# What energy critical metals are required to achieve net zero emissions and where will they come from?

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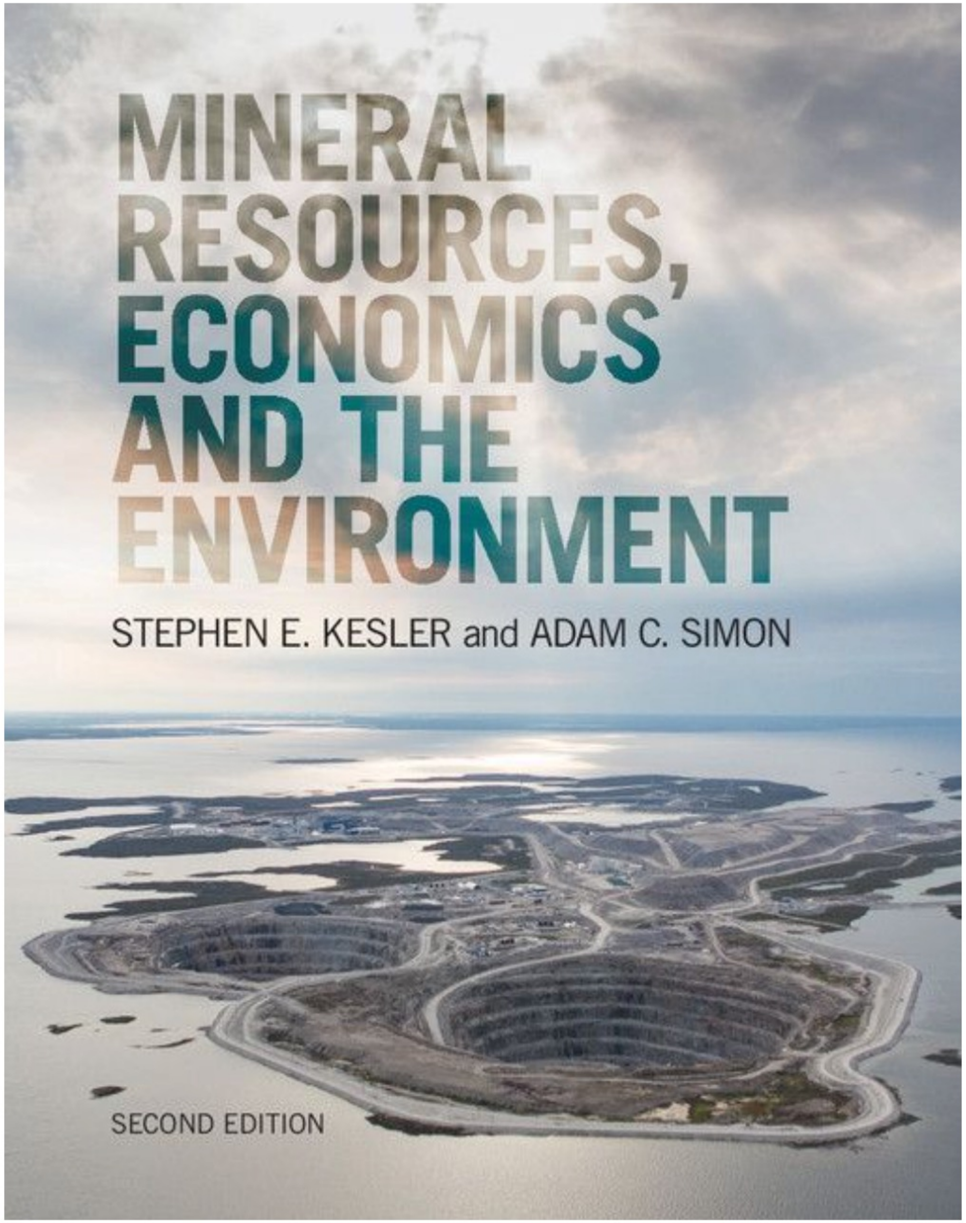
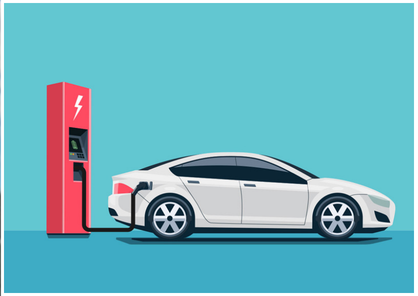



# Economic Geology

The scientific discipline concerned with the distribution of mineral deposits, the economic considerations involved in their recovery, and an assessment of the reserves available.

# U.S. Goals

- …create a carbon pollution-free power sector by 2035
- Target of 50% electric vehicle sales share in 2030
- $3.1 billion in federal funds to make electric vehicle batteries in the U.S.
- Net zero energy and vehicles by 2050

**Achieving net zero emissions by 2050 requires renewable technologies provide ~90% of energy consumption.**

# Electrify Everything

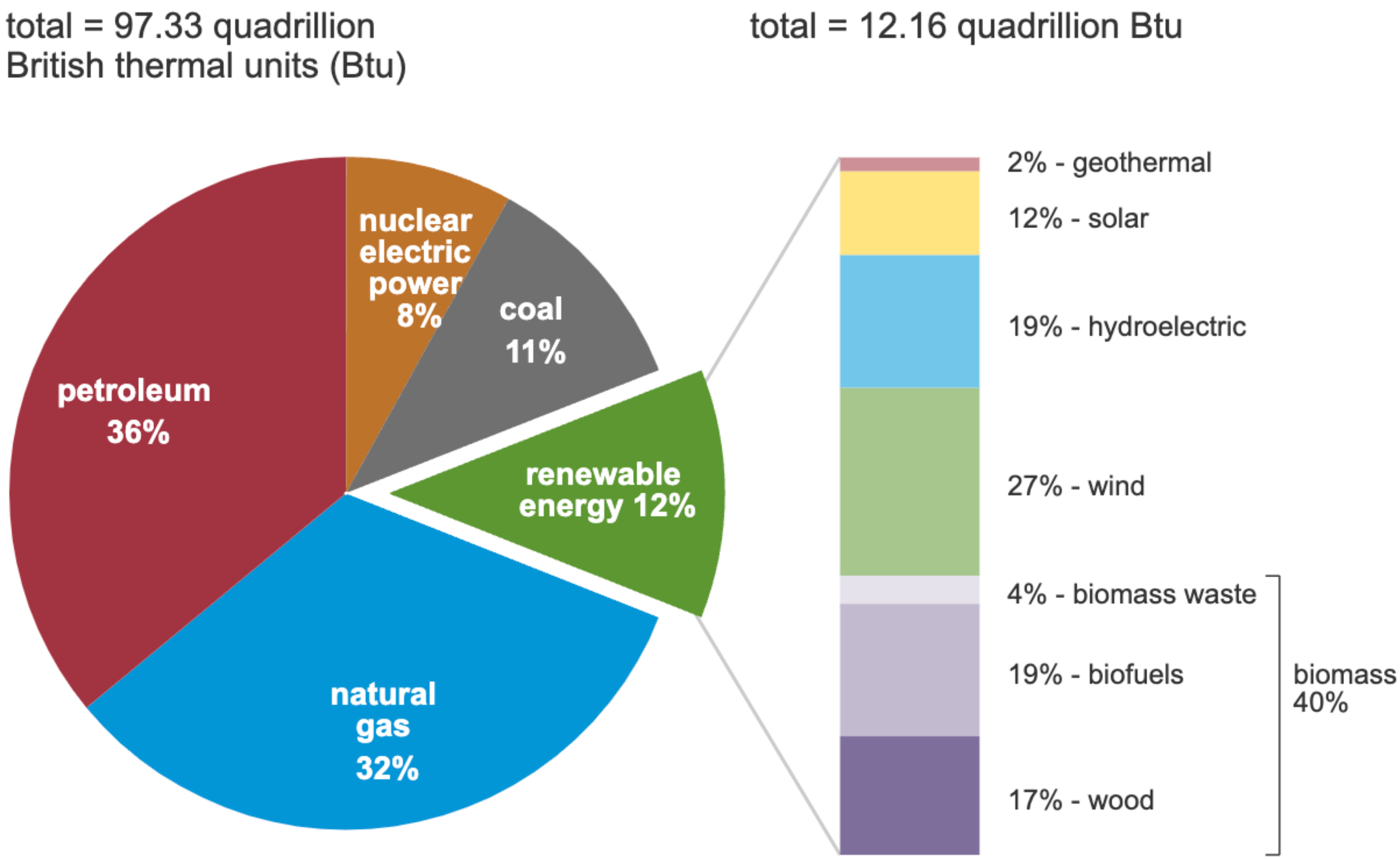
Electric Vehicles

Heat Pumps


Solar Panels


Battery Storage

# United States primary energy consumption




**coal + natural gas + oil = 79% of energy consumption**

# 100% Renewable Energy by 2050

## E+ RE+
## 100% Renewable

- Nearly full electrification of transport and buildings by 2050
- No fossil fuel use allowed by 2050
- No land-use change for biomass supply allowed
- No new nuclear power construction allowed, existing plants retired
- No underground storage of CO2 allowed

