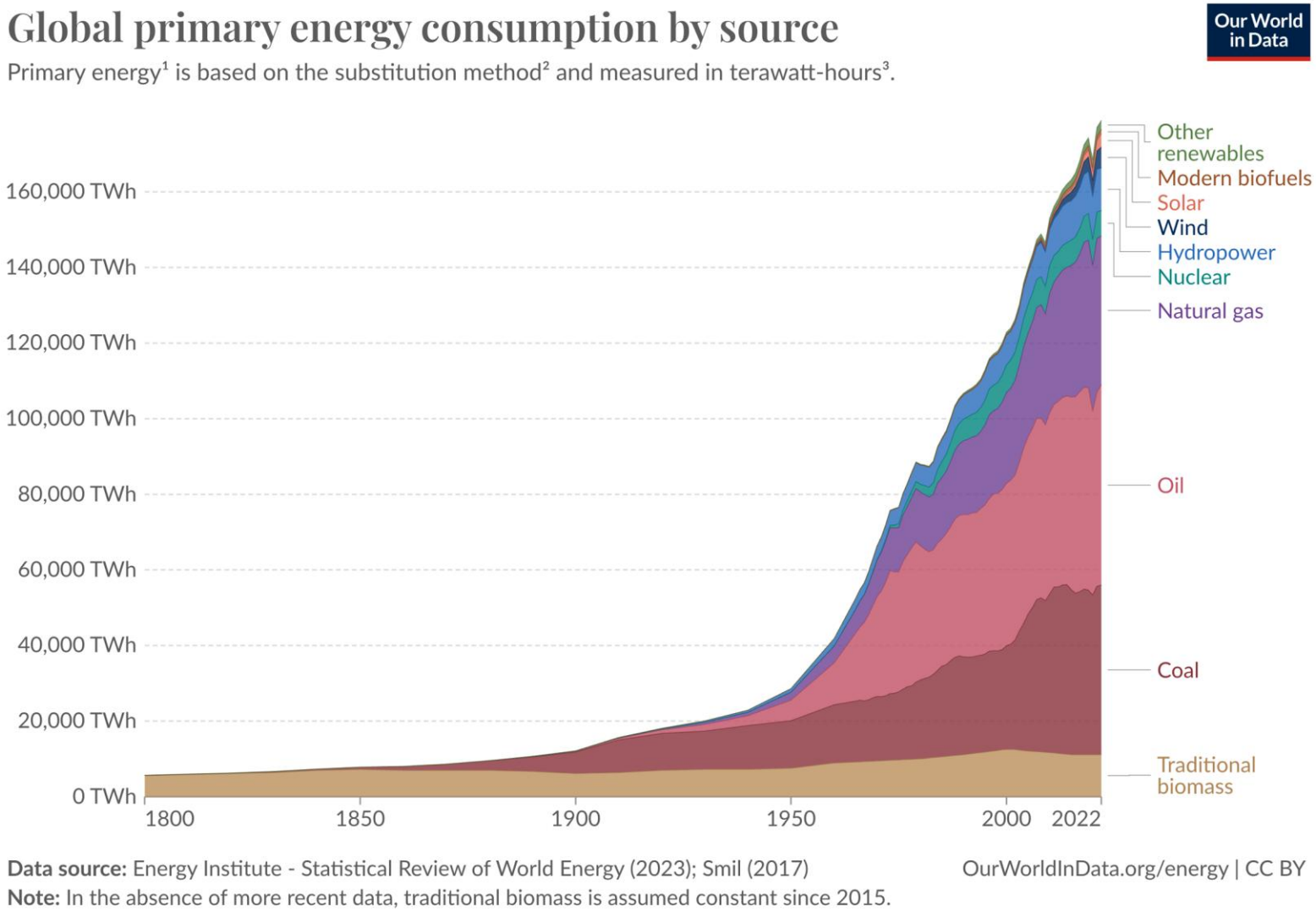
The mining workforce gap

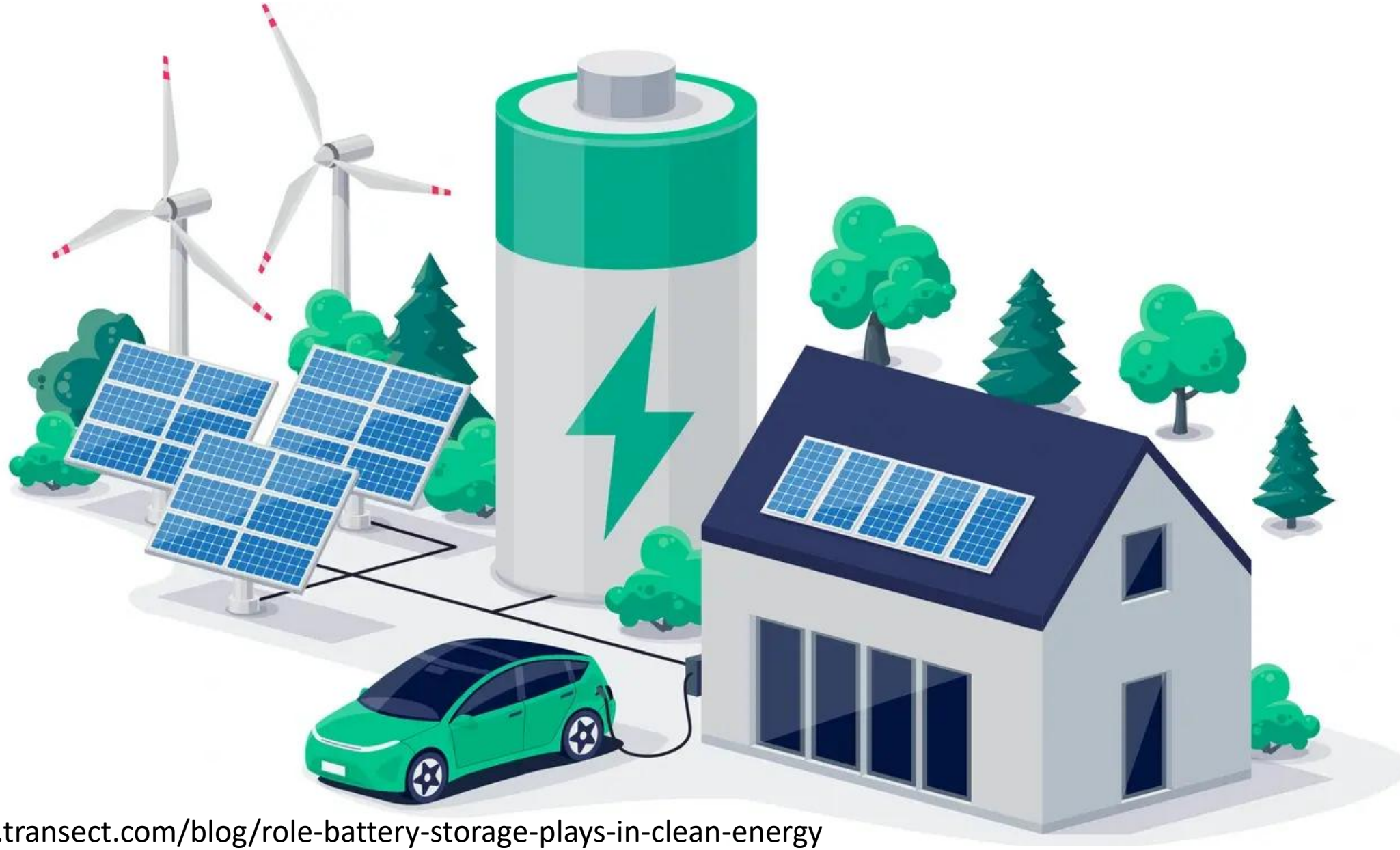
John Bradford

Vice President for Global Initiatives

Colorado School of Mines

A Brief History of Energy Transitions





https://www.transect.com/blog/role-battery-storage-plays-in-clean-energy

Minerals in

ELECTRIC VEHICLES VS GAS CARS

Electric vehicles require a wider range of minerals for their motors and batteries compared to gas cars.

In fact, an EV can have 6 times more minerals than a gas car and be on average 340 kg heavier.

Mineral content kg/vehicle *Steel and aluminum not included.*

Electric Vehicle | Gas Car

