



Defining Critical Minerals & Their Uses

What are “Critical Minerals?”

Why are they “Critical?”

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Illinois State Geological Survey



Prairie Research
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UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

ILLINOIS STATE GEOLOGICAL SURVEY
ENERGY & MINERALS | CRITICAL AND STRATEGIC MINERALS

Brief Introduction

I ILLINOIS

Illinois State Geological Survey

PRAIRIE RESEARCH INSTITUTE



Prairie Research Institute
Critical Minerals Research and Development Center



Illinois Basin
ORE-CM

IRENES

Illinois Rare Earth
Novel Extraction
and Supply



Please Get Out your Smart Phone

I know you have one, get it out 😊



- 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

A BREAKDOWN OF THE CRITICAL

METALS IN A SMARTPHONE

Some vital metals used to build these devices are considered at risk due to geological scarcity, geopolitical issues or trade policy.

This infographic details the critical metals that you carry in your pocket.

ALKALI METAL ALKALINE EARTH TRANSITION METAL BASIC METAL LANTHANOID

TOUCH SCREEN

It contains a thin layer of **indium** tin oxide, highly conductive and transparent, allowing the screen to function as a touch screen.



MICROPHONE, SPEAKERS, VIBRATION UNIT

Nickel is used in the microphone diaphragm (that vibrates in response to sound waves). Alloys containing **neodymium**, **praseodymium** and **gadolinium** are used in the magnets contained in the speaker and microphone. **Neodymium**, **terbium** and **dysprosium** are used in the vibration unit.



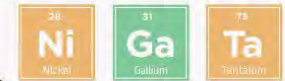
DISPLAY

The display contains several **rare earth elements**. Small quantities are used to produce the colors on the liquid crystal display. Some give the screen its glow.



ELECTRONICS

Nickel is used in electrical connections. **Gallium** is used in semiconductors. **Tantalum** is the major component of micro capacitors, used for filtering and frequency tuning.



CASING

Nickel reduces electromagnetic interference. **Magnesium** alloys are superior at electromagnetic interference (EMI) shielding.



BATTERY

The majority of smartphones use **lithium-ion** batteries.

Source: University of Birmingham





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What is “Critical Mineral?”

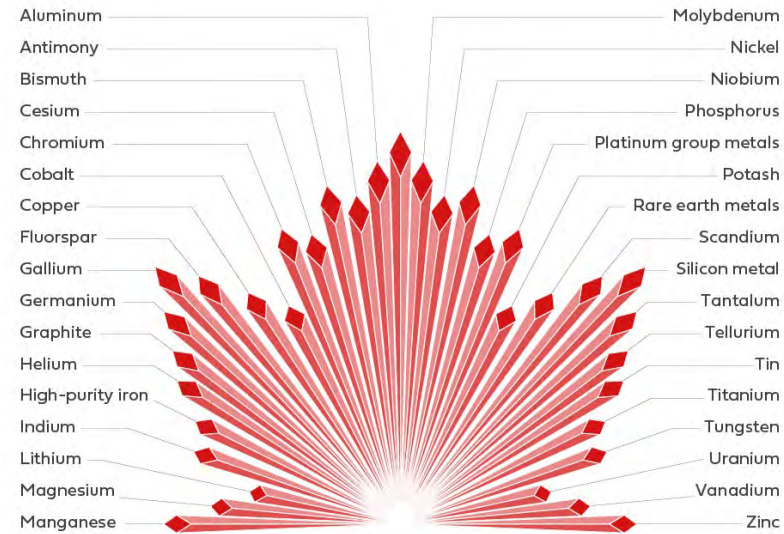
Statute definitions

What it means



Statute Definitions

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



Government of Canada

EXPLANATION

Atomic number
Element symbol
Element name
NA, not available
W, withheld

Net import reliance
(% of apparent consumption)

Time series
(2003-23)

*Blue graphs show elements that were assessed.

Source: USGS Minerals Information Service
US Dept. of Interior

1 H Hydrogen																	2 He Helium	
3 Li Lithium	4 Be Beryllium																	10 Ne Neon
11 Na Sodium	12 Mg Magnesium																	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton	
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon	
55 Cs Cesium	56 Ba Barium	57-71 La-Lu Lanthanides	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon	
87 Fr Francium	88 Ra Radium	89-103 Ac-Lr Actinides	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson	



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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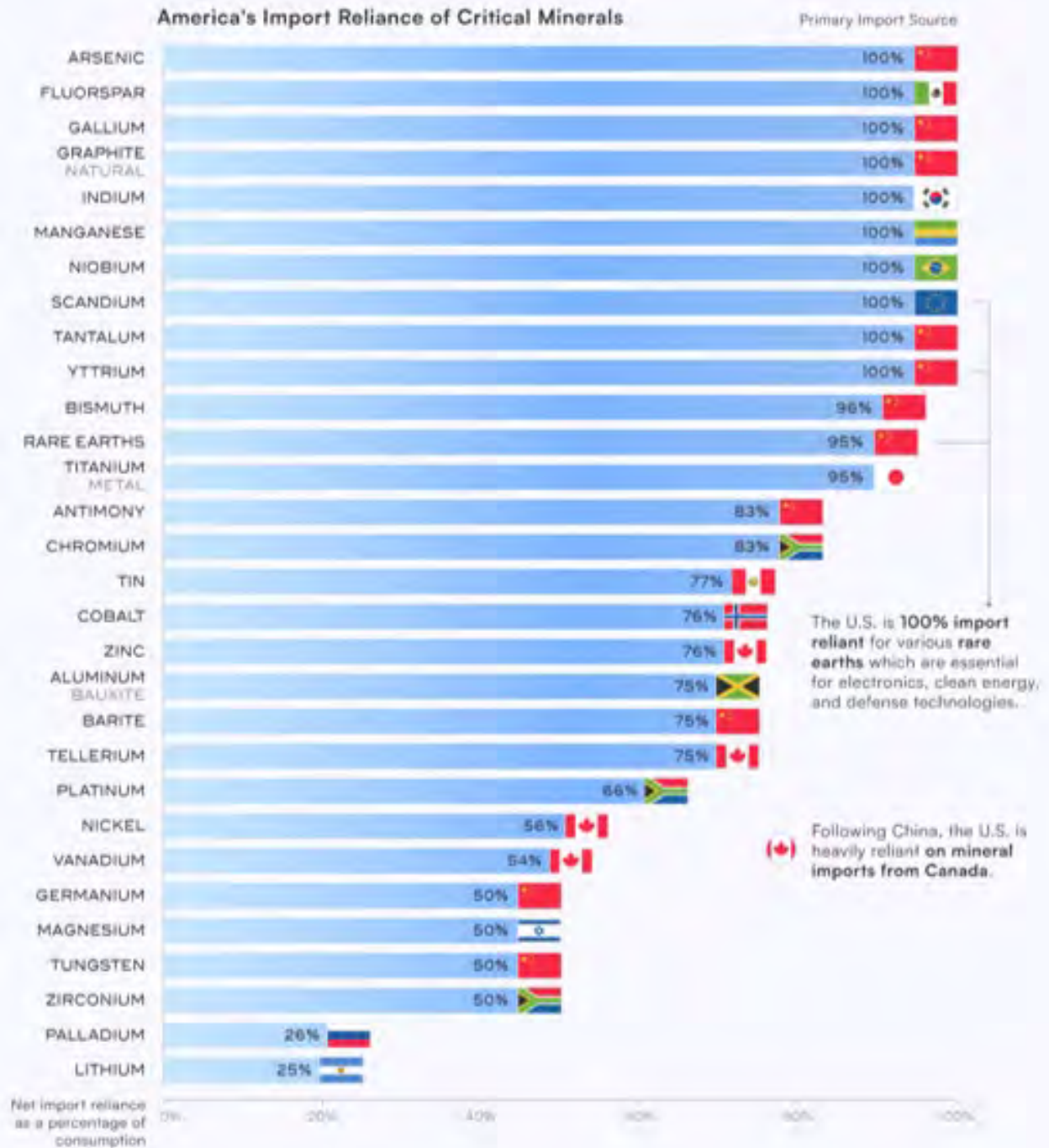
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US CM Imports

