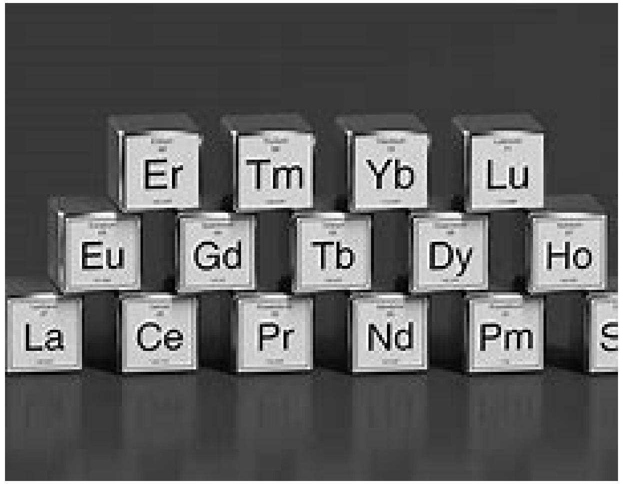
Current Issues 2022

PINCH POINT: Critical Minerals and the Looming Supply Chain

Vulnerability in the Quest for Clean Energy

Critical Minerals and Rare Earth Elements:

A brief introduction



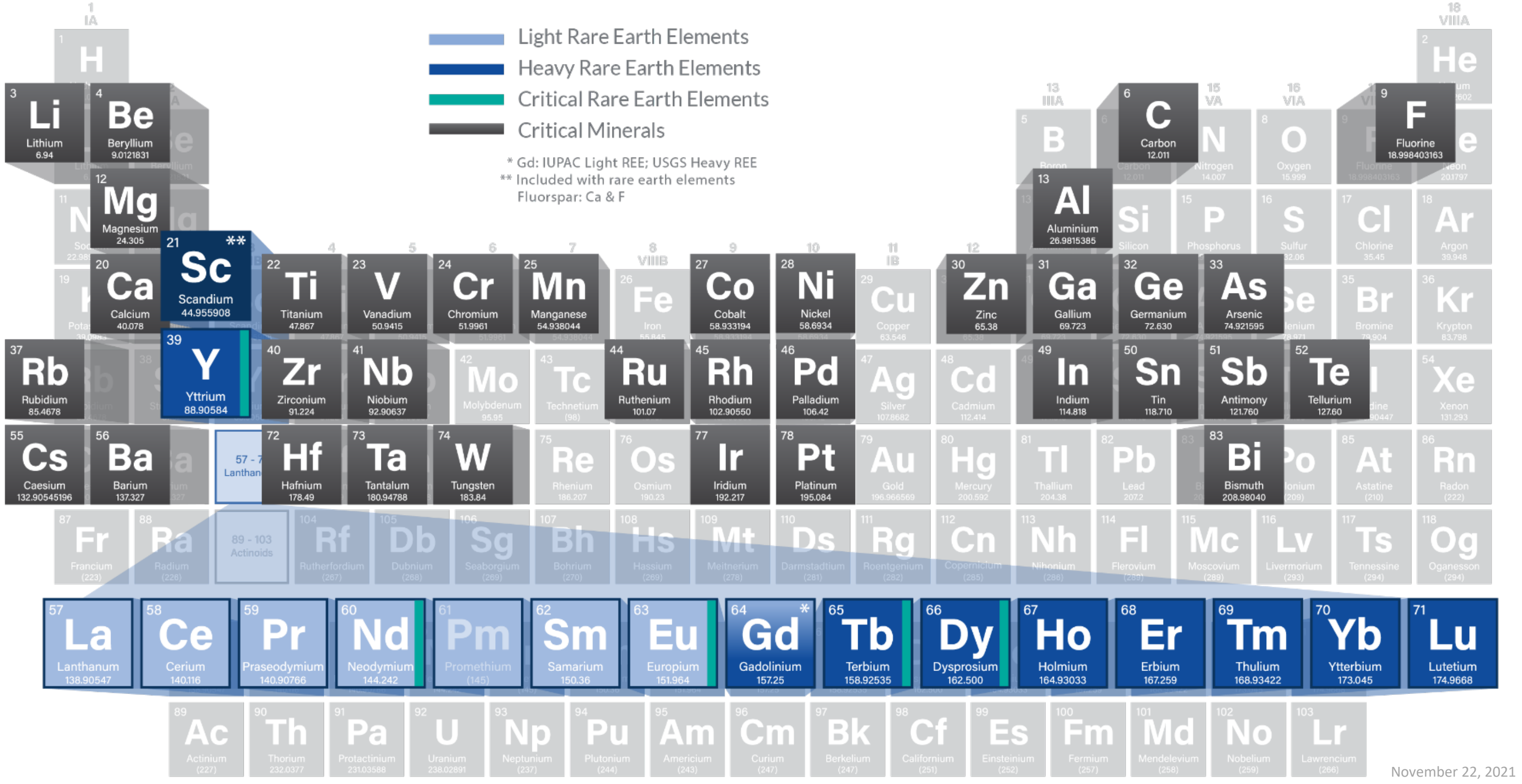
Terminology

- **Critical Minerals:**
  - Metals and non-metals that are necessary for the economic well-being of the economy, with important uses and no viable substitutes, yet whose supply may be at risk due to geological scarcity, geopolitical issues, trade policy or other factors.
  - The term “critical minerals” can include “rare earth minerals”.
- **Rare Earth Elements (REE):**
  - The 15 metallic chemical elements with atomic numbers 57–71, from lanthanum through lutetium. These elements, along with elements scandium and yttrium, are often collectively known as the rare-earth elements, metals or oxides.

Challenge: Absence of Domestic U.S. REE and CM Supply Chains – U.S. DEPARTMENT OF ENERGY

Offshore Dependance for Critical Materials

- Import-dependent on >80% of U.S. rare earth element (REE) demand
- Import-dependent (>50% from foreign source) on >40 of 50* critical minerals
- Import-reliant (100% from foreign source) for at least 12 critical minerals



*USGS released new draft list of critical minerals
Source: USGS Minerals Commodity Summaries

Source: Alex Moyes, Dominion Energy

The Critical Minerals

Critical Mineral	Use	Import Reliance
Arsenic	Semi-conductors, lumber preservatives, pesticides	100%
Cerium	Catalytic converters, ceramics, glass, metallurgy	100%
Cesium	Research, development	100%
Dysprosium	Data storage devices, lasers	100%
Erbium	Fiber optics, optical amplifiers, lasers	100%
Europium	Phosphors, nuclear control rods	100%
Fluorspar	Manufacture of aluminum, cement, steel, gasoline	100%
Gadolinium	Medical imaging, steelmaking	100%
Gallium	Integrated circuits, LEDs	100%
Graphite	Lubricants, batteries	100%
Holmium	Permanent magnets, nuclear control rods	100%
Indium	Liquid crystal display screens	100%
Lanthanum	Catalysts, ceramics, glass, polishing compounds	100%
Lutetium	Scintillators for medical imaging, cancer therapies	100%
Manganese	Steelmaking, batteries	100%
Neodymium	Rubber catalysts, medical, industrial lasers	100%
Niobium	Steel, superalloys	100%
Praseodymium	Permanent magnets, batteries, aerospace alloys	100%
Rubidium	Research, development in electronics	100%
Samarium	Cancer treatment, absorber in nuclear reactors	100%
Scandium	Alloys, ceramics, fuel cells	100%
Tantalum	Electronic components, superalloys	100%
Terbium	Permanent magnets, fiber optics, lasers	100%
Thulium	Metal alloys, lasers	100%
Ytterbium	Catalysts, scintillometers, lasers, metallurgy	100%
Yttrium	Ceramic, catalysts, lasers, metallurgy, phosphors	100%