EVs can contain more than a mile of copper wiring inside the stator to convert electric energy into mechanical energy.

	Electric Vehicle	Gas Car
Nickel	39.9 kg	11.2 kg
Manganese	24.5 kg	
Cobalt	13.3 kg	
Lithium	8.9 kg	
Copper	53.2 kg	22.3 kg
Graphite	66.3 kg	

Many EV motors use magnetic materials typically made with rare earths.

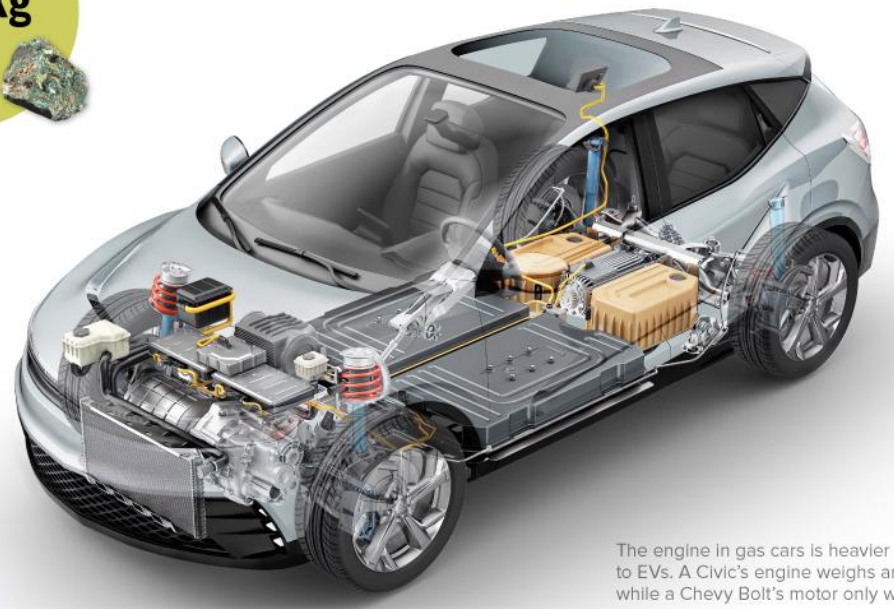
Rare Earths 0.5 kg

0.1 kg

0.1 kg Zinc

0.3 kg

0.3 kg Others



Graphite is the anode material in a lithium-ion battery and is the single largest component by weight.

The engine in gas cars is heavier compared to EVs. A Civic's engine weighs around 184 kg while a Chevy Bolt's motor only weighs 76 kg.

