CM and REE through geologic time
- Some nations may include significant resources within their borders, others may not
- **Reserves** are not the same as *resources*
  - *Resources* are potential
  - **Reserves** are economically viable and under production (or close)

REE Reserves



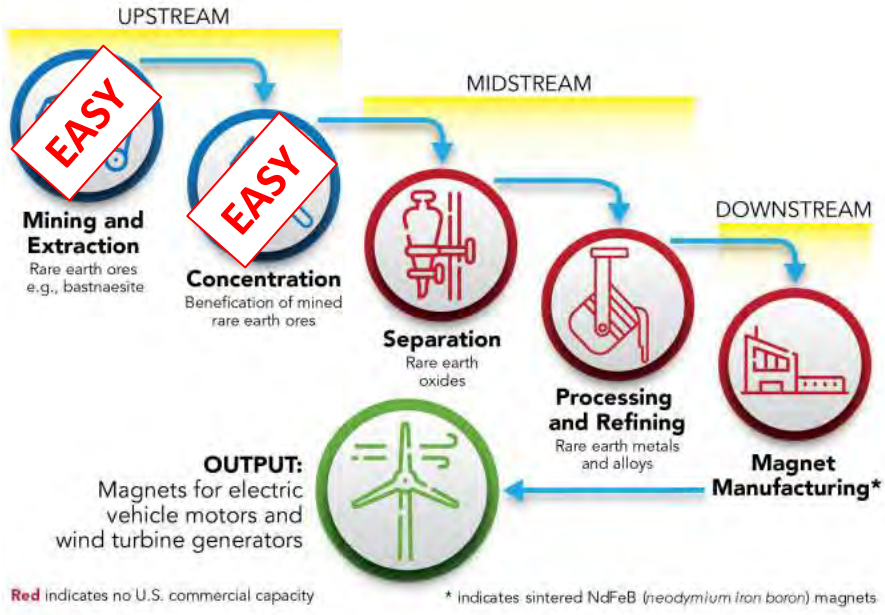
Lithium Reserves



Chinese Supply: Ionic Clays

- Chinese production of REE includes large percentage of Ionic Clay
- Significant mining advantages:
  - Near surface
  - Easy mining
  - Easy extraction of REE
  - Low cost for above
- Bottom line: ionic clay is easy & cheap
- **Environmental impacts have been severe**

REE Mine in Jiangxi, China (via AP), from: https://e360.yale.edu/features/china-wrestles-with-the-toxic-aftermath-of-rare-earth-mining



Supply Chain in Pictures

What does a mine look like?

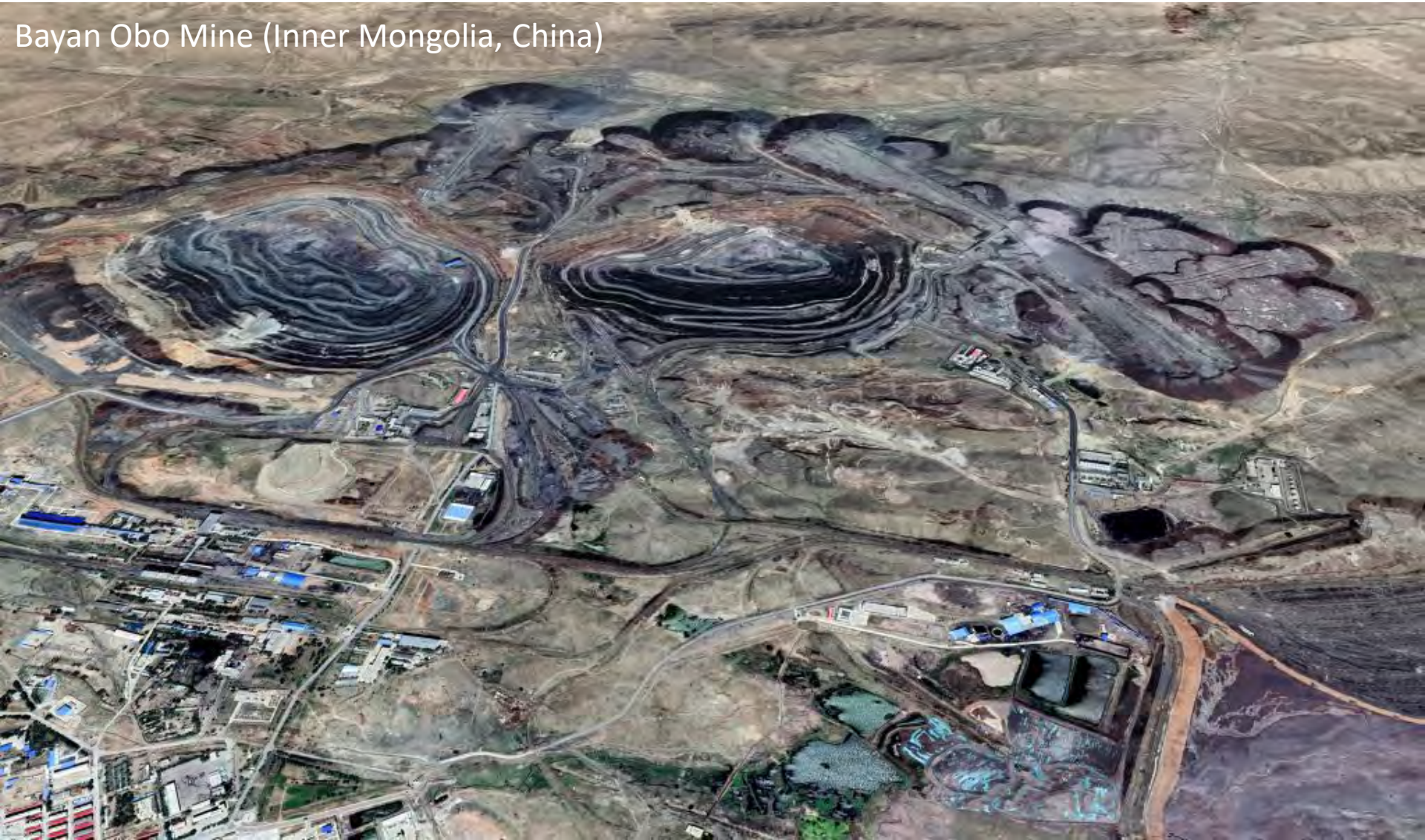
What does an REE facility look like?

Mines can be Obvious…

MP Materials Mine (California, USA)

Mines can be Obvious…

Bayan Obo Mine (Inner Mongolia, China)



Mines can also be subtle…

- This is a shot of an operating coal mine in southern Illinois
- Can you spot the mine?

Mines can also be subtle…

- Second entrance to Illinois coal mine is located directly under the camera in this shot

Real View: REE Processing

- This facility is an operating REE processing and manufacturing facility
- Products: crystals, light bulb components, refined rare earth elements

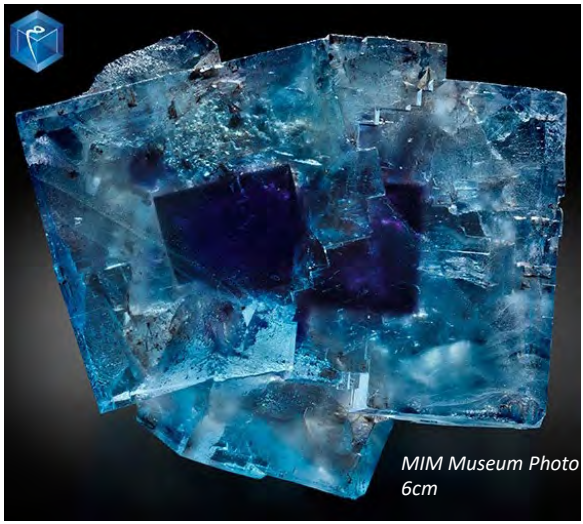
Real View: REE Processing

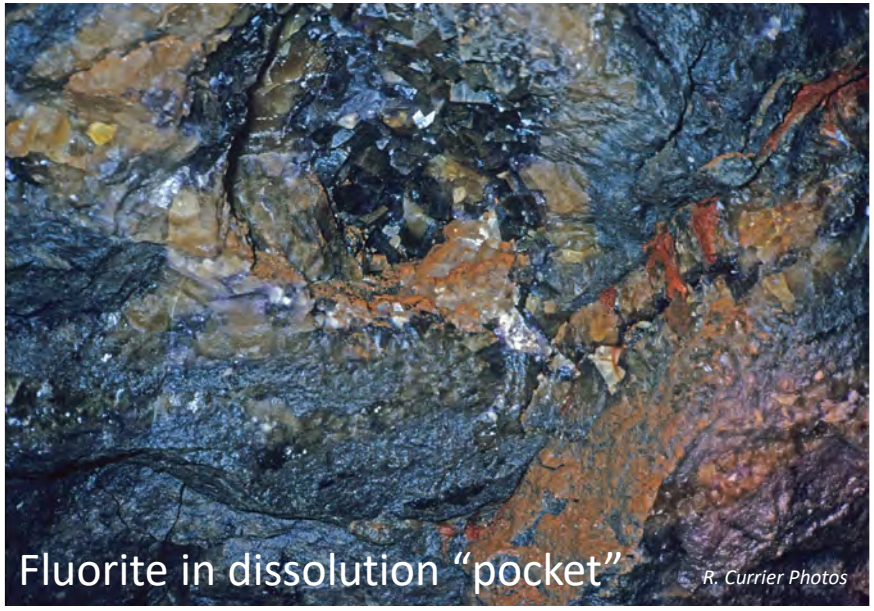
Selected Critical Minerals

Critical Minerals in the

Fluorite (1)

