Critical Minerals, Rare Earth Elements & the Opportunities for Circular Economies in a U.S. Supply Chain

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Outline

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- The Need for a Domestic Supply Chain
  - Challenges: Economic, Legal, Environmental & Social
- The Role for Circular Economies & Secondary Recovery Methods
  - Coal-based sources & hard-rock mine tailings
  - Opportunities & Challenges

Nice to Meet You

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- BA, Sociology & Anthropology (2016), Carleton College
- JD, MA in Environment and Natural Resources (2019), University of Wyoming
- Clerk for U.S. District Court Judge Nancy D. Freudenthal, 2019–20
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Acknowledgement and Disclaimer

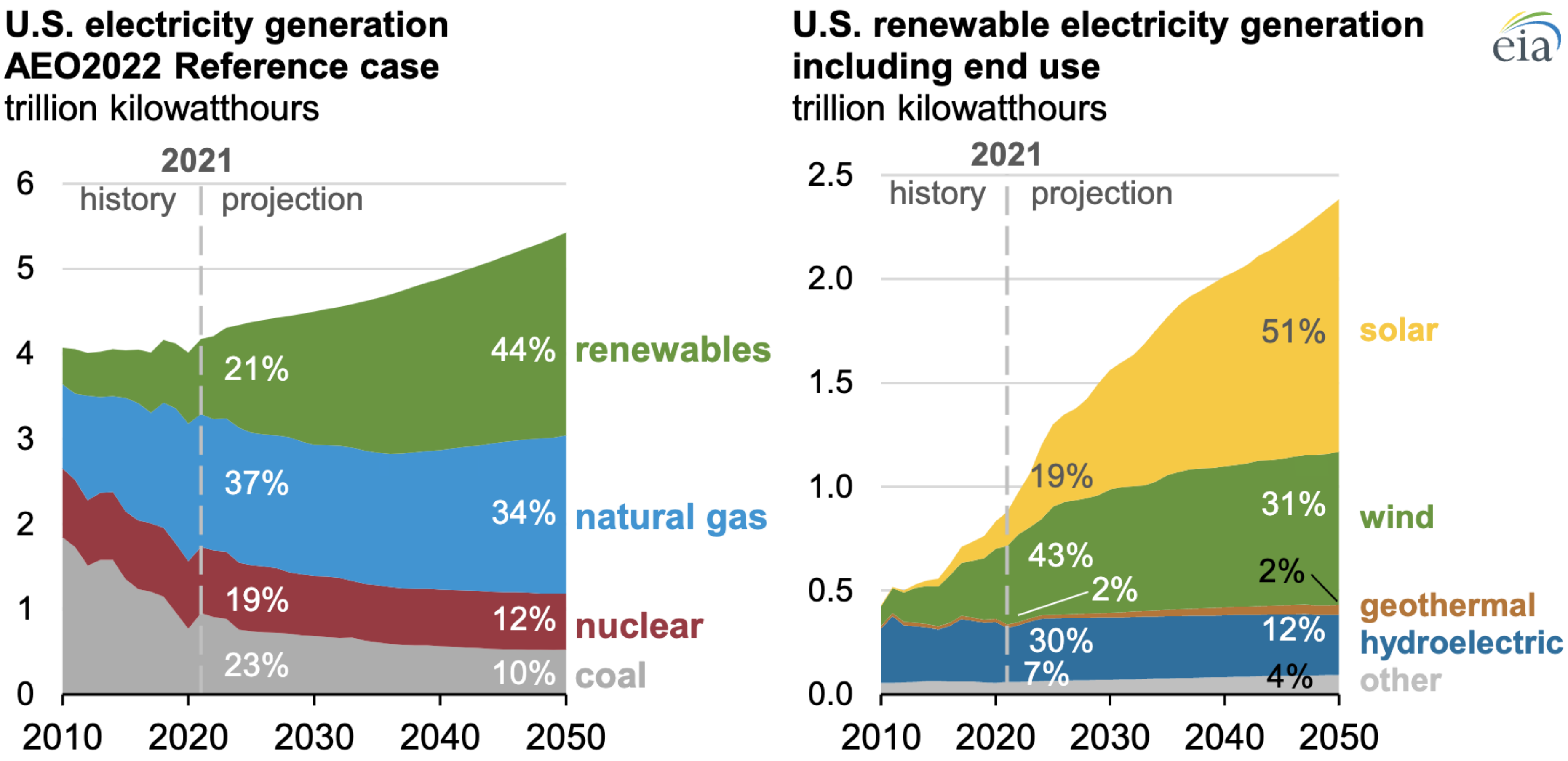
Acknowledgement: Thank you to the Alfred P. Sloan Foundation for supporting this research.

Disclaimer: This work does not necessarily reflect the views and/or positions of the Alfred P. Sloan Foundation, the University of Wyoming, or the University of Wyoming School of Energy Resources.

Setting the Stage:
A Shifting Energy Mix

MARCH 18, 2022

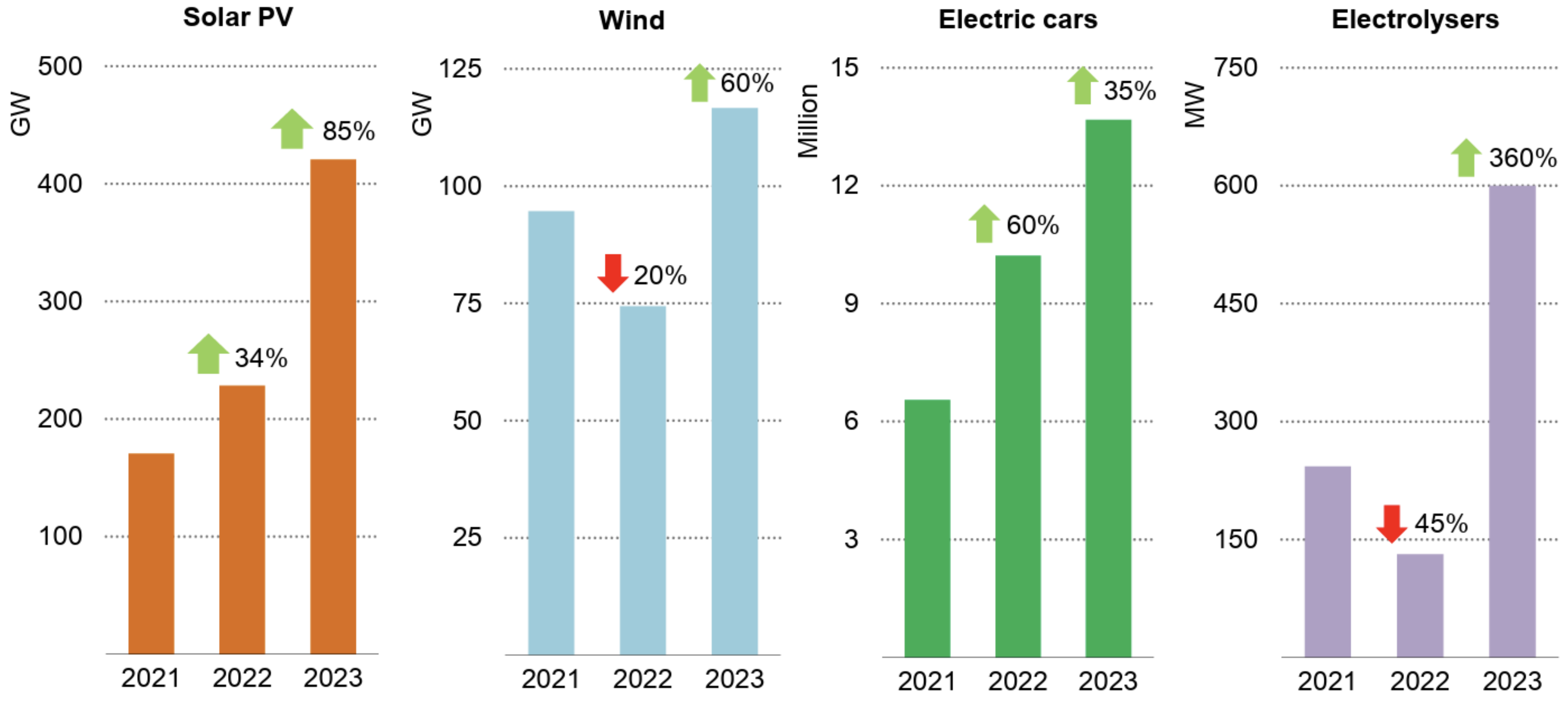
EIA projects that renewable generation will supply 44% of U.S. electricity by 2050



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022* (AEO2022)
Note: Biofuels are both shown separately and are included in petroleum and other liquids.