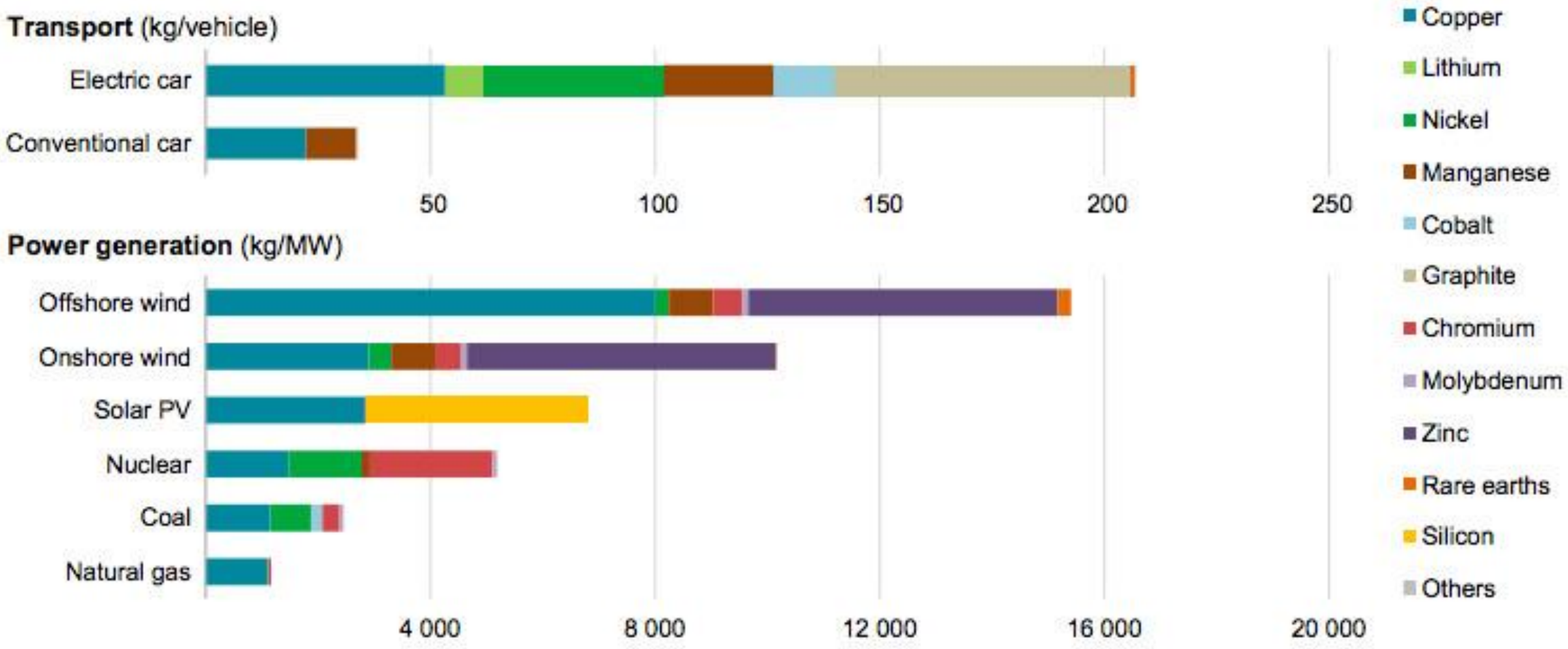
Source: IEA

The values are for the entire vehicle including batteries and motors. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode.

Source: elements.visualcapitalist.co

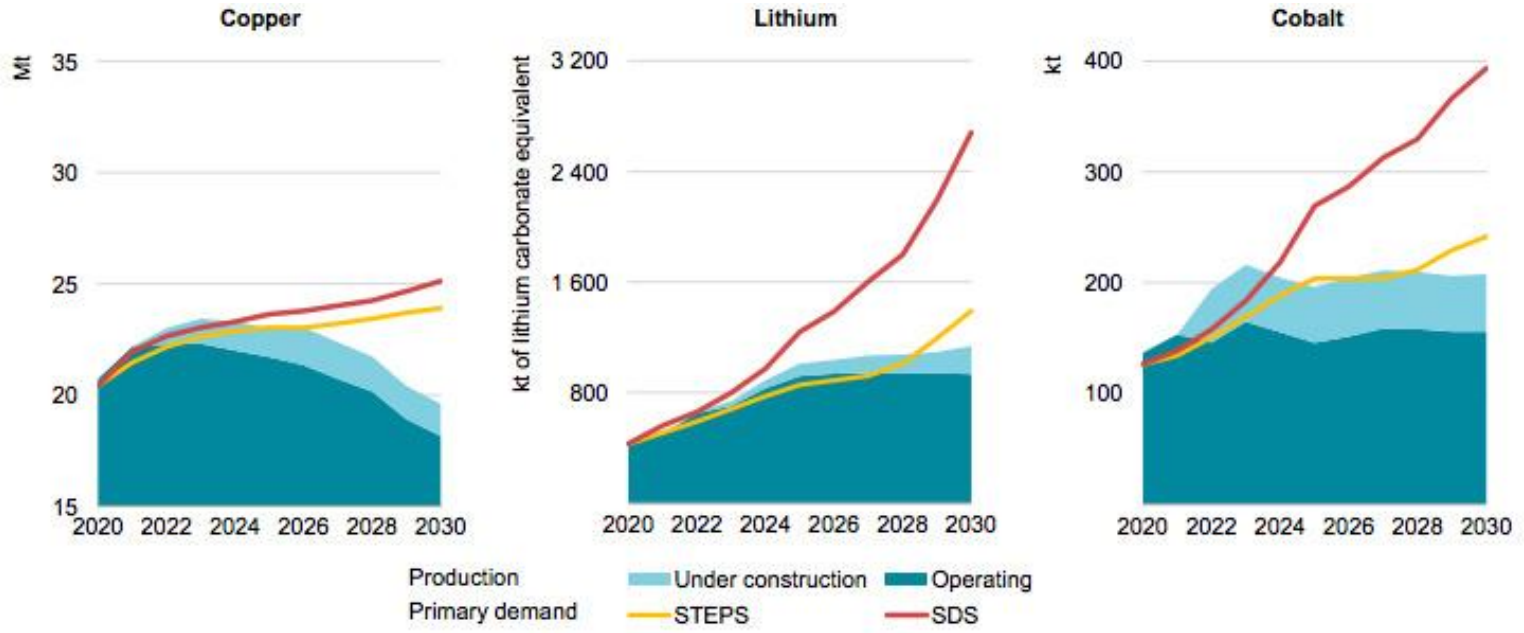
"[W]ind turbines, solar power stations and other facilities ... will require vast amounts of metals and other raw materials"

Vidal et al., 2013, Nature Geoscience



Source: International Energy Agency

Projected supply and demand for select critical minerals



IEA

Massive growth in demand for energy minerals and metals creates opportunity for the next generation

Energy Transition and Key Minerals at a Glance, *The Looming Minerals Famine, Clareo, 2023*

Source: International Energy Agency

State of the Workforce Global Case Studies

United States, Uzbekistan, Saudi Arabia

What is a critical mineral?