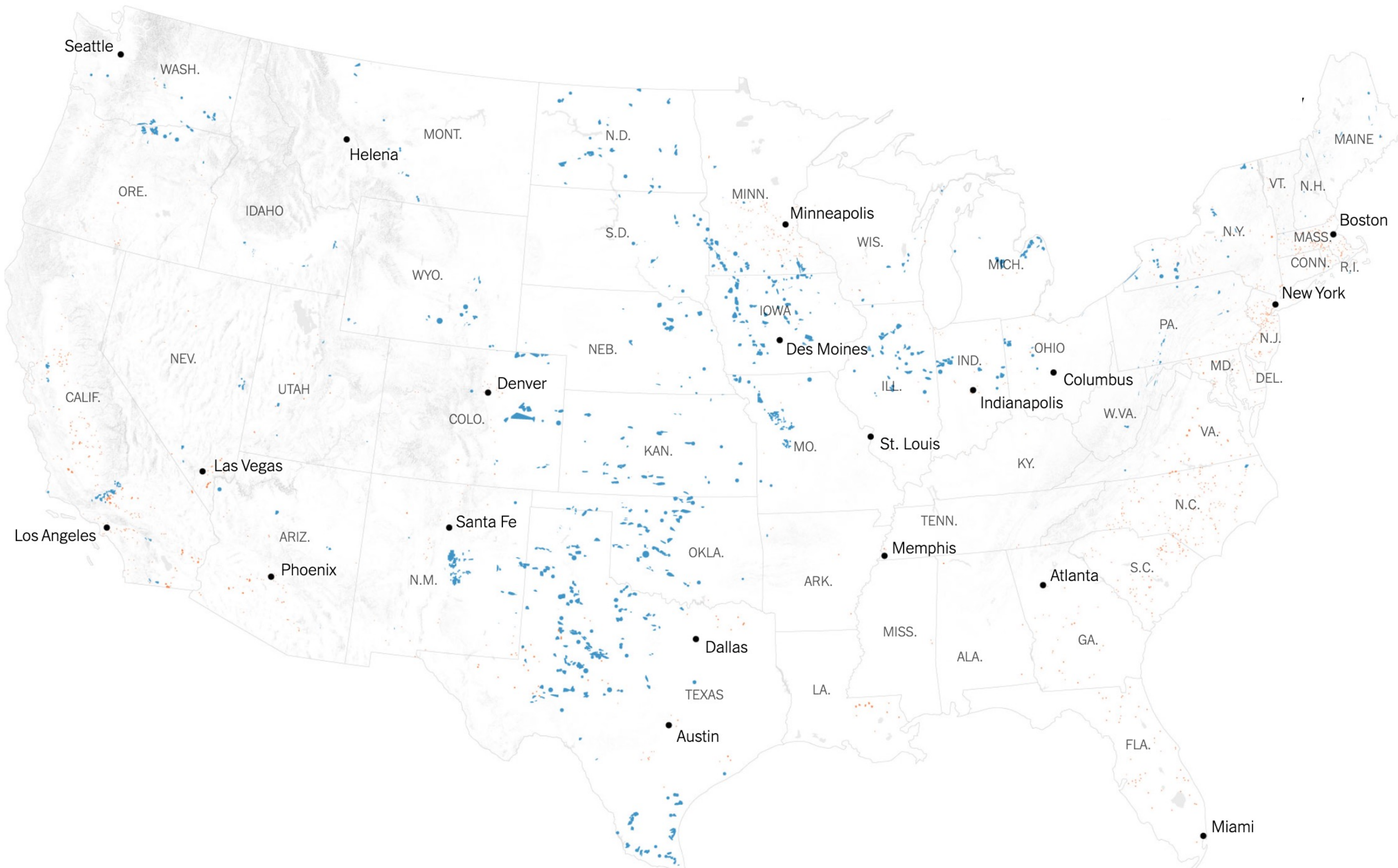
| PRIMARY ENERGY | | |
|---|---|---|
| 1.1.1 | Biomass (EJ) | 12.3 |
| 1.1.2 | Coal and Coke (EJ) | 0.001 |
| 1.1.3 | Geothermal (EJ) | 0.107 |
| 1.1.4 | Hydro (EJ) | 1.07 |
| 1.1.5 | Natural Gas (EJ) | 0.022 |
| 1.1.6 | Oil (EJ) | 0.006 |
| 1.1.7 | Solar (EJ) | 20.9 |
| 1.1.8 | Uranium (EJ) | -0.001 |
| 1.1.9 | Wind (EJ) | 38.8 |

Mission net-zero America: The nation-building path to a prosperous, net-zero emissions economy

Jesse D. Jenkins [6] • Erin N. Mayfield [5, 7] • Eric D. Larson • Stephen W. Pacala • Chris Greig •

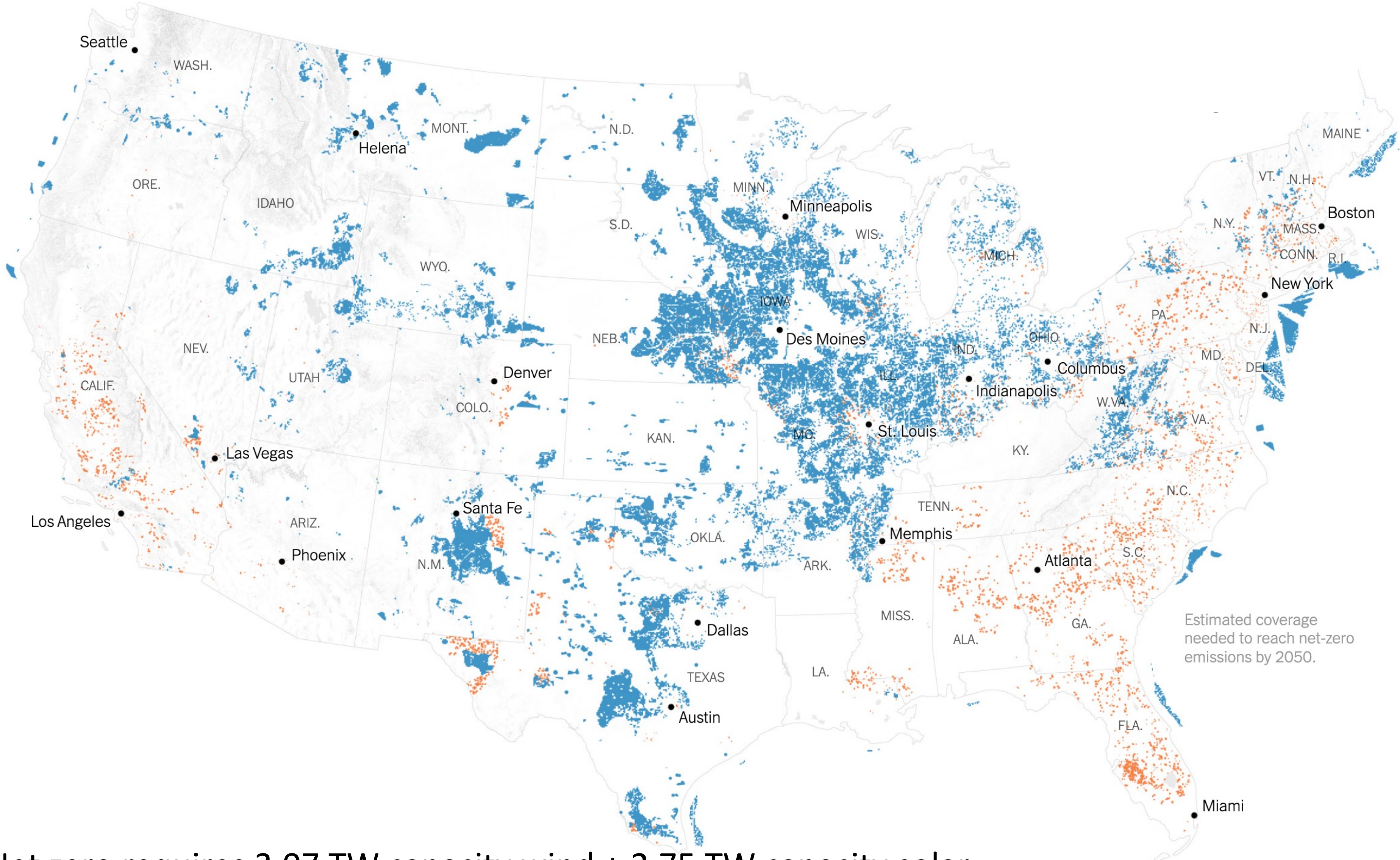
PRINCETON UNIVERSITY

# Wind and Solar today




Current solar about 1,000 square miles; about the size of Rhode Island.
Current number of wind turbines = 89,000 ; wind turbines do not reduce land use area.

# Wind and Solar needed to reach net zero by 2050



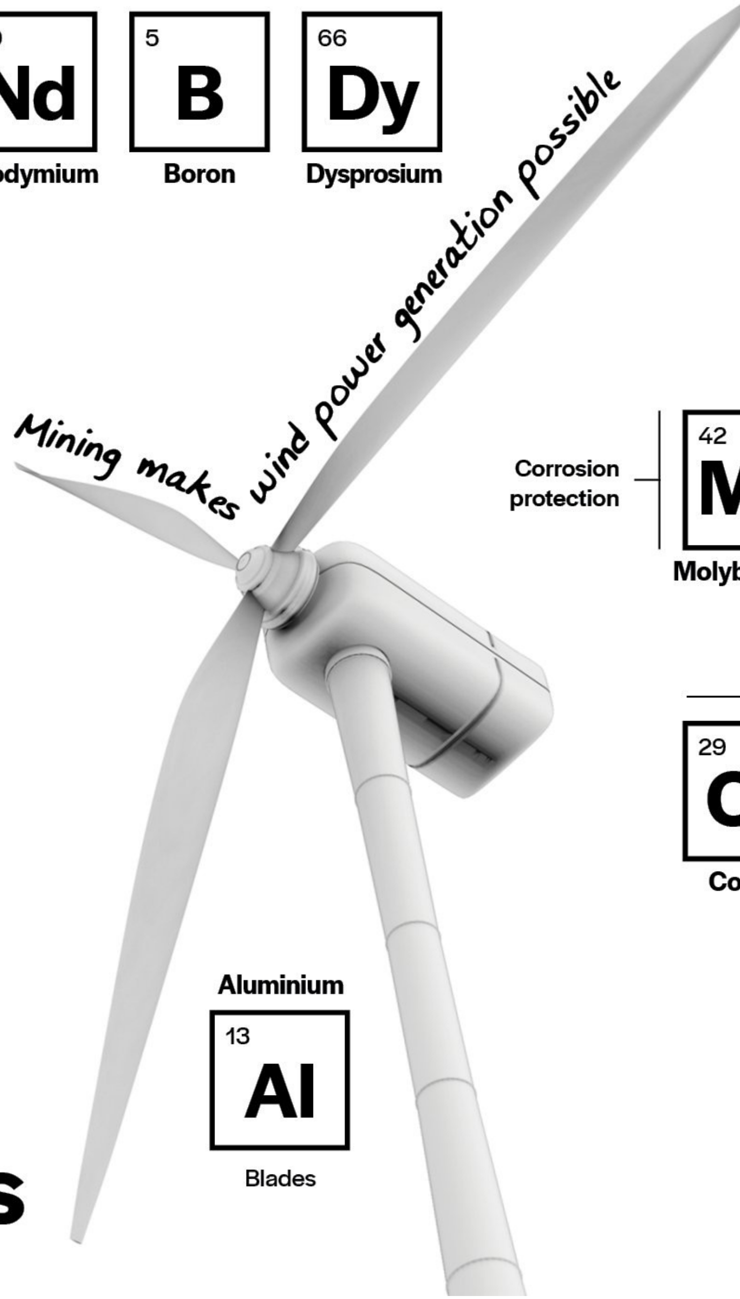

Net zero requires 3.07 TW capacity wind + 2.75 TW capacity solar

About 24,000 square miles of solar needed for net zero by 2050; about to equal Lake Michigan

About 10,000 square miles; about wind turbines

# Windfarms

Mining makes wind power generation possible



**Magnet generation**

| 26 Fe | 60 Nd | 5 B | 66 Dy |
|---|---|---|---|
| Iron | Neodymium | Boron | Dysprosium |