- State mineral of Illinois!
- Historically mined in Illinois-Kentucky Fluorspar District


MIM Museum Photo
6cm


Fluorite in dissolution "pocket"
R. Currier Photos


J. Scovil Photo

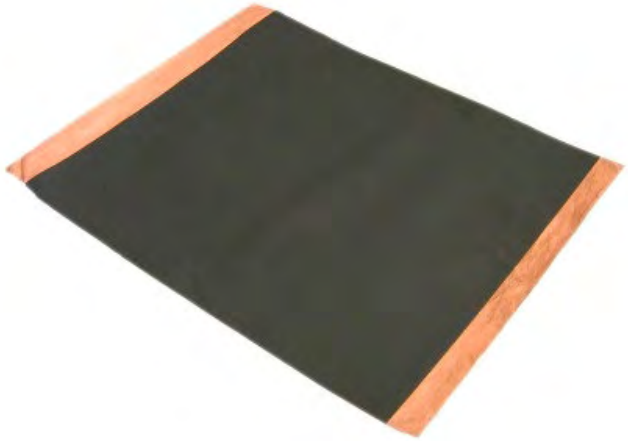
Fluorite (2)

- Currently: low levels of fluorspar production in domestic US
- Fluorspar may be metallurgical or acid grade
  - Metallurgical fluorspar is used as a flux during steelmaking
  - Acid-grade is used to make hydrofluoric acid
    - Many advanced technology applications
    - Batteries (cathodization)
    - Semiconductors
    - Other uses
- One (1) operating fluorspar mill in southern Illinois to this day, almost entirely using imported feedstock

Carbon/Graphite/Graphine

- Carbon ore is prevalent in Illinois: coal
- Other carbon ores:
  - Natural graphite
  - Fossil sources
- Graphite/Graphine synthesis is energy intensive

Carbon/Graphite/Graphine Uses



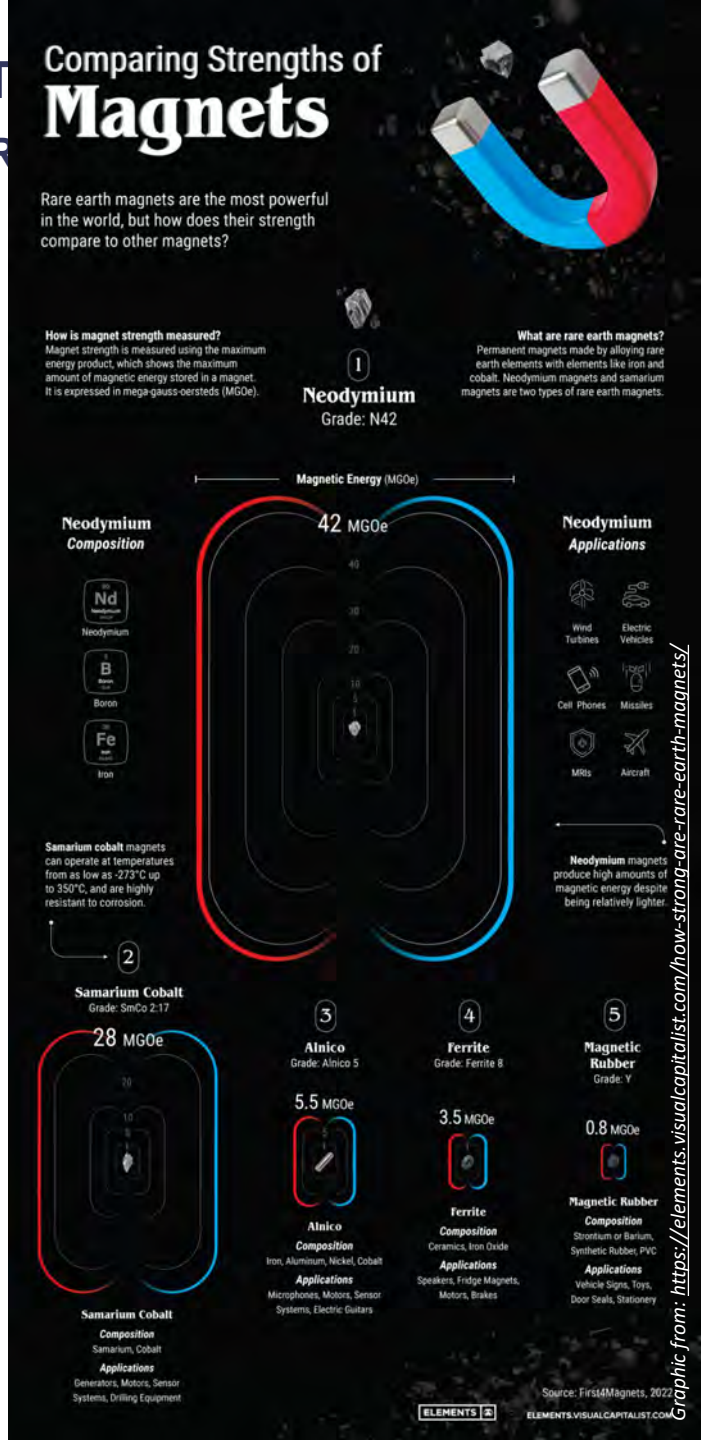
- Purified/activated carbon
- Graphite is an essential material for the anode of almost all battery designs
  - Up to 40% of a battery is carbon!
  - Tesla Model X: 65lbs graphite
- Supercapacitors
- Carbon fibers

Germanium

- Byproduct of zinc production, coal combustion
- At least 50% import reliance
- Applications:
  - Optics (fiberoptics, infrared & night vision, spectroscopes)
  - Electronics (high-speed logic, solar panels)
  - Catalysts (PET production)
  - Semiconducting radiation detectors
  - Quantum computing applications