- Definitions vary by jurisdiction
- Some common factors
  - Economically important
  - Supply chain is threatened
  - Important to national security

Key Critical Minerals and Primary Uses

- **Copper:** Moves electricity efficiently; essential for power grids, electric vehicles, wind and solar infrastructure, data centers, and digital networks.
- **Lithium:** Stores energy in lithium-ion batteries used in electric vehicles, grid-scale storage, and consumer electronics.
- **Nickel and Cobalt:** Improve battery energy density and durability; also used in aerospace and industrial superalloys.
- **Uranium:** Fuel for nuclear power generation, providing reliable, low-carbon baseload electricity and long-term energy security.

Rare Earth Elements (REEs): A Distinct Subset

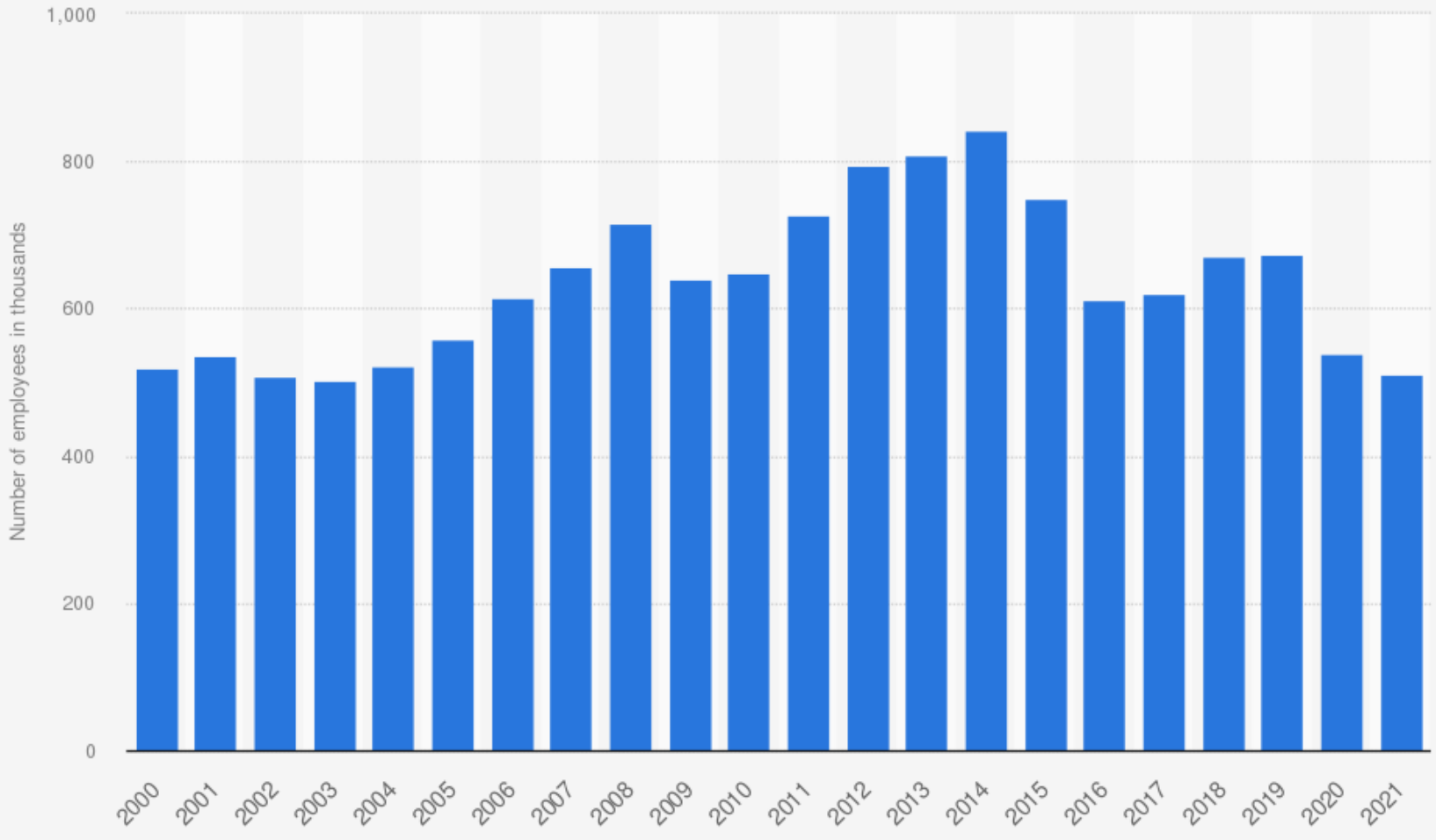
- 17 metallic elements comprising the 15 lanthanides plus scandium and yttrium
- **Permanent Magnets (Most Critical Use):** Neodymium, samarium, and dysprosium are used to create the strongest magnets known. These are essential for EV motors, wind turbines, computer hard drives, and robotics.
- **Electronics:** Cerium, terbium, and europium are crucial in flat-screen TVs, smartphones, and laptop displays.
- **Green Energy:** Used in catalysts for oil refining and in battery alloys for electric vehicles.
- **Defense Technology:** Essential for guidance systems, lasers, radar, and sonar.
- **Polishing and Glass:** Cerium oxide is a critical abrasive for polishing glass and manufacturing high-refractive-index glass for cameras.
- **Medical Applications:** Gadolinium is used in MRI contrast agents, and others are used in portable X-ray machines and laser technology.