Global clean energy deployment climbed to new heights in 2023

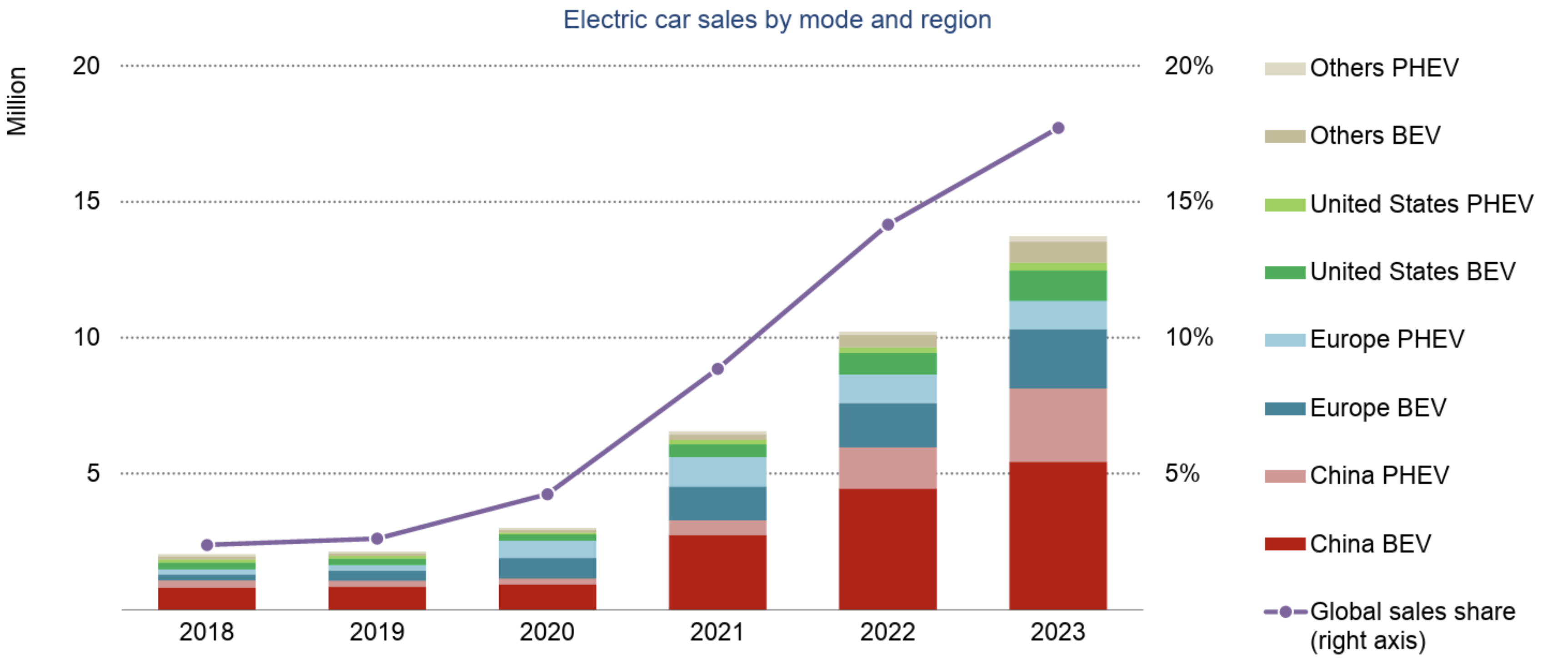
Annual capacity additions for selected clean energy technologies



Sources: IEA (2024), Clean Energy Market Monitor – March 2024, and IEA (2024), Global EV Outlook 2024.

IEA, Global Critical Minerals Outlook 2024

The growth story continued in 2023 for EVs



Note: BEV = Battery electric vehicle; PHEV = Plug-in hybrid electric vehicle.
Source: IEA (2024), Global EV Outlook 2024.

IEA, Global Critical Minerals Outlook 2024

What materials do these technologies depend on?

Critical Minerals (CM)

- A **critical mineral** is defined as:
  - a non-fuel mineral or mineral material essential to the economic and national security of the United States,
  - the supply chain of which is vulnerable to disruption,
  - that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security of the United States (Energy Act of 2020).
- In 2022, the US Geological Survey finalized a revised list of 50 critical minerals (Federal Register 2022-04027).
- Include, *inter alia*, aluminum, germanium, graphite, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, tin, titanium vanadium, zinc, and zirconium.

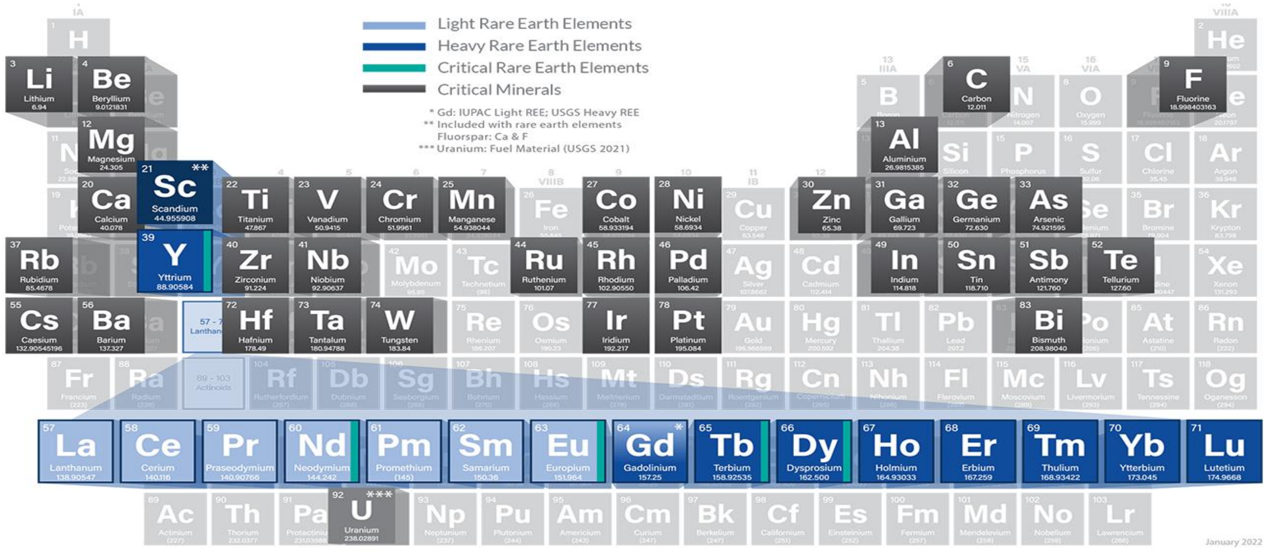
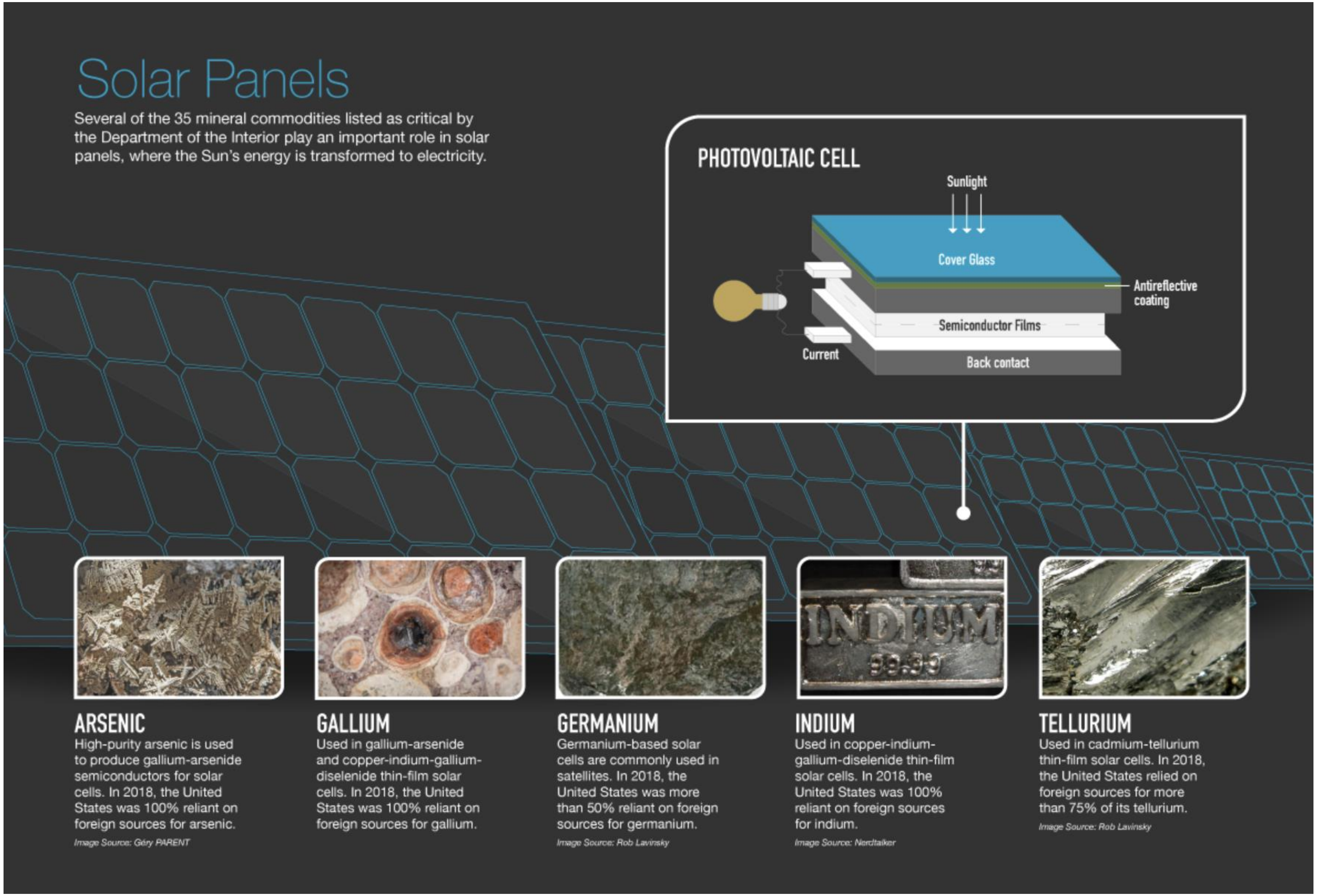