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

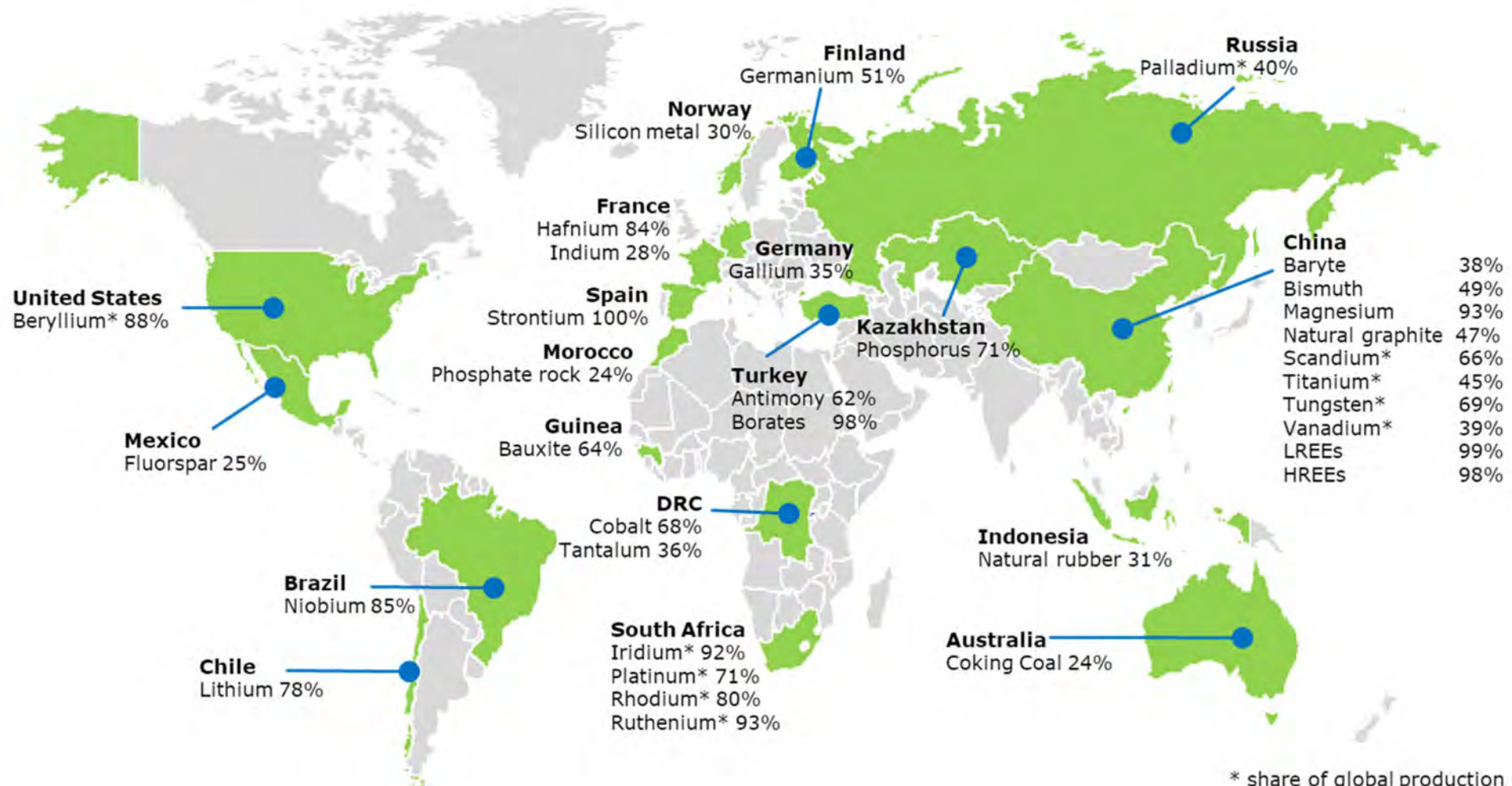
- China
- The EU
- Canada

Canada exports significant raw & finished minerals to the US





CM Industry: Production Worldwide

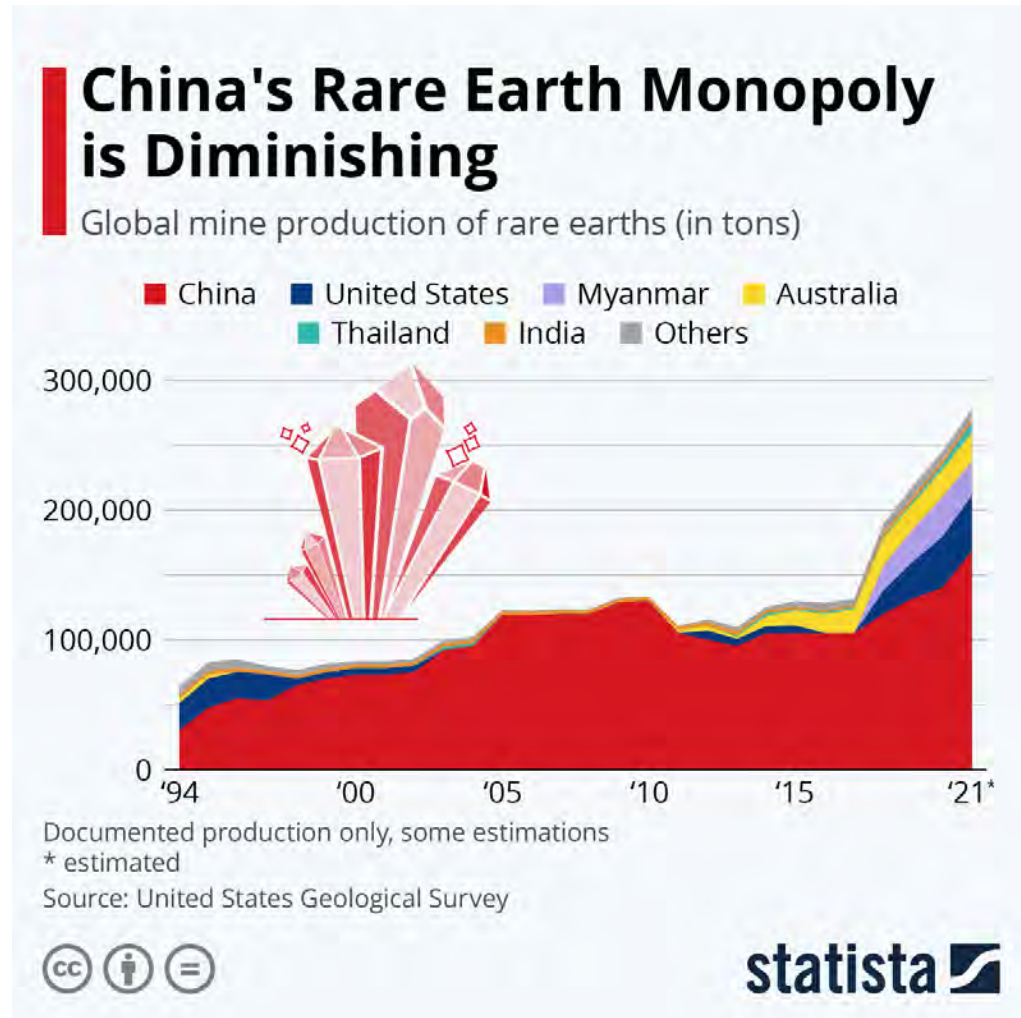


* share of global production



CM Mining is Diversifying ...

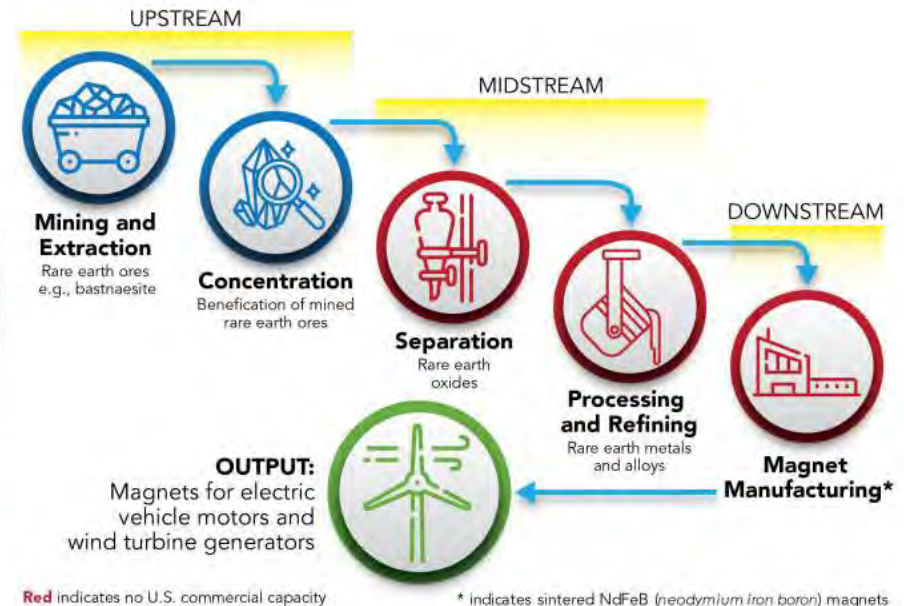
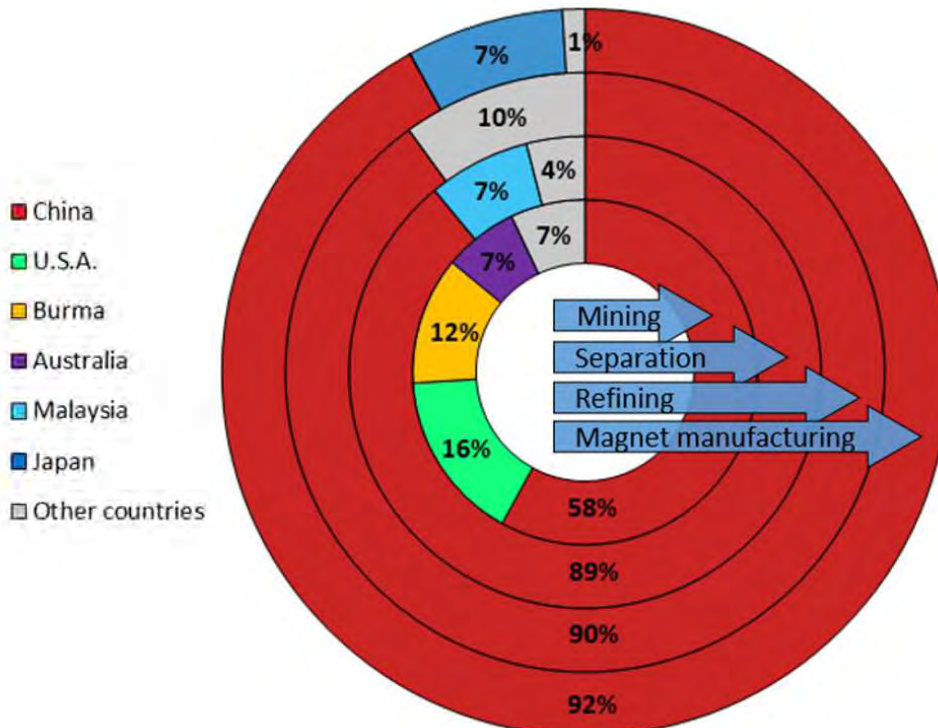
- Since the end of the cold war, China has dominated REE mining and production
- Since mid 2010's, supply has diversified
- 2021: 58% of REEs produced in China





The Problem in Processing...

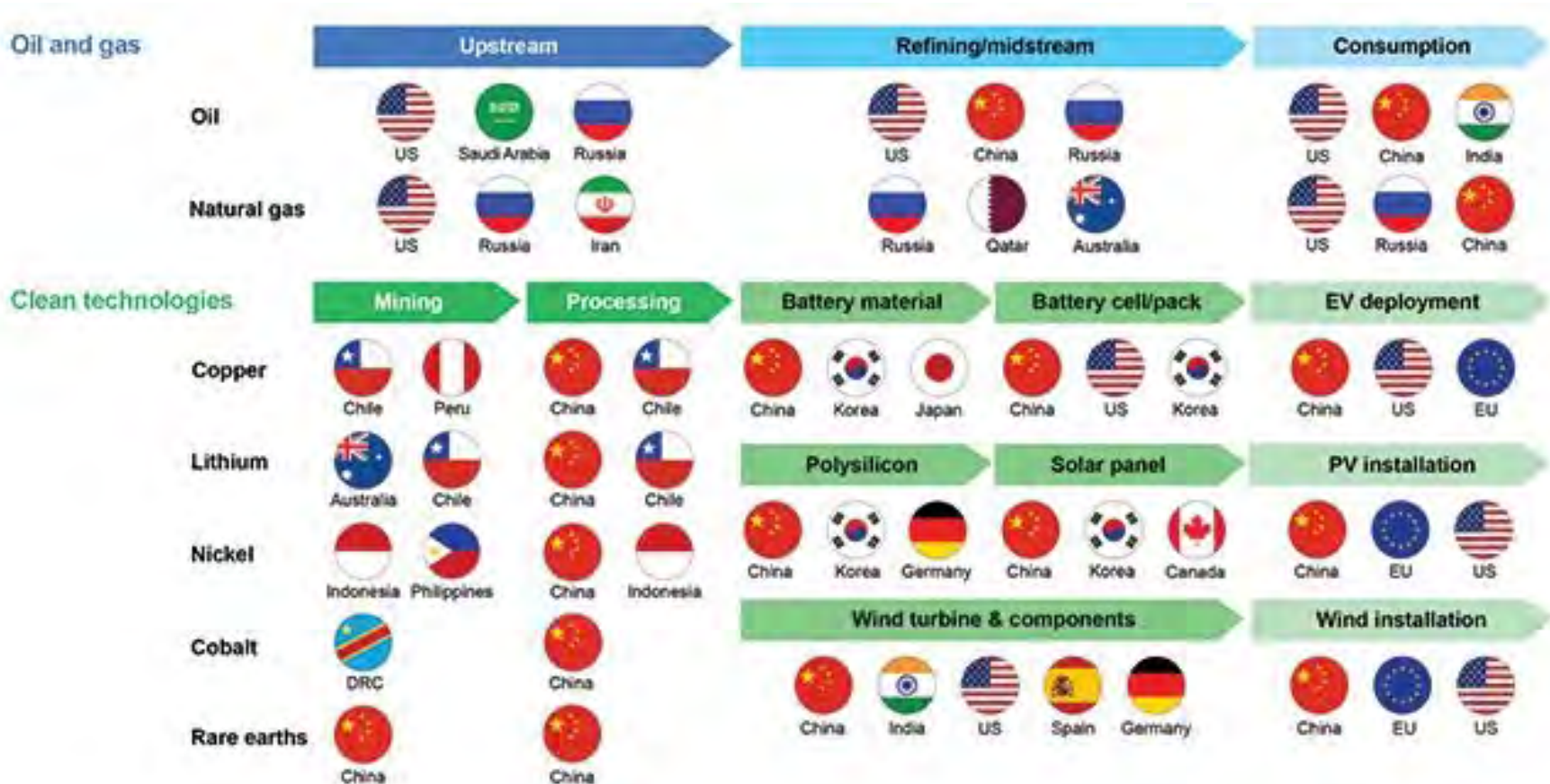
- While raw REE has diversified, processing into metals suitable for production has not





The Problem in Processing...