Magnet Minerals

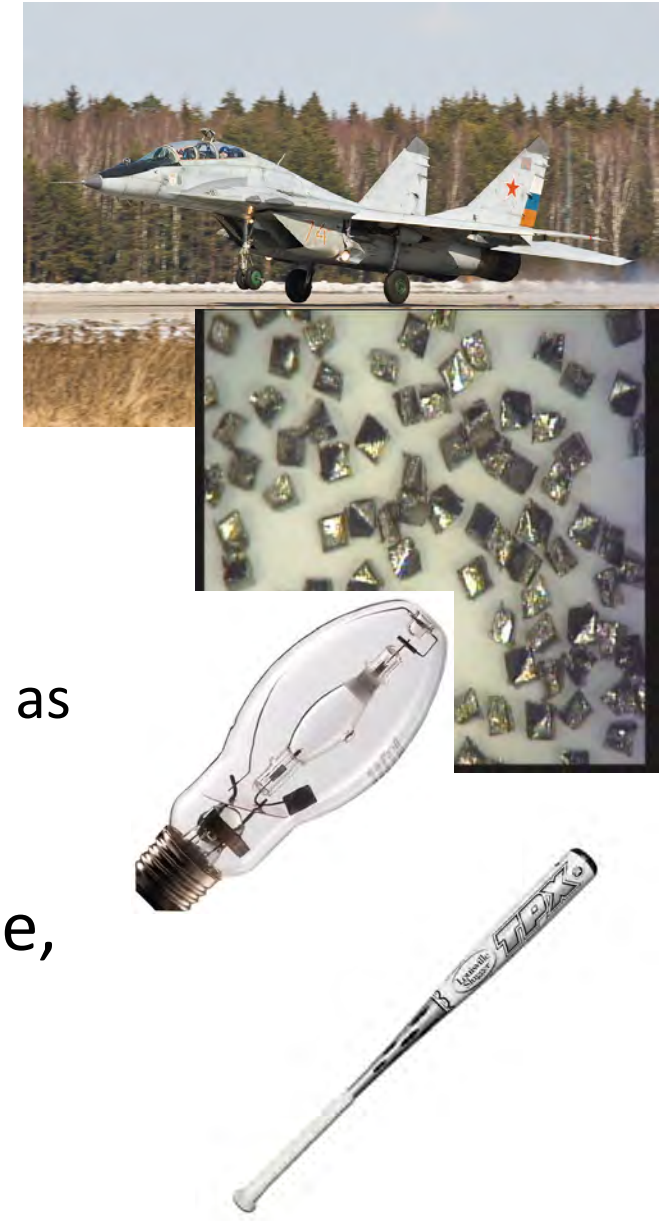
- Dysprosium, Nd/Pr
- Found with other REE in igneous, ionic clay deposits
- Significant processing and refining challenges
- REE permanent magnets are significantly more powerful than regular, ferric magnets
- Essential for: electric motors & actuators, generators (wind & conventional turbines), speakers, microphones, MRI, munitions, sensors



Graphic from: https://elements.visualcapitalist.com/how-strong-are-rare-earth-magnets/

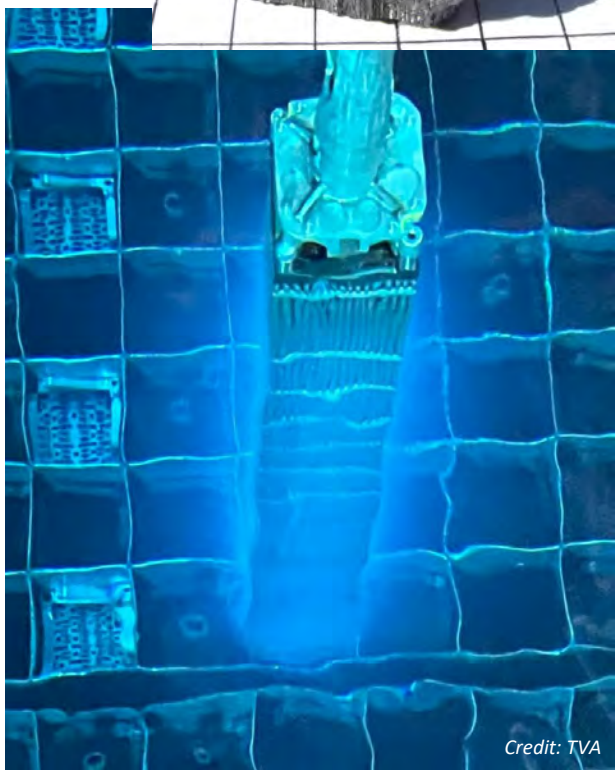
Scandium

- Common metal that rarely forms significant concentrations
  - Sc is often a by-product of titanium mining
- Scandium uses:
  - Metal-Halide light bulbs
  - Aluminum-scandium alloys (as strong as titanium)
  - Experimental fuel cells
- Industries: lighting, national defense, aerospace, sport equipment



Beryllium

- Beryllium is extracted from beryl
- Processing and purification are challenging
- Applications:
  - Atomic power
  - Atomic weapons
  - Radiation shielding & windows (X-ray)
  - Semiconductor manufacture
- Domestic (US) production of Be was increased by public-private investment in processing plant in Ohio (online in 2011)



Credit: TVA

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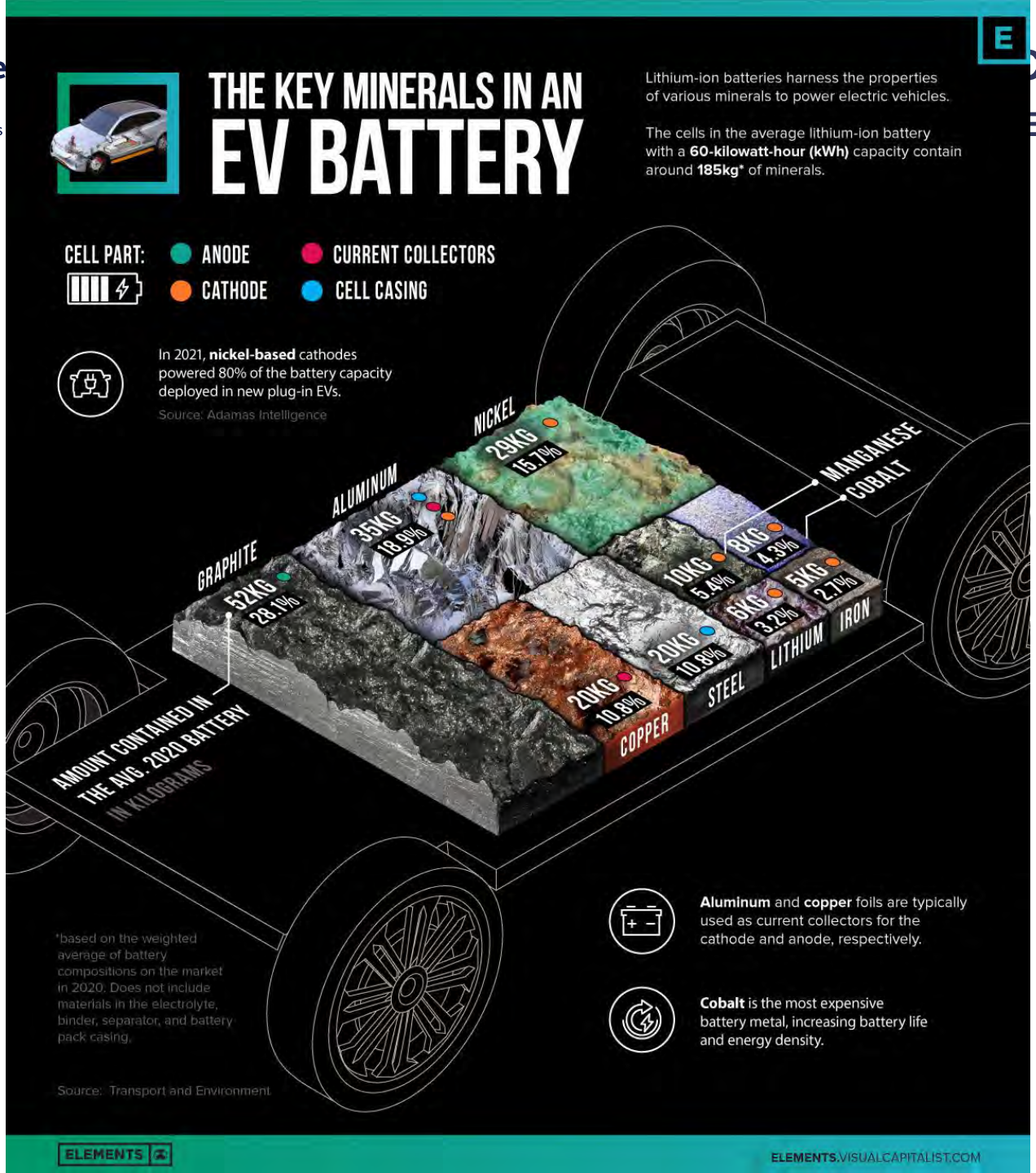
CAL SURVEY
EGIC MINERALS