Image: U.S. DOE (2022)


Solar Panels
Several of the 35 mineral commodities listed as critical by the Department of the Interior play an important role in solar panels, where the Sun's energy is transformed to electricity.
PHOTOVOLTAIC CELL
Sunlight
Cover Glass
Antireflective coating
Semiconductor Films
Current
Back contact
ARSENIC
High-purity arsenic is used to produce gallium-arsenide semiconductors for solar cells. In 2018, the United States was 100% reliant on foreign sources for arsenic.
Image Source: Géry PARENT
GALLIUM
Used in gallium-arsenide and copper-indium-gallium-diselenide thin-film solar cells. In 2018, the United States was 100% reliant on foreign sources for gallium.
GERMANIUM
Germanium-based solar cells are commonly used in satellites. In 2018, the United States was more than 50% reliant on foreign sources for germanium.
Image Source: Rob Lavinsky
INDIUM
Used in copper-indium-gallium-diselenide thin-film solar cells. In 2018, the United States was 100% reliant on foreign sources for indium.
Image Source: Nerdtalker
TELLURIUM
Used in cadmium-tellurium thin-film solar cells. In 2018, the United States relied on foreign sources for more than 75% of its tellurium.
Image Source: Rob Lavinsky

USGS, 2019

Batteries

Batteries play an important supporting role for renewable energy sources like wind and solar, allowing excess power to be stored for usage when direct solar or wind power are unavailable. Just like the energy sources they complement, modern batteries rely on critical mineral commodities, particularly cobalt, graphite, lithium, and manganese.

COBALT

On a global basis, the leading use of cobalt is in rechargeable battery electrodes. In 2018, the United States relied on foreign sources for 61% of the cobalt it consumed.

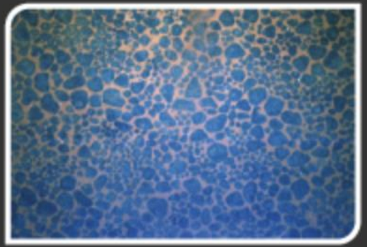
Image Source: James St. John

GRAPHITE

Graphite serves as an electrode in many lithium batteries. In 2018, the United States was 100% reliant on foreign sources for graphite.

LITHIUM

Lithium has a long history in batteries and is a common material used in batteries today. In 2018, the United States was more than 50% reliant on foreign sources for lithium.



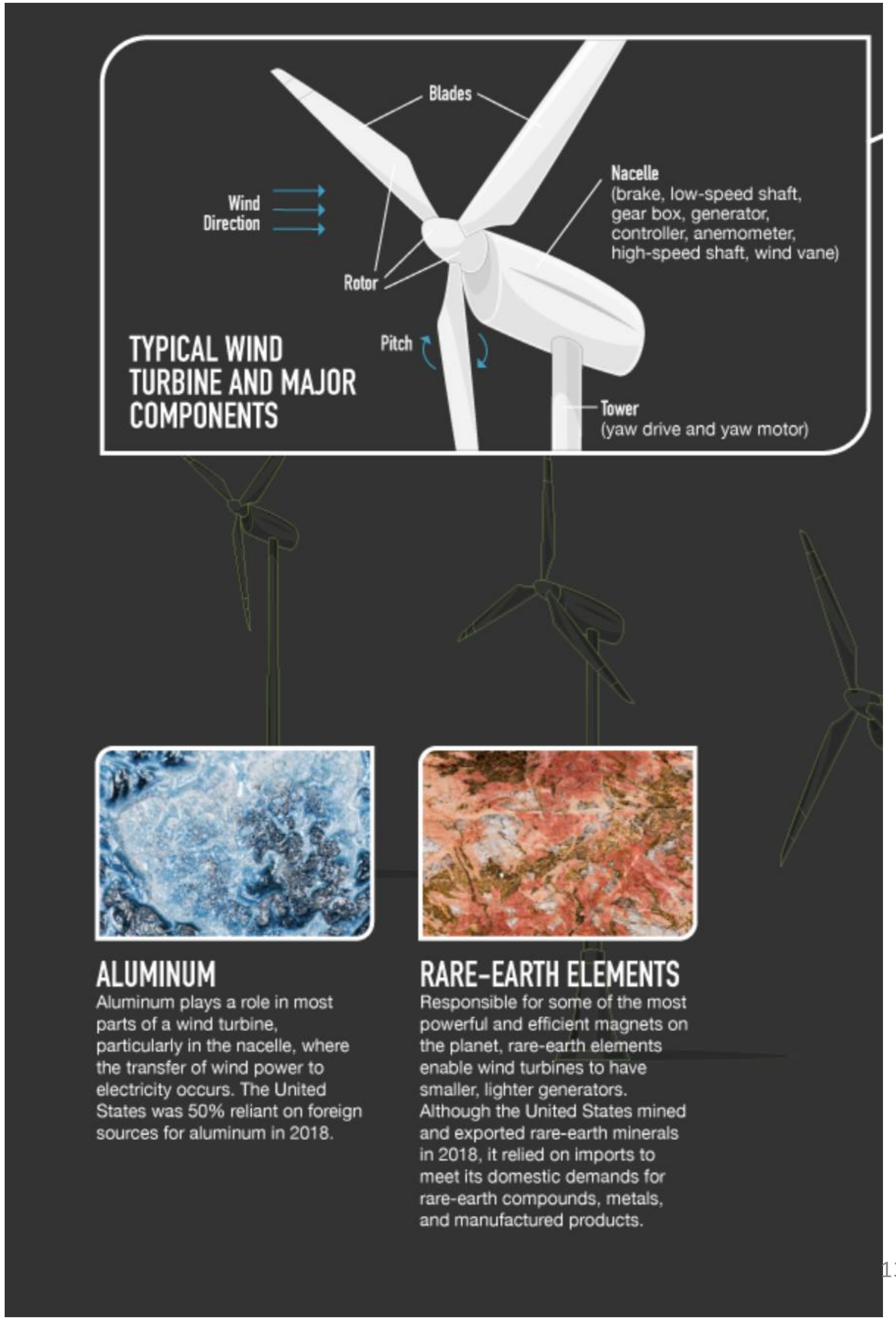
MANGANESE

Manganese serves as an electrode in many lithium batteries. The United States was 100% reliant on foreign sources for manganese in 2018.

USGS, 2019

Wind Turbines

USGS, 2019



A **BATTERY (nickel-metal hydride)**
antimony, aluminum, arsenic, barium, calcium, cerium, cobalt, chromium, lanthanum, magnesium, manganese, nickel, titanium, vanadium, yttrium, zinc

BATTERY (lithium-ion)
aluminum, cobalt, graphite, lithium, manganese, nickel, tin, titanium, vanadium

BATTERY (lead-acid)
aluminum, antimony, arsenic, calcium, tin, zinc

E **LCD SCREEN**
calcium, cerium, europium, indium, magnesium, yttrium

F **AIR-CONDITIONER**
fluorine

J **BRAKES**
graphite

K **OXYGEN SENSOR**
yttrium

L **ELECTRONIC BRAKES**
dysprosium, neodymium

B **PAINT**
bismuth

C **AUTOMATED MANUAL TRANSMISSION**
dysprosium, neodymium

D **ELECTRONICS**
aluminum, arsenic, beryllium, cobalt, germanium, lithium, samarium, tantalum, tin, yttrium