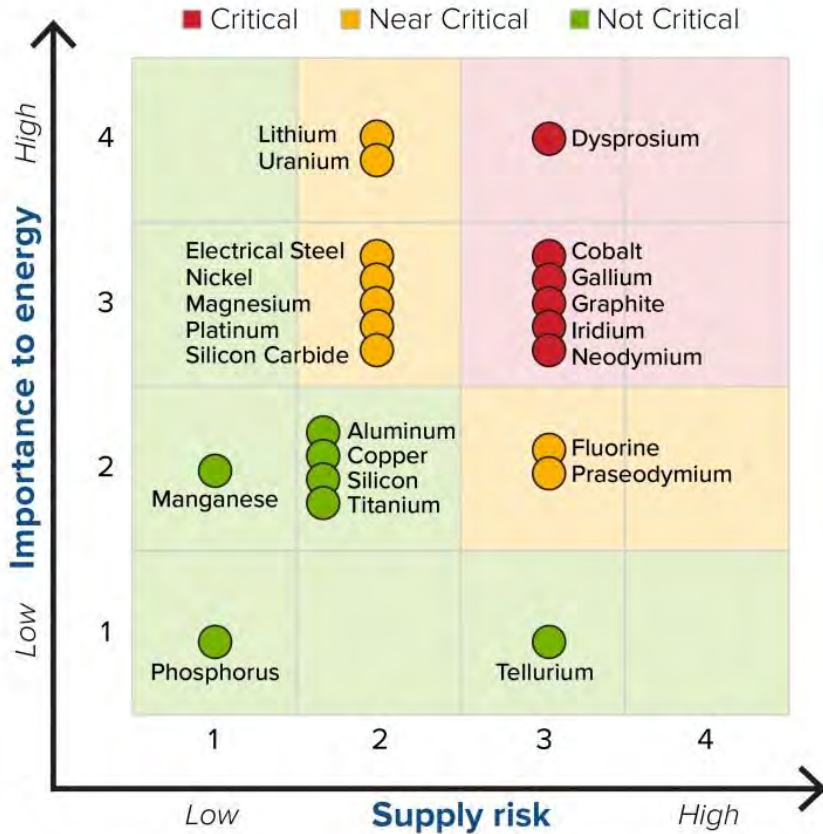
Many critical mineral supply chains are highly transnational: **Mining ≠ Independence**





US DOE: CM Supply Risk

SHORT TERM 2020-2025



MEDIUM TERM 2025-2035





Occurrence of Critical Mineral Resources

Occurrence of minerals and resources in general

Why aren't critical minerals everywhere?

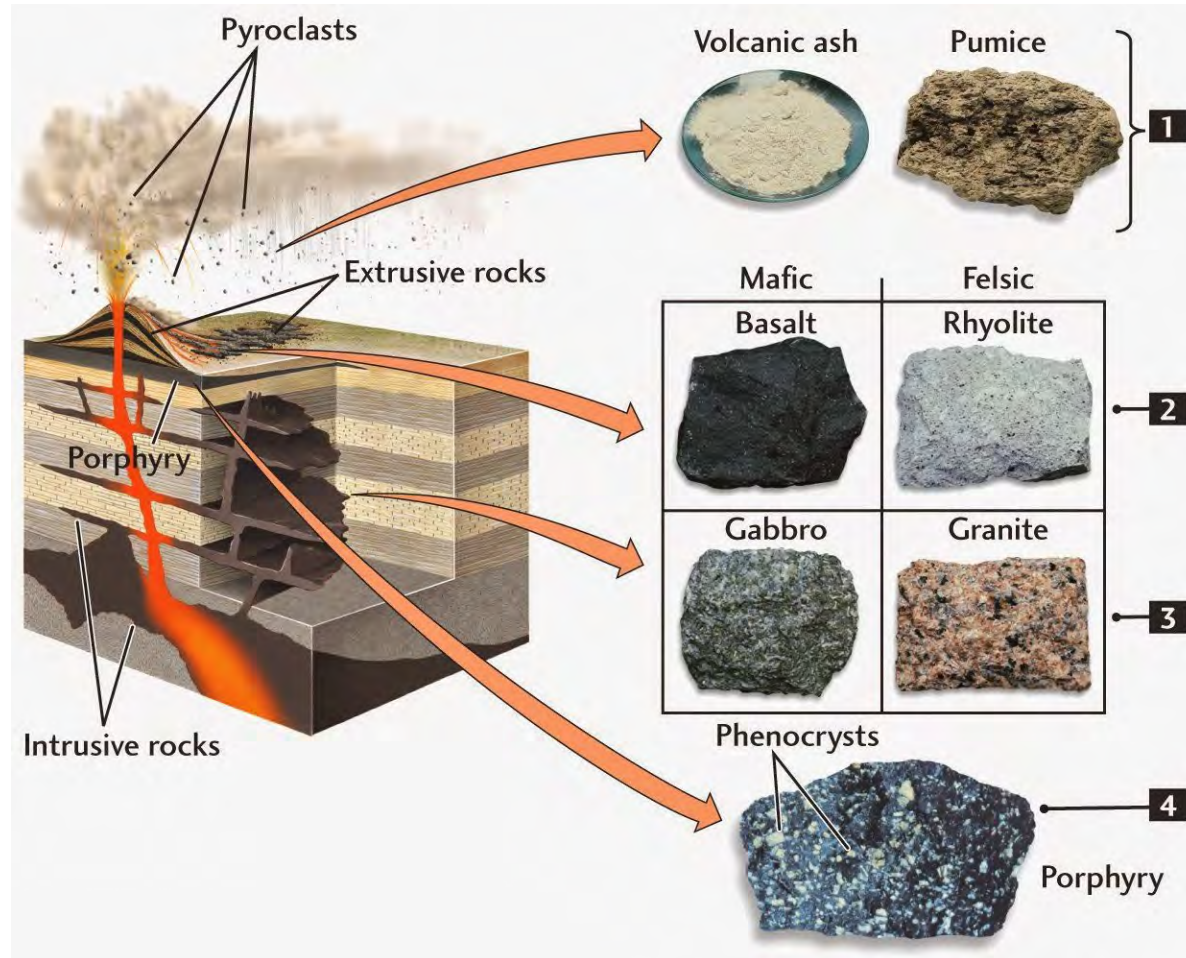
Why is China so good at this?

What is a Mine?



CM Geology 101: Igneous Rocks

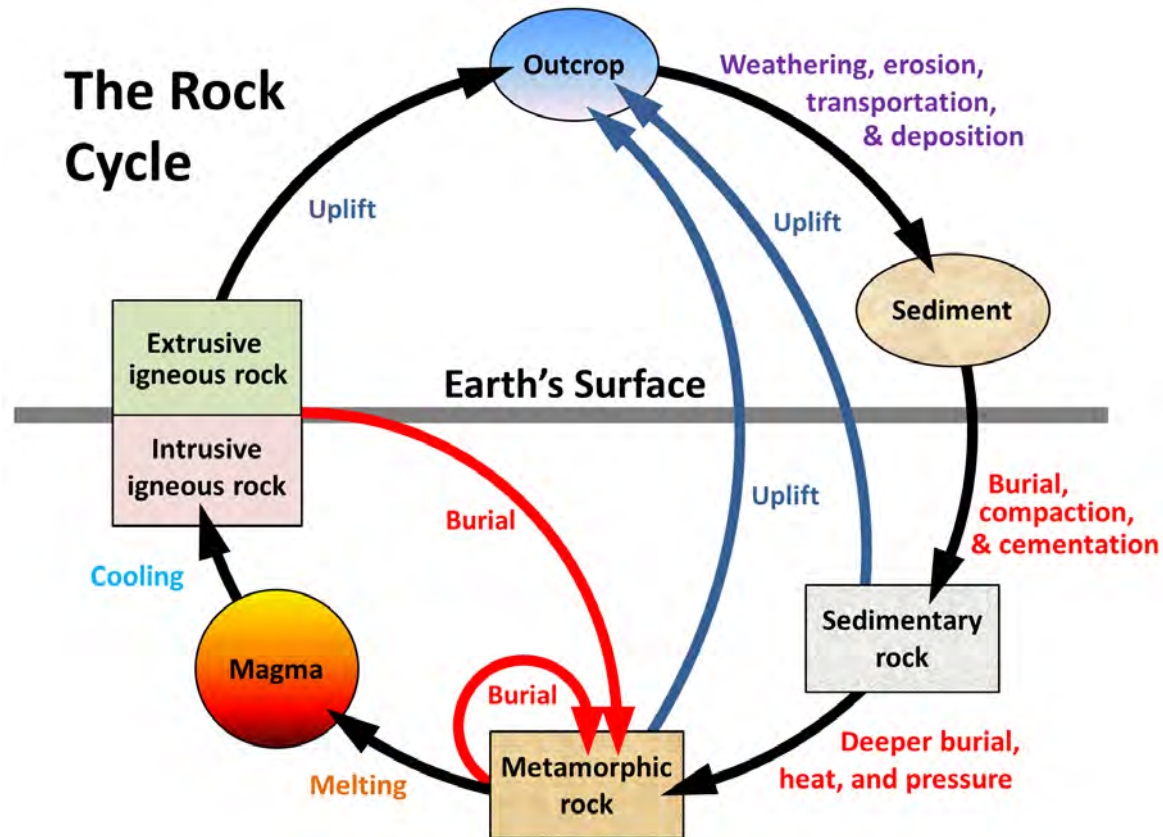
- Igneous: “from fire”
- Magma/lava cools to form various igneous rocks
- Major source of many different minerals and ores
- Can be directly mined, or can support nearby mineral formation





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

Global distribution of rare earth element deposits



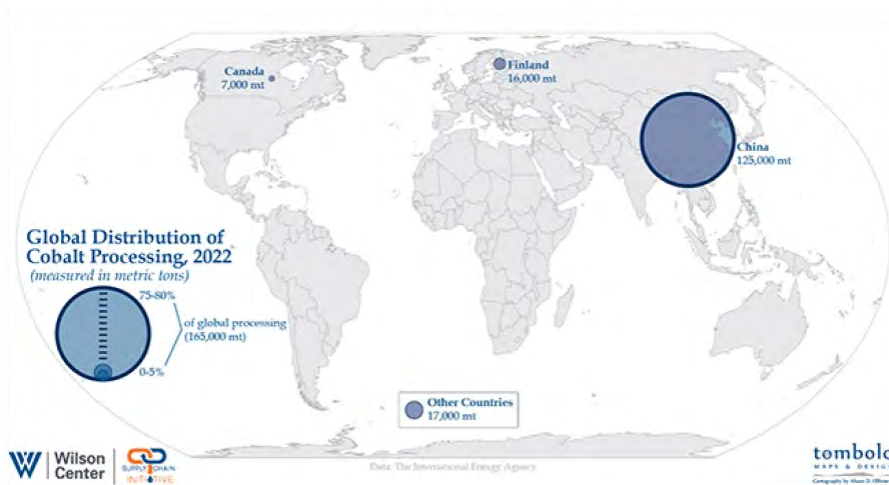
- Ion-adsorption type REE deposits (● this study)
- ◇ Alkaline complex-hosted REE deposits
- ▲ Carbonatite-hosted REE deposits

Are “rare earth elements” actually *rare*?