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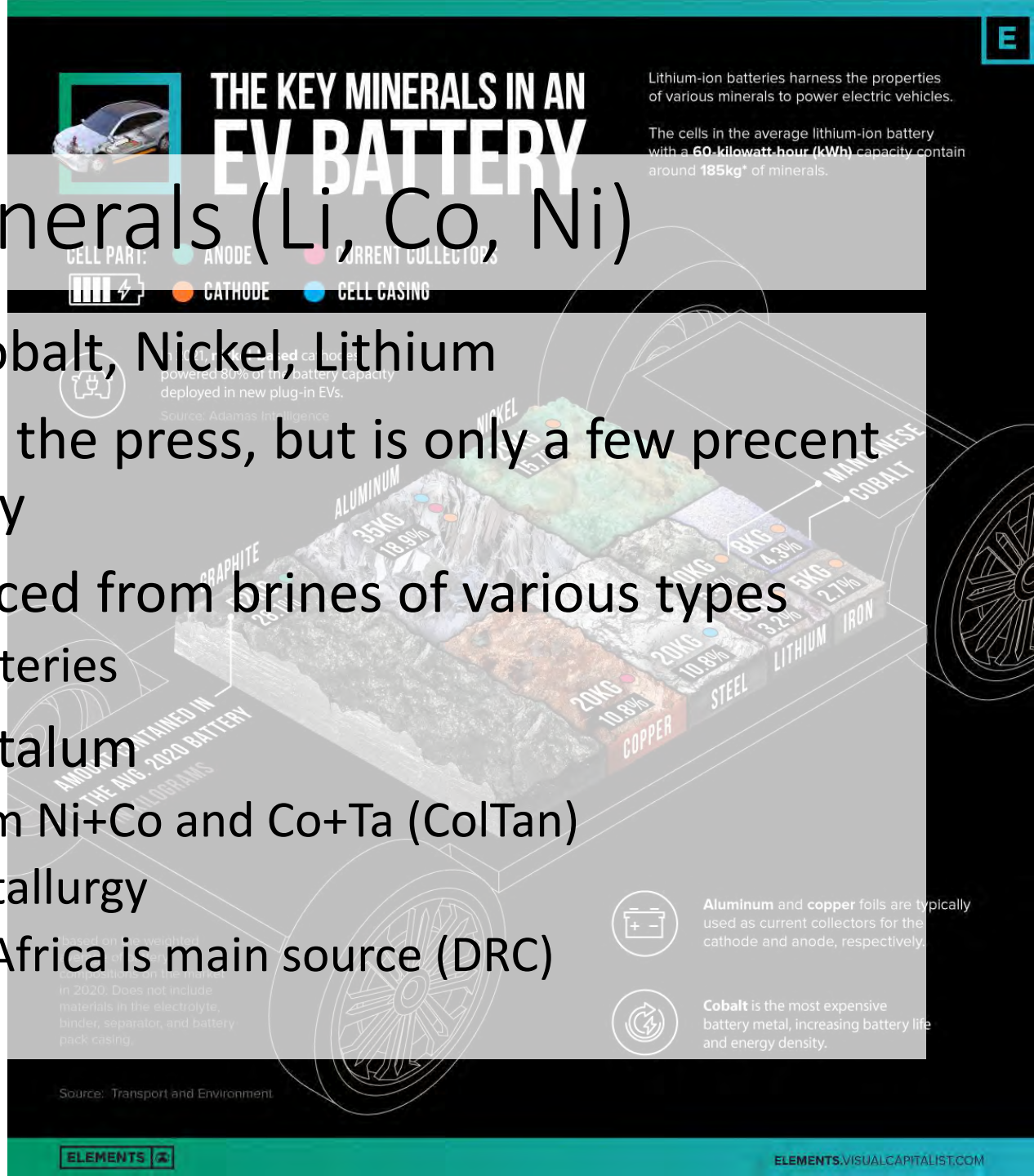
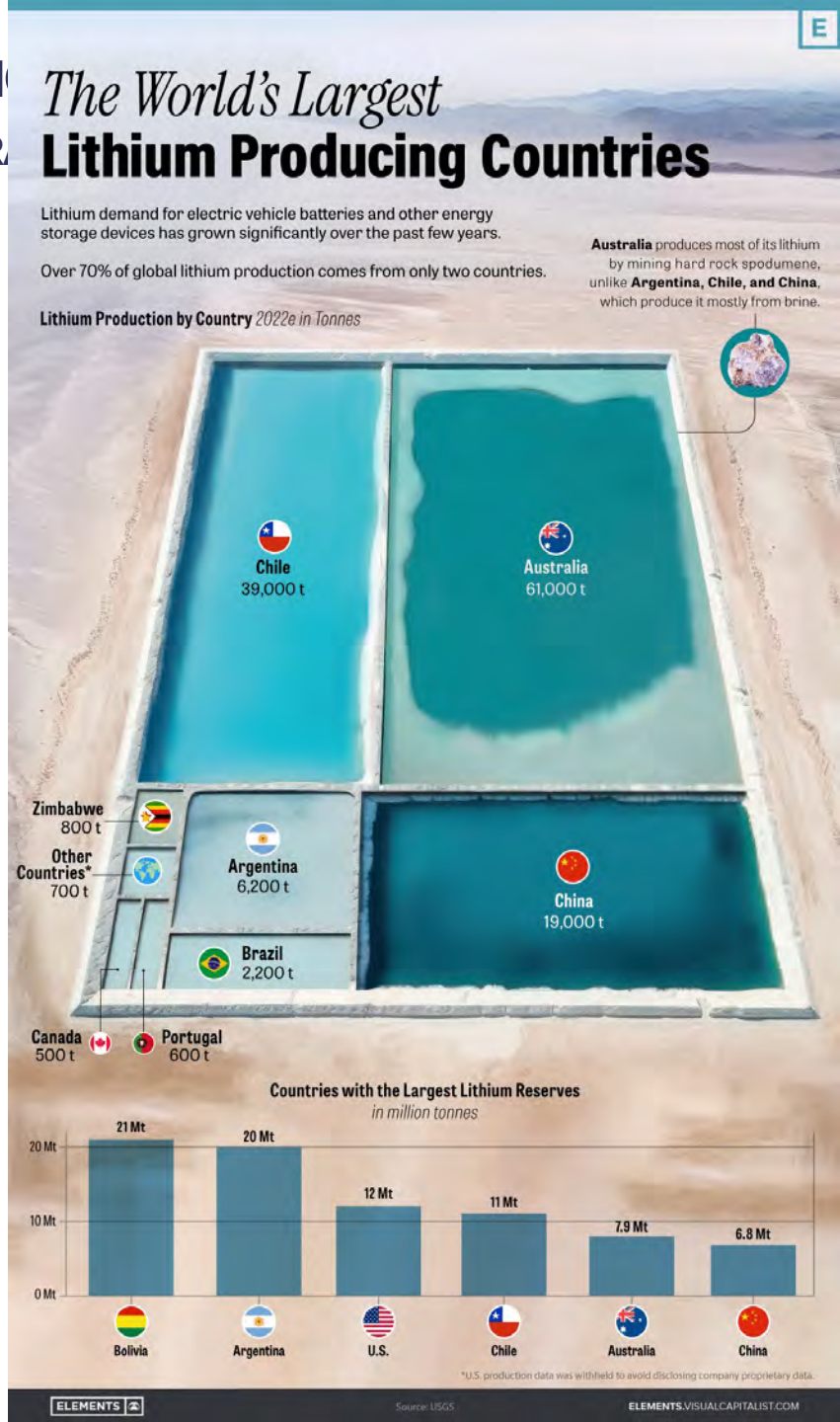
Battery Minerals (Li, Co, Ni)

- Manganese, Cobalt, Nickel, Lithium
- Lithium gets all the press, but is only a few precent of an EV battery
- Lithium: produced from brines of various types
  - Medicine, batteries
- Cobalt and Tantalum
  - produced from Ni+Co and Co+Ta (ColTan)
  - Batteries, metallurgy
  - Sub-Saharan Africa is main source (DRC)



More on Lithium

- Mostly produced from brines (exception: Australia)
- Essential to Li-ion batteries for electrification
  - Electric vehicles
  - Portable electronics
  - Grid-attached storage
- Lithium processing is environmentally hazardous



Platinum Group Elements (PGE)

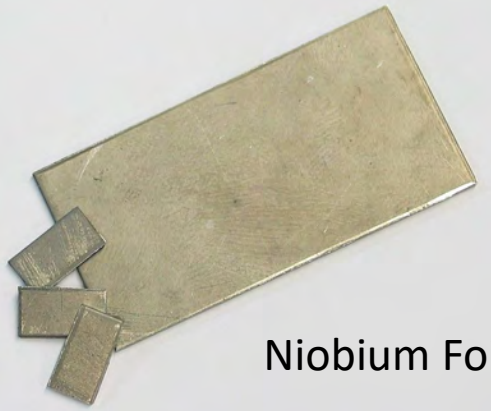
- Platinum, Palladium, Rhodium, Osmium, Ruthenium, & Iridium*
- Occur mainly in basic igneous rocks
- Processing, use, & handling can be hazardous
- Uses:
  - Catalysts (industrial and VECs – catalytic converters)
  - Alloys & Bimetals and mischmetal
  - Medical
    - Medical alloys (dental, implants)
    - Carboplatin medications (chemotherapy)