**Steel used to build turbines**

| 26 Fe | 6 C |
|---|---|
| Iron | Carbon |

**Battery energy storage**

| 3 Li | 28 Ni | 25 Mg |
|---|---|---|
| Lithium | Nickel | Manganese |
| 27 Co | 6 C | 23 V |
| Cobalt | Carbon | Vanadium |

**Corrosion protection**

| 42 Mo | 30 Zn |
|---|---|
| Molybdenum | Zinc |

**Controls**

| 29 Cu | 14 Si |
|---|---|
| Copper | Silicon |

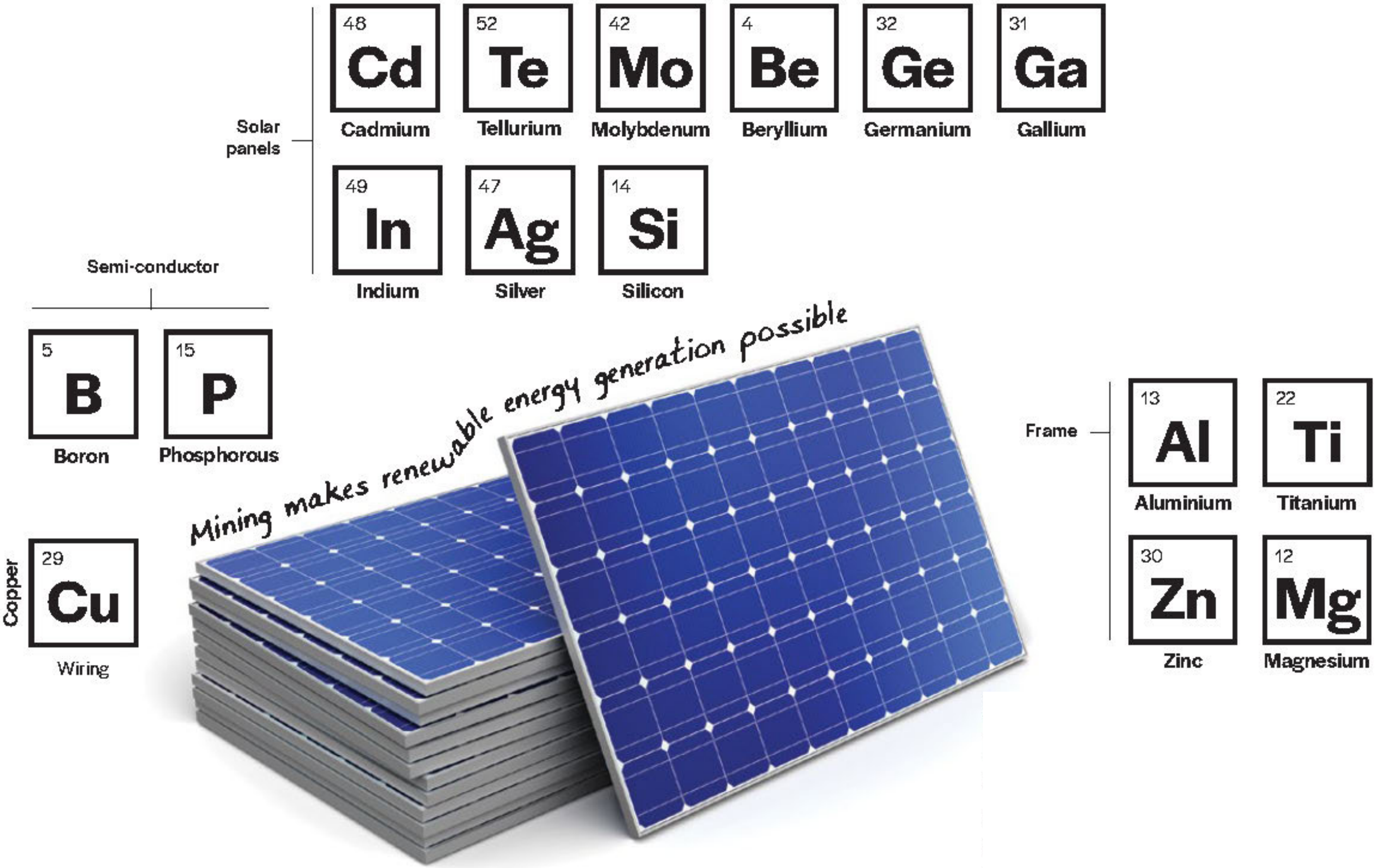
**Aluminium**

| 13 Al |
|---|
| Blades |

**More than 220 tonnes of coal is required to build a wind turbine.**

# Metals required per year for wind turbines assuming a 5% annual capacity addition

| | Annual Need (Pounds) | Annual U.S. Mine Production (Pounds) |
|---|---|---|
| **Iron for steel** | 30 billion | 99 billion |
| **Coking coal for steel** | 22 billion | 110 million |
| **Aluminum** | 0.7 billion | zero |
| **Copper** | 0.25 billion | 2.6 billion |
| **Rare earths** | 0.15 billion | 0.095 billion |




Clean Energy Canada

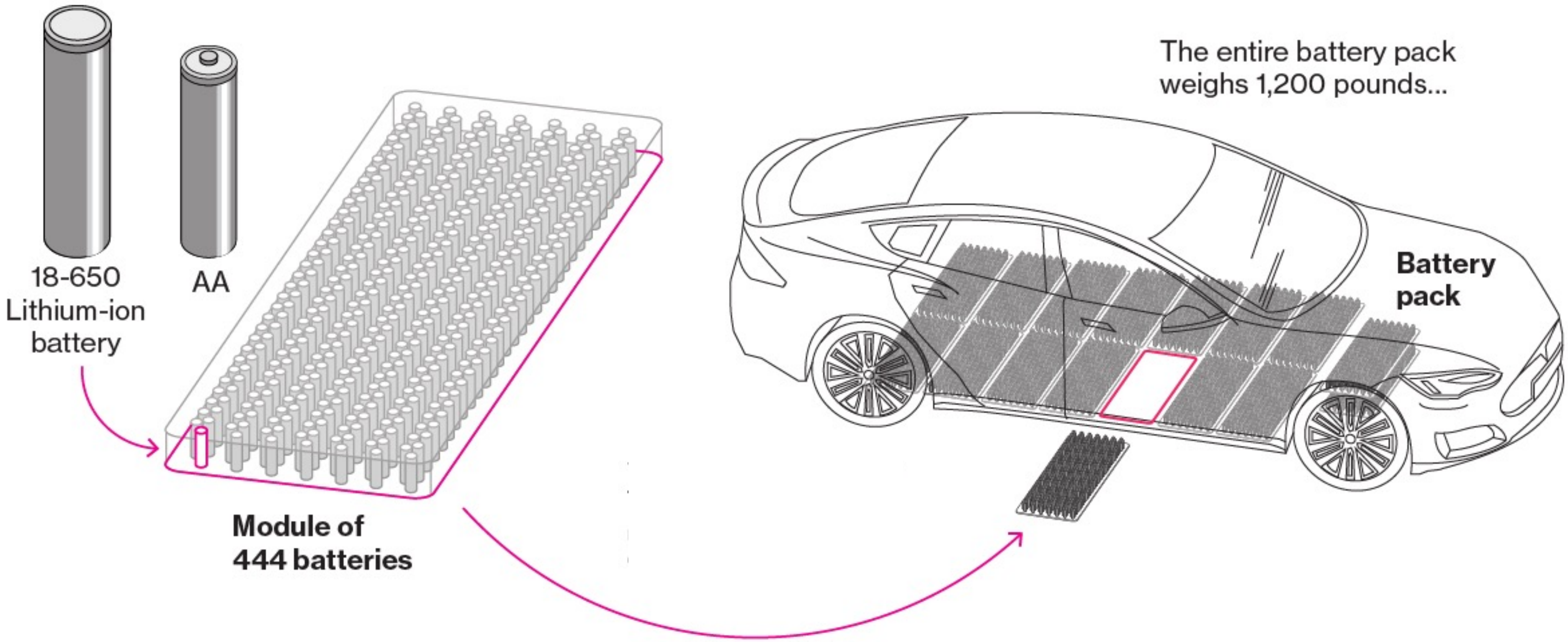
# Metals required per year for photovoltaic solar assuming a 5% annual capacity addition

| | Annual Need (Pounds) | Annual U.S. Mine Production (Pounds) |
|---|---|---|
| **Iron for steel** | 20 billion | 55 billion |
| **Aluminum** | 2 billion | zero |
| **Copper** | 1.5 billion | 2.6 billion |
| **Silica** | 1 billion | 682 million |
| **Silver** | 4.5 million | 2.2 million |
| **Indium** | 14 million | zero |
| **Gallium** | 1 million | zero |
| **Selenium** | 5 million | zero |
| **Cadmium** | 12 million | zero |
| **Tellurium** | 15 million | zero |
| **Germanium** | 9 million | zero |

# Target of 50% electric vehicle sales share in 2030

**There are 300 million cars and other light vehicles in the U.S. with annual sales of 15 million.**

**This is about 8 million electric vehicles *per year* by 2030, but has to increase to 16 million per year to achieve net zero by 2050.**




# A typical battery electric vehicle contains

| | |
|---|---|
| Copper | 200 pounds |
| Lithium | 25 pounds |
| Nickel | 60 pounds |
| Manganese | 44 pounds |
| Cobalt | 31 pounds |
| Rare Earth Metals | 5-11 pounds |

# U.S. Demand for 8 million BEV's per year

| | Demand | Annual U.S. Mine Production |
|---|---|---|
| **Copper** | 1.6 billion pounds | 2.6 billion pounds |
| **Lithium** | 200 million pounds | 10 million pounds |
| **Nickel** | 480 million pounds | 40 million pounds |
| **Manganese** | 352 million pounds | zero |
| **Cobalt** | 248 million pounds | 1 million pounds |
| **Rare Earths** | 40 – 80 million pounds | 95 million pounds |