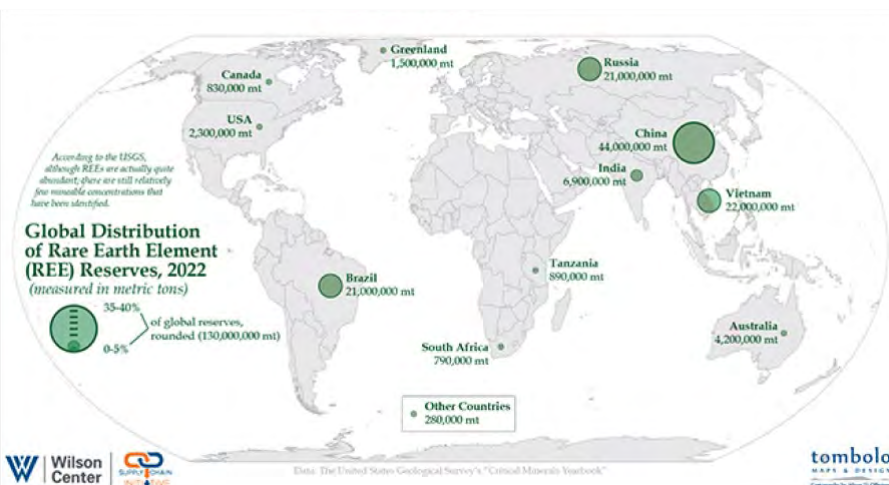
CM Geology 101: CM Reserves

Cobalt Processing

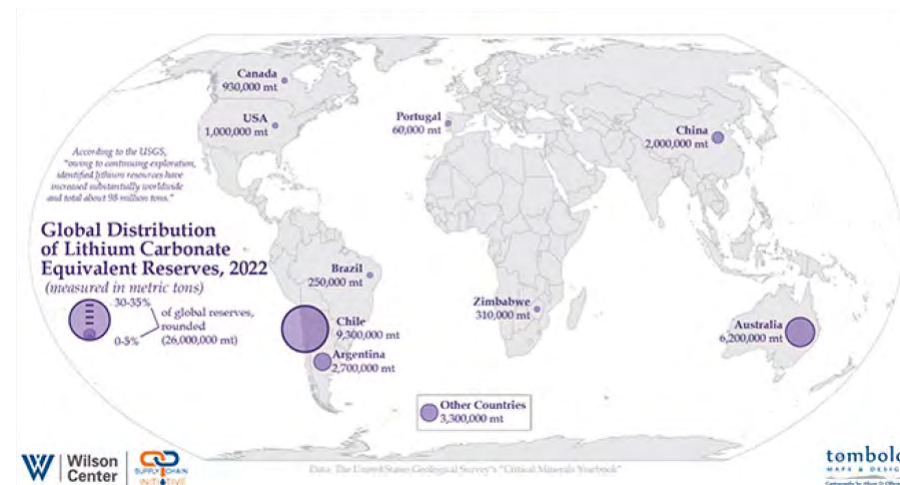


- Ongoing geologic processes reorganize CM and REE through geologic time
- Some nations may include significant resources within their borders, others may not
- **Reserves** are not the same as *resources*
 - *Resources* are potential
 - **Reserves** are economically viable and under production (or close)

REE Reserves



Lithium Reserves



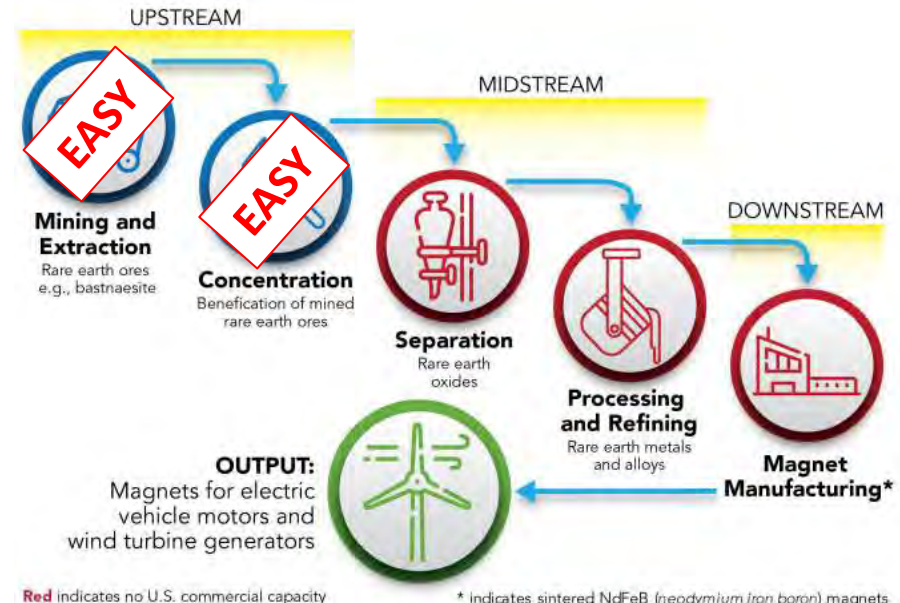


Chinese Supply: Ionic Clays

- 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?



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Mines can be Obvious...

MP Materials Mine (California, USA)





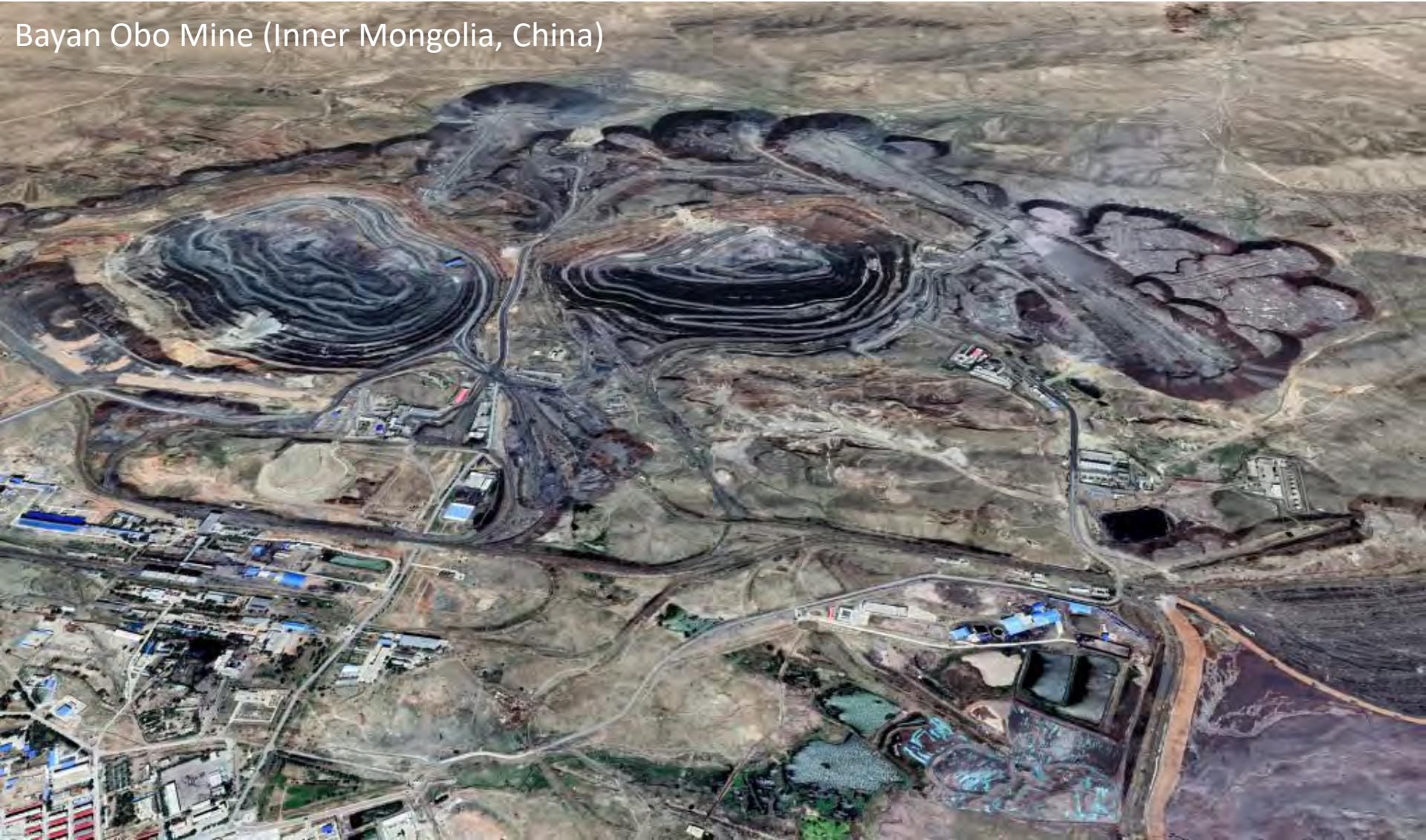
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Mines can be Obvious...

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





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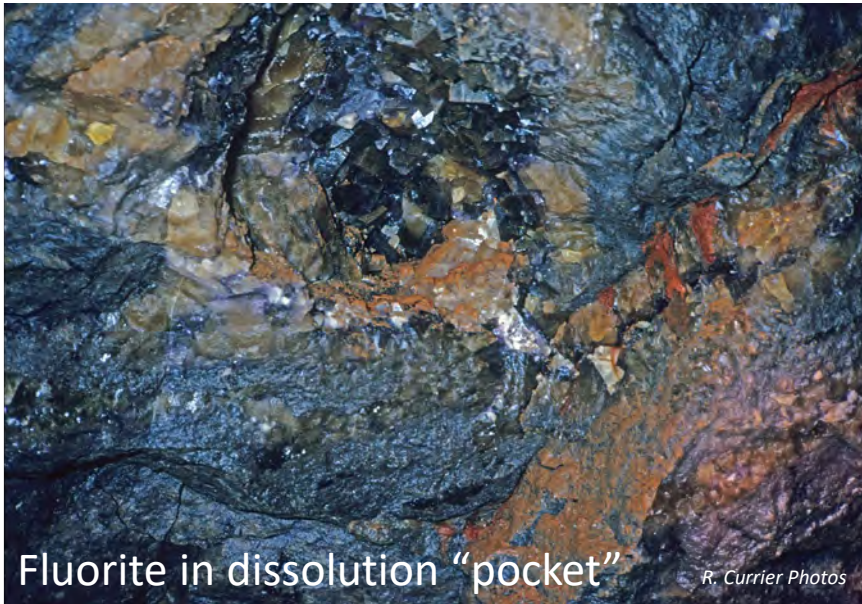
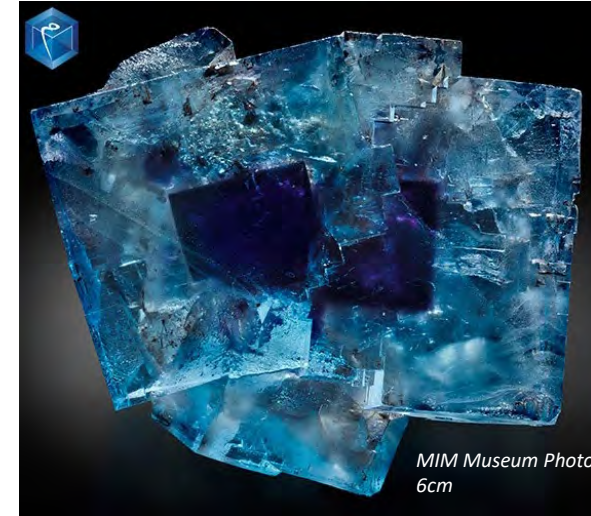
Selected Critical Minerals

Critical Minerals in the



Fluorite (1)

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





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/Graphene

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





Carbon/Graphite/Graphene Uses



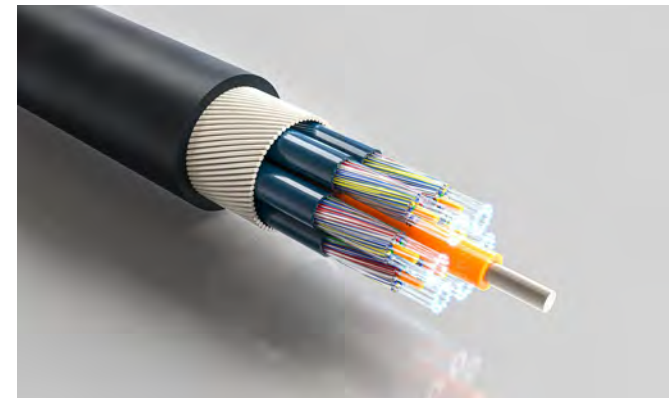
- Purified/activated carbon
- Graphite is an essential material for the anode of almost all battery designs
 - Up to 40% of a battery is carbon!
 - Tesla Model X: 65lbs graphite
- Supercapacitors
- Carbon fibers