Niobium

- Primarily produced from pyrochlore
  - 85% production from Brazil
  - Balance from Canada
- Processing & refining are environmentally challenging

Niobium Pentachloride

By Rob Lavinsky, iRocks.com – CC-BY-SA-3.0, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=10152705



Niobium Foil

Niobium: Applications

- Steel production
- Superalloys
- Superconductors
- (electro)ceramics
- Niobium Alloys
- Medicine
- Atomic applications
- Aerospace: jet engines, turbines
- Spaceflight: rocket engine nozzles
- Hypersonic missiles
- Engine components
- Power turbines
- Smart phones

Barite/Barium

- Barite is produced in the western US
  - Significant import: 2.5m metric tons
- Primary use is as weighting agent in drilling mud for hydrocarbon industry
  - Also densifier & additive to plastics, concrete, others

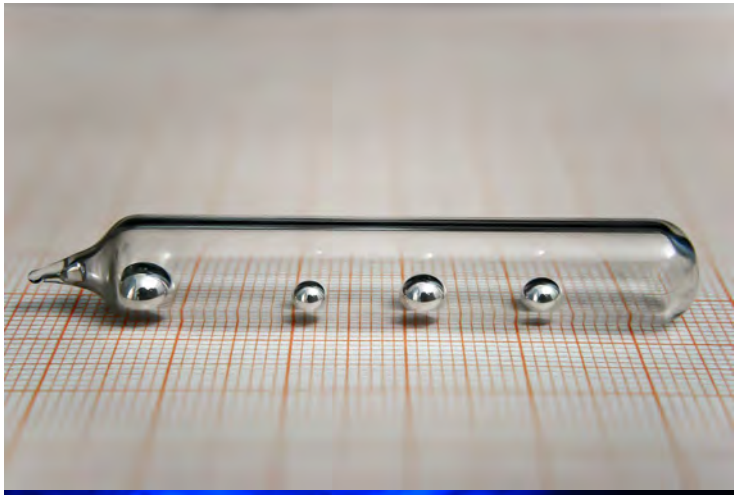
All parts of the energy system depend on critical minerals

Aluminum

- Aluminum occurs mainly as bauxite
- Refining is very energy-intensive, tends to be located where electricity is cheap (e.g. hydropower)
- Transportation, packaging, building components, electronics, aerospace, household goods, machinery

Gallium

- Byproduct of Aluminum Production from bauxite
- 95% of world gallium consumption is used for semiconductors
  - Blue LEDs
  - Ultra high speed logic chips
  - MESFET transistors
  - Infrared lasers (blu-ray discs)
  - Satellites
  - wireless infrastructure
  - Solar panels
- 100% imported



Critical Minerals in Illinois

What critical minerals occur in Illinois?

What work is ongoing to understand the issue?

Critical Mineral Sources in Illinois

Conventional Deposits

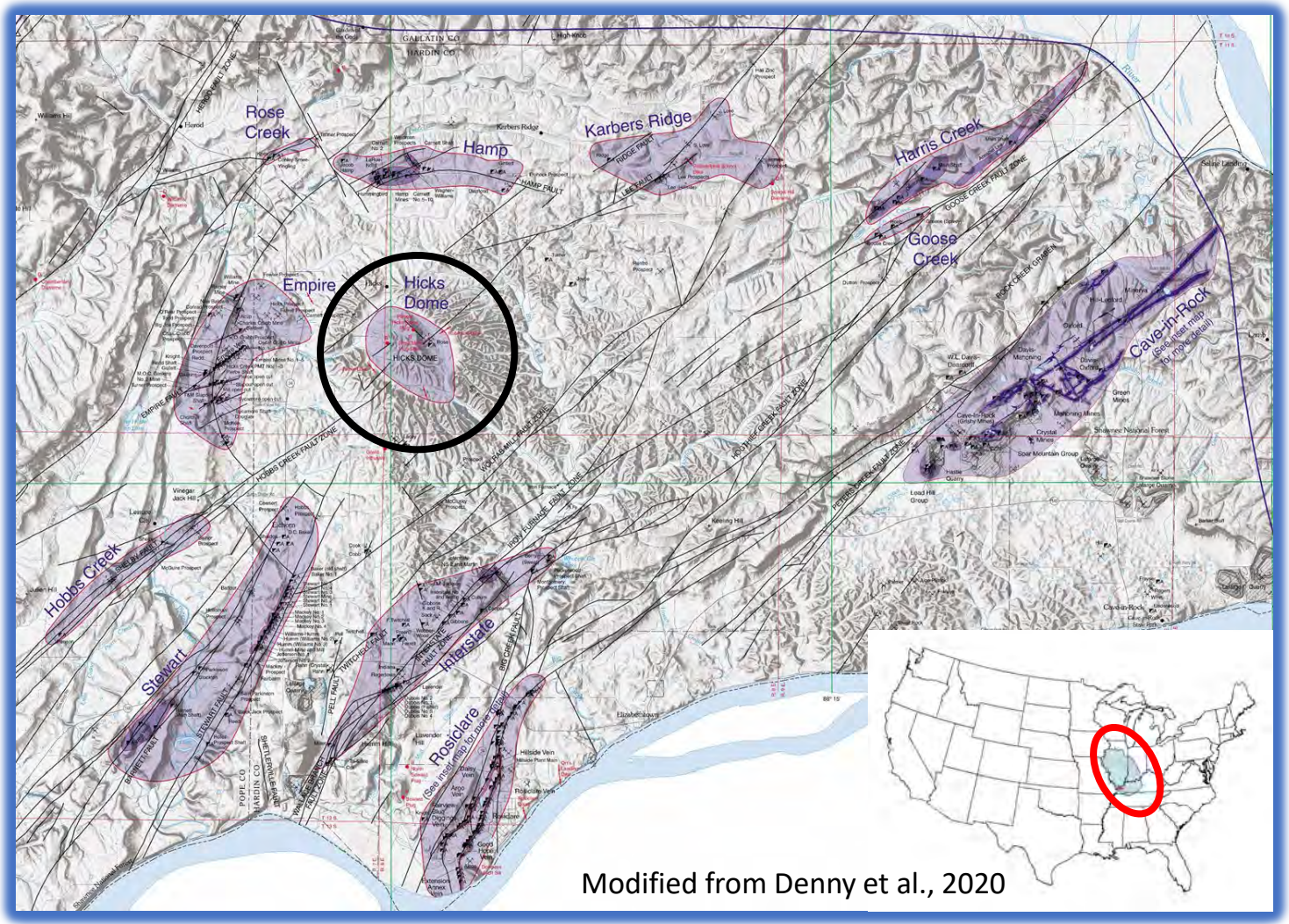
- Illinois-Kentucky Fluorspar District
  - Hicks Dome
  - Other mines
- MVT deposits in NW Illinois
  - Historic area of lead, zinc mining
  - Galena, IL

Unconventional Sources

- Coal
  - Coal ash
  - Coal mine wastes
  - Coal preparation plant wastes
- Other mine spoils and tailings
- Aggregate production spoils and coproduction
- Black shales
- Phosphates