Critical Mineral	Use	Import Reliance
Vanadium	Alloying agent for iron and steel	96%
Tellurium	Solar cells, thermoelectric devices	95%
Bismuth	Medical, atomic research	94%
Titanium	White pigment, metal alloys	88%
Zinc	Metallurgy to produce galvanized steel	83%
Antimony	Lead-acid batteries, flame retardants	81%
Platinum	Catalytic converters	79%
Cobalt	Rechargeable batteries, superalloys	76%
Barite	Hydrocarbon production	75%
Chromium	Stainless steel	75%
Tin	Coatings, alloys for steel	75%
Germanium	Fiber optics, night vision applications	50%
Lithium	Rechargeable batteries	50%
Magnesium	Alloys, electronics	50%
Nickel	Stainless steel, rechargeable batteries	50%
Tungsten	Wear-resistant metals	50%
Palladium	Catalytic converters	40%
Zirconium	High-temparature ceramics production	25%
Aluminum	Power lines, construction, electronics	13%
Beryllium	Alloying agent in aerospace, defense industries	11%
Hafnium	Nuclear control rods, alloys	0%
Iridium	Coating of anodes for electrochemical processes	NA
Rhodium	Catalytic converters, electrical components	NA
Ruthenium	Electrical contacts, chip resistors in computers	NA

The Geopolitics of Critical Minerals Supply Chains

Current Issues Conference
Santa Fe, NM
April 11, 2022

Jane Nakano
Senior Fellow
Energy Security and Climate Change Program
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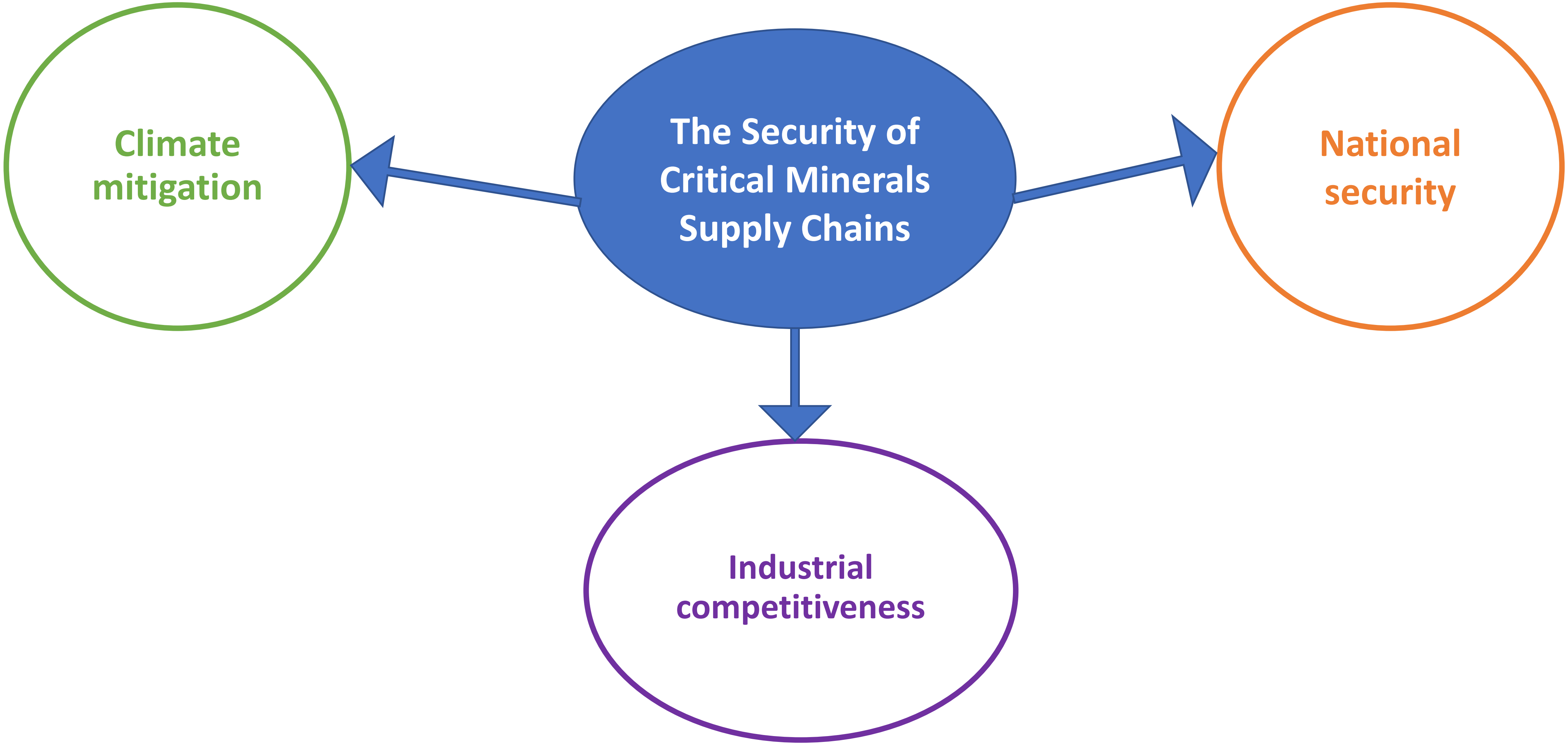
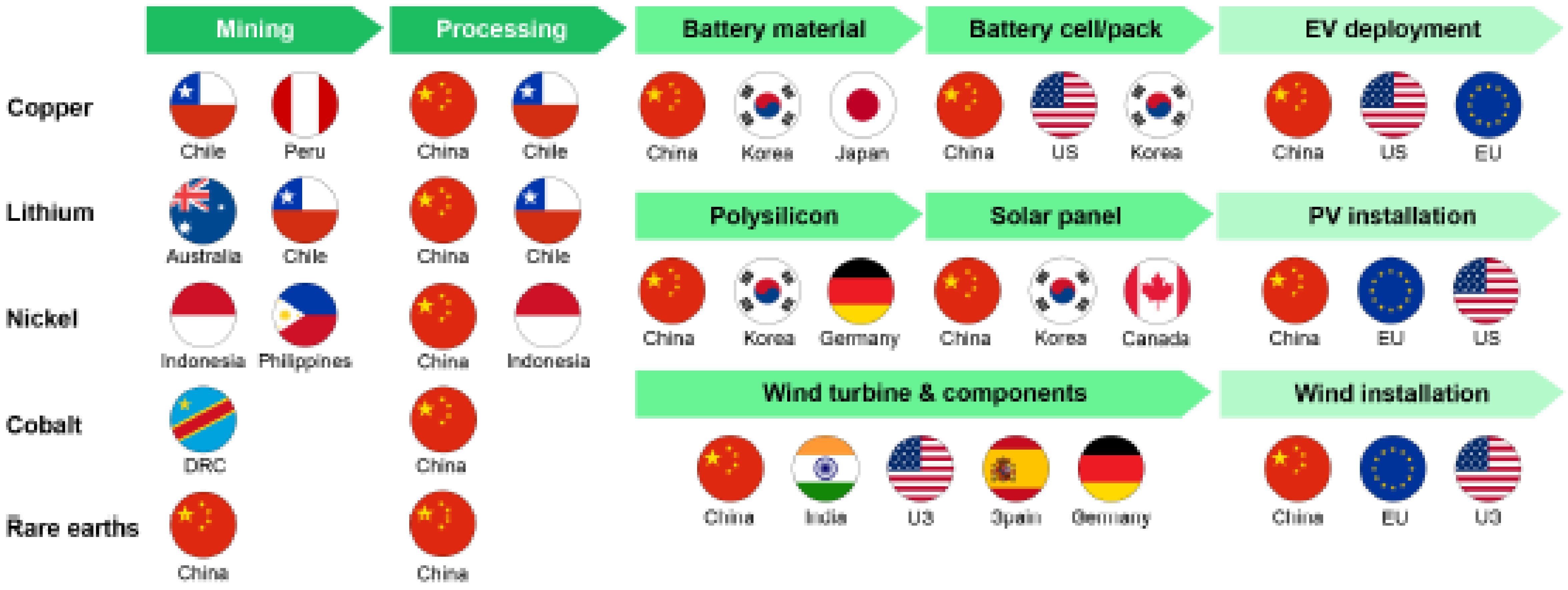
CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

Safeguarding the supply chains for critical minerals is a strategic priority.