Germanium

- Byproduct of zinc production, coal combustion
- At least 50% import reliance
- Applications:
 - Optics (fiberoptics, infrared & night vision, spectrosopes)
 - 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

Comparing Strengths of Magnets

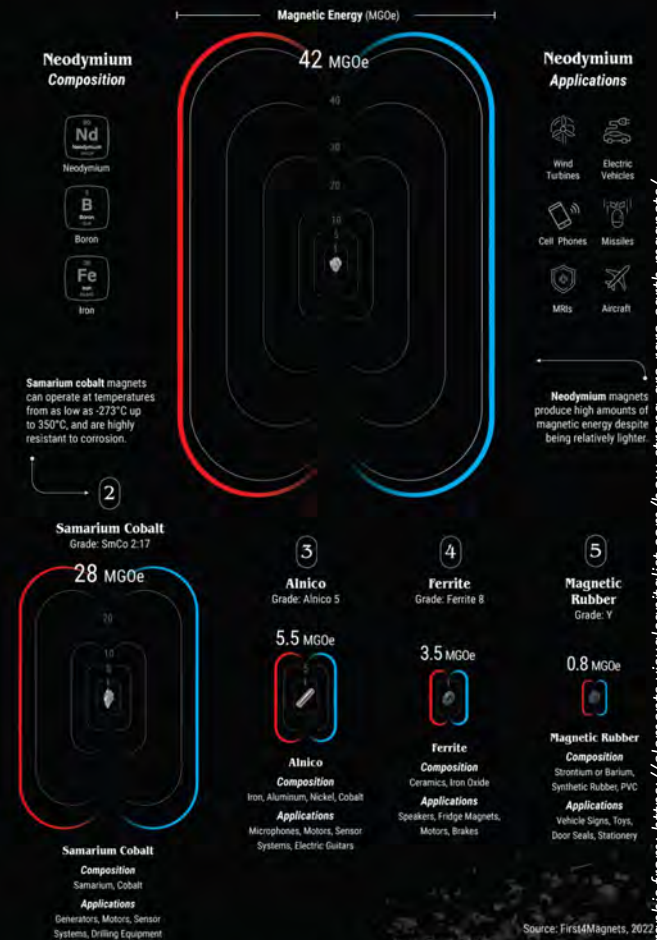


Rare earth magnets are the most powerful in the world, but how does their strength compare to other magnets?

How is magnet strength measured?
Magnet strength is measured using the maximum energy product, which shows the maximum amount of magnetic energy stored in a magnet. It is expressed in mega-gauss-oersteds (MGOe).

1
Neodymium
Grade: N42

What are rare earth magnets?
Permanent magnets made by alloying rare earth elements with elements like iron and cobalt. Neodymium magnets and samarium magnets are two types of rare earth magnets.

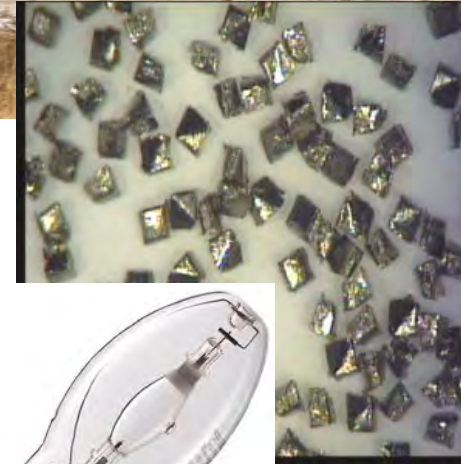


Graphic from: <https://elements.visualcapitalist.com/how-strong-are-rare-earth-magnets/>



Scandium

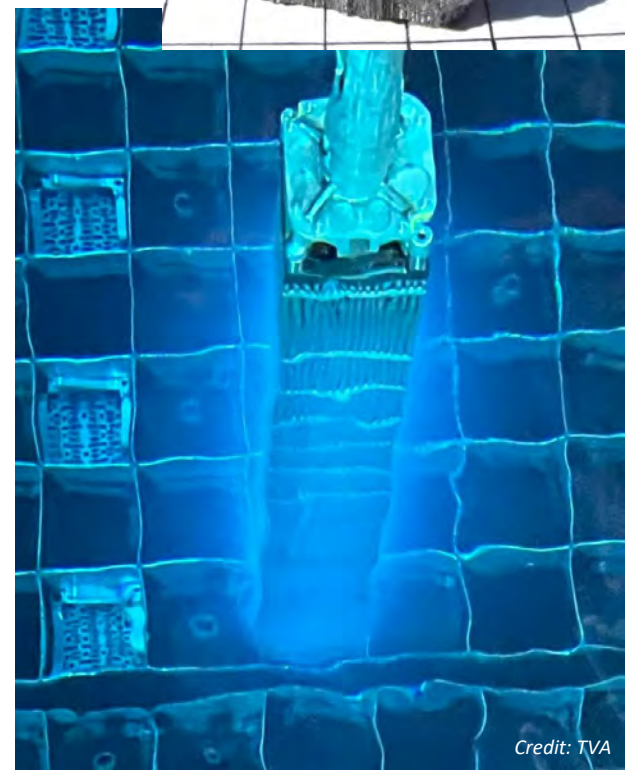
- Common metal that rarely forms significant concentrations
 - Sc is often a by-product of titanium mining
- Scandium uses:
 - Metal-Halide light bulbs
 - Aluminum-scandium alloys (as strong as titanium)
 - Experimental fuel cells
- Industries: lighting, national defense, aerospace, sport equipment





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)





THE KEY MINERALS IN AN EV BATTERY

Lithium-ion batteries harness the properties of various minerals to power electric vehicles.

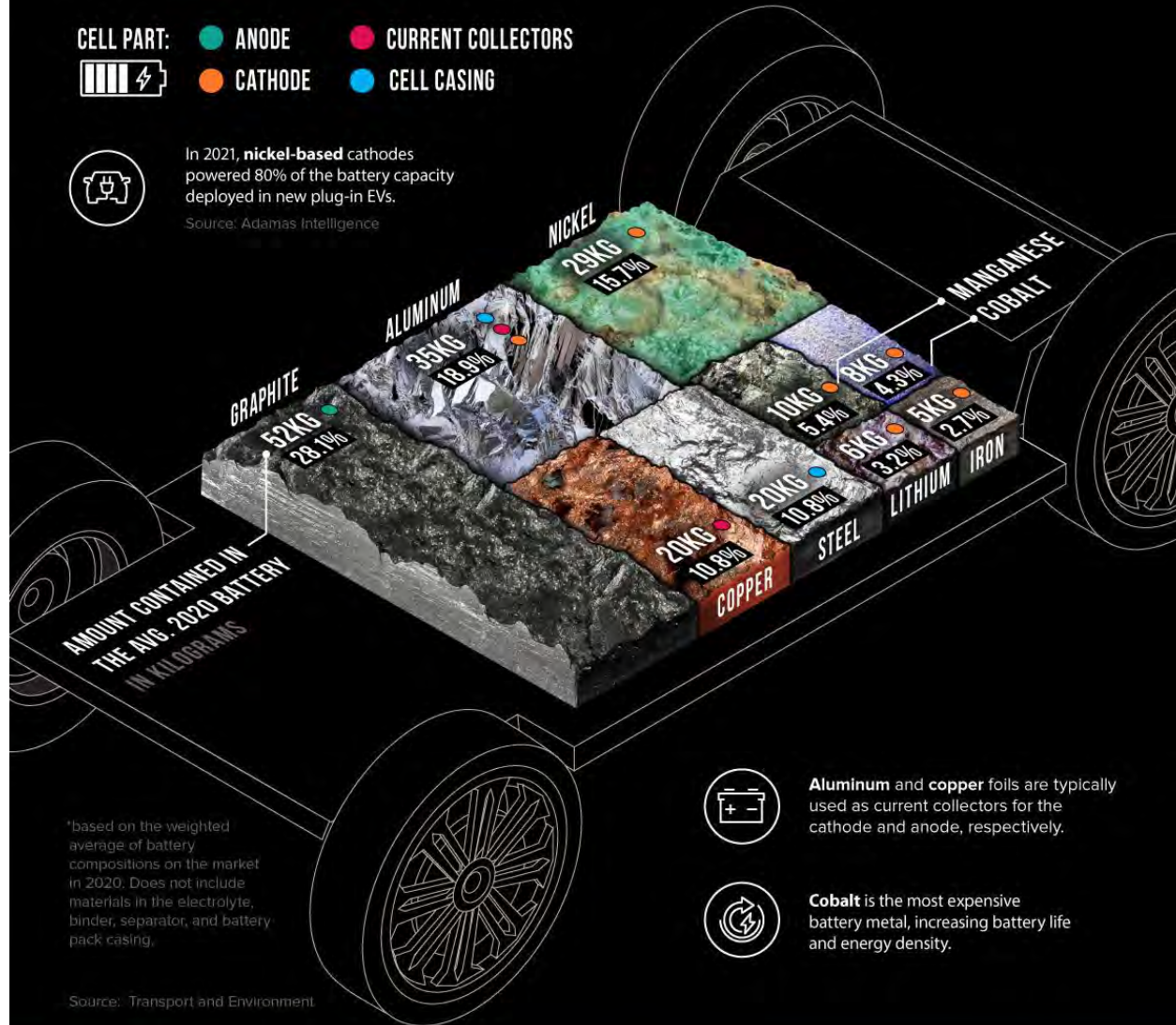
The cells in the average lithium-ion battery with a **60-kilowatt-hour (kWh)** capacity contain around **185kg*** of minerals.

- CELL PART: ● ANODE ● CURRENT COLLECTORS
● CATHODE ● CELL CASING



In 2021, **nickel-based** cathodes powered 80% of the battery capacity deployed in new plug-in EVs.

Source: Adamas Intelligence



AMOUNT CONTAINED IN THE AVG. 2020 BATTERY IN KILOGRAMS

*based on the weighted average of battery compositions on the market in 2020. Does not include materials in the electrolyte, binder, separator, and battery pack casing.