G **POWER STEERING**
dysprosium, neodymium

H **GLASS/MIRRORS**
calcium, cerium, neodymium

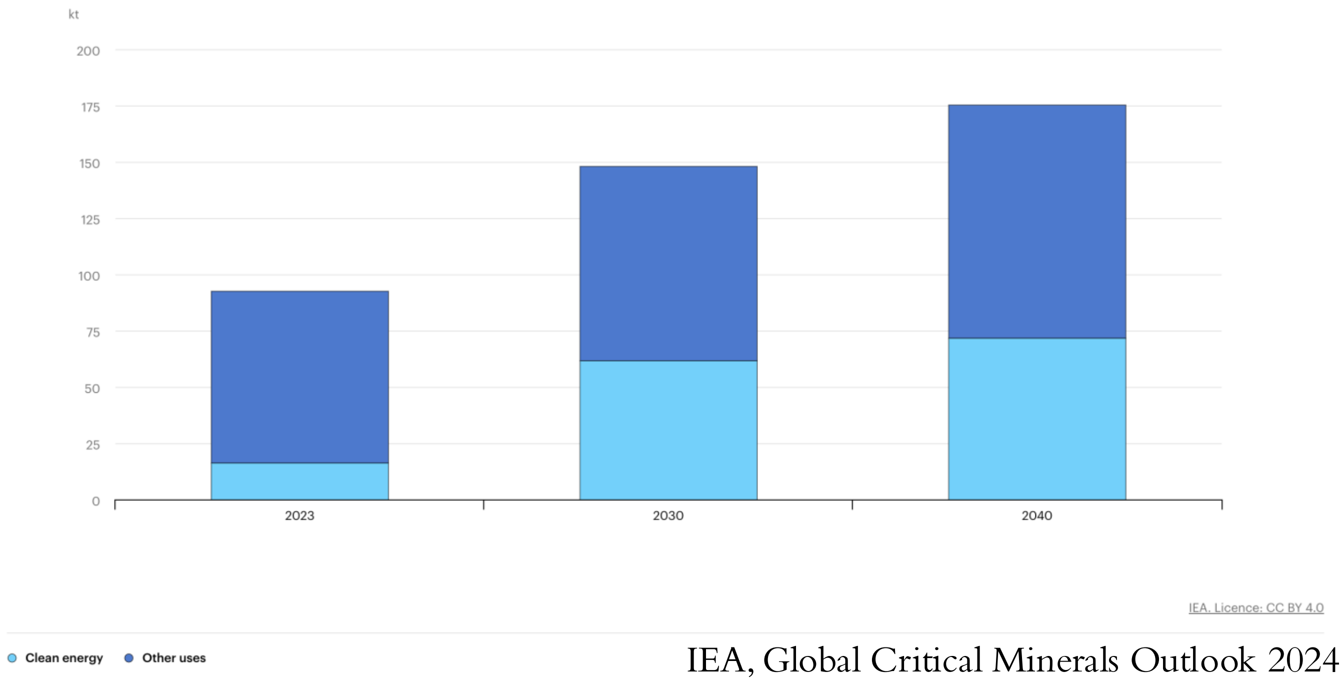
I **CATALYTIC CONVERTER**
cerium, lanthanum, palladium, platinum, zirconium

M **BODY/CHASSIS/ENGINE (exact list will vary depending on type of motor)**
aluminum, cerium, chromium, cobalt, dysprosium, magnesium, manganese, neodymium, nickel, niobium, palladium, praseodymium, tantalum, terbium, titanium, tungsten, vanadium, zinc, zirconium

Illustration by University of North Dakota Energy & Environment Research Center (EERC), Williston Basin CORE-CM Program

Rare Earth Elements (REE)

- REE are considered a subset of critical minerals
- REEs are typically distributed throughout other minerals and substances, but only in low concentrations.
- REEs include: cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, praseodymium, samarium, scandium, terbium, thulium, ytterbium, and yttrium
- By 2040, demand for REEs is expected to increase by 3-7 times current levels



IEA, Global Critical Minerals Outlook 2024

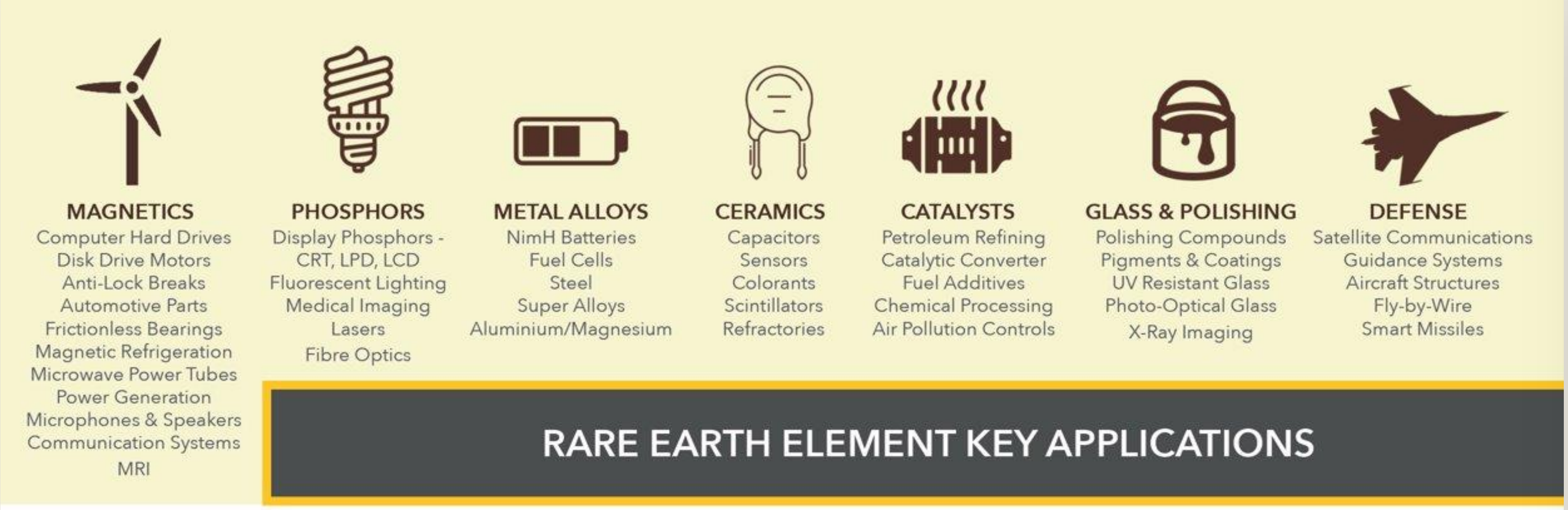


Illustration by Christine Reed, UW School of Energy Resources

Illustration by University of North Dakota Energy & Environment Research Center (EERC), Williston Basin CORE-CM Program

A Complex Supply Chain

Rare Earth
Supply Chain

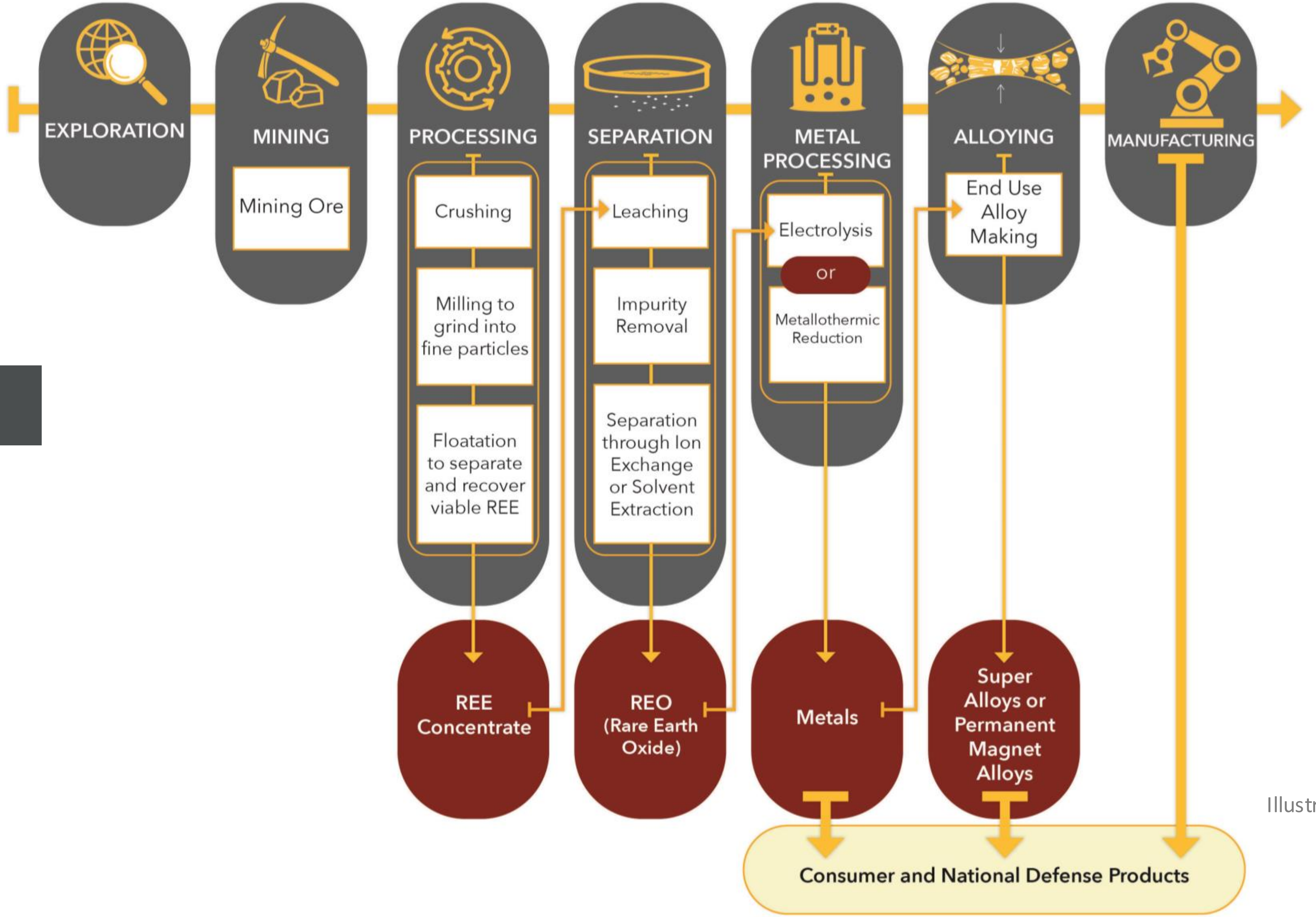
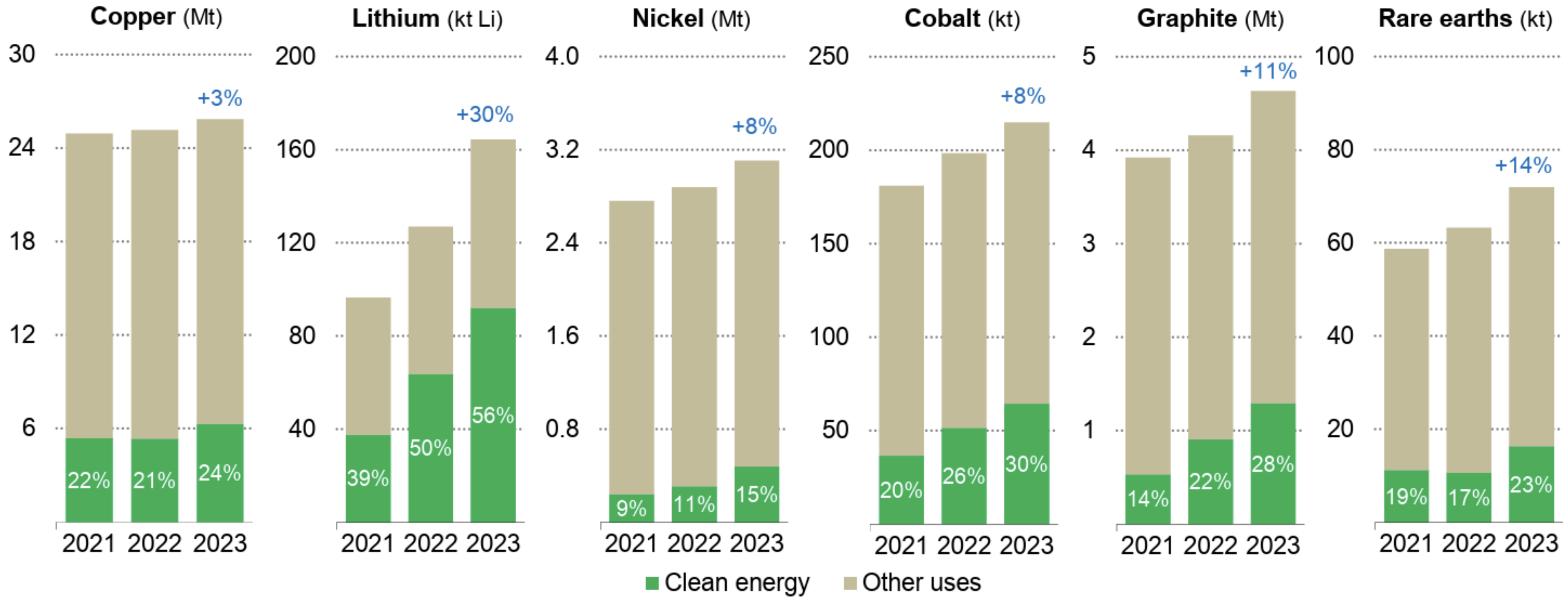