IKFD: Brief Overview

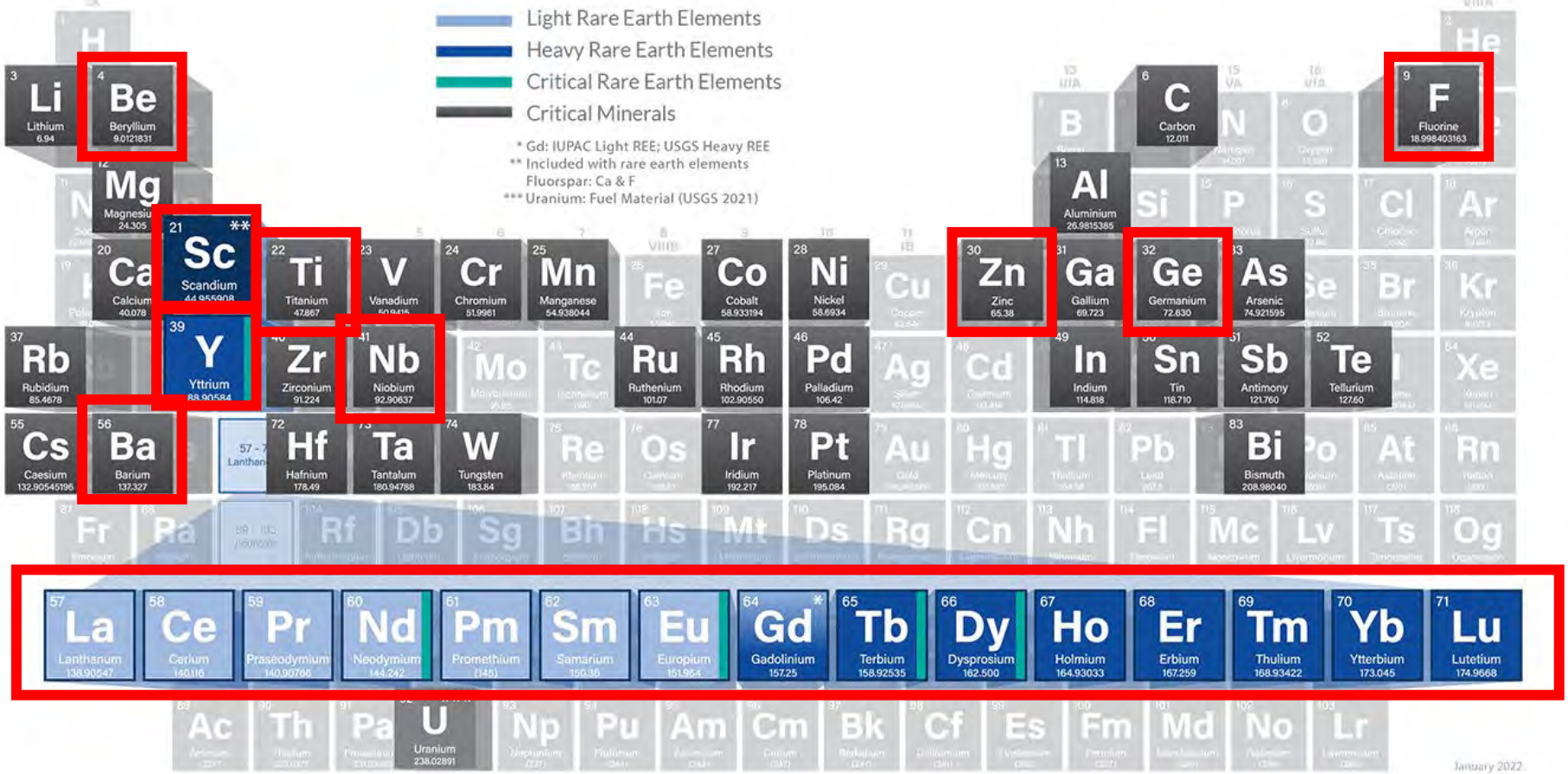
- 12 sub-districts with many mines among numerous outlying prospects/mines. Note the 11 sub-districts surrounding Hicks Dome. Mineral portion of presentation will largely focus on 2 sub-districts: Cave-in-Rock and Harris Creek
- Hicks Dome and the Permian Wauboukigou Igneous Province (PWIP)



Modified from Denny et al., 2020

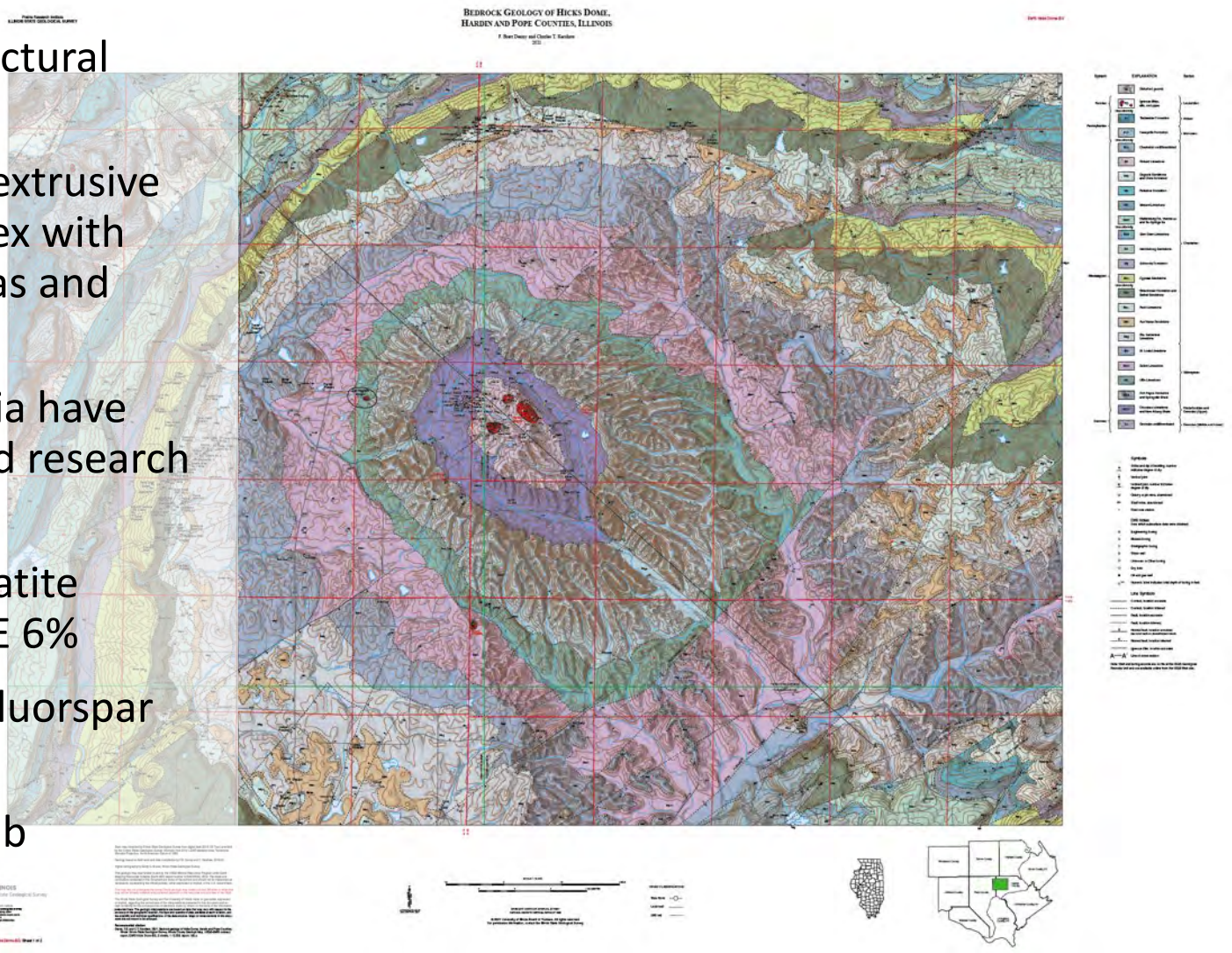
Critical Minerals in the IKFD

Critical Minerals in the Illinois-Kentucky Fluorspar District (IKFD), mainly around the Hicks Dome area, highlighted in red