Indicative Supply Chains for Clean Energy Technologies



(Source: The Role of Critical Minerals in Clean Energy Transition, IEA (2021), p.29.)

China's Measures and Efforts to Develop and Secure Critical Minerals Supply Chains

Measures to Develop Midstream and Downstream:

- **The 7th National Five-Year Plan for Rare Earth Industry (1986–1990)**
- **Investment policies**
- **State-sponsored R&D**
- **Export quotas (1999-2014) & production quotas (2006-present)**
- **"Made in China 2025" industrial initiative (2015)**
- ***China's production of rare-earth end-use products grew by about 70%, 2005-2015.***
    - ***2004-2014: Chinese rare earth consumption grew at 7.5% annually***
      China's share of the global consumption rose from 43% to 70%.
    - ***By 2015, consumption accounted for over 80% of the domestic production of rare earths.***

Recent Actions to Secure CM Supply Chains:

- **Rare Earth: Approval process for mining, processing and trade (Jan '21); and mega-merger (Jan '22).**
- **Lithium: Order to a "rational return" in the market (March 2022)**

Several major economies have taken actions to secure the supply chains for clean energy technology & component minerals.

EUROPEAN UNION

Resource potential
R&D base
Manufacturing

UNITED STATES

Resource wealth
Upstream experience
R&D base
Private sector ingenuity
Manufacturing experience

JAPAN

Midstream capacity
CM stockpile
R&D base
Manufacturing

CANADA

Resource wealth
Favorable upstream

AUSTRALA

Resource wealth
Favorable upstream

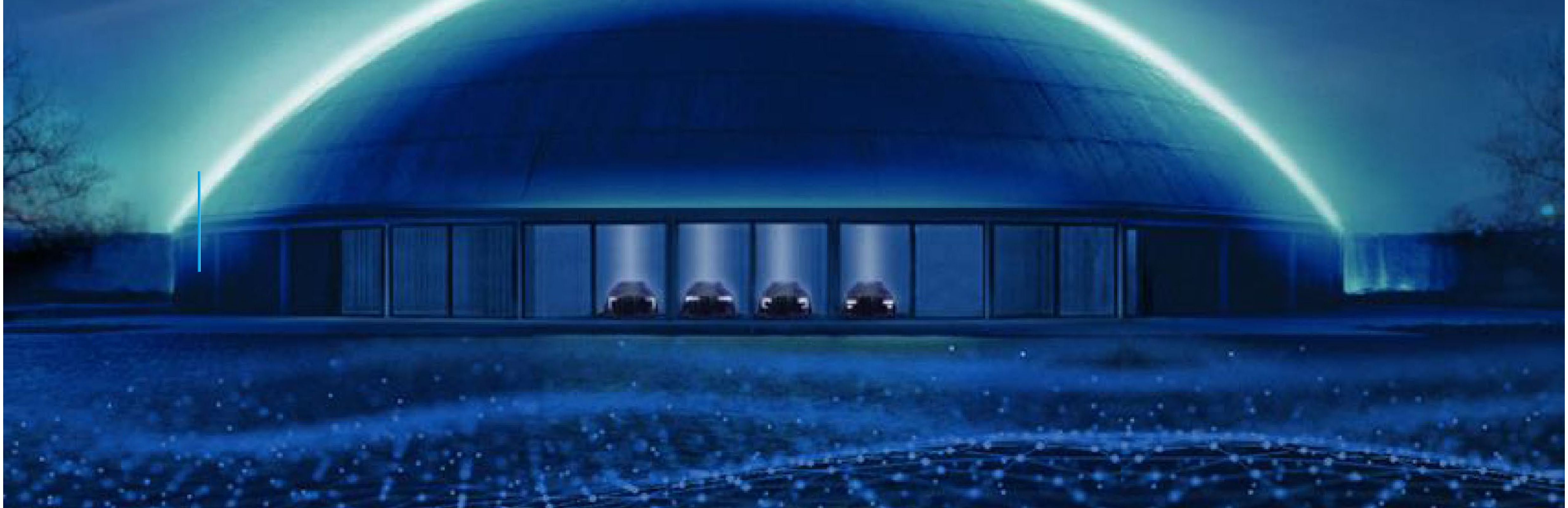
CHINA

Resource wealth
Industrial policy
Long-term R&D support
Manufacturing

Note: These characteristics are representative and not comprehensive; they are relative as well as dynamic.

Roadmap to an All-Electric Future

Michael Maten
Director, EV Policy and Regulatory Affairs
General Motors



BY THE NUMBERS:

GM INVESTS IN A ZERO-EMISSIONS FUTURE

35
BILLION
is the amount GM is committing to EVs and AVs through 2025

>50%
OF PRODUCT DEVELOPMENT
team will be devoted to electric and electric-autonomous vehicle programs

30
EVs LAUNCHED
by 2025, with more than two-thirds of those being available in North America

Engineering advances have increased the max range of Ultium-based vehicles on a full charge to

450[1]
MILES

By mid-decade, Ultium packs are projected to deliver twice the energy density of today's product, but cost

60%
LESS

[1]GM estimated. EPA estimates not available. Vehicle range may vary based on several factors, including temperatures, terrain, battery age, and vehicle use and maintenance.

GM’S EV FUTURE

Why the Focus on Batteries?

- Single largest cost component of EVs
  - Raw Material costs (Lithium, Nickel, Cobalt, etc.) are the single largest component of pack costs
- A pack capable of supplying 300+ miles of range (80-100 kWh) remains high
- Industry trying to rapidly ramp production while also developing batteries that are more energy dense, cost less, take less time to charge, and last longer than previous generations
  - Global Li-ion production expected to increase from 220 GWh in 2019 to 3,500 GWh by 2030 (McKinsey)
- There is a global race for IP, raw materials and footprint for EV and battery technology with global ambitions pushing industrial policies