# U.S. Demand for 16 million BEV's per year

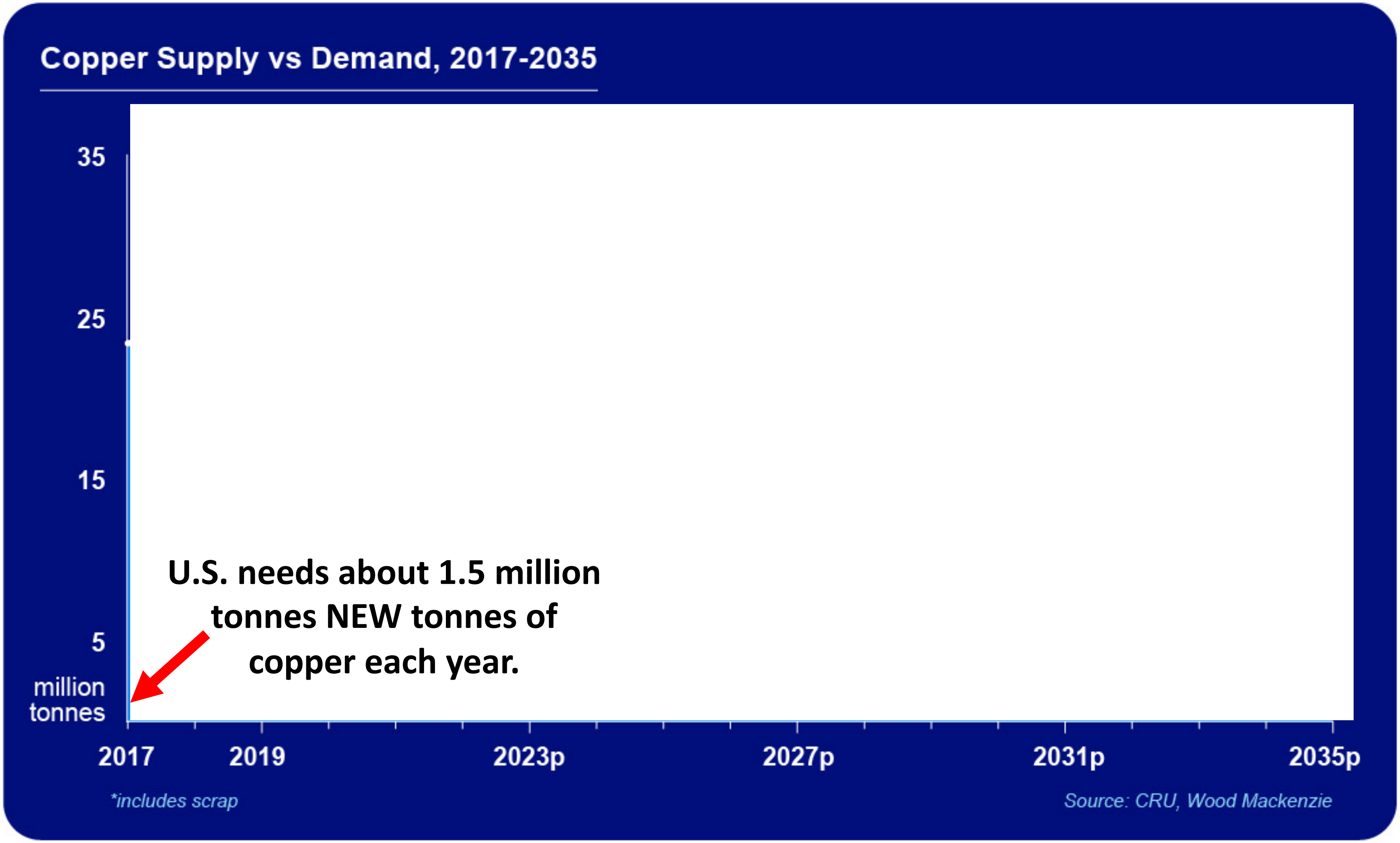
| | Demand | Annual U.S. Mine Production |
|---|---|---|
| **Copper** | 3.2 billion pounds | 2.6 billion pounds |
| **Lithium** | 40 million pounds | 10 million pounds |
| **Nickel** | 960 million pounds | 40 million pounds |
| **Manganese** | 704 million pounds | zero |
| **Cobalt** | 498 million pounds | 1 million pounds |
| **Rare Earths** | 80 – 160 million pounds | 95 million pounds |

# U.S. Demand for 8 million BEV's plus PV solar + wind turbines per year + chargers, transmission lines, etc.

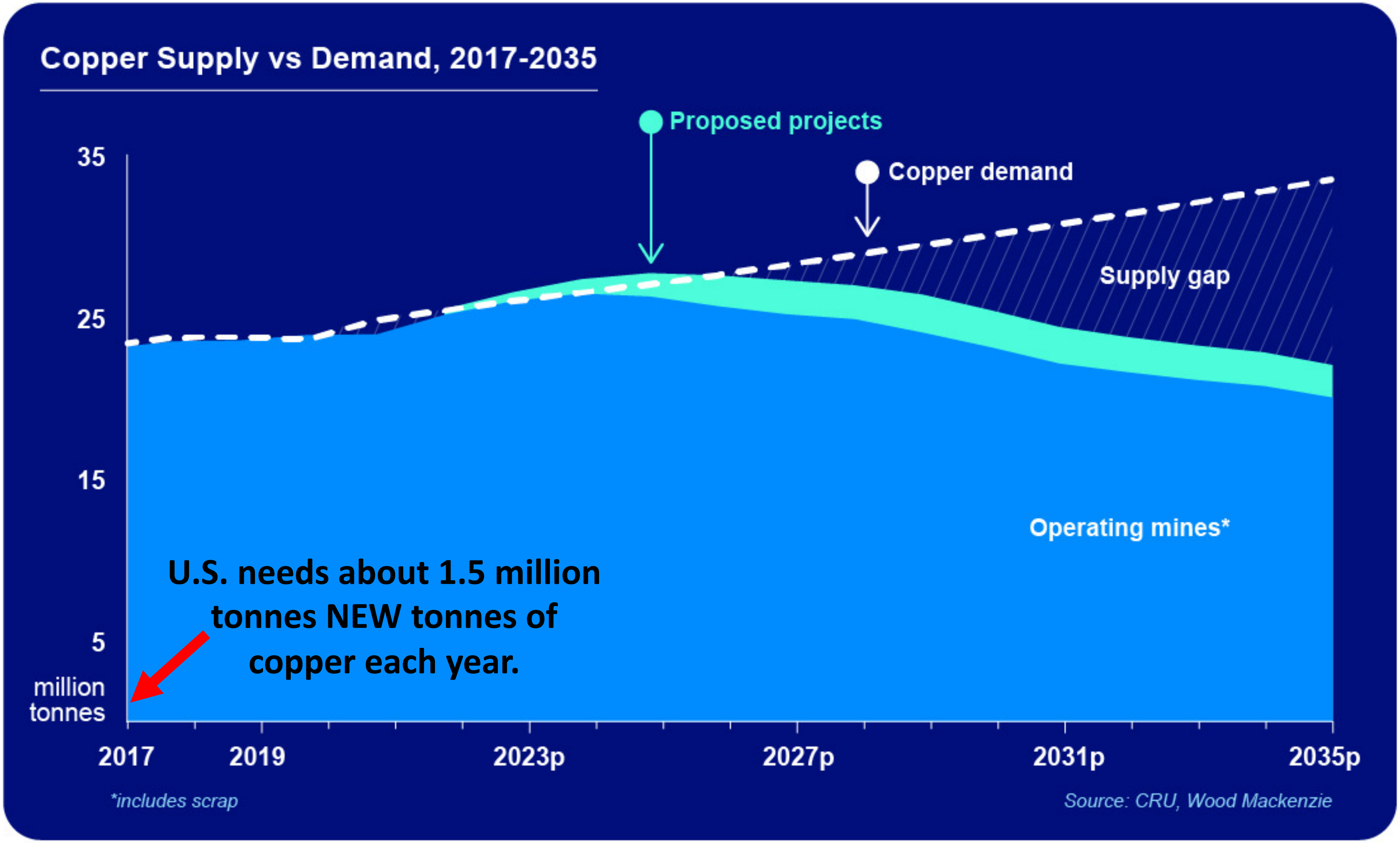
| | U.S. Demand | Annual U.S. Mine Production |
|---|---|---|
| **Copper** | 1.5 million tonnes | 1.2 million pounds |

This is 1.5 million tonnes of **NEW copper** in addition to current production.