Illustration by Christine Reed

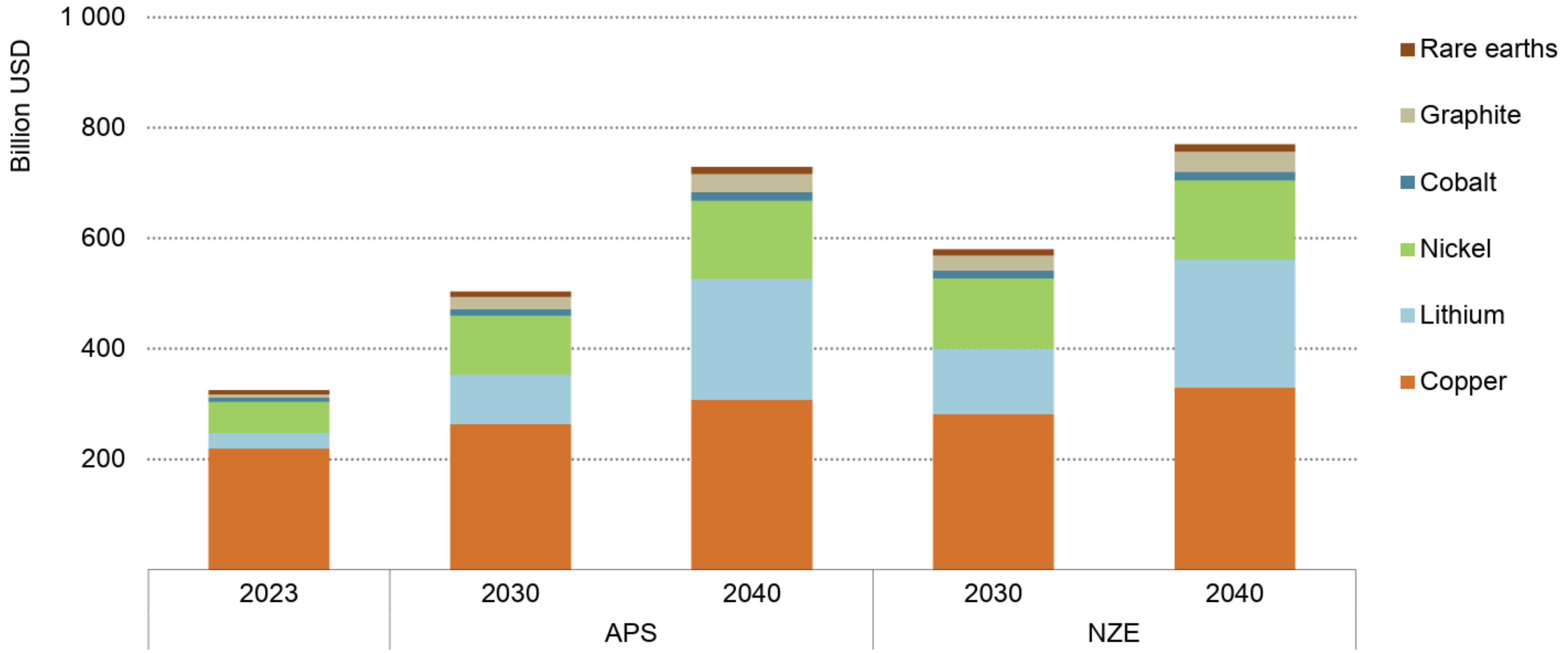
Demand for key energy transition minerals continued to grow strongly in 2023, propelled by the expansion of clean energy technologies

Demand outlook for selected minerals, 2021-2023



The combined market value of key energy transition minerals more than doubles by 2040 in climate-driven scenarios, reaching USD 770 billion in the NZE Scenario

Market value of key energy transition minerals in the APS and the NZE Scenario



Note: 2023 annual average price levels are assumed to estimate the market size for the projection period.

IEA, 2024

Some Uncertainties

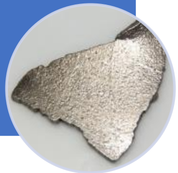
- The new presidential administration will emphasize the use of traditional fossil fuels such as coal, oil, and gas over certain low-carbon, clean, and renewable energy sources and technologies, targeting wind, solar, and EVs
- Certain incentives and subsidies likely to be rolled back
- Despite the uncertainties surrounding federal funding and incentives, the Trump Administration continues to prioritize the growth of a domestic CM/REE supply chain (e.g., E.O. "Declaring a National Energy Emergency," Jan. 20, 2025).
- CM/REE will remain pertinent and "critical" for a long list of uses.