Source: Transport and Environment



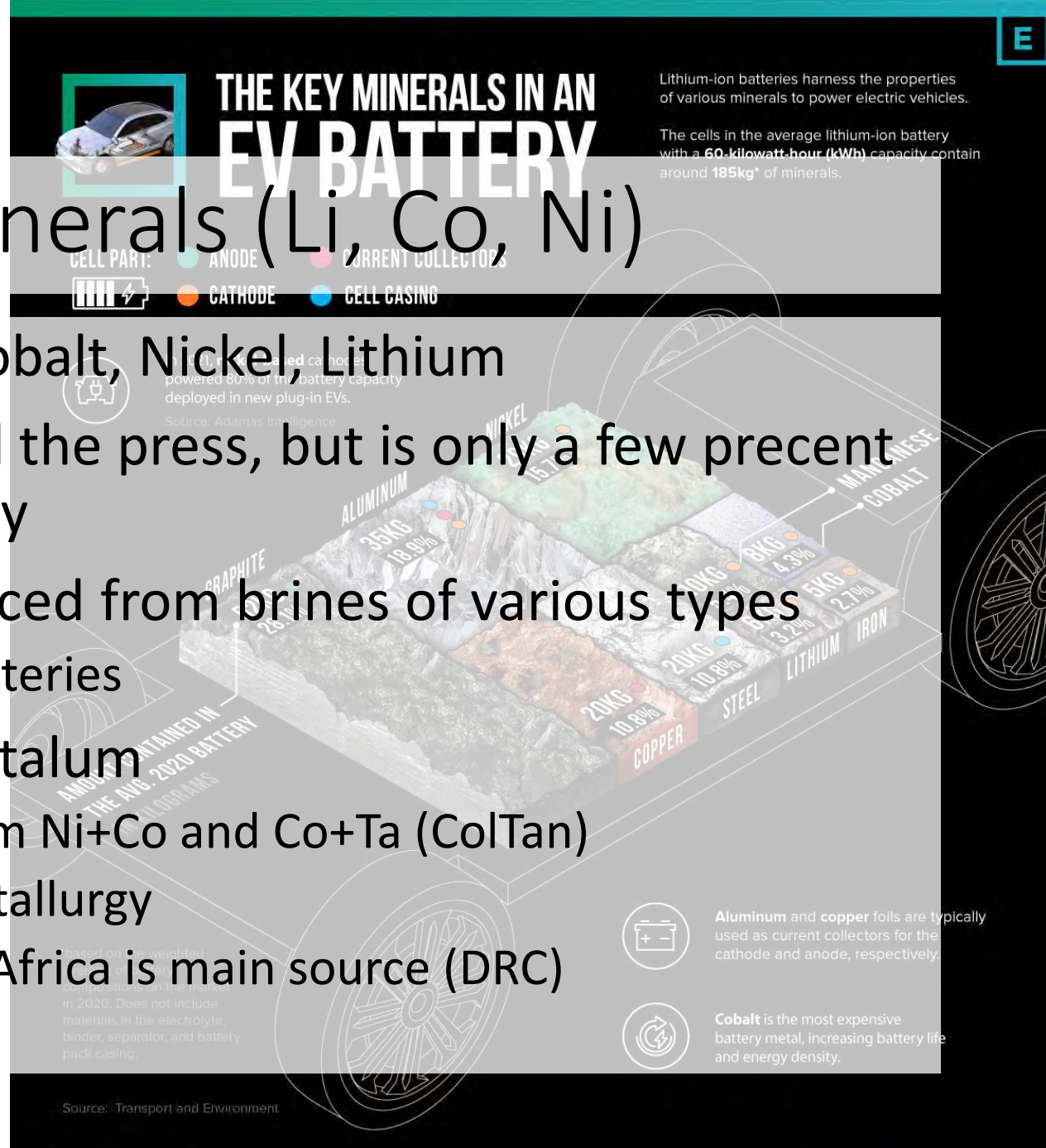
Aluminum and **copper** foils are typically used as current collectors for the cathode and anode, respectively.



Cobalt is the most expensive battery metal, increasing battery life and energy density.

Battery Minerals (Li, Co, Ni)

- Manganese, Cobalt, Nickel, Lithium
- Lithium gets all the press, but is only a few percent 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

The World's Largest Lithium Producing Countries

Lithium demand for electric vehicle batteries and other energy storage devices has grown significantly over the past few years.

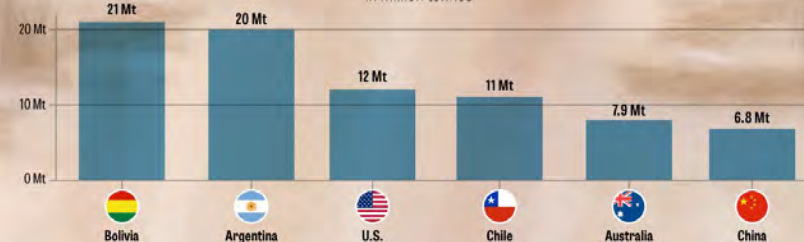
Over 70% of global lithium production comes from only two countries.

Australia produces most of its lithium by mining hard rock spodumene, unlike **Argentina, Chile, and China**, which produce it mostly from brine.

Lithium Production by Country 2022e in Tonnes



Countries with the Largest Lithium Reserves
in million tonnes



*U.S. production data was withheld to avoid disclosing company proprietary data.



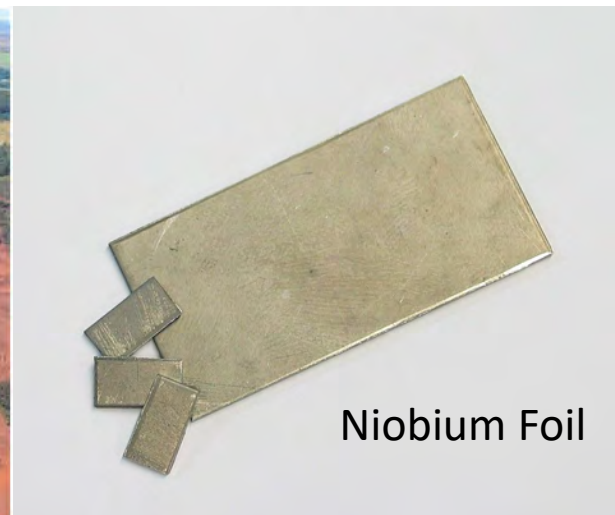
Platinum Group Elements (PGE)

- 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 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

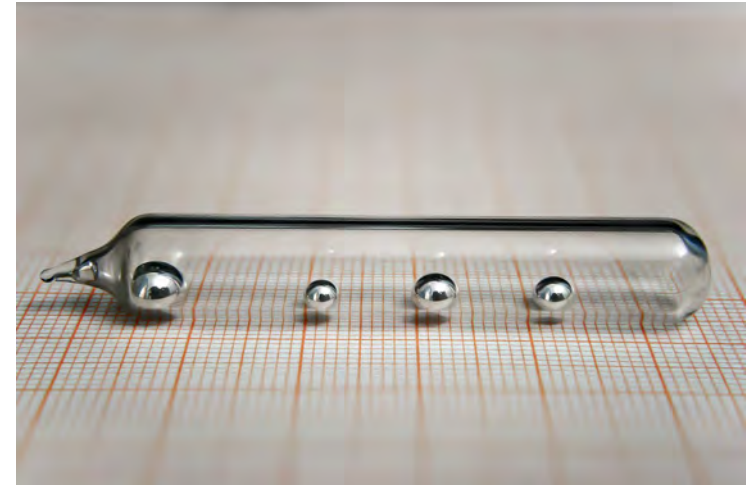
- Aluminum occurs mainly as bauxite
- Refining is very energy-intensive, tends to be located where electricity is cheap (e.g. hydropower)
- Transportation, packaging, building components, electronics, aerospace, household goods, machinery





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

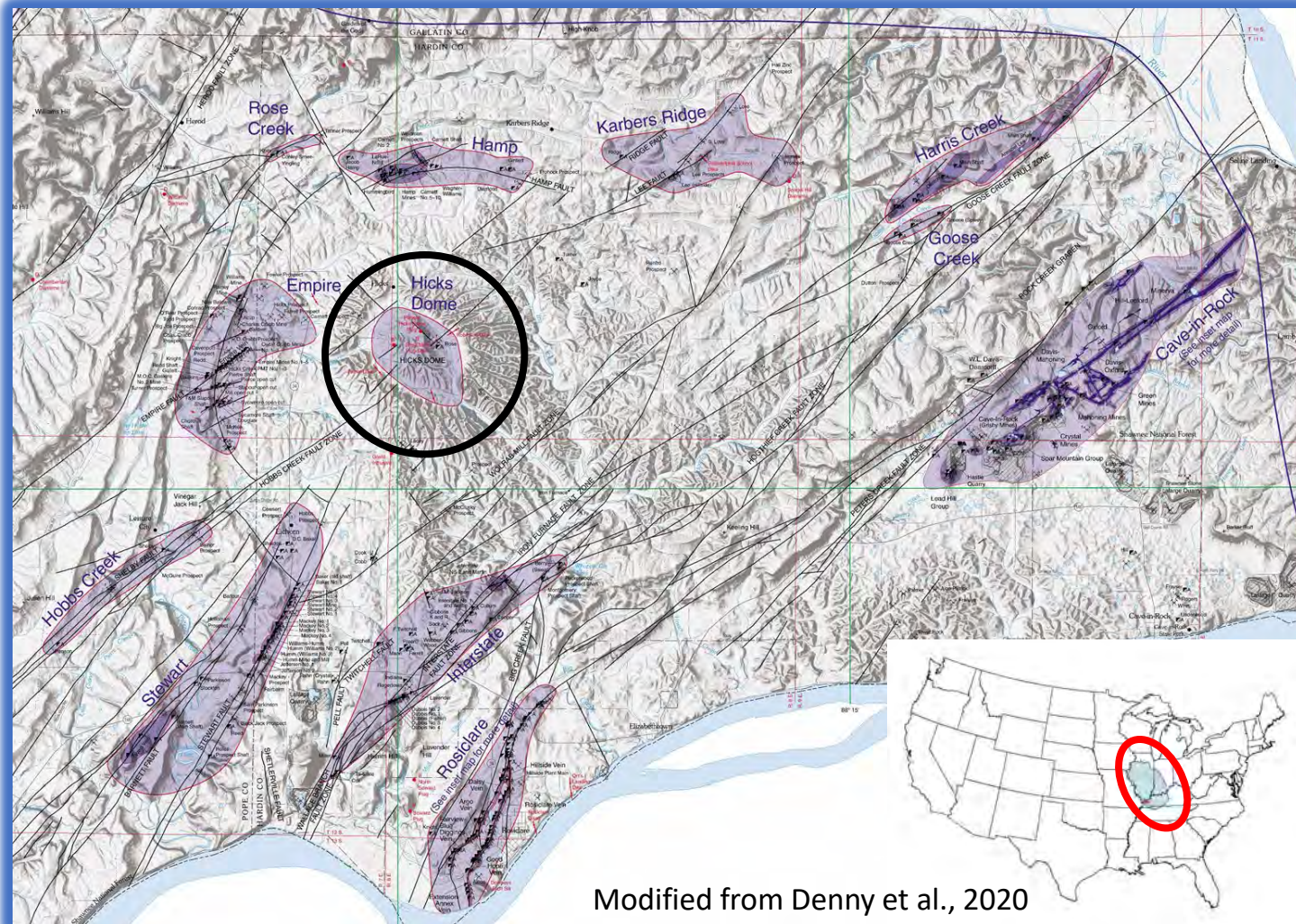
Unconventional Sources

- 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

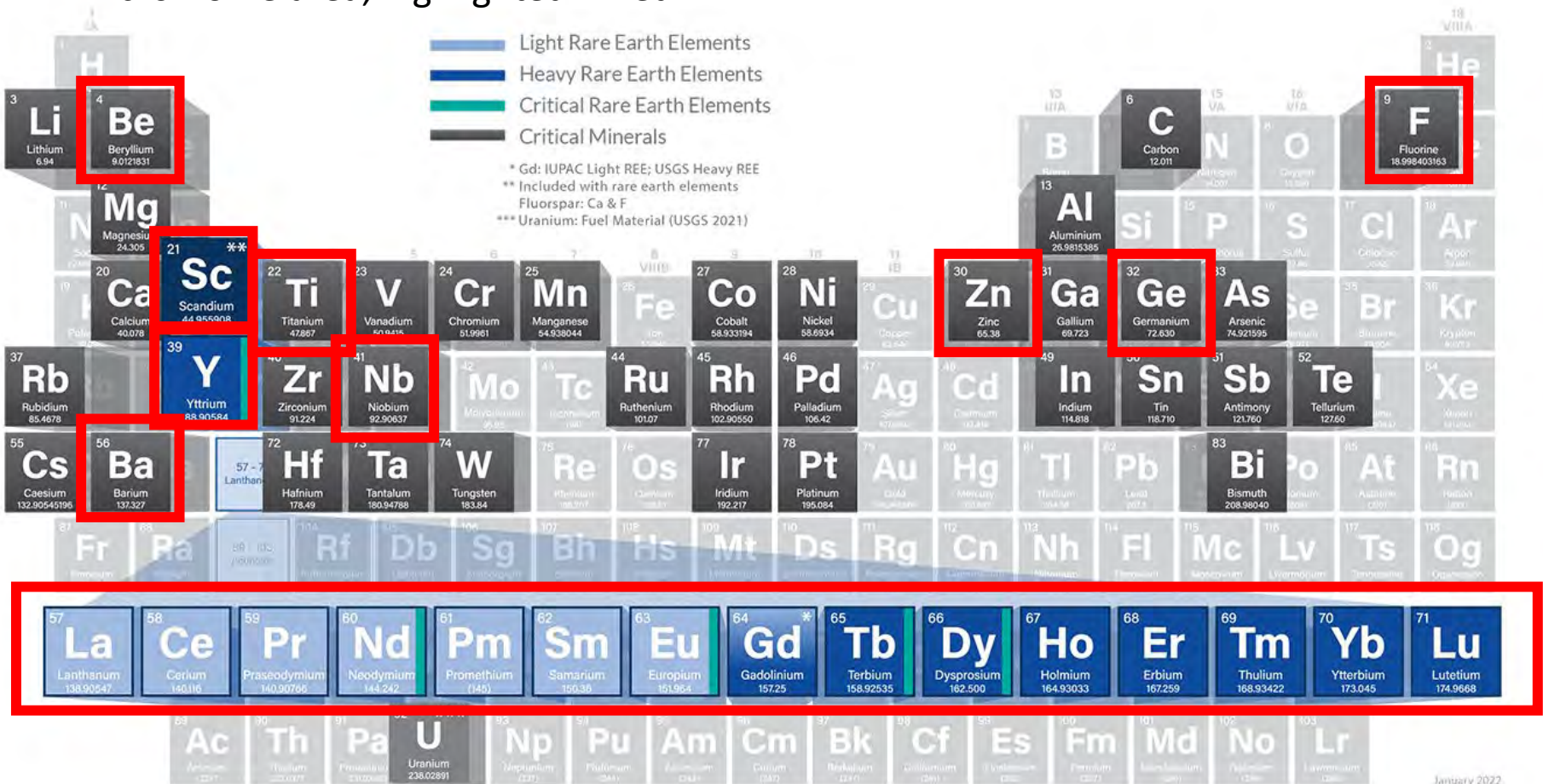
- 12 sub-districts with many mines among numerous outlying prospects/mines. Note the 11 sub-districts surrounding Hicks Dome. Mineral portion of presentation will largely focus on 2 sub-districts: Cave-in-Rock and Harris Creek
- Hicks Dome and the Permian Wauboukigou Igneous Province (PWIP)