Packs/ Vehicles

Cells

Processing

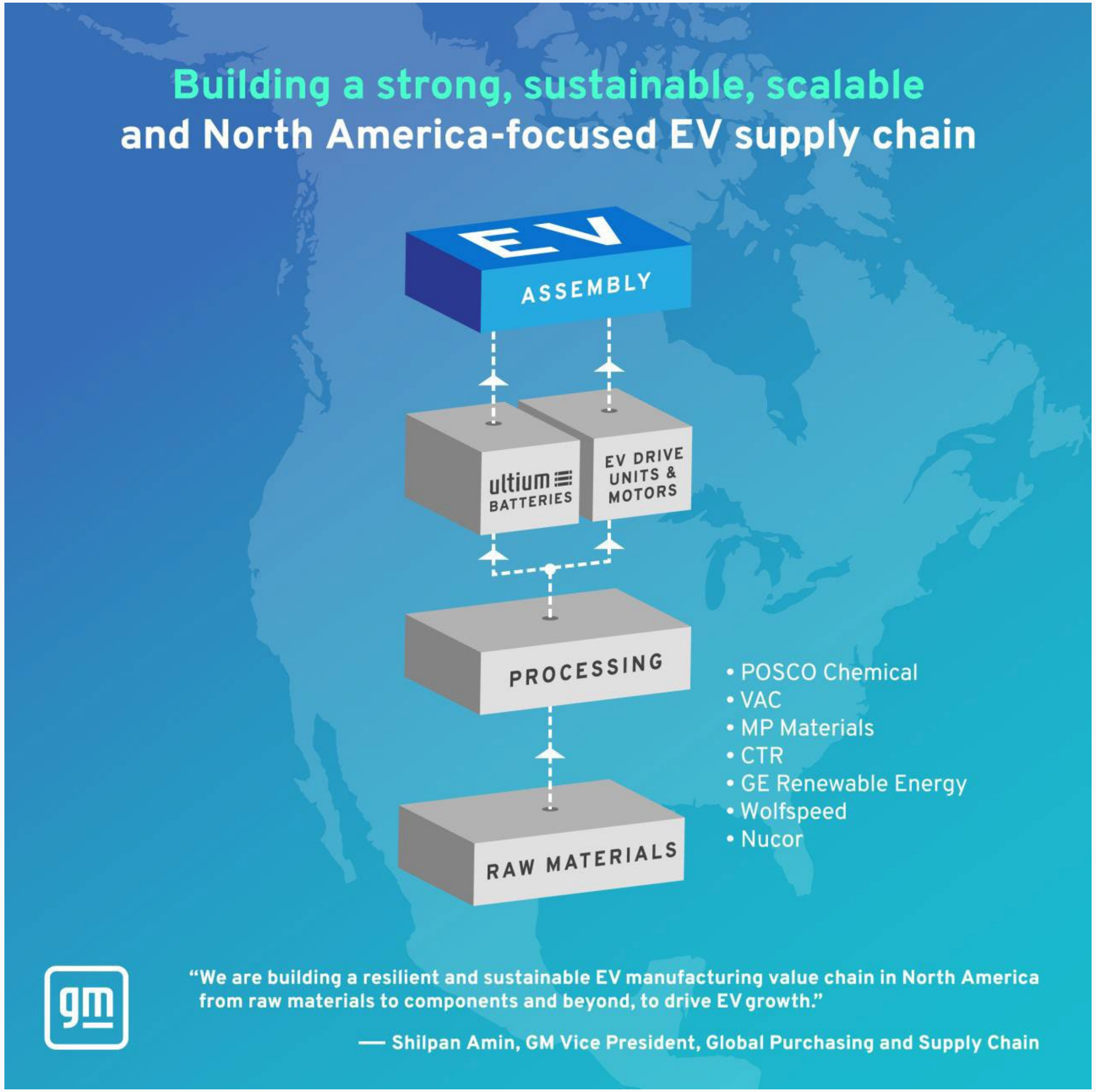
Raw Materials

Key Supply Chain Priorities

Secure | **Sustainable** | **Scalable** | **Cost Competitive**

Identify and execute strategic long-term partnerships to secure each critical level of the complete value chain

Recent Supply Chain Investments in North America



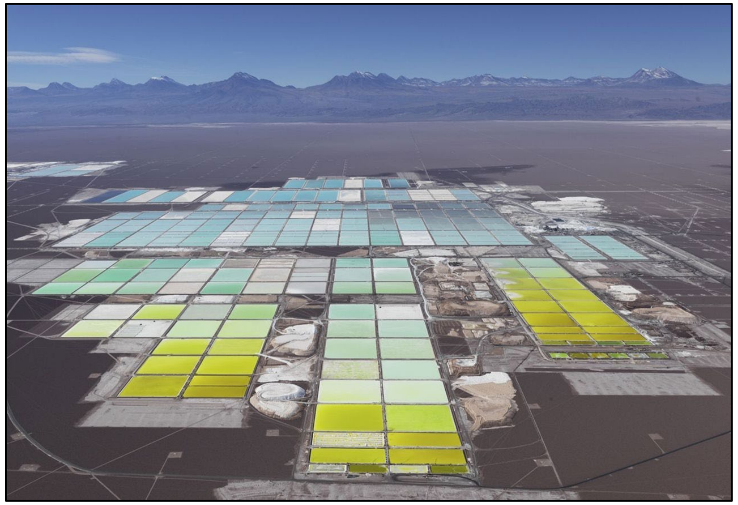
- **Ultium Cells** - Four battery cell plants in US through JV with LGES
- **POSCO** – Cathode Active Material
- **CTR** - Sustainable Lithium supply
- **MP Materials** - Rare earth materials magnets for electric motor
- **VAC** – Permanent magnets for electric Motors
- **GM (Lockport, NY)** – Stator modules for electric motors

Critical Minerals and Why Utilities Should Care

Alex Moyes – Director of Innovation at Dominion Energy

What Are the Critical Minerals?

- ❑ The transition to renewable energy requires a multitude of critical minerals
- ❑ The United States has identified 50 critical minerals
- ❑ What is a critical mineral? Mineral commodities that have important uses and no viable substitutes, yet face potential disruption in supply
- ❑ When we say critical minerals, that includes both minerals (such as barite) and elements (such as dysprosium)
- ❑ All critical minerals must be mined – and it is not pretty in some parts of the world



Lithium production in Chile

Rare earth element refining Bayan Obo China

Cobalt mining in the DRC

Critical Minerals Challenges

- U.S. production of critical minerals is extremely limited – for over half on the list, the U.S. is 100% dependent upon other countries
    - China is the largest supplier to the US of critical minerals – after that, it is Canada who supplies 16 different elements
- The IEA estimates that critical mineral production (collectively) will need to increase by 400% by 2040 to hit Paris Accord Goals and 600% to be net-zero by 2050
- There is significant geographical concentration for the production and refining of critical minerals (for lithium, cobalt, and REE, the top 3 producing countries control 75% of the global market)
- Long project development lead times make ramping up difficult
    - According to the IEA, the average time from exploration to production is 16.5 years - often much longer in the U.S.
- It has been well documented that global resources are experiencing declining grades
- Many end users of clean energy technologies are demanding high ESG standards which are difficult to track and enforce given the lack of global options for production and processing