The Need for a Domestic Supply Chain

State of the Global Supply Chain

- 69% of extraction occurs from the Democratic Republic of the Congo
- 65% of processing occurs in China

Cobalt



- 52% of extraction occurs in Australia
- 22% of extraction occurs in Chile
- 58% of processing occurs in China, 29% in Chile

Lithium

- 64% of extraction occurs in China

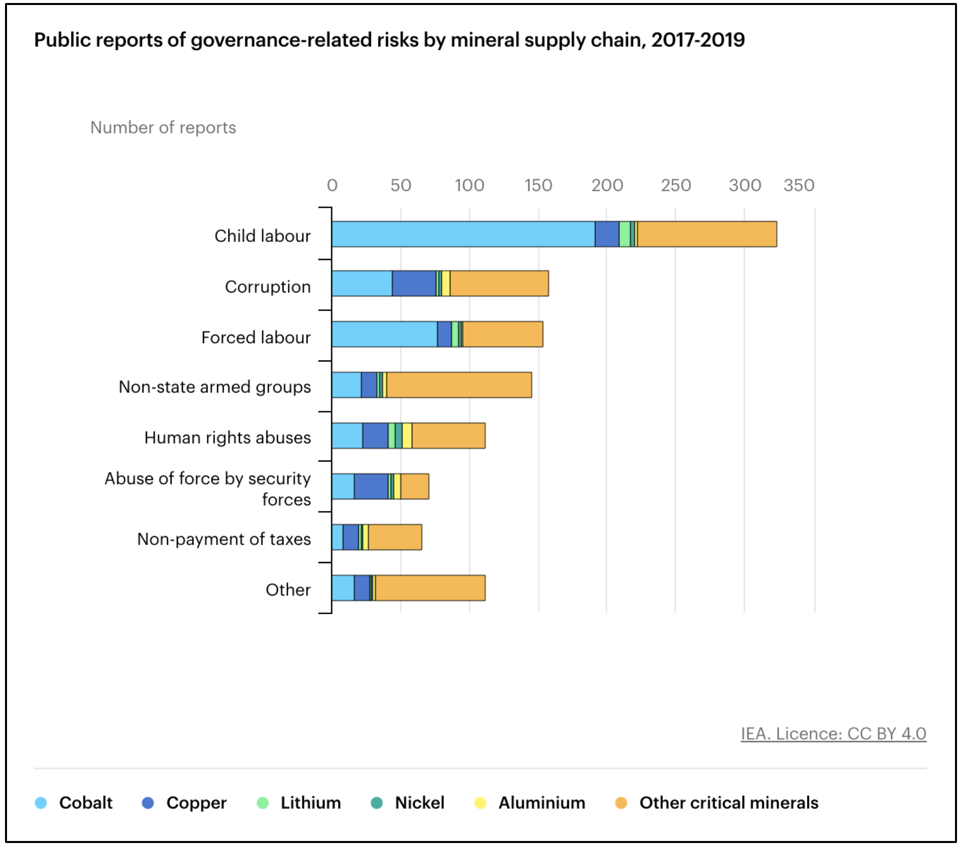
Graphite

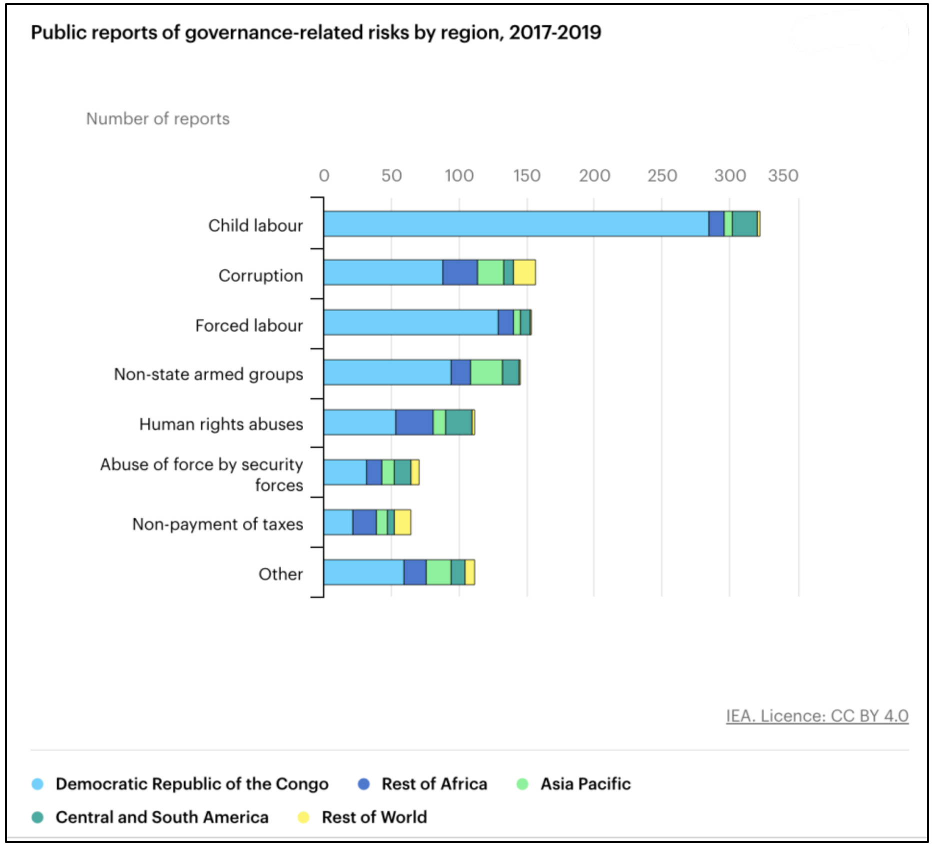
- 60% of extraction occurs in China
- 87% of processing occurs in China

Rare Earths

Source: IEA, Critical Minerals Policy Tracker, *Ensuring supply reliability and resiliency* (2019).

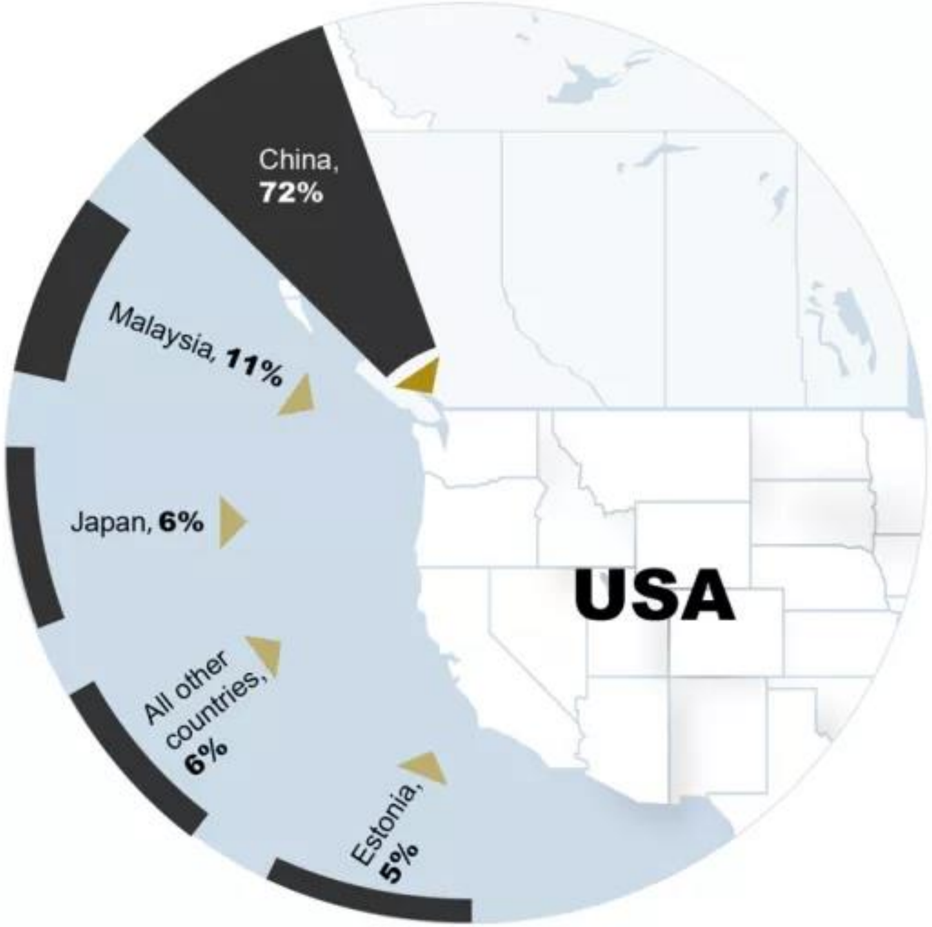
Human Rights Challenges in the Existing Supply Chain:
Concentration of Industry in Areas with High Social and Environmental Risk





Source: IEA, Why is ESG so important to critical mineral supplies, and what can we do about it? (2022).

National Security Risks Within the Global Supply Chain



Source: GAO analysis of United States Geological Survey 2024 Annual Commodity Summary Estimates; (map) switchpipi/stock.adobe.com | GAO-24-107176

According to the U.S. GAO:

"Between 2019 and 2022, the U.S. imported more than 95% of the total rare earths it consumed. Much of it was from China.
If China decided to no longer sell to the United States, we would lose access to this supply and need to look for alternatives."

U.S. GAO, 2024

The path to a domestic supply chain:
Government Incentives for Domestic Growth 2020-2024

Executive Order 14017

In 2021, the Biden Administration ordered a review of ordered a review of vulnerabilities in the U.S. critical mineral supply.

The 2022 report calls for new social and environmental standards for the extraction and processing of critical minerals, both domestically and abroad.

Infrastructure, Investment, and Jobs Act (IIJA)

Allocated funding for critical minerals extraction, pilot projects for processing, and research activities.

Inflation Reduction Act (IRA)

Commits to increasing the domestic supply of lithium, cobalt, nickel, graphite, tin and aluminum.