Critical Minerals in the IKFD

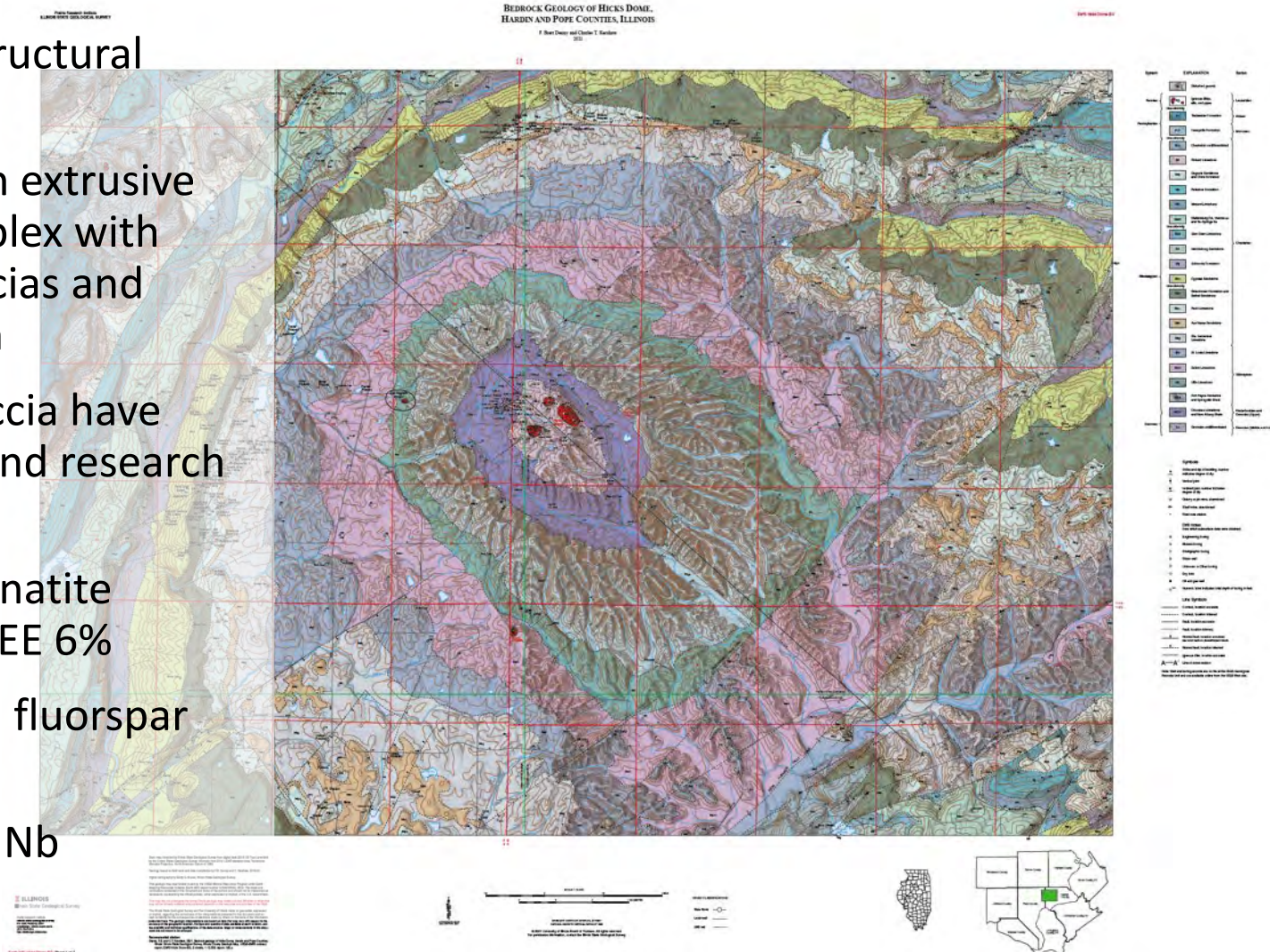
Critical Minerals in the Illinois-Kentucky Fluorspar District (IKFD), mainly around the Hicks Dome area, highlighted in red





Hicks Dome

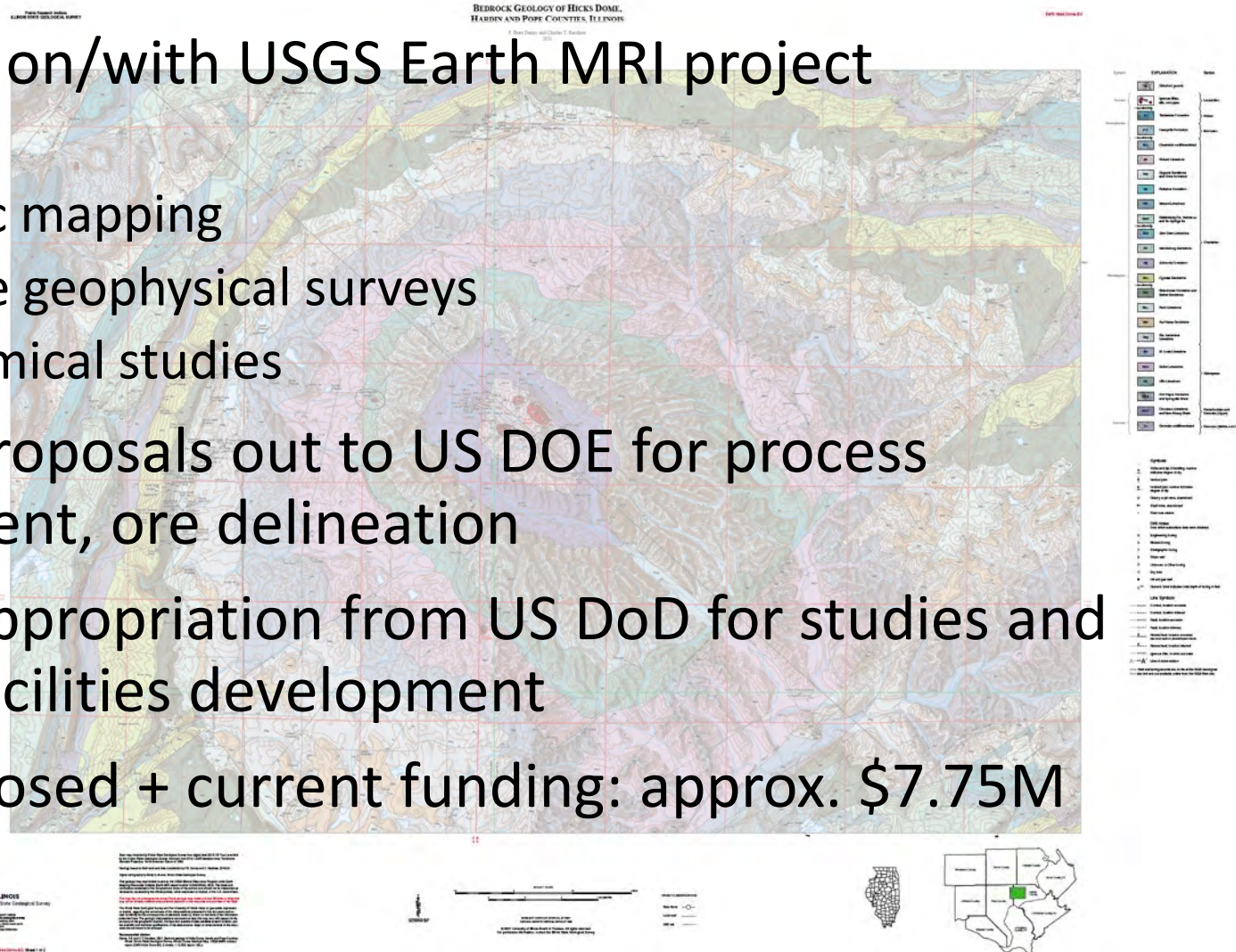
- Topographic & structural dome
- The orebody is an extrusive carbonatite complex with mineralized breccias and overlying regolith
- Regolith and breccia have been evaluated and research is underway
- Underlying carbonatite samples up to TREE 6%
- Largest untapped fluorspar resource in US
- Significant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





ISGS Programs at Hicks Dome

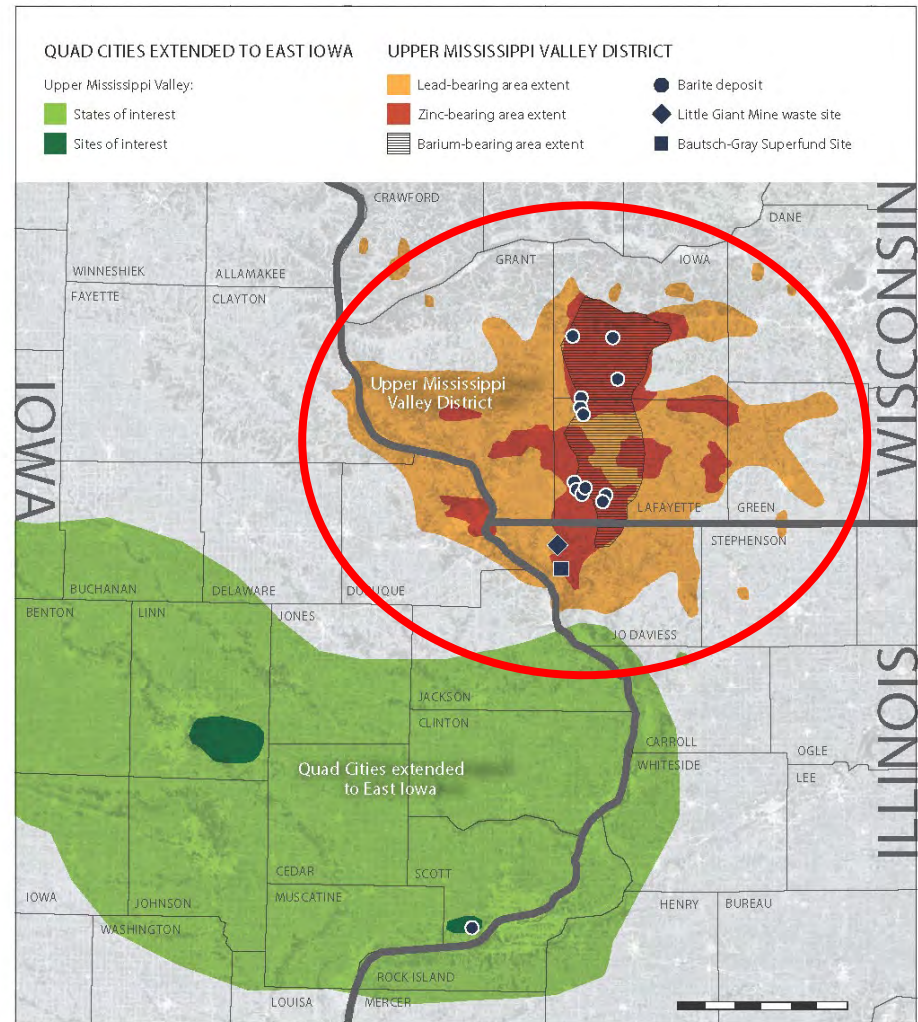
- ISGS work on/with USGS Earth MRI project (ongoing)
 - Geologic mapping
 - Airborne geophysical surveys
 - Geochemical studies
- ISGS led proposals out to US DOE for process development, ore delineation
- ISGS led appropriation from US DoD for studies and process/facilities development
- Total proposed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