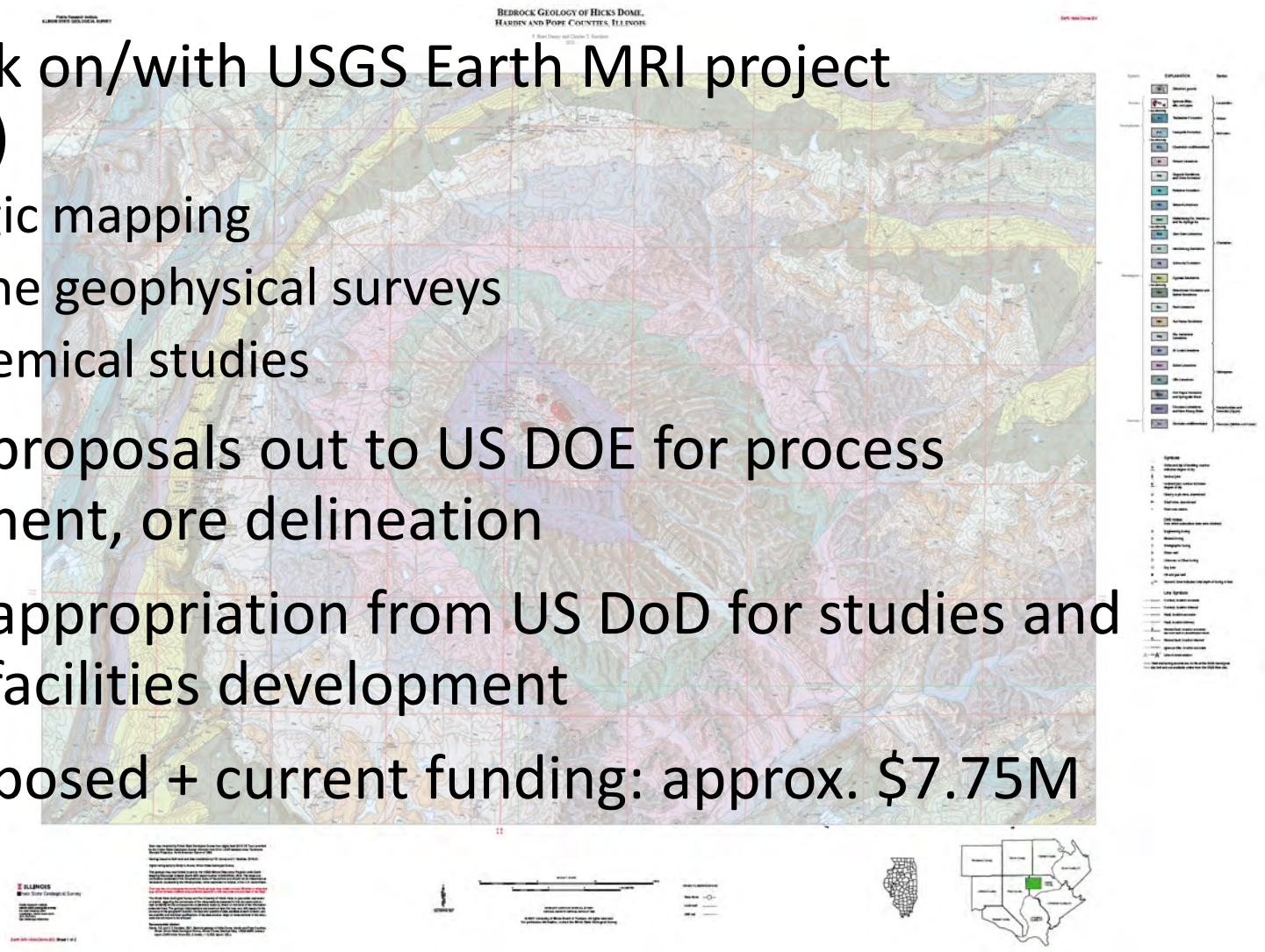


Hicks Dome

- Topographic & structural dome
- The orebody is an extrusive carbonatite complex with mineralized breccias and overlying regolith
- Regolith and breccia have been evaluated and research is underway
- Underlying carbonatite samples up to TREE 6%
- Largest untapped fluorspar resource in US
- Significant REE & Nb



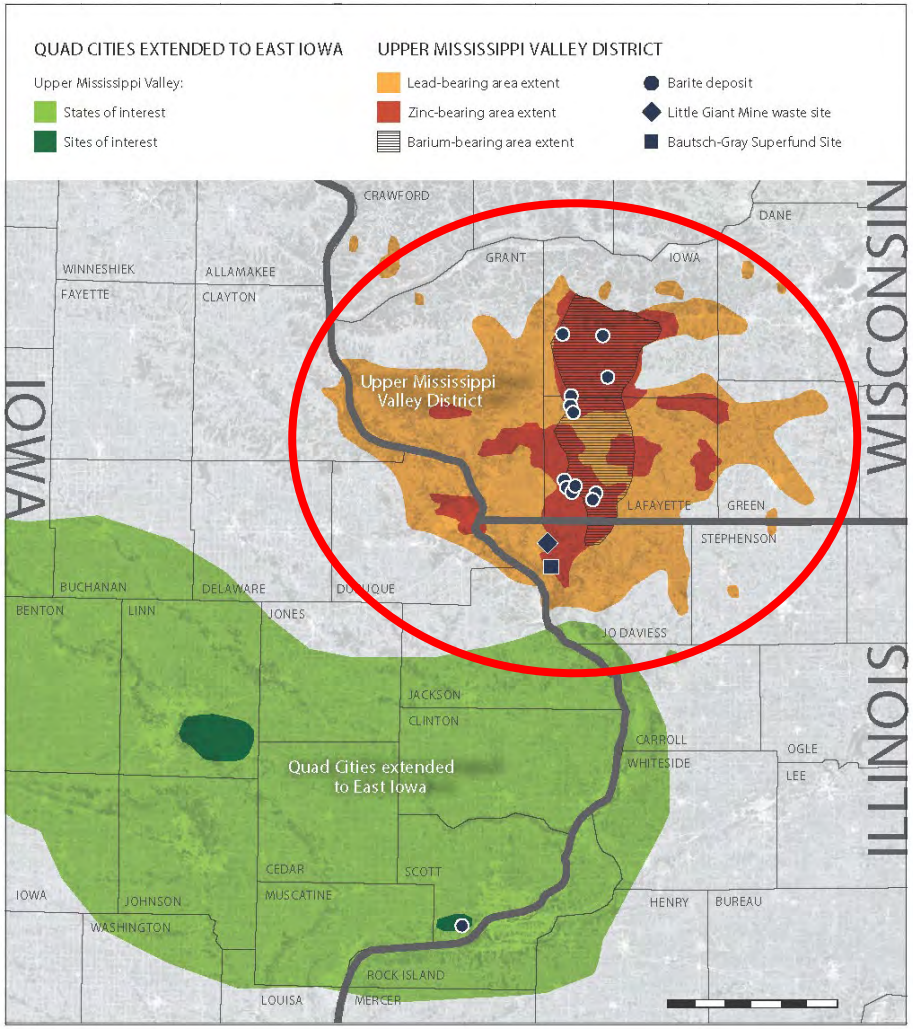
ISGS Programs at Hicks Dome



- ISGS work on/with USGS Earth MRI project (ongoing)
  - Geologic mapping
  - Airborne geophysical surveys
  - Geochemical studies
- ISGS led proposals out to US DOE for process development, ore delineation
- ISGS led appropriation from US DoD for studies and process/facilities development
- Total proposed + current funding: approx. $7.75M

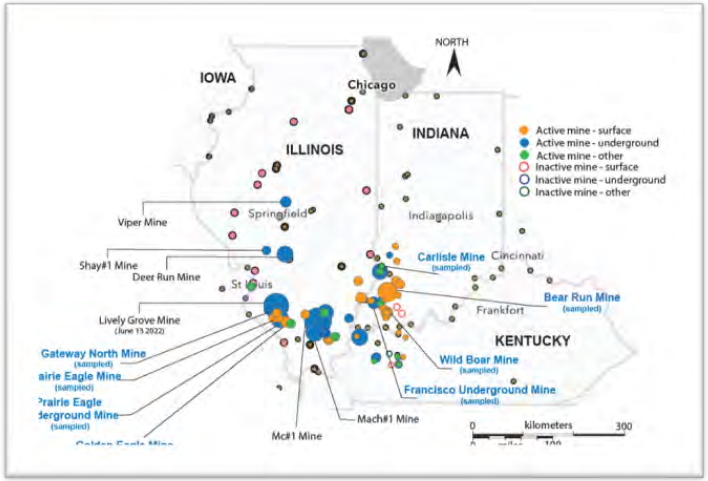
Upper Mississippi Valley: Unconventional Critical Mineral Dist.