U.S. Mining Workforce

Meeting the needs of the economy and energy requires more mining – and mining innovation

- Half of the current U.S. mining workforce (~221,000 workers) will be eligible for retirement by 2030
- U.S. conferred 327 mining and mineral engineering degrees in 2020
- 2023-4: 590 enrollments in U.S. undergrad programs, 126 graduates
- Industry demand: 400-600 per year
- Number of U.S. mining & mineral engineering schools: 15

Total employment in the United States mining industry from 2000 to 2021 (in 1,000s)*

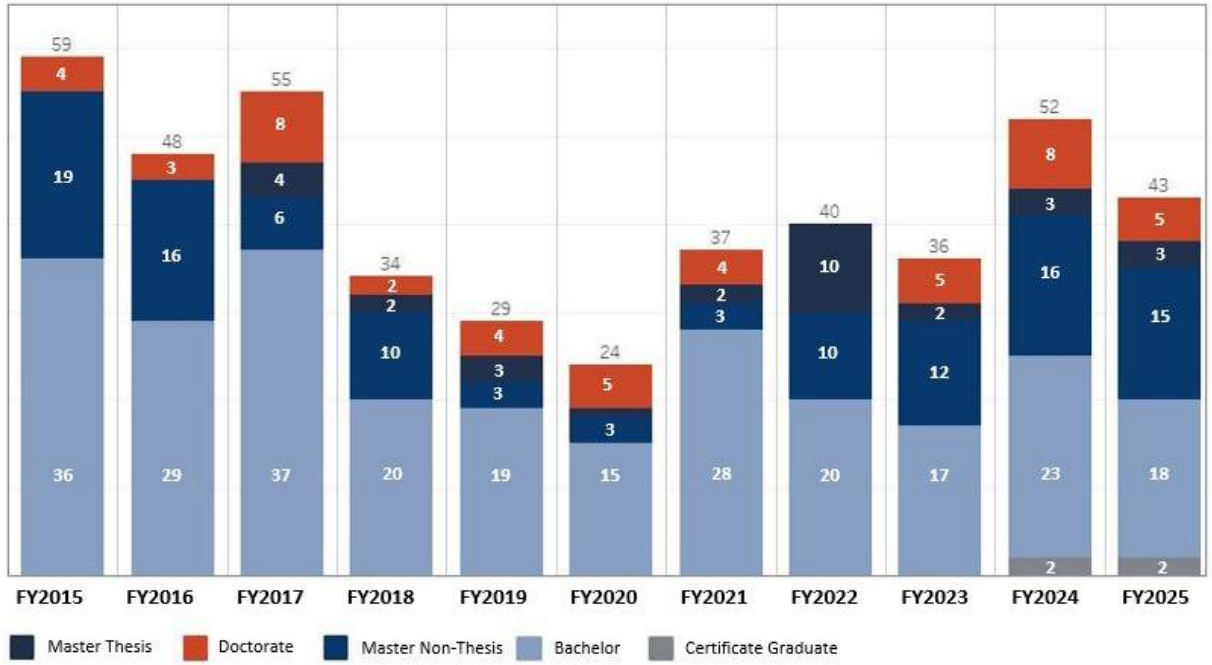


Source
BEA
© Statista 2023

Additional Information:
United States; 2000 to 2021

Mining Engineering

Degrees Awarded by Fiscal Year

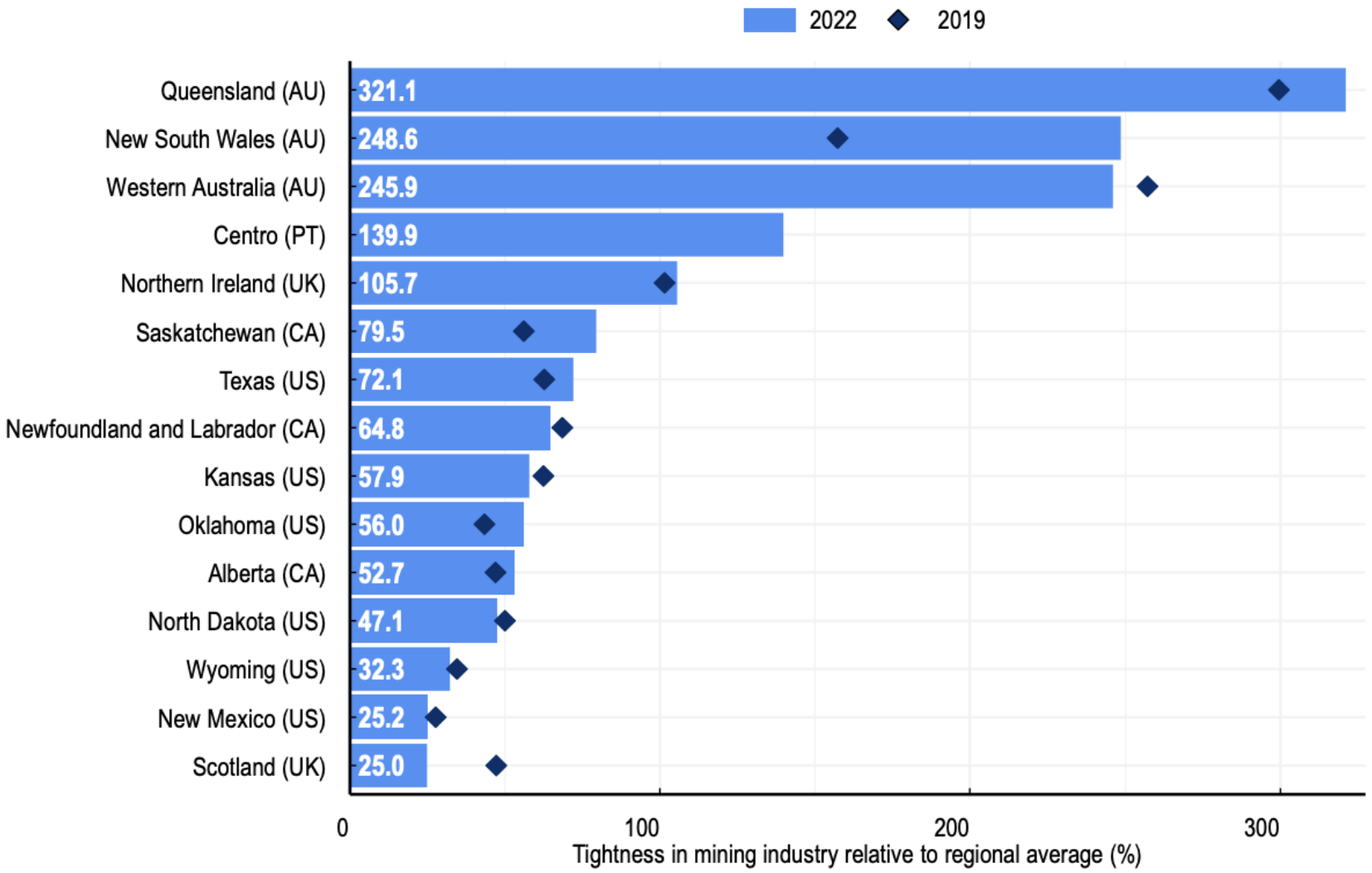


All Majors

Degrees Awarded by Fiscal Year

Workforce Gap remains large in many parts of the world

OECD, 2025



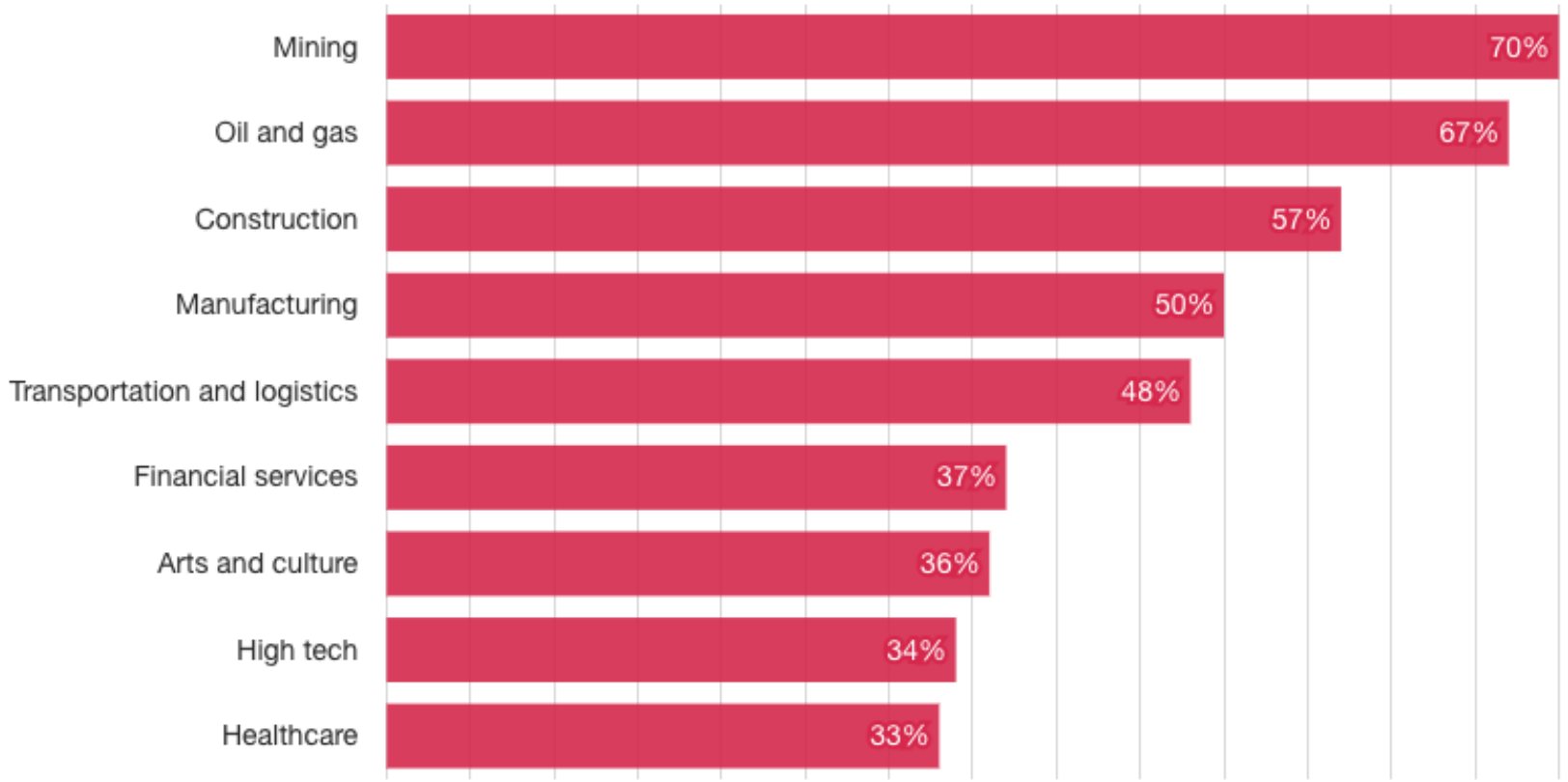
These are high paying jobs, so what's the problem?