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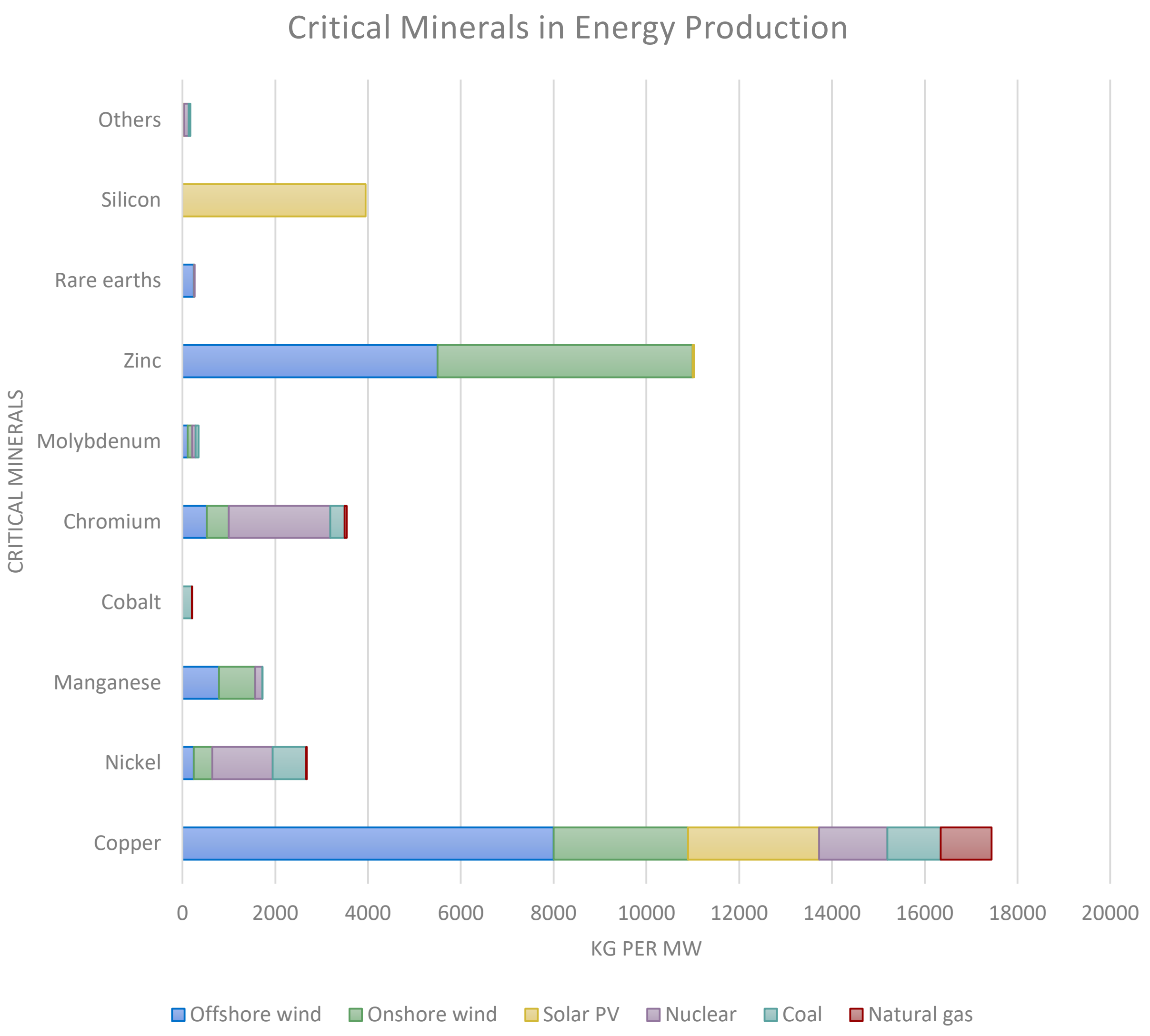
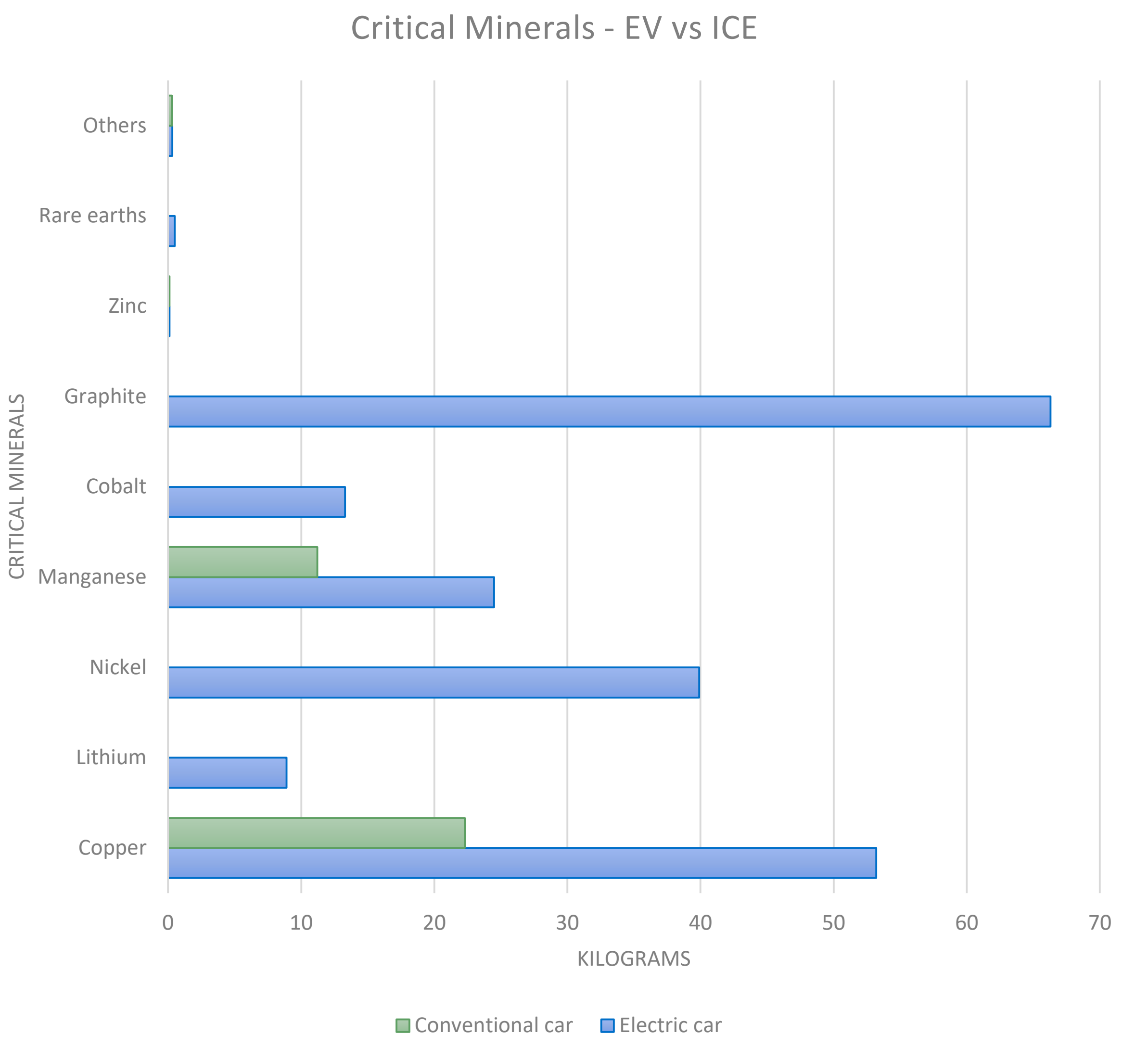
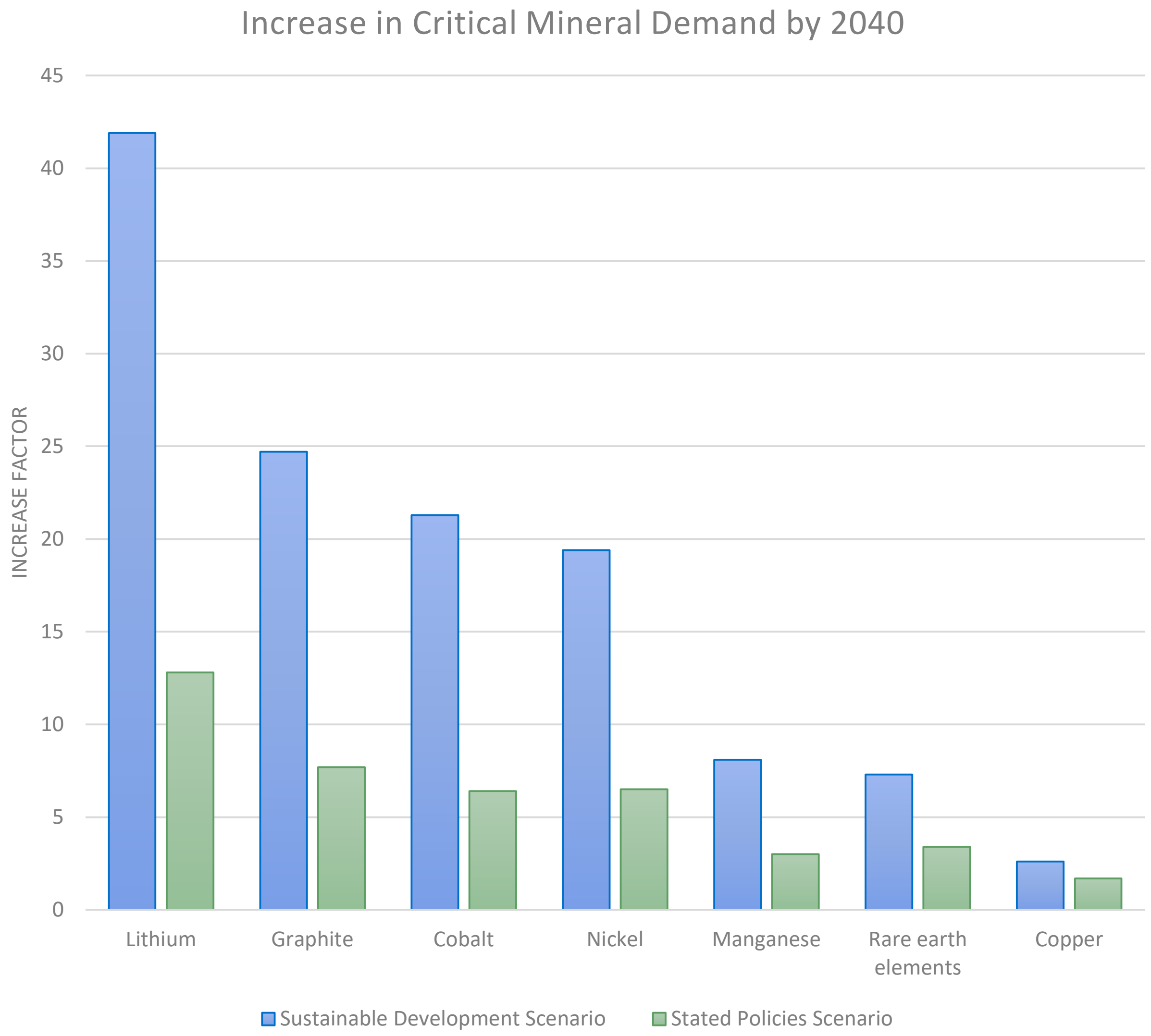
Critical Minerals in Energy Production