# Copper demand vs. supply



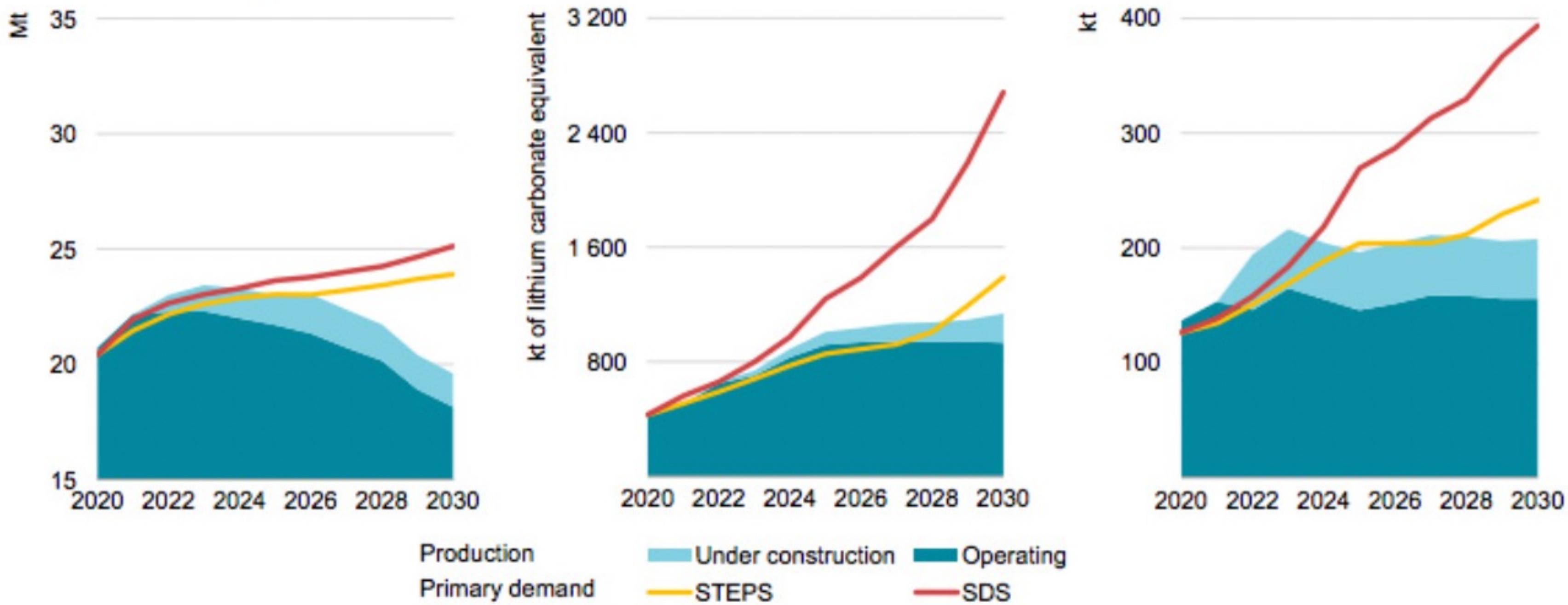
# Global copper demand vs. supply



# Copper<br>10 Mt

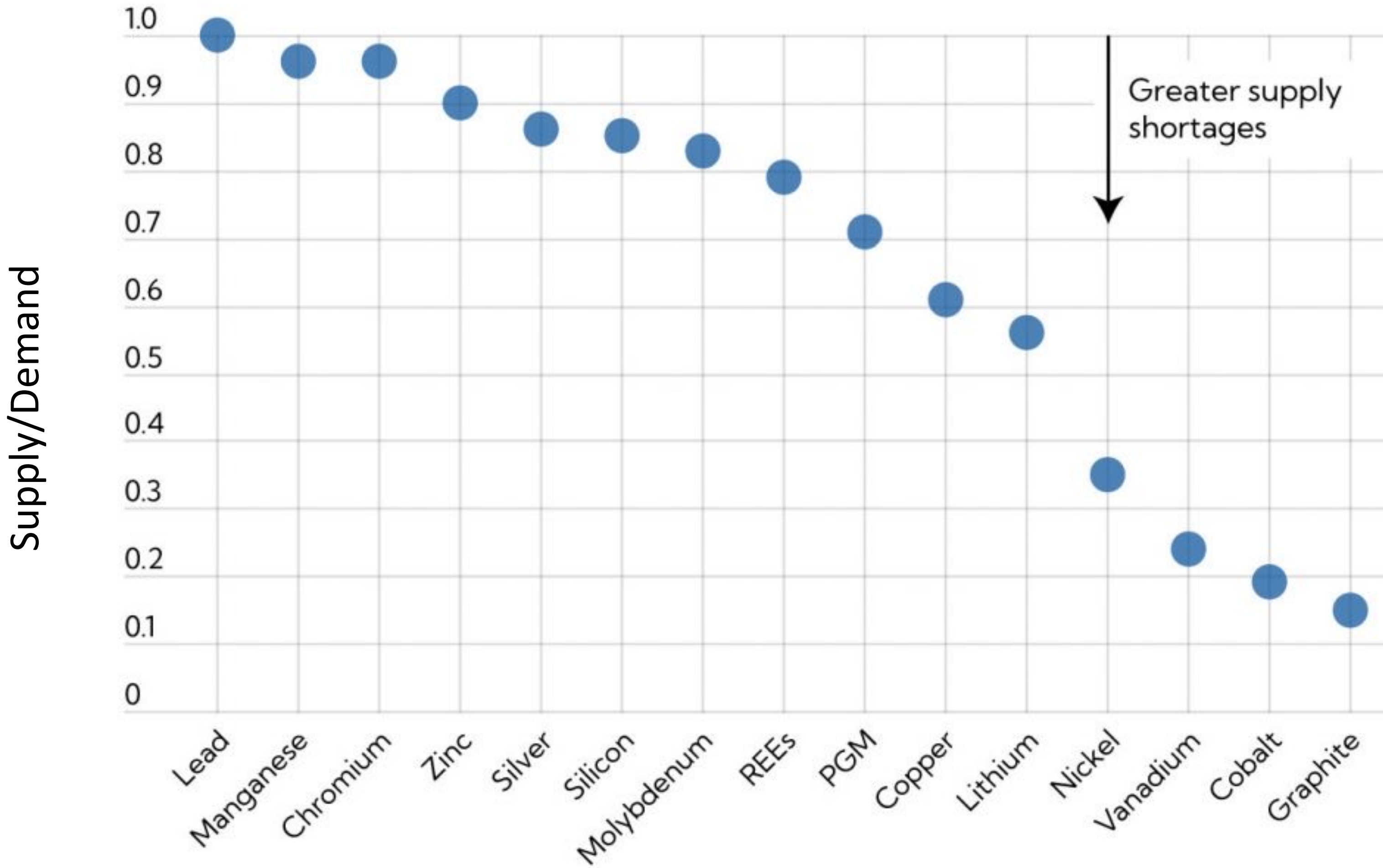
# Lithium<br>500 – 2000 kt

# Cobalt<br>100 – 200 kt



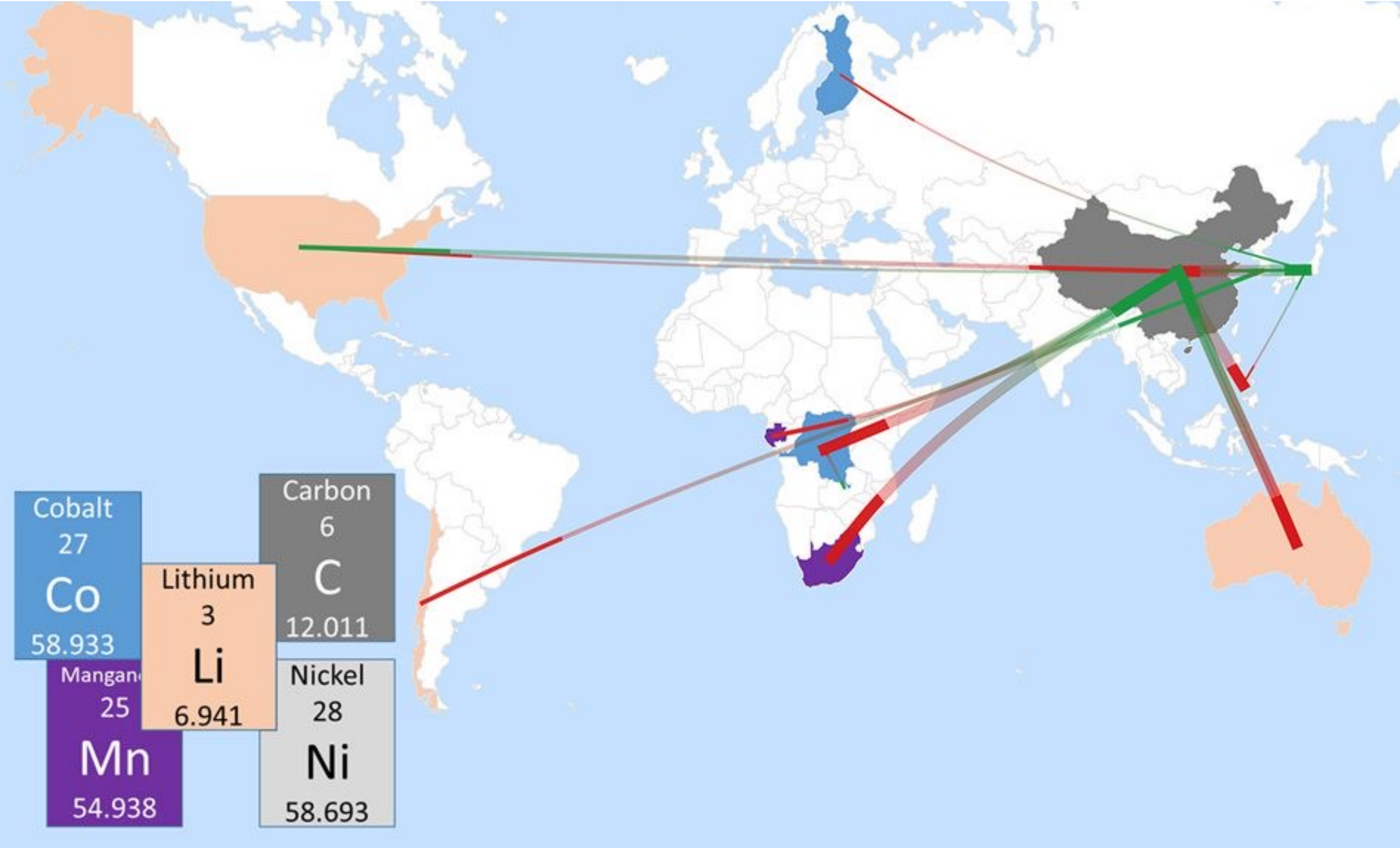

**Projected mineral resources demand in the United Nations Sustainable Development Scenario (SDS) and the Stated Policy Scenarios (STEPS) are greater than expected production from all mines globally.**