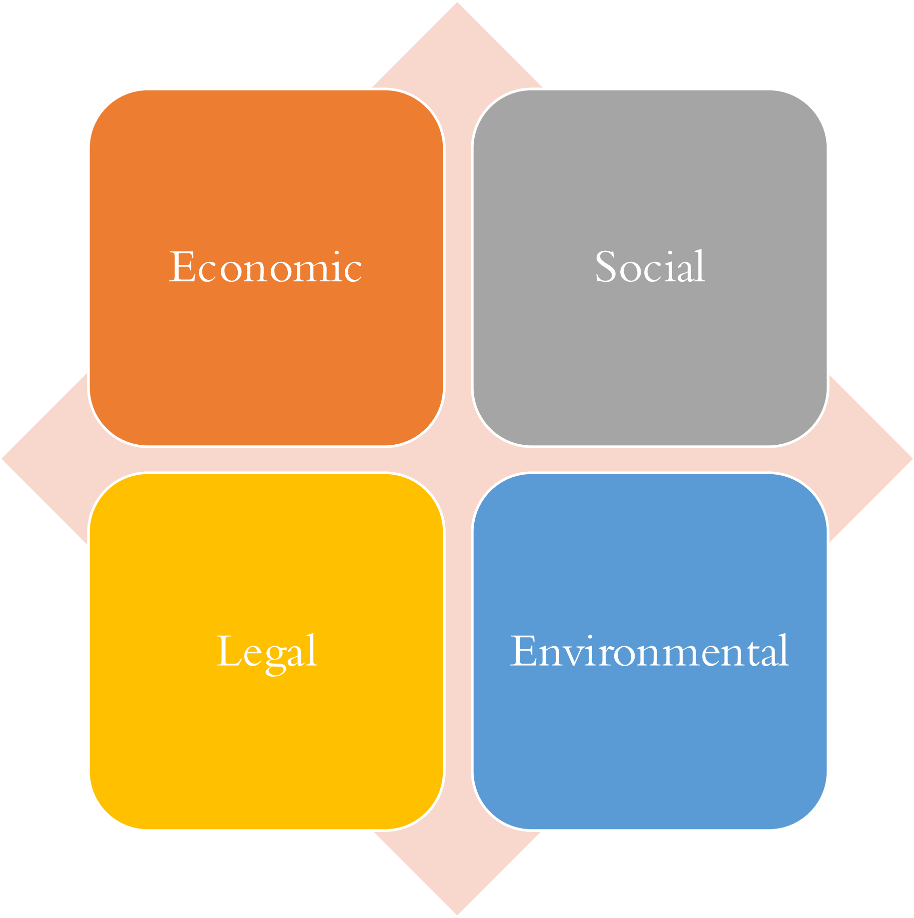
Restricts tax incentives for EVs with battery components sourced from "foreign entities of concern"

State Permitting Guidance

States like Wyoming have passed legislation to clarify permitting procedures for rare earth mining and streamline processing. See Wyoming H.B. 61 (2023).

Under the Trump Administration, the future of some federal incentives and direct funding is currently unclear.

Challenges for Domestic Mining Growth


Economic
Social
Legal
Environmental

Economic Challenges

Difficult for the U.S. to compete with cheaper foreign CM/REE produced in countries with lower environmental and labor-related regulation and standards

Federal incentives and direct funding under the IRA and IIJA have helped subsidize new mining projects, but significant challenges remain, especially amidst the uncertain future of incentives.

Social, Legal & Environmental Challenges

- The vast majority of CM/REE deposits in the U.S. are believed to be located on or within 35 miles of Native American reservations
- Social, environmental, and cultural opposition to new conventional mining has been met with significant protest and legal challenges.
- High-Profile Example: *Apache Stronghold v. United States* (pending petition for review)

Lacking the votes for a standalone bill, Senators McCain and Flake in 2014 attached the land-transfer bill to the must-pass National Defense Authorization Act, authorizing transfer of a 2,422-acre parcel including Oak Flat to Resolution Copper in exchange for about 5,344 acres scattered elsewhere. Pub. L. No. 113-291, § 3003(b)(2), § 3003(b)(4), § 3003(c)(1) and § 3003(d)(1), 128 Stat. 3732-3736. The bill revokes the presidential orders protecting Oak Flat from mining and directs the Secretary of Agriculture to prepare an environmental impact statement (EIS) for the proposed mine. Pub. L. No. 113-291, § 3003(i)(1)(A), § 3003(a) and § 3003(c)(9)(B), 128 Stat. 3732. Within 60 days of publishing the EIS, it requires the Secretary to "convey all right, title, and interest" in Oak Flat to Resolution Copper. Pub. L. No. 113-291, § 3003(c)(10), 128 Stat. 3736-3737.

5. The Secretary published the EIS on January 15, 2021. As the EIS confirms, the mine would destroy Oak Flat. To mine the ore, Resolution Copper will use a technique called panel caving, which involves tunneling beneath the ore, fracturing it with explosives, and removing it from below. App.710a. This method has lower operating costs than other feasible techniques, but is far more destructive of Oak Flat's surface. App.928a-936a.

Once the ore is removed, approximately 1.37 billion tons of waste ("tailings") will need to be stored "in perpetuity." App.461a, 726a. That will "permanently bury or otherwise destroy many prehistoric and historic cultural artifacts, potentially including human burials." App.461a. And Oak Flat itself will collapse (or "subside") into a crater nearly 2 miles across and 1,100 feet deep, destroying it forever. App.611a.

Social, Legal & Environmental Challenges

THACKER PASS LITHIUM MINE IN NEVADA

TWIN METALS/POLYMET COPPER-SULFIDE MINE IN MINNESOTA

PEBBLE MINES COPPER-GOLD MINE IN ALASKA

Opportunities with Circular Recovery Methods

Lignite coals

Fly ash

Nontraditional sources of critical minerals

Coal-based sources | **Hardrock mining wastes** | **Brines**

Source: West Virginia University Water Research Institute (photo, coal-based sources); GAO (photos, hardrock mining wastes and brines). | GAO-24-106395

Acid Mine Drainage

Tailings

Other sources include: refuse piles, recycled battery components and other materials, produced water from oil and gas, and trona

Recovery Potential

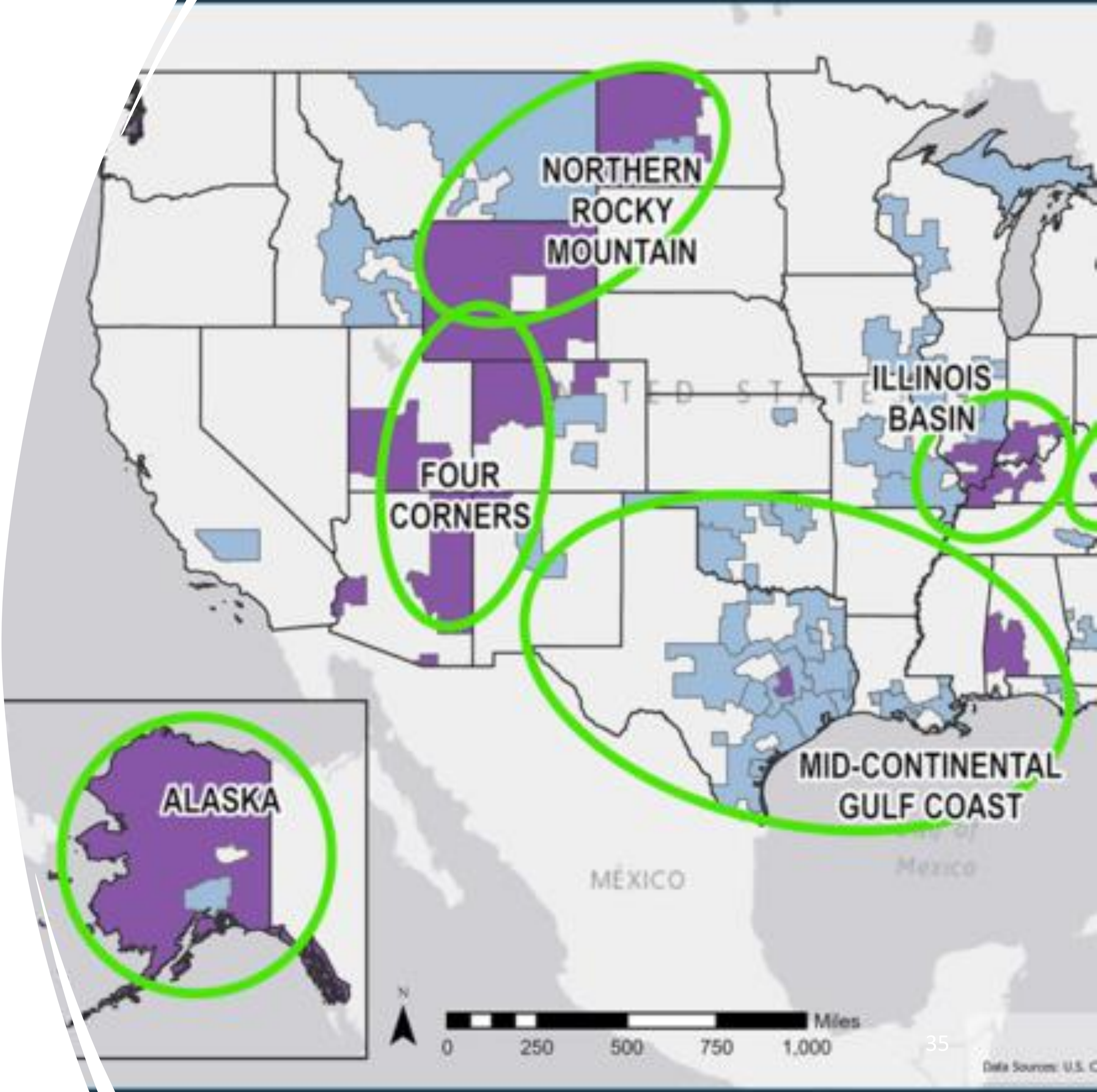
- According to DOE, "initial estimates suggest unconventional and secondary sources currently contain . . . more than 10 million tons of rare earth elements, which is equivalent to more than a 300-year supply at the current rate of U.S. consumption.