- New mapping of structure and historical mines
- CM assessments ongoing (Zn, Ge, Ga, Be)
- Mine wastes under evaluation
- Geochemical studies & reconnaissance



Coal Combustion and Mine Wastes: IB-CORE-CM Program

Illinois Basin CORE-CM



Power Plants

Mines/Mine Waste

Resource Overview

- **Coal Resources**
  - Coal
  - Ash
  - Refuse
- **Data**
  - Historical
  - Local
  - National
  - Industry
- **Geologic Models**
  - Strat/structure
  - Coal and Refuse
  - Resource Estimates

Assessment

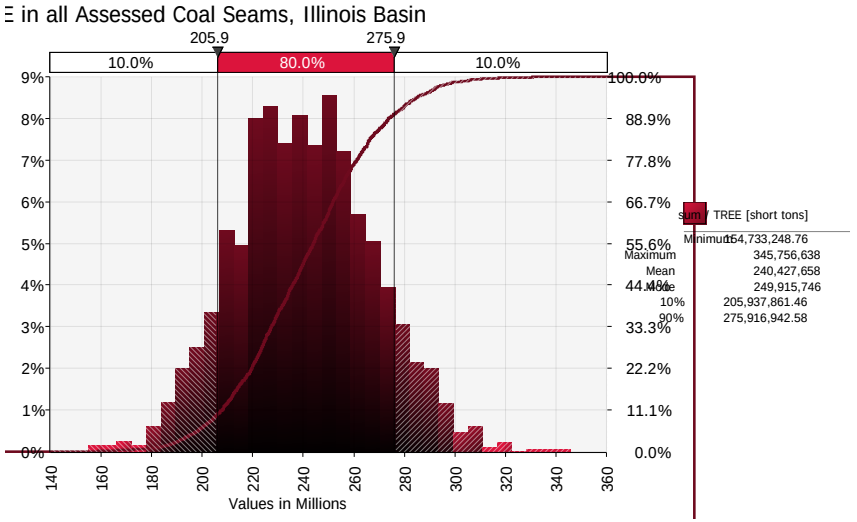
- **Characterization**
  - Mineral/ Element
  - REE
  - Carbon
- **Technologies**
  - Mining
  - Separation
  - Product Incorporation
- **Infrastructure**
  - Active
  - inactive
  - Supply Chain
  - Businesses
- **Environmental**
  - EJ
  - Resources
  - Legacy
  - SCI

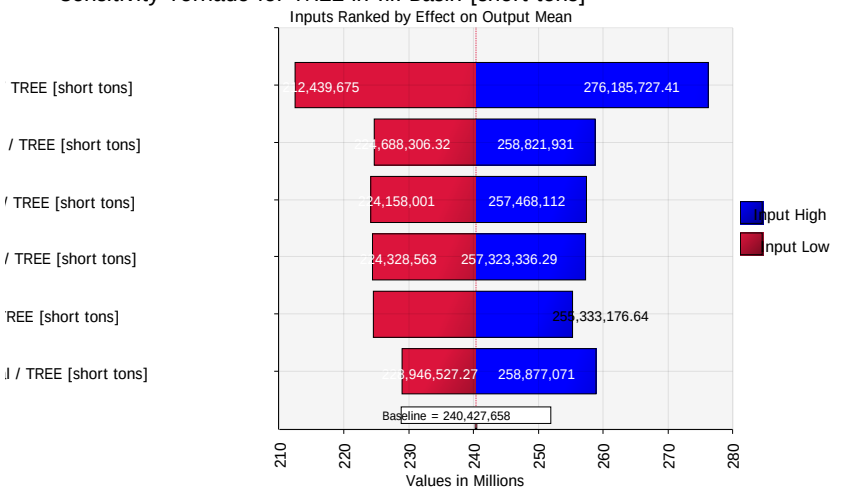
Development

- **Innovation Center**
  - Public-Private
  - Technology Development
  - Education/ Workforce
- **Outreach**
  - Education
  - Public-Private Engagement
  - Stakeholders
- **Processing**
  - Pilot
  - Commercial
  - Manufacturing

Illinois Basin CORE-CM Results

- Phase 1 studies completed summer 2024
- Potential total REE originally in coal seams: 240 million tons
  - Adjusted for available resource: 18 million tons
  - Over 60,000 tons in waste piles
- Includes: Sc, REE, Zn, Mn, Li

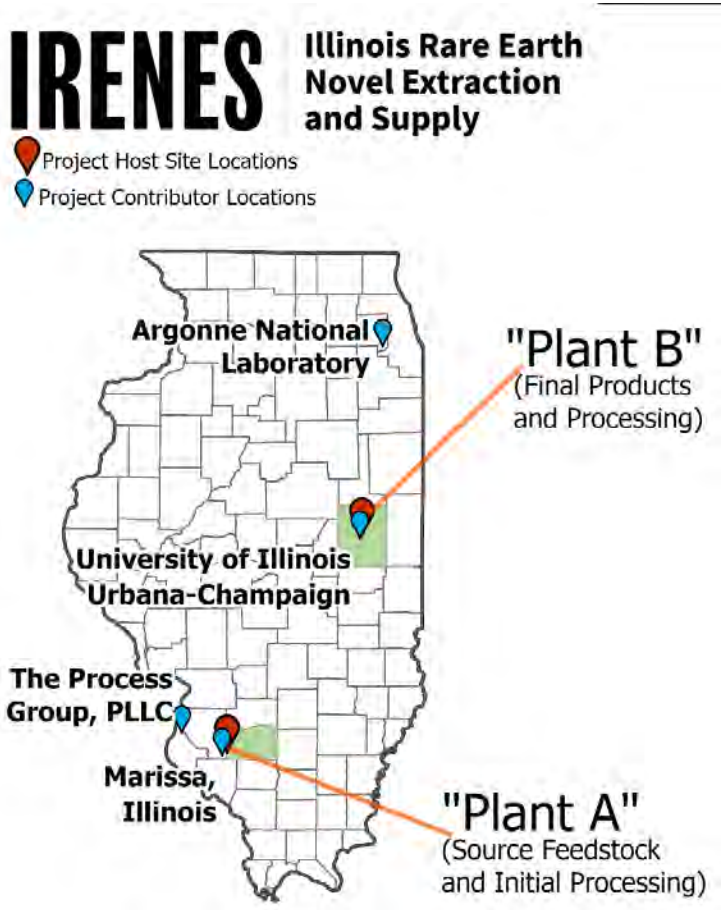




Illinois Basin CORE-CM

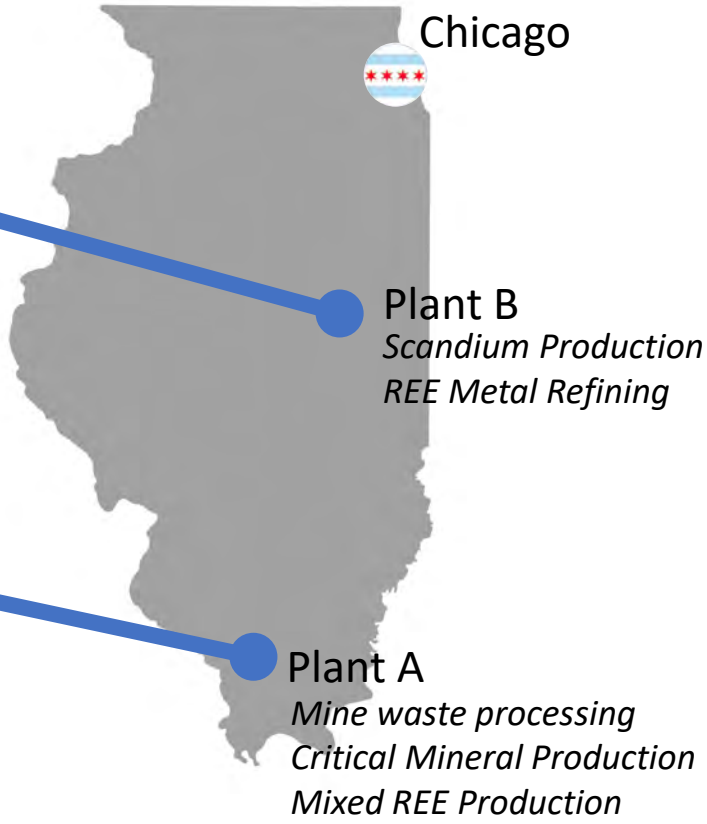
IRENES Project

- Illinois Rare Earth Novel Extraction and Supply
- Design a facility to reprocess 300k short tons of coal mine waste/year for CM and REE production
- Vertically-integrated CM supply chain entirely within Illinois



IRENES Project: Products

- Rare earths
  - (Scandium)
  - Didymium
  - Dysprosium
  - MREO
- Critical Minerals
  - Aluminum
  - Zinc
  - Manganese
  - Lithium
  - Cobalt
  - Nickel
- Geopolymer Block



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U.S. DEPARTMENT OF ENERGY

Illinois Basin CORE-CM

NATIONAL ENERGY TECHNOLOGY LABORATORY

IRENES Illinois Rare Earth Novel Extraction and Supply

USGS science for a changing world

EARTH MRI Earth Mapping Resources Initiative USGS Mineral Resources Program