# Metals supply vs. demand

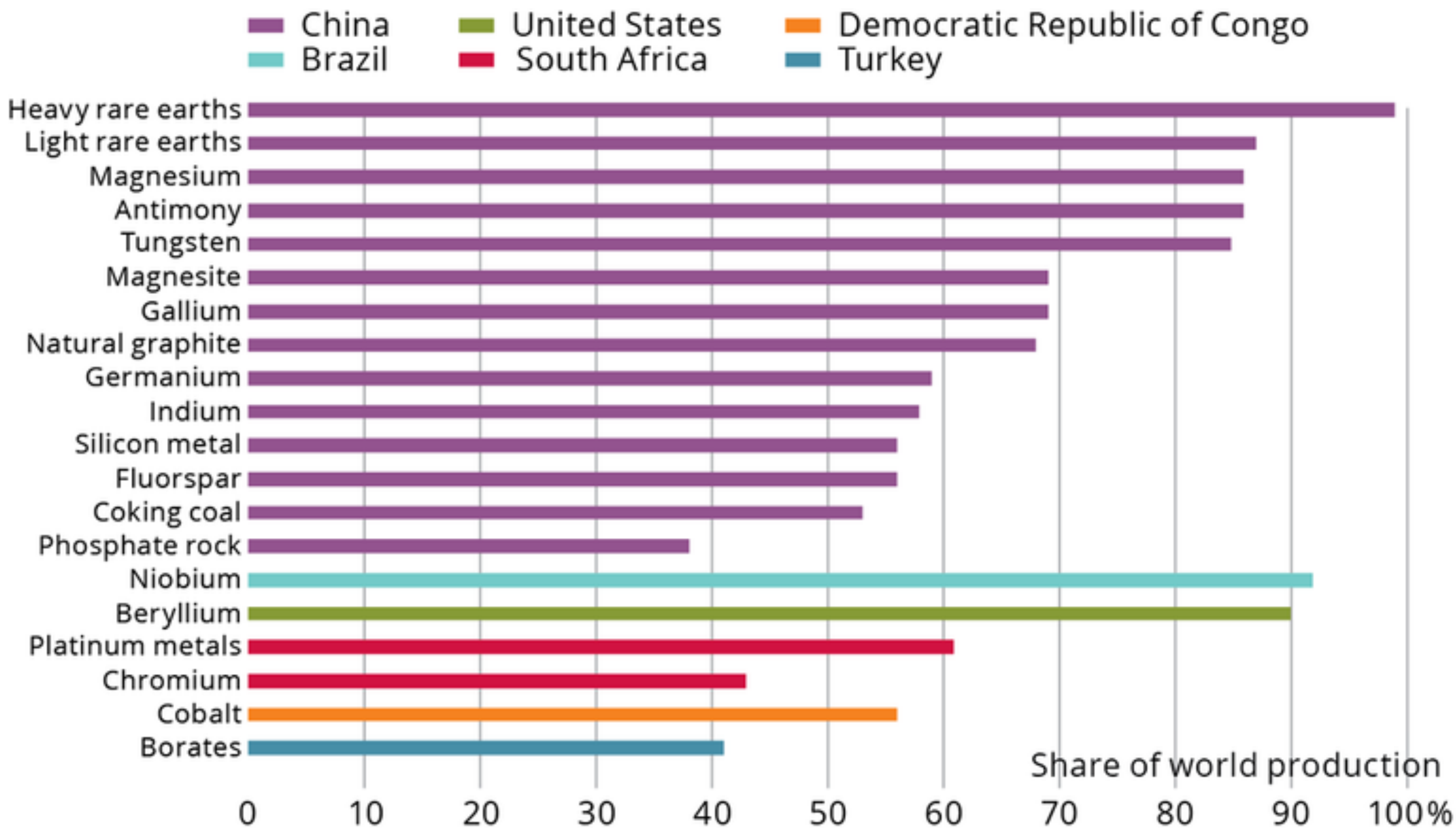


# Carbon neutrality requires new mining. Lots.

# Global Supply of EV Battery Metals Goes Through China

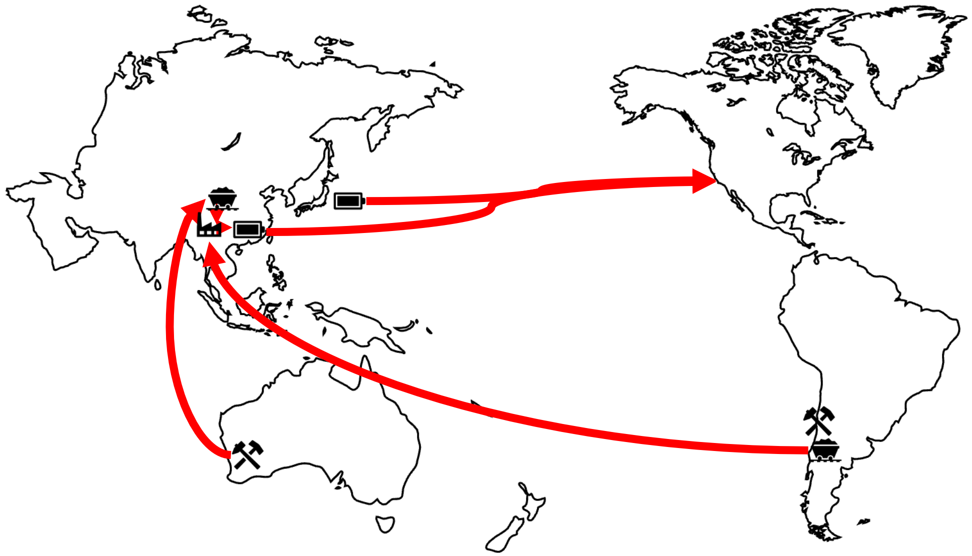


# Percentage of global production



# The Traditional Lithium Supply Chain

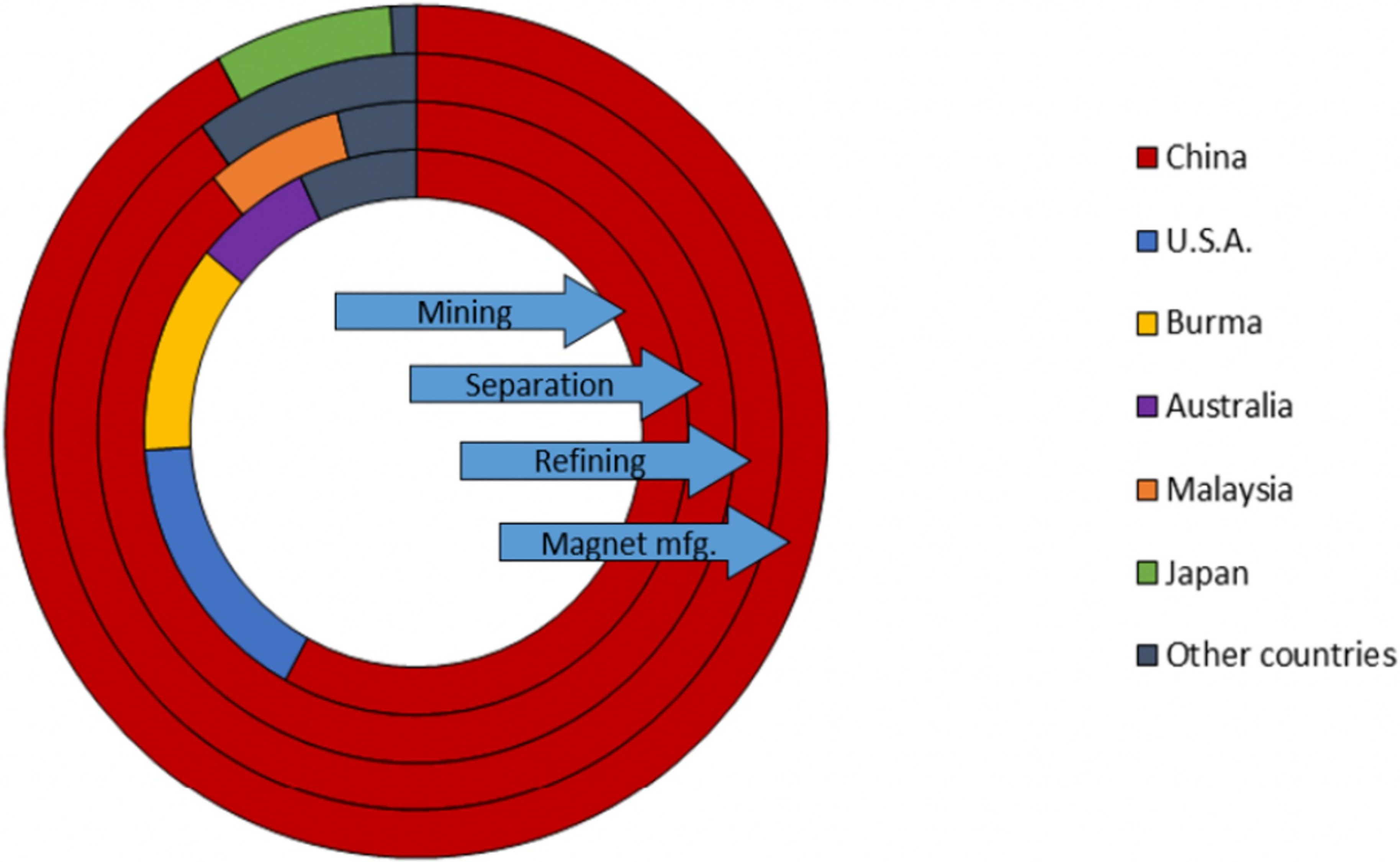
- Chilean and Australian Mining
- Chinese and Chilean Refining
- Chinese Cathode Production
- Chinese and Japanese Cell Production



**Transported ~30,000 – 40,000 km**

Zakariah Harner, MSc. thesis, UT Austin, 2022

# China dominates rare earth refining and magnet manufacturing

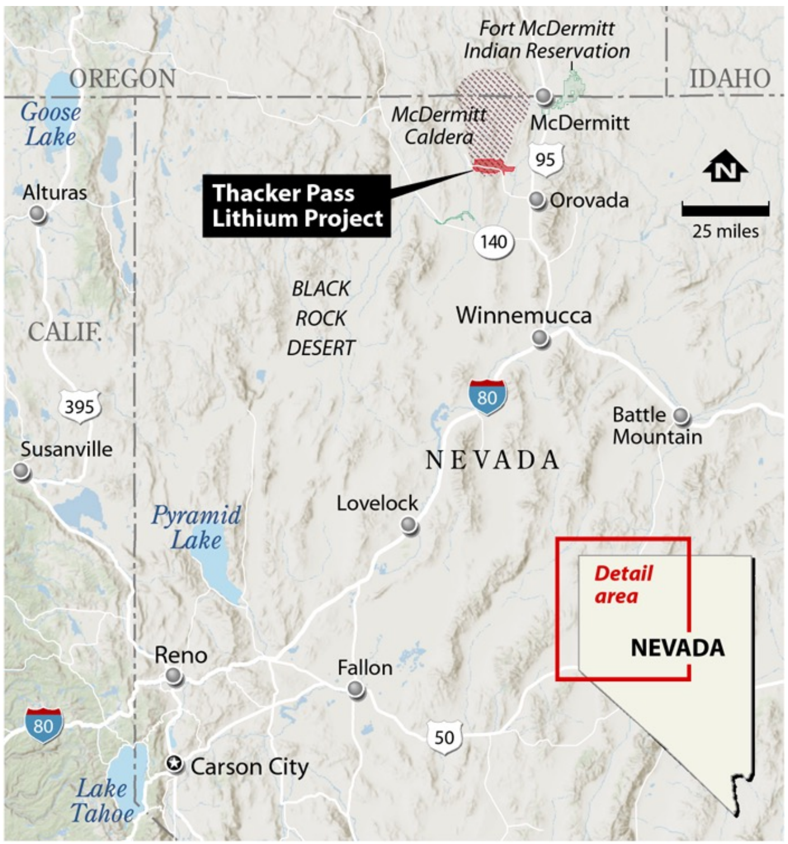


**Where will all these metals come from?**

**Can they be domestically sourced?**

# Thacker Pass Proposed Lithium Mine

| | Demand for 8 million vehicles | Annual Production | Number of electric vehicles |
|---|---|---|---|
| **Lithium** | 213 million pounds | 16 million pounds | 664 thousand |




SOURCE: ESRI PAUL HORN / Inside Climate News

Tribes including the **Burns Paiute of Oregon, the Winnemucca Indian Colony and the Reno-Sparks Indian Colony** consider the land sacred. The mine threatens a massacre site where at least 31 Paiute men, women, children, and elders were killed by the U.S. Army in a surprise attack on Sept. 12, 1865.