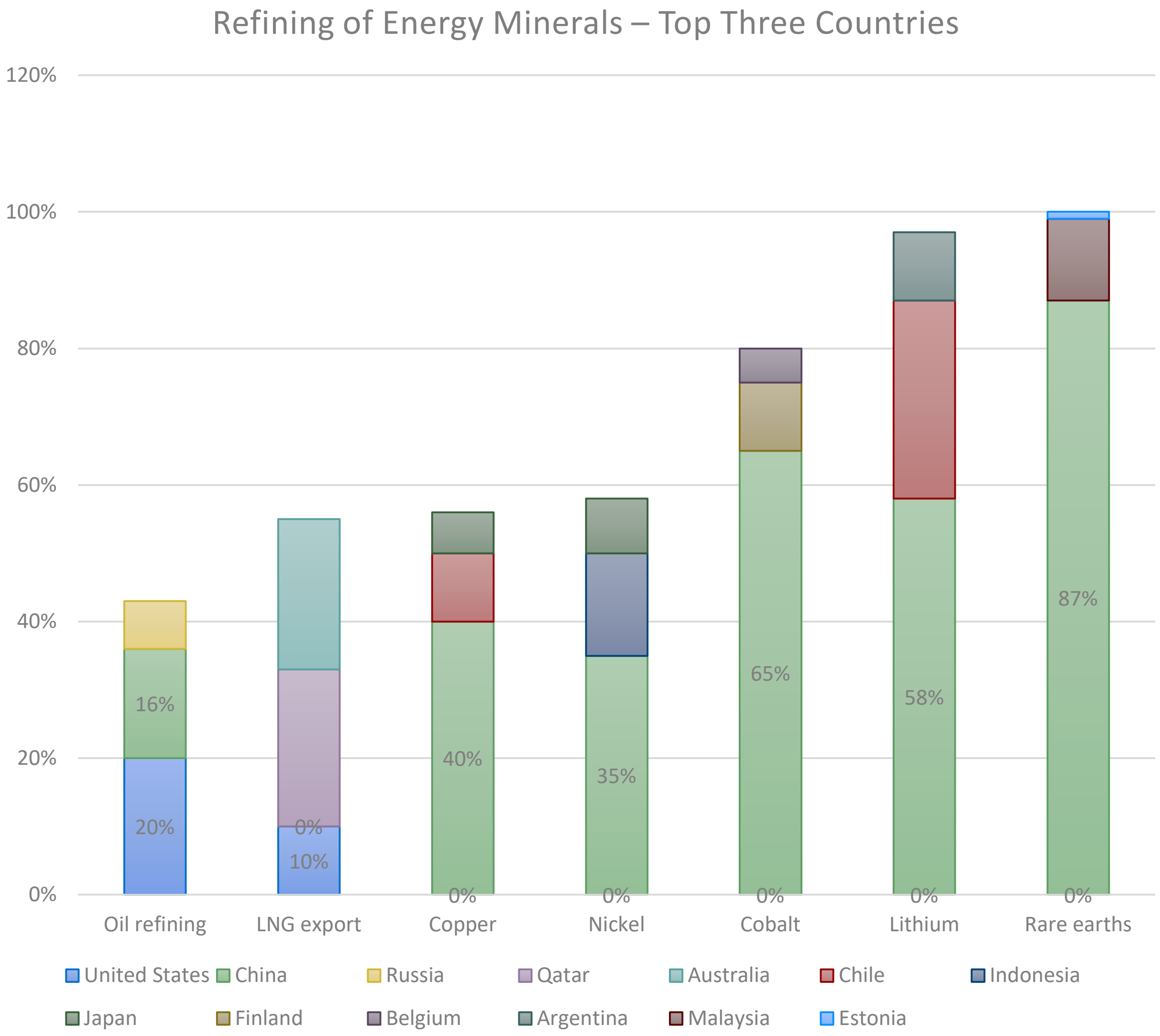




Dominion Energy

Critical Minerals in Energy Production





Critical Minerals for Energy

LYRA INNOVATION LAB

- Lithium is used in batteries
  - Compared to other metals, lithium is lighter and holds way more energy (energy density) for example, iron air battery hold 40 watt-hours per kg compared with Li at 100 watt-hours per kg, compared with oil at 12,222 watt-hours
  - Most batteries lose a bit of their power during use - Lithium-ion batteries do too, but much less – only about 5% in the first month
- Rare earth elements are used in offshore wind turbines and EV motors
  - The elements samarium, praseodymium, neodymium, dysprosium are used in permanent magnets to create large energy products, for corrosion resistance, and temperature stability
- Cobalt is used in batteries
  - Cobalt helps to maintain cathode structure and improve performance predictability – cobalt can be replaced with more nickel, but nickel releases large amounts of oxygen during the reaction which can be a fire hazard
  - Other metals can be used to replace cobalt but at the expense of energy density and thermal stability
- Nickel is used in batteries
  - Used for its excellent durability and energy density in battery cathodes
  - Many battery manufactures trying to use more nickel due to price - cathodes account for ~25% of the battery

Lithium

- Currently, there is only one active lithium mine in the US – a brine operation in Nevada
- 74% of global end-use markets are for batteries
- The US currently imports 2,500 metric tons annually
- 2020 import sources for US
  - Argentina: 54%
  - Chile: 37%
  - China: 5%

Greenbushes in Australia

- Global production of lithium increased 21% compared to 2020 to approximately 100,000 tons – global consumption was estimated to be 90,000 tons
- The US currently has 750,000 tons of reserves – Chile has the most at 9,200,000 tons – global resources have increased significantly and are estimated to be 89,000,000 tons
- World production is dominated by Australia (55%), Chile (26%), and China (14%)

Cobalt

- The US produces minor amounts of cobalt as associated elements (0.5% of world production)
  - Congo is the largest producer at 71%, next largest producer is Russia at 4%
  - Total world production is 170,000 tons
- Import sources to the U.S. are from Norway (20%), Canada (16%), and Japan (13%)
  - The US imported 10,000 metric tons of cobalt in 2021
- World reserves of Cobalt are 7,600,000 tons
  - Largest reserve base is the Congo at 3,500,000 (46%)
  - Australia (18%)
  - U.S. represents less than 1% of world reserves
  - The U.S. has identified significant resources for cobalt in Idaho (one mine in permitting), Missouri, and other states where cobalt would be byproduct resource estimate is 1,000,000 tons
  - To put that into perspective, Congo has an additional 25 million tons of resource and seafloor mining has resources of more than 120,000,000 tons

First Cobalt, Iron Creek Idaho

Nickel

- Domestic production of nickel is limited to the Eagle Mine in Michigan (18,000 tons of nickel concentrate in 2021)
- The leading use of nickel in the US is for alloys and steels – accounting for 85% of domestic consumption
- The US imports 145,000 tons of nickel annually primarily from Canada (43%), Norway (10%), and Finland (9%)
- Total consumption of nickel is around 210,000 tons – but the U.S. recycles nickel which makes up the major difference
- The world produces approximately 2,700,000 tons of nickel per year with Indonesia dominating global production (37%), then the Philippines (14%), followed by Russia (9%)
- World reserves are near 100,000,000 tons with Indonesia and Australia at 21% each
    - The US has 340,000 tons of reserves or less than 0.5% of world reserves