Mining not yet recognized as critical to energy transition

Petroleum seen as dying industry

Both seen as dirty industries that harm the environment

Not recognized for high tech opportunities: Robotics, AI, quantum computing, satellite imaging …



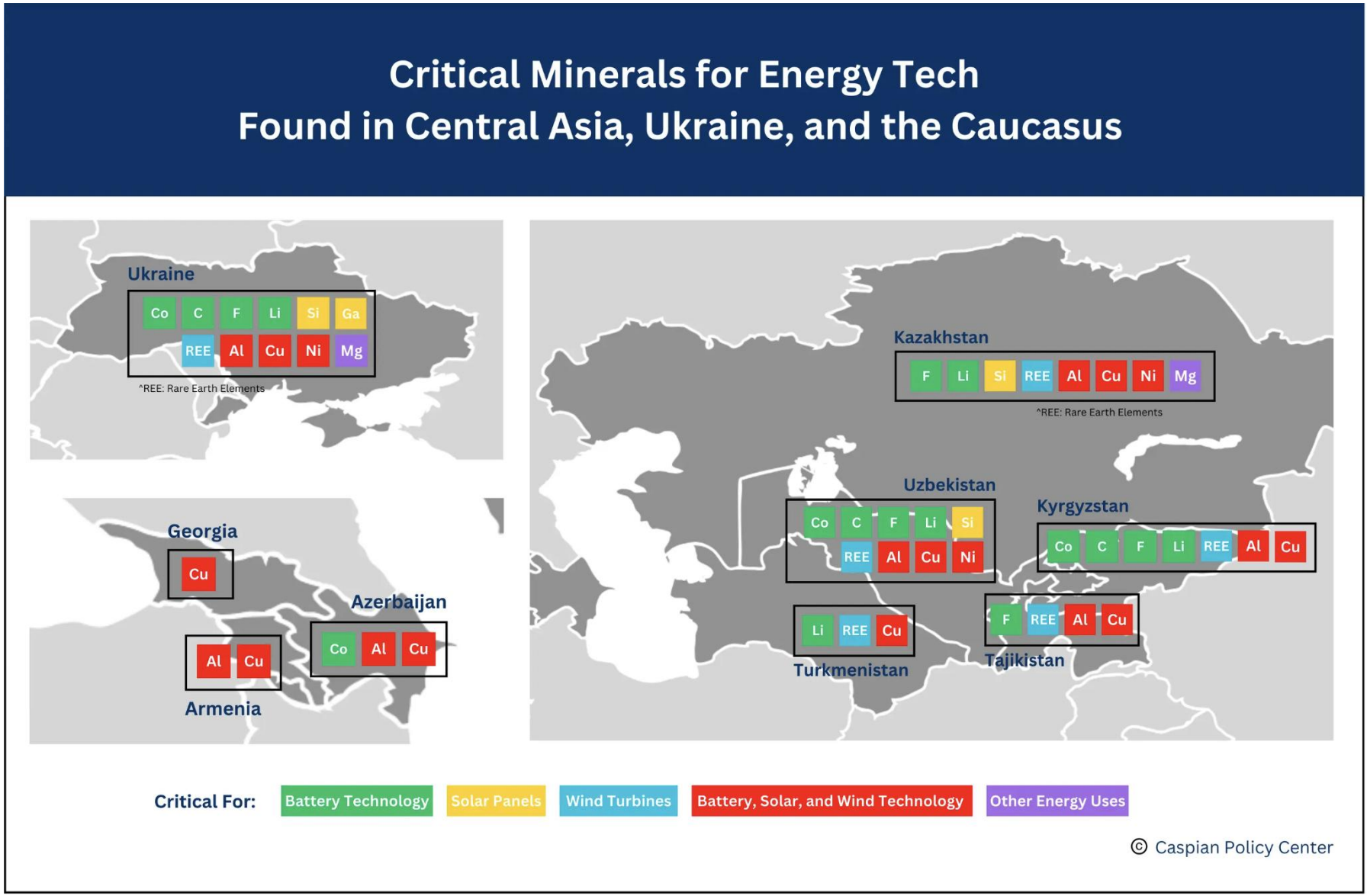
Note: In December 2020, 3,000 Canadians aged 15-30 were asked, 'How likely, if at all, would you consider working in these sectors?'
Source: Mining Industry Resources Council

*The **combined market value of key energy transition minerals** – copper, lithium, nickel, cobalt, graphite and rare earth elements – **more than doubles** to reach USD 770 billion by 2040 in the NZE Scenario.*

IEA Global Critical Minerals Outlook 2024

<u>Global reserves</u> – 38.6% of manganese ore, 30.1% of chromium, 20% of lead, 12.6% of zinc, 8.7% of titanium, 5.8% of aluminum, 5.3% each of copper and cobalt, and 5.2% of molybdenum.

The Hague Research Institute



Uzbekistan – Rapid Expansion and Skills Bottleneck

- **Gold** – Top-10 global producer; anchor of exports and fiscal revenues
- **Copper** – Aggressive production expansion targets tied to industrial policy
- **Uranium** – Strategic energy mineral with planned production growth
- **Rare Earths and Battery Metals** – Lithium, tungsten, molybdenum, vanadium gaining prominence
- **Magnesium and Aluminum** – Supporting downstream metallurgical and manufacturing ambitions

Mining represents approximately 12% of GDP and 40% of exports

- Copper targeted to increase from ~150,000 tpa to **~500,000 tpa by 2030**
- Requires **thousands of additional skilled technical workers**
  - Mining engineering and supervision
  - Mineral processing and refinery operations
  - Safety, ESG, and regulatory compliance
  - Technical training and faculty development
- **Implication:** Uzbekistan faces an **acute workforce bottleneck** driven by rapid production growth and limited domestic training capacity.