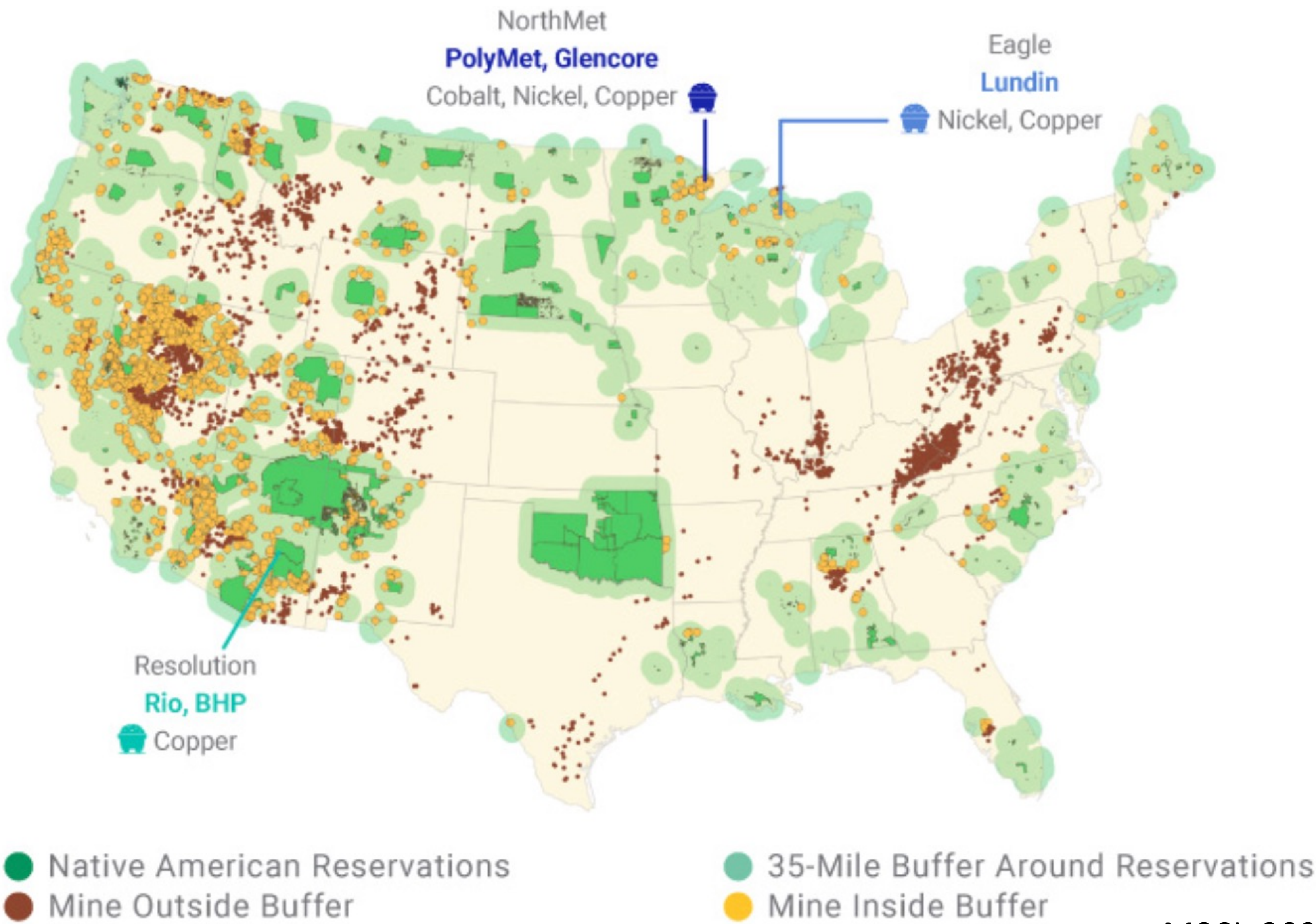
# The only U.S. cobalt mine

Cobalt from the Idaho mine will be shipped and processed in São Paulo, Brazil.

| | Demand for 8 million vehicles | Annual Production | Number of vehicles |
|---|---|---|---|
| **Cobalt** | 267 million pounds | 1 million pounds | 23 thousand |

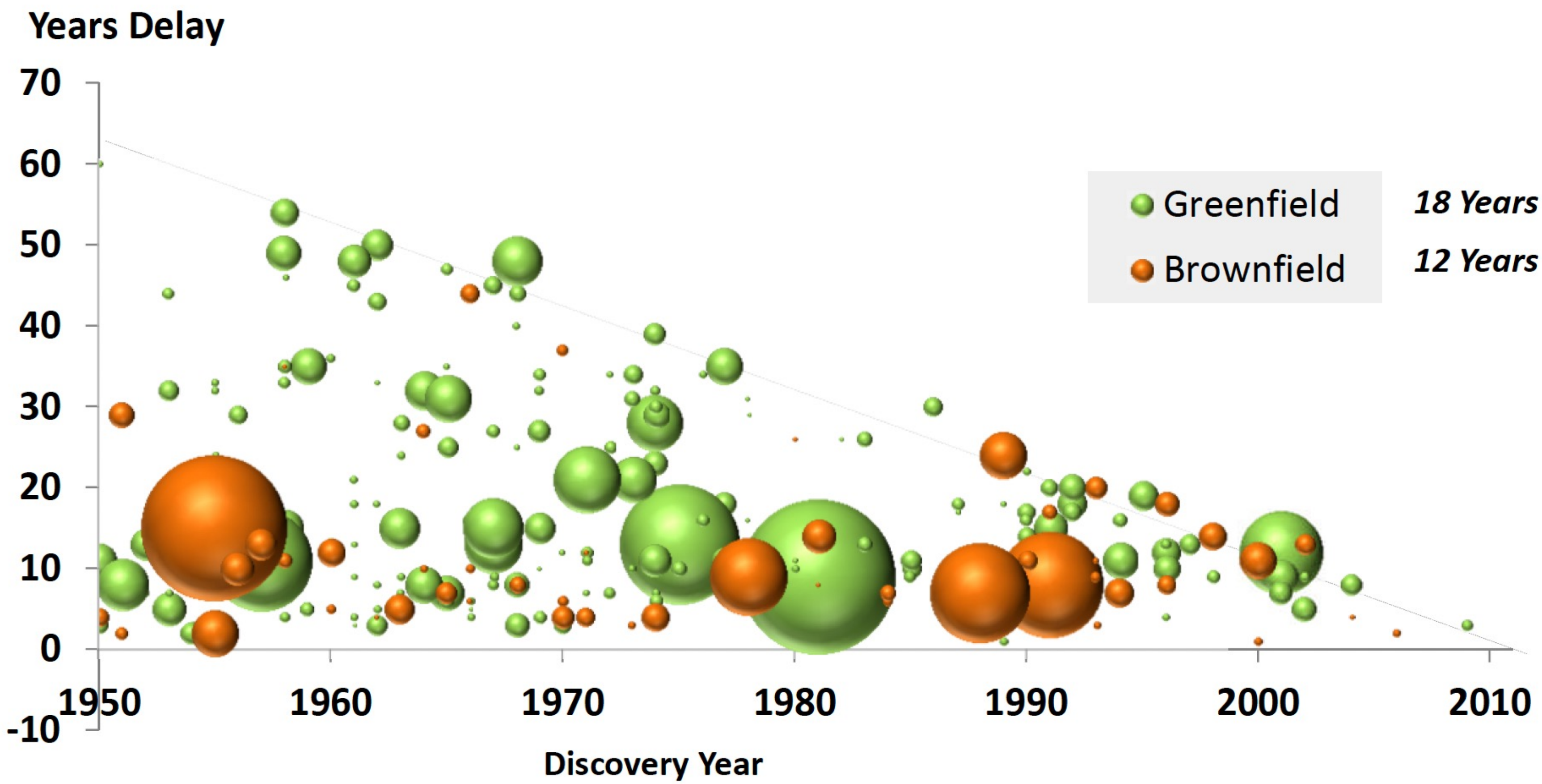

# Potential U.S. Rare Earth Metals Deposits

# U.S. Critical Metals Proximity to Indigenous Communities

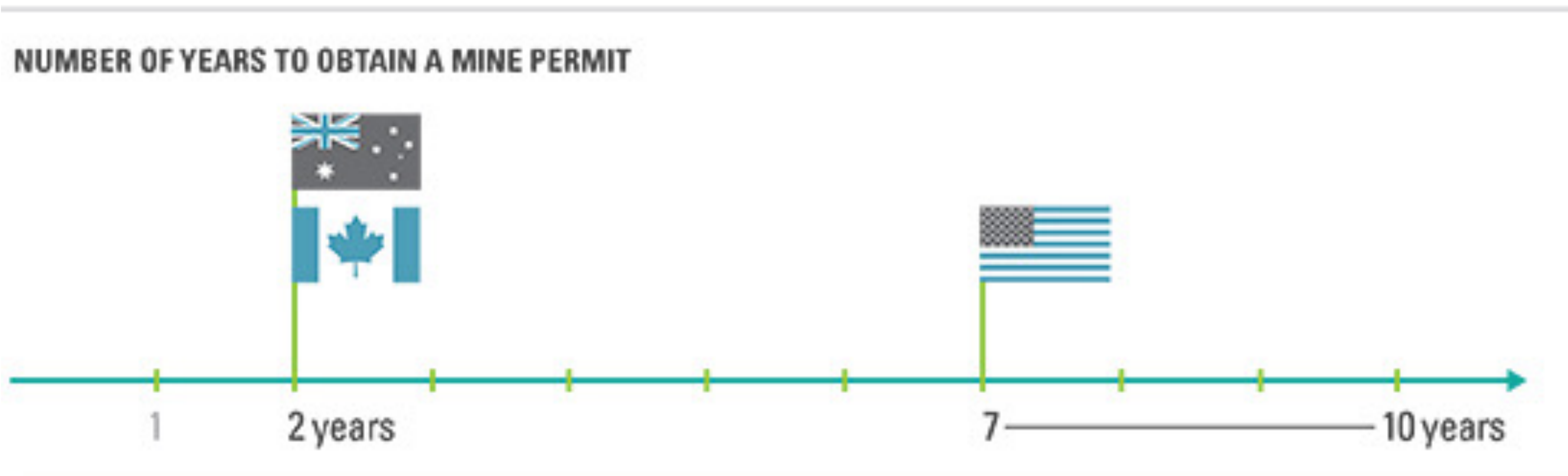



MSCI, 2021

# From Ore Deposit Discovery to Production



# From Ore Deposit Discovery to Production



# Economic Geology

The scientific discipline concerned with the distribution of mineral deposits, the economic considerations involved in their recovery, and an assessment of the reserves available.