Hengjaya nickel mine, Indonesia

Critical Minerals Challenges

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  - China is the largest supplier to the US of critical minerals – after that, it is Canada who supplies 16 different elements
- The IEA estimates that critical mineral production (collectively) will need to increase by 400% by 2040 to hit Paris Accord Goals and 600% to be net-zero by 2050
- There is significant geographical concentration for the production and refining of critical minerals (for lithium, cobalt, and REE, the top 3 producing countries control 75% of the global market)
- Long project development lead times make ramping up difficult
  - According to the IEA, the average time from exploration to production is 16.5 years - often much longer in the U.S.
- It has been well documented that global resources are experiencing declining grades
- Many end users of clean energy technologies are demanding high ESG standards which are difficult to track and enforce given the lack of global options for production and processing

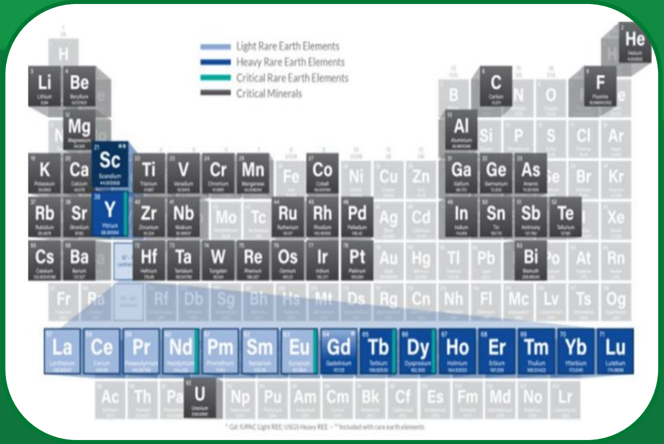
U.S. DEPARTMENT OF
ENERGY
Fossil Energy and Carbon Management

Critical Minerals Sustainability
For a Clean Energy Economy

Grant S. Bromhal
Director, Minerals Sustainability Division

March 2022



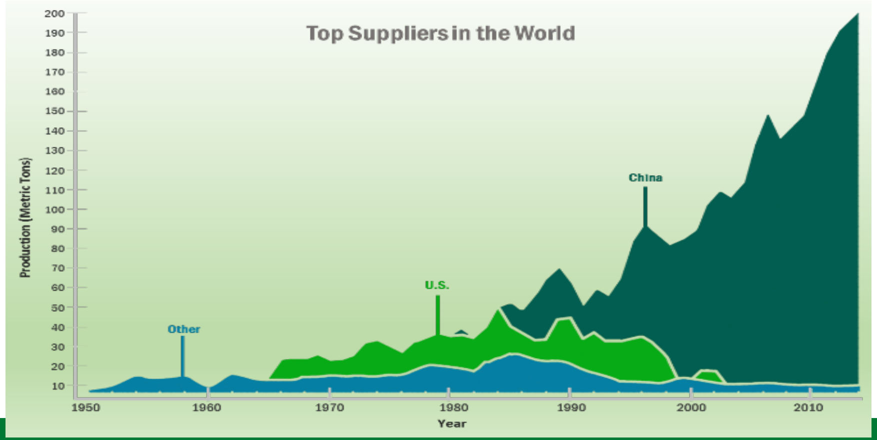


Critical Minerals & Materials Supply Chain Challenges

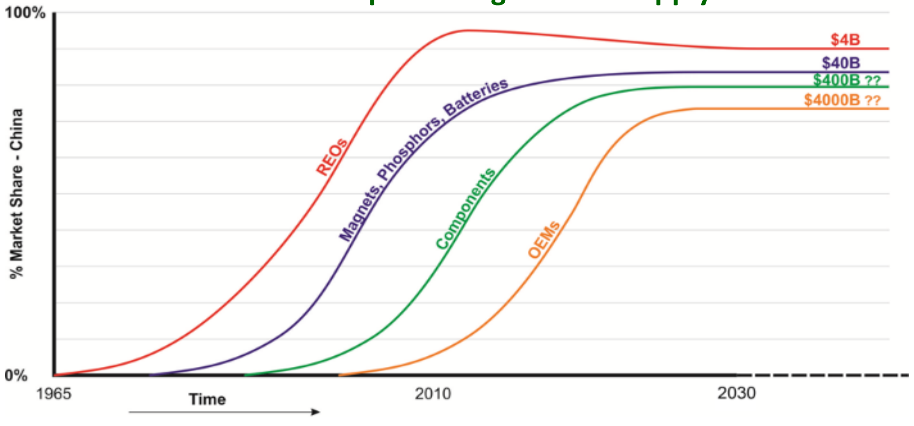
Key Challenges

- U.S. supply dependence spans from limited imported sources to lack of downstream processing and manufacturing capability to end-of-life and waste management
- Supply chain vulnerability will be amplified by increased demand
- Commodity specific mitigation strategies are needed
- Global and domestic supply chains face many challenges, including sustainability, market issues, and financing

Rare Earth Production by Country



Estimated Market Impact along the REE Supply Chain



This figure is adapted from a presentation made by Professor K.G. van den Boogaart at the SME Critical Minerals Conference in Denver in August 2014.

DOE Critical Minerals & Materials Activities

U.S. DEPARTMENT OF ENERGY

Core RDD&D Activities

Basic Science → **Applied R&D** → **Demonstration** → **Deployment**

Diversify Supply
- Develop new sources (geosciences, mine tailings, ...)
- Improve extraction, separations, and processing
- Develop new uses for co-products

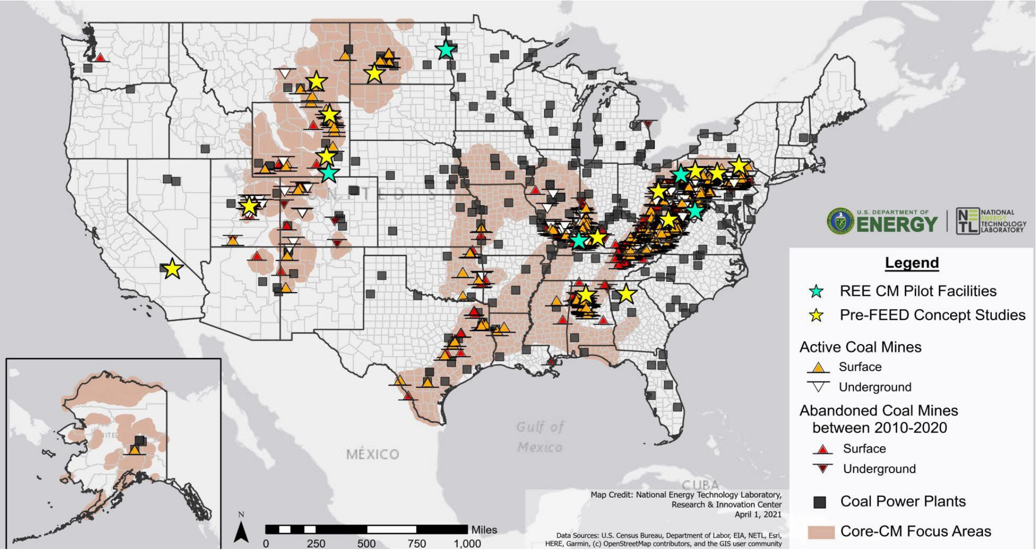
Develop Substitutes
- Discover new magnet alloys, phosphors, catalysts
- New manufacturing methods
- Develop new components and systems