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

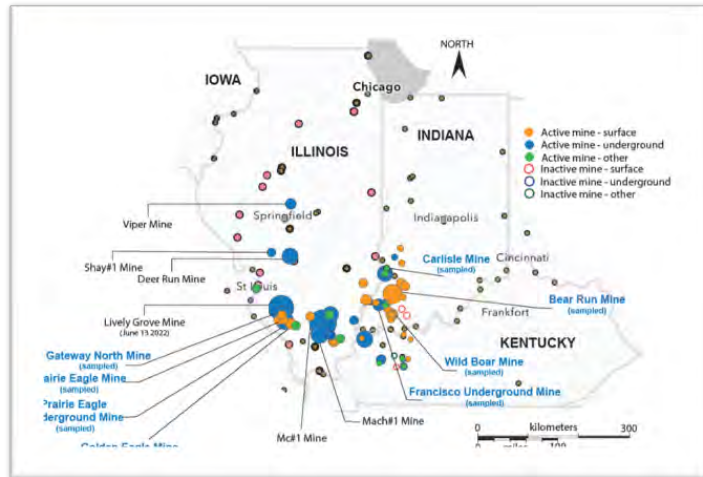
- Public-Private
- Technology
Development
- Education/
Workforce

Outreach

- Education
- Public-Private
Engagement
- Stakeholders

Processing

- Pilot
- Commercial
- Manufacturing



Power Plants



Mines/Mine Waste

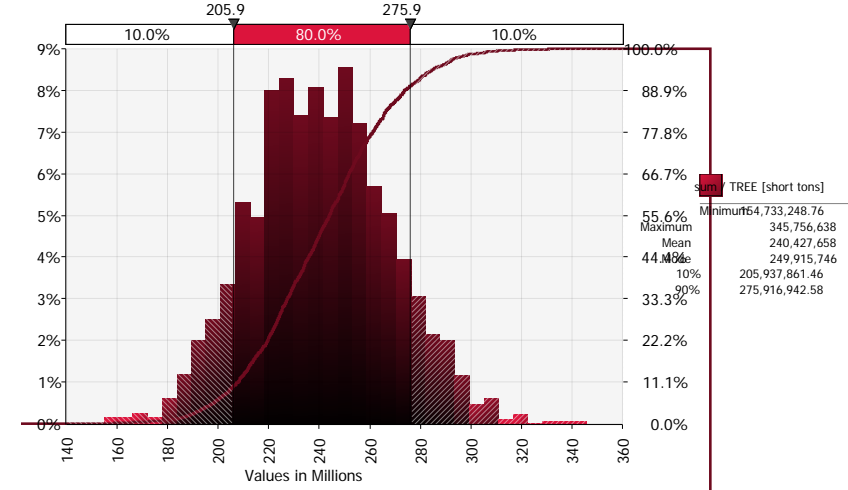




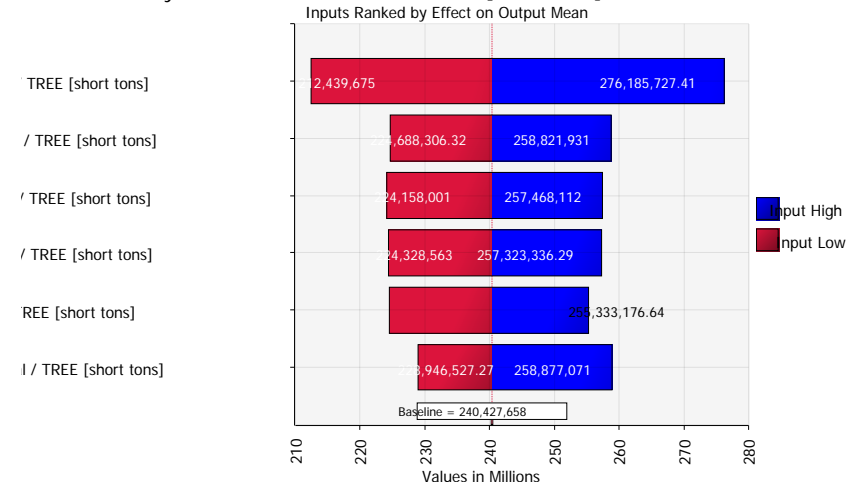
Illinois Basin CORE-CM Results

- 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

REE in all Assessed Coal Seams, Illinois Basin



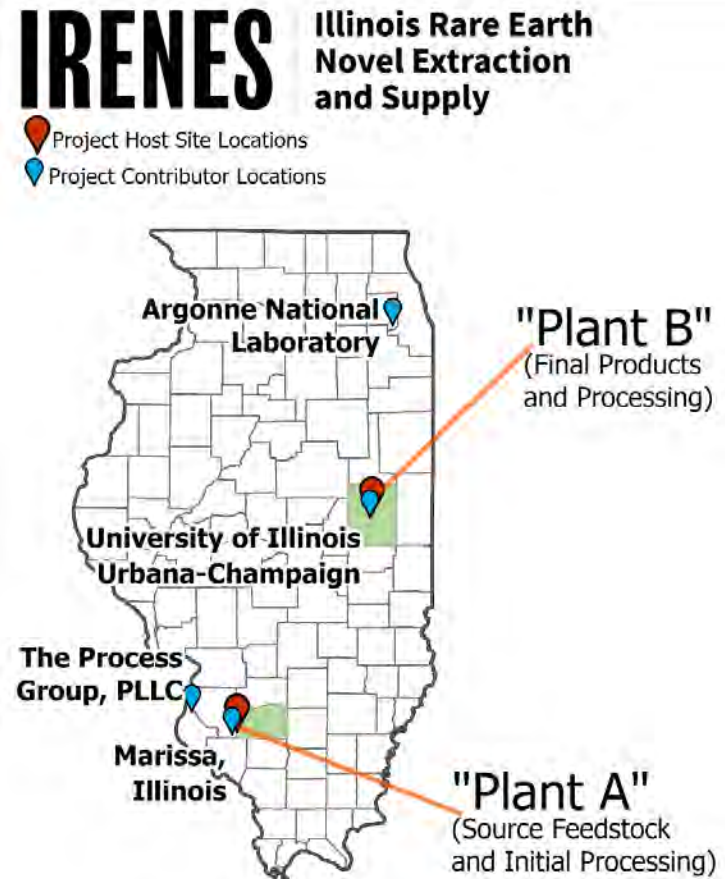
Sensitivity Tornado for TREE in Ill. Basin [short tons]





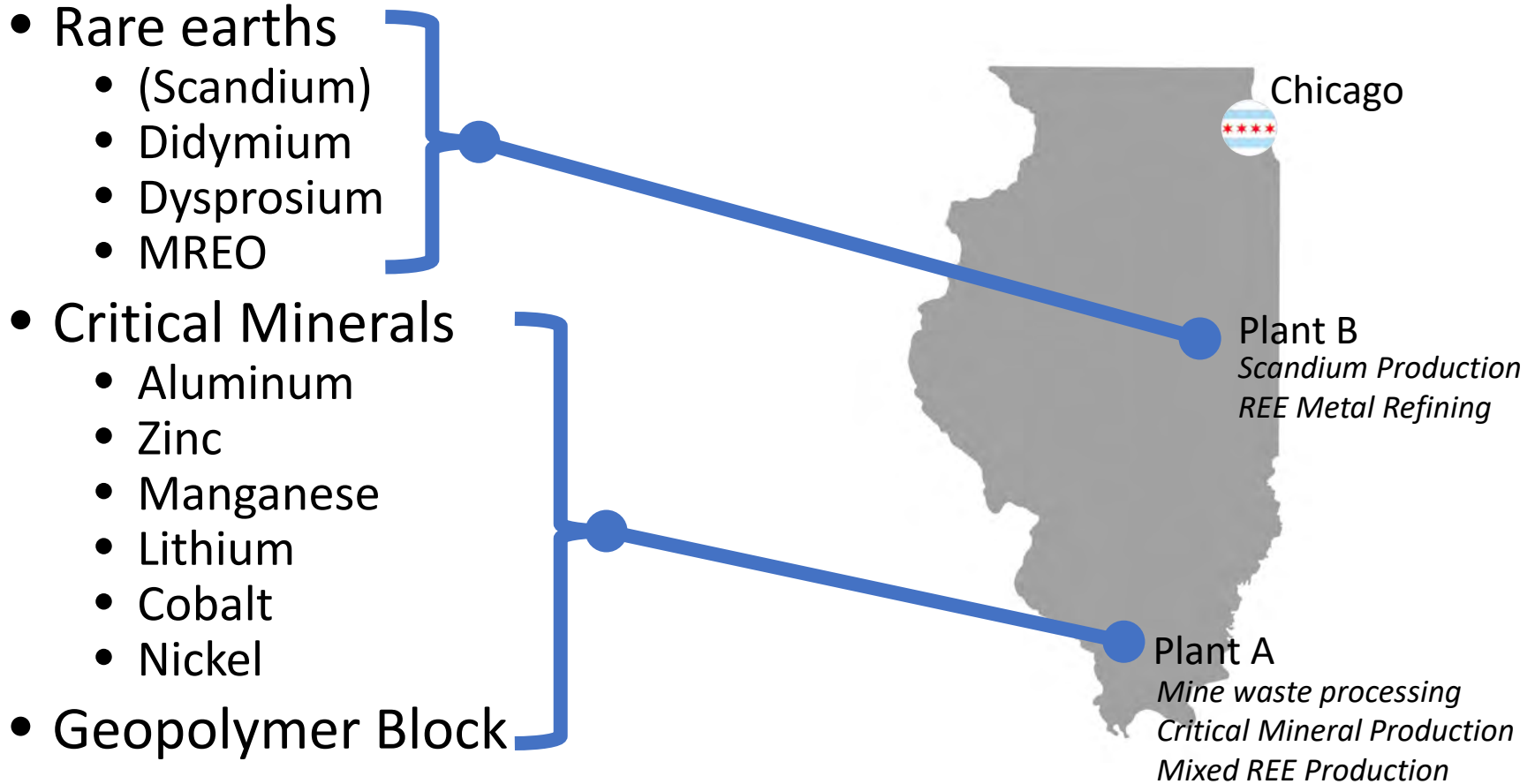
IRENES Project

- 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





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Cautionary Note: estimates of mineral volumes presented here are provided for scientific and indicative purposes only and should not form the basis of any financial or legal transaction or scheme. The State of Illinois, the University of Illinois, Prairie Research Institute or the Illinois State Geological Survey are not responsible for any legal or financial decisions or outcomes based on this presentation.