Drainage from an abandoned mine in Clear Creek County, Colo. (Wyoming Public Media 2024)

Focusing on Coal Sources & Hardrock Mining. . .

I. Recovery from coal-based sources: Aiding Priority Energy Communities

- Circular recovery methods have the potential to vitalize priority energy communities that may face potential future job and revenue losses from the projected decline of traditional fossil fuel industries.



Recovery from coal waste/byproducts:

- Initial efforts to extract REE from coal waste have been successful and even offer numerous advantages over some other recovery methods
- Technology is still being proven at scale

(1) The absence of capital costs associated with raw ore mining, including but not limited to necessary infrastructure, initial processing, transportation, environmental impacts, and reclamation.

(2) Low-expense licensing and certification to permit REE extraction compared to conventional mining operations that can involve very high capital investment and associated risk assessments.

(3) Availability of large volumes of current production and legacy coal byproducts, which are held in accessible industrial landfills.

(4) The particle size of coal byproducts (specifically FA) is small (typically <500μm with large relative surface areas [3], which facilitates simple chemical extraction.[2]

(5) Avoiding radiogenic processing considerations such as removal of thorium and uranium.

– Davin Bagdonas (UWyo), et al., *Rare earth element resource evaluation of coal byproducts: A case study from the Powder River Basin, Wyoming*, 158 RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 112148 (2022).

Lessons Learned from Wyoming CORE-CM

- Utilizing existing waste streams
- Promoting energy trained workforce
- Utilizing existing infrastructure
- Education and training
- Reclamation, reuse, and recycling
- Meaningful engagement with/empowerment of communities

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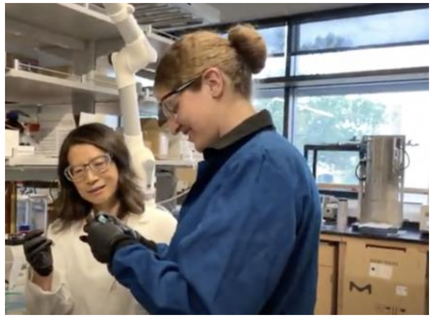
GilletteCollege
Northern Wyoming Community College District



II. Recovery from Hardrock Mine Tailings: Remediating Legacy Mine Contamination

- General Mining Act of 1872
- Law allowed homesteaders to "locate" claims on "valuable mineral deposits" such as platinum, gold, silver, copper, lead, zinc, uranium, zinc, and tungsten, without reclamation obligations (30 U.S. Code § 22 *et seq.*).
- Thousands of mine sites and waste piles sit abandoned today, with western states having no "consistent source of funding . . . to address hazards at abandoned hardrock mines." (U.S. GAO 2020).
- ~60% of documented abandoned mines pose environmental or safety risks
- Tribes have been disproportionately burdened, with many mining projects sited close to tribal lands (reservations or cultural or ancestral lands) (Nat'l Wildlife Federation, 2013)
    - E.g., There are over 500 abandoned uranium mines on and near Navajo Nation (EPA 2025)

Joshua Lott, NYT ("An abandoned uranium mine on the Navajo reservation in Cameron, Ariz., emits dangerous levels of radiation.") (2012)

Recovery from Hardrock Mine Tailings

- According to Sarker, et al., 2022:
  - "The [cost of secondary recovery from mine tailings] is significantly reduced as the ores have already been collected and partly processed and ground.
  - [B]ecause [mining] technologies used in the past were less efficient than they are now[,] the likelihood of finding valuable minerals at economic concentration is higher in older tailings than in newer ones. . . these by-products minerals had very little uses in the past, which resulted in a little desire to extract them regardless of their concentration."

- Shuronjit Kumar Sarker, et al., *Recovery of strategically important critical minerals from mine tailings*, 10 J. ENVTL. CHEMICAL ENG'G 107622 (2022).

Problems that secondary recovery might alleviate within the supply chain:

- Reduction of new landscape burdens from new conventional mining
- Ability to leverage existing infrastructure & workforce
- Encourage reclamation of waste
- Reduce changes to land use
- Provide opportunities for fossil fuel-reliant "energy communities" faced with declining coal markets
- Ability to site industry in communities that have existing social license for extraction

What remains unsolved:

Permitting & Liability Challenges

- Operators attempting secondary recovery methods from hard rock mine tailings could face liability
- The Good Samaritan Remediation of Abandoned Hardrock Mines Act of 2024 does not resolve all issues

Economic Challenges

- The economic viability of conducting secondary recovery at scale remains uncertain, but significant work is being done in this area

Other:

- Not a one-size-fits-all solution!

Remaining Permitting & Liability Challenges

- Operators attempting secondary recovery methods from tailings (abandoned mines in particular) could face liability for historical contamination
- Sources of liability: Clean Water Act & CERCLA
- Plus, to the extent legal liability could arise, operators must meet heightened financial assurance requirements
- New legislation has begun to change the landscape, however. . .

Creation of the Abandoned Hardrock Mining Reclamation (AHMR) Program Under the IIJA

- 2021: The 2021 IIJA instructed DOI to:
  - establish a program to inventory abandoned hardrock mine lands and
  - provide grants to states and tribes to conduct eligible activities on abandoned hardrock mine land under their jurisdiction
- Applies to land and water resources that were:
  - used for, or affected by, hardrock mining activities; and
  - abandoned or left in an inadequate reclamation status before November 15, 2021; and where
  - there is no continuing reclamation responsibility of a claim holder, liable party, operator, or other person that abandoned the site prior to completion of required reclamation under Federal or State law.
- The IIJA also provided additional funding for the Office of Surface Mining Reclamation and Enforcement's (OSMRE's) Abandoned Mine Reclamation Fund (established in 1977 under the Surface Mining Control and Reclamation Act (SMCRA)).
- The appropriations do not appear to address reprocessing of any associated CM/REE– only remediation.

Good Samaritan Legislation

- **The Good Samaritan Remediation of Abandoned Hardrock Mines Act of 2024 helps, but does not resolve all issues:**
- Establishes a pilot program of fifteen (15) permits to incentivize mine waste cleanups over the next seven (7) years on abandoned hardrock mine sites
  - Eliminates certain liabilities under the Clean Water Act and CERCLA
  - Provides funding for projects
- Applies only to sites:
  - On federal or non-federal land used for the production of minerals other than coal
- Who can apply: A person or entity that is not a past or current owner or operator of the abandoned hardrock mine site (or a portion of the site), that had no role in the creation of the historic mine residue, and that is not potentially liable for the historic mine residue.
- Permit Requirements: Applications are submitted to EPA and must include, inter alia:
  - A description of the baseline conditions caused by historic mine residue, a remediation plan, detailed engineering plans, and plans for monitoring to determine the success of the remediation activities;
  - A demonstration of the applicant's financial ability to carry out the remediation, or a showing of the applicant's ability to secure third-party financial assurance;
  - A demonstration of the applicant's ability to ensure the work is completed and carry out any long-term operation and maintenance of remediation activities.
- Other features: When the project involves long-term operations or maintenance on federal lands, the Good Samaritan permitee can negotiate an agreement with the relevant federal agency to take over and terminate the permit.

Good Samaritan law considerations and limitations:

- **Does not apply to sites:**
  - Where a responsible owner or operator has been identified who is potentially liable for remediation activities under applicable law;
  - Where active mining or mineral processing occurred after December 11, 1980;
  - In temporary shutdown or cessation; or
  - That are listed on the CERCLA National Priorities List
- A Good Samaritan permittee can recover (i.e., "reprocess") valuable materials from the cleanup site only if the land is owned by the U.S. and if proceeds from the reprocessing are used to defray the costs of remediation.
  - Any remaining funds go to to the Good Samaritan Mine Remediation Fund established by the Act (for use by federal land management agencies and the EPA).
- The proposed project must pose a low risk to the environment, as determined by the EPA administrator;
- The issuance of a Good Samaritan Permit will be considered a major agency action, subject to the National Environmental Policy Act (NEPA).

The Bottom-Line for Bringing Benefits to Communities & the Environment

A place-based approach should be implemented to understand and address the unique social, economic, and environmental aspects of a region.

Strategies for growing circular industries should generally work with communities to ensure:

Procedural Fairness

- Fair labor practices (health, safety, wages, etc.)
- Community partnerships, engagement, or express community benefit agreements
- Meaningful involvement of communities in decision-making
- Tribal sovereignty in decision-making

Economic Benefits

- Job creation
- Local tax revenue generation
- Decrease energy burden
- Local workforce development & re-development

Environmental Stewardship

- Mitigate and minimize emissions, pollutants, and wildlife impacts
- Minimize land use change and freshwater use
- Utilize and redirect existing waste streams
- Remediate legacy environmental impacts

THANK YOU

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