# FUTURE OF ECONOMIC GEOLOGY IN ACADEMIA

October, 1994

**Marco T. Einaudi**

Department of Geological and Environmental Sciences

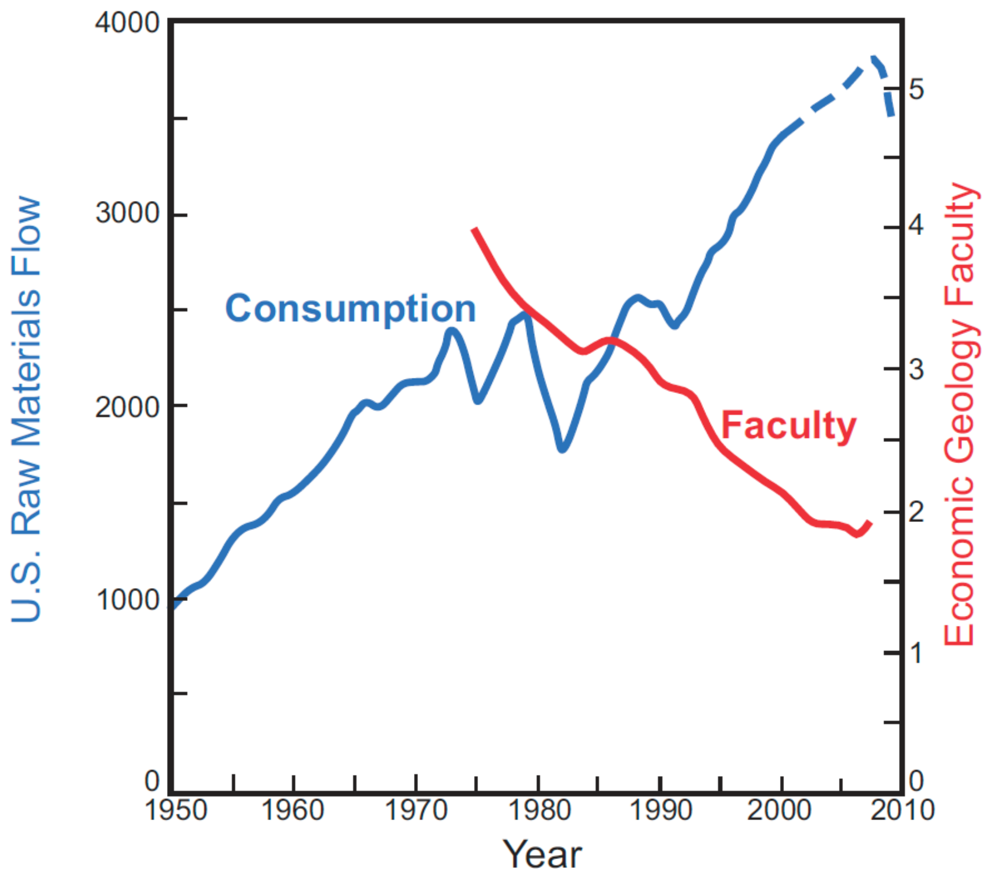
Stanford University, Stanford, CA 94305

## The Bottom Line

The view of the future is hazy, but one thing is clear: in order for Universities to make a contribution to maintaining compatibility of mining and the environment, they must maintain faculty who study ore deposits.

# Mineral resource geology in academia: An impending crisis?

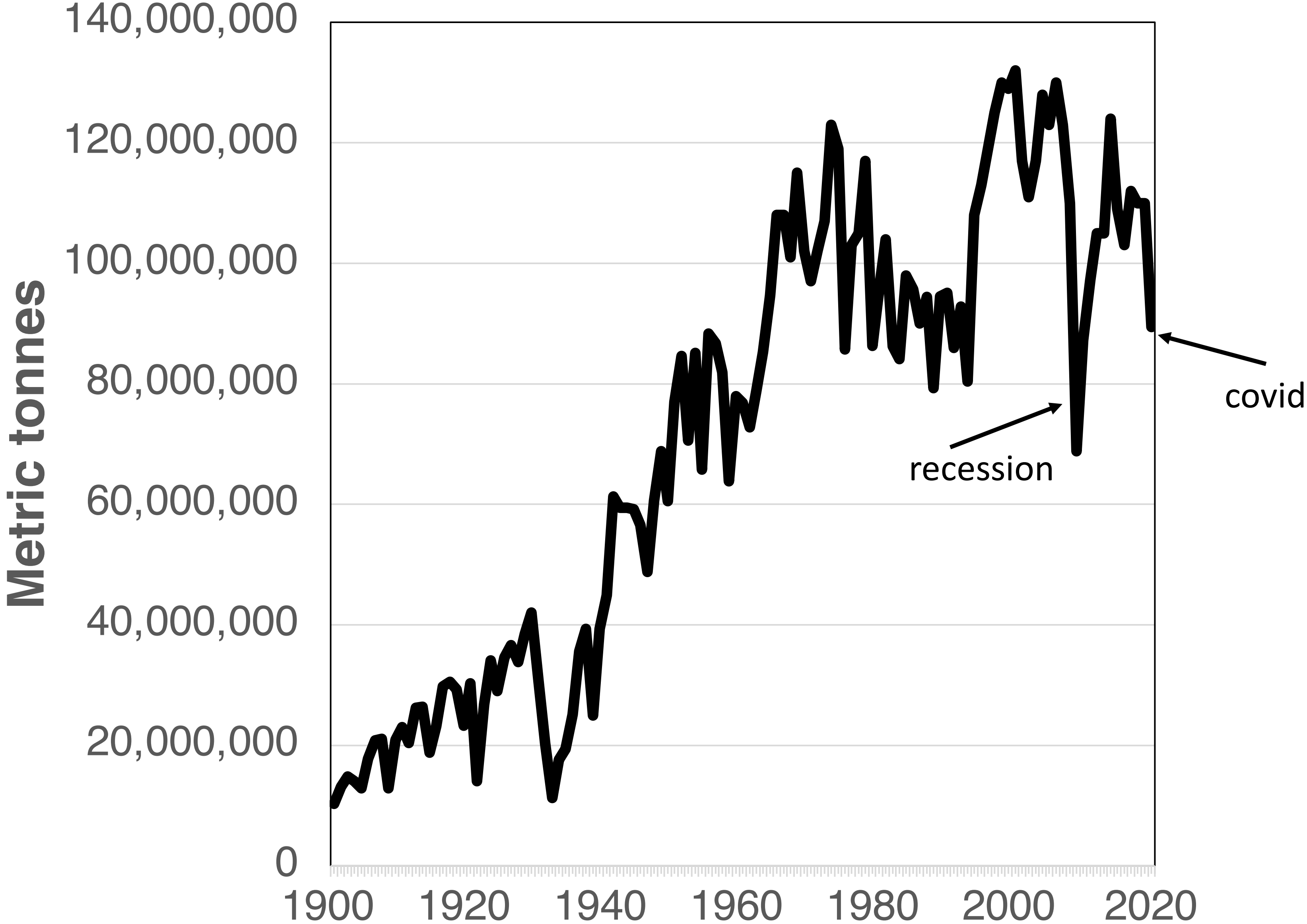
Hitzman et al., 2009, Mineral resource geology in academia: An impending crisis? GSA Today, v. 19, no. 8, doi: 10.1130/GSATG33GW.1




Graph illustrating a steady increase in U.S. consumption of raw materials and a steady decline in economic geologists as a percentage of total geoscience faculty.

Fewer faculty = fewer students = fewer workforce ready economic geologists

# U.S. Primary Metals Consumption



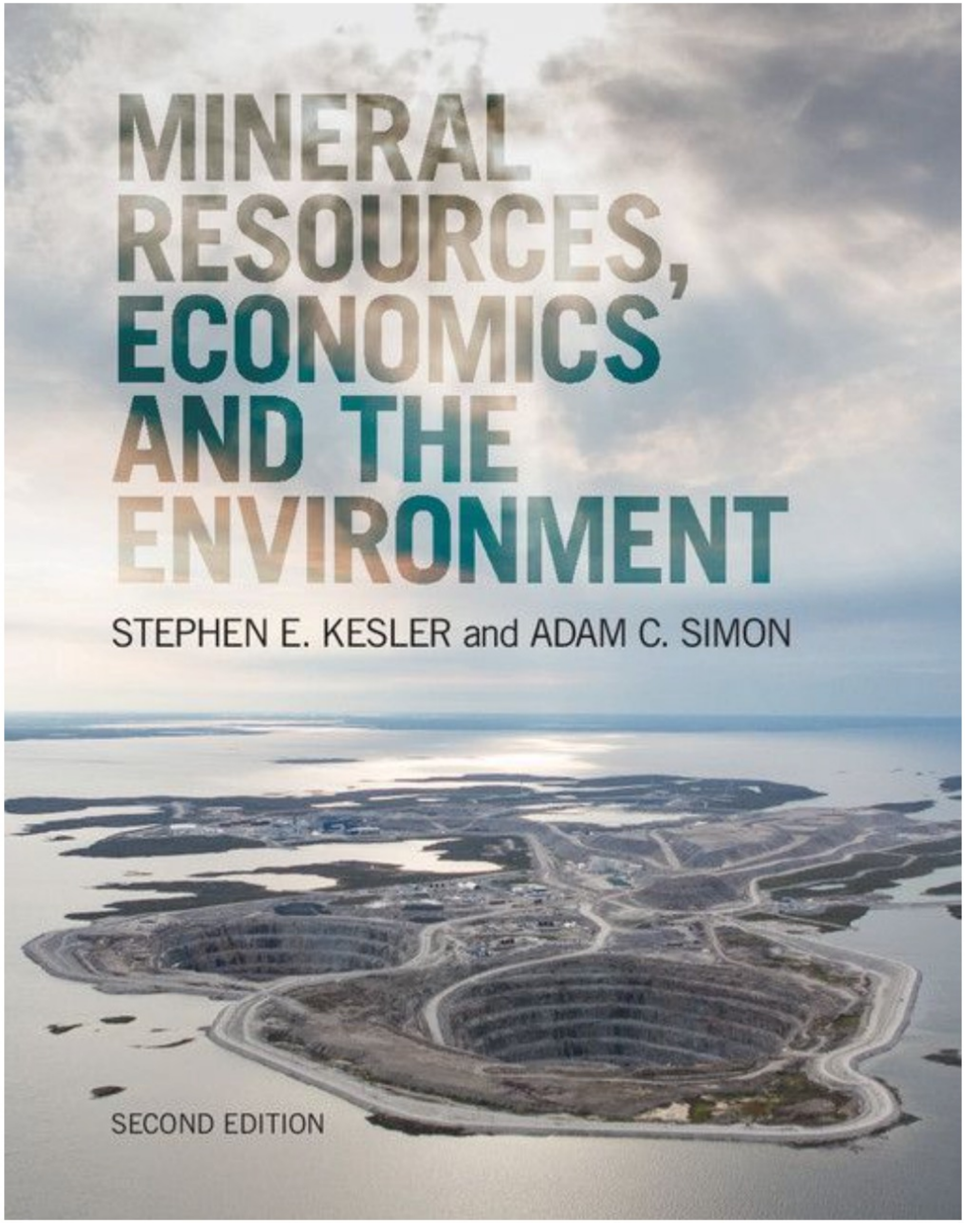
# U.S. Universities

Geoscience faculty (all ranks) = 15,000

Economic Geology faculty (all ranks) = **27**

# Future atmospheric temperature


Mining is necessary,
but where?
Mining is evil
UNPLEASANT TRUTHS
COMFORTING LIES

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