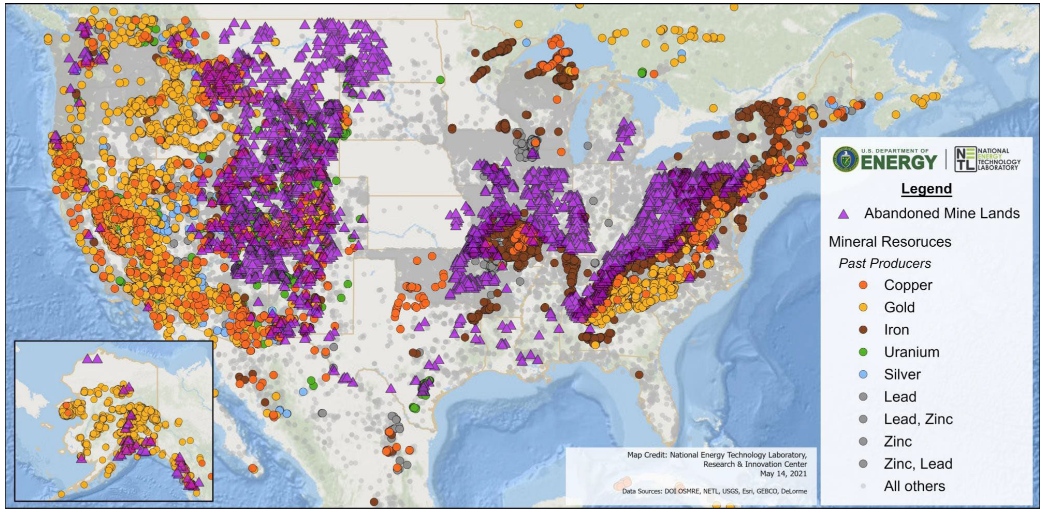
Improve Recycling/Reuse
- Recovery from electronics, disk drives
- Chemical/biochemical extraction of critical elements from waste streams
- Additive manufacturing of recycled materials

Financing
- Loan financing under Title XVII and ATVM (10 CFR 609 and 611; 86 FR 3747)
- Applicable to critical minerals and mining projects

CM—Unconventional, Secondary Sources

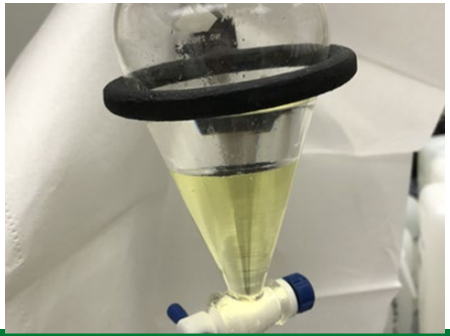
- **High-Level Resource Potential Estimates form coal-based resources**
  - **11 - 17 million tonnes** REE from known coal reserves,
    - ~30,000t/yr based on current production
  - 68,000 t from Appalachia coal refuse
    - 12,300 t/yr REE (2018*; 50% recovery), active refuse
  - 331,000 t from PA ash impoundments.
    - Over 10,000 t/yr REE (2018*; 50% recovery), active ash
  - Between 400-1700 tons/yr REE (50% recovery), Appalachia AMD
- **Opportunities to develop CM from metal mine wastes and sequester carbon**



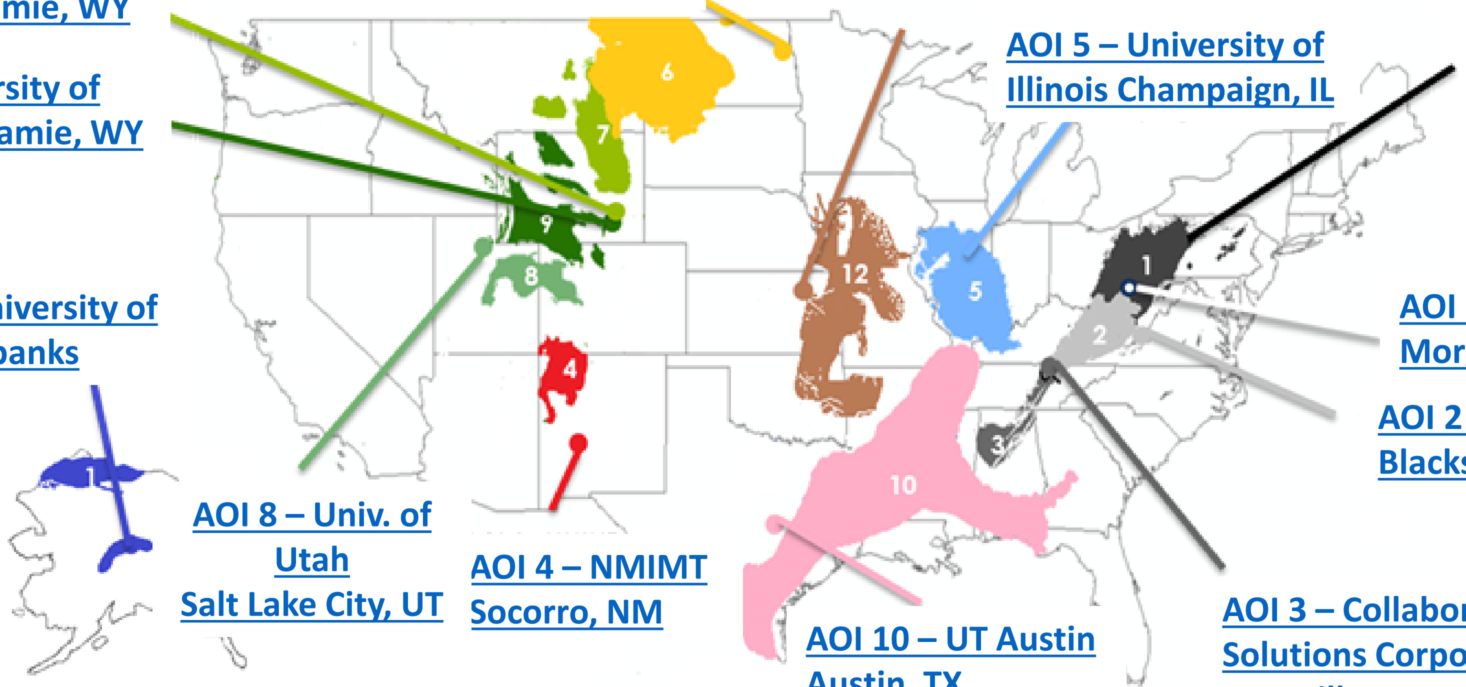


DOE Investing in Technology Advancements

- **First-of-a-Kind small-scale projects demonstrated technical feasibility to produce high purity REE from dilute sources (e.g., coal, refuse, ash, AMD)**
- **Feasibility studies for large-scale pilot projects (1-3 metric tons/day CM-REE)**
  - integrate conventional with advanced separation technologies and novel techniques
  - economically recoverable and environmentally sustainable production of CM-REE
- **Advance novel extraction and separations technologies to improve cost and environmental performance**
- **See link for more information:** Critical Minerals Sustainability | netl.doe.gov



CORE-CM Assessing Regional Opportunities



- Build broad-based regional coalition teams
- Investigate regional resources (materials, facilities, infrastructure, workforce)
- Catalyze regional economic growth and job creation
- Enable production of REE, CM and high-value, nonfuel, carbon-based products

International Engagement is Necessary

Responsible stewardship of critical materials is a domestic and international issue requiring high environmental standards across the entire supply chain

DOE engages in ISO efforts to improve sustainability in global critical material supply chains

- ISO TC 298 Rare Earth Elements
  - U.S. proposed developing a sustainability standards for rare earth mining, separation and processing to include environmental, economical and societal impacts
  - Working Group 5 has been established specifically for sustainability, and will be beginning work soon
- ISO TC 333 Lithium
  - New technical committee that is still developing strategic business plan, but is meant to include the full supply chain, excluding LIB as end products
  - Sustainability proposal put forth by the U.S. and is currently posted for a 12-week ballot

OSTP NSTC CMS, International Bilaterals/Trilateral interactions are opportunities to coordinate responsible development of supply chains

Related BIL provisions

U.S. DEPARTMENT OF ENERGY

Battery-specific (~$6B)

- 40207(b) – Battery Materials Processing Grants
- 40207(c) – Battery Manufacturing and Recycling Grants **NOI**
- 40208 – Electric Drive Vehicle Battery Recycling and Second-Life Applications

REE and Critical Material-related (~$1B)

- 40205 (c) – REE Demonstration Facility **RFI** *(closed 3/31)*
- 41003 (b) – Rare Earth Minerals Security
- 41003 (c) – Critical Material Innovation, Efficiency, and Alternatives
- 41003 (d) – Critical Material Supply Chain Research Facility

REE RFI: FedConnect: Opportunity Summary

Battery NOI: Financial Opportunities: Funding Opportunity Exchange (energy.gov)

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Questions?

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