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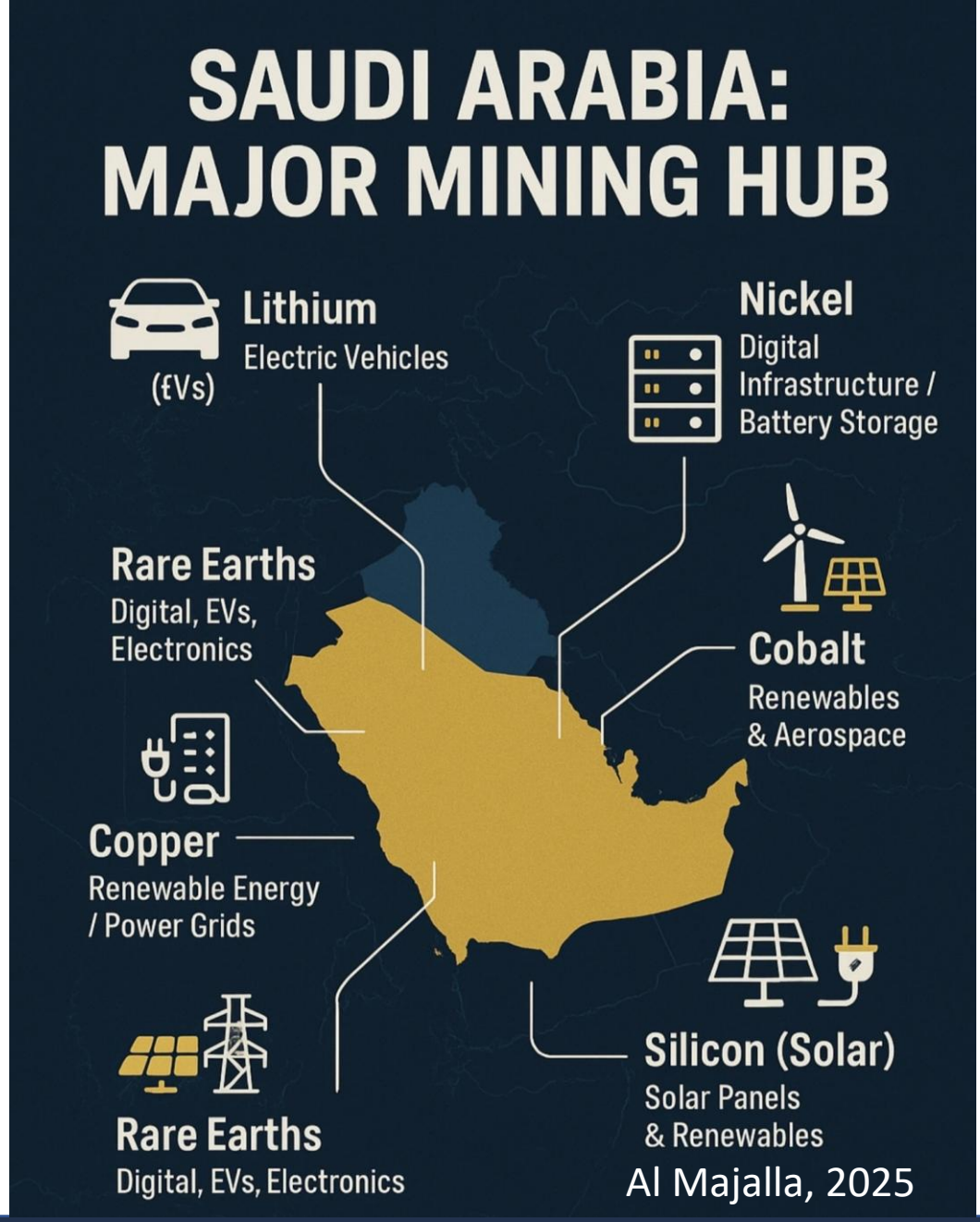
IEA Global Critical Minerals Outlook 2024

Saudi Arabia estimates its untapped mineral reserves to be worth approximately $2.5 trillion.



Al Majalla, 2025

Saudi Arabia – Vision 2030 Mineral Growth and Job Creation

- **Gold and Copper** – Dominant exploration focus and early-stage growth anchors
- **Phosphate** – Fertilizer and food-security value chains
- **Bauxite** – Aluminum and industrial manufacturing integration
- **Rare Earth Elements** – Electric vehicles, renewables, and advanced manufacturing
- **Zinc and Nickel (emerging)** – Supporting clean-tech and specialty materials

Saudi Arabia's Vision 2030 targets mining: Aims to create tens of thousands of new jobs

- Exploration spending has increased by roughly **500% since 2020**
  - Exploration geologists and geophysicists
  - Mining and mineral processing engineers
  - Automation, AI, and digital-mining specialists
  - National workforce development and training capacity (Saudization)
- **Implication:** Saudi Arabia represents the **large workforce gap**

What skills are needed?

- Mining Sector
  - Exploration Geophysics
  - Economic Geology
  - Mining Engineering
  - Extractive Metallurgy
  - Environmental Engineering
  - Data Science, AI
  - Robotics
  - Engineering Management
  - Resource Economics
  - Policy, regulation, global best practice
  - Community relations
  - …
- Petroleum Sector
  - Exploration Geophysics
  - Petroleum Geology
  - Petroleum Engineering
  - Petrochemical Processing
  - Environmental Engineering
  - Data Science, AI
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  - Petrochemical Processing
  - **Environmental Engineering**
  - **Data Science, AI**
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  - Resource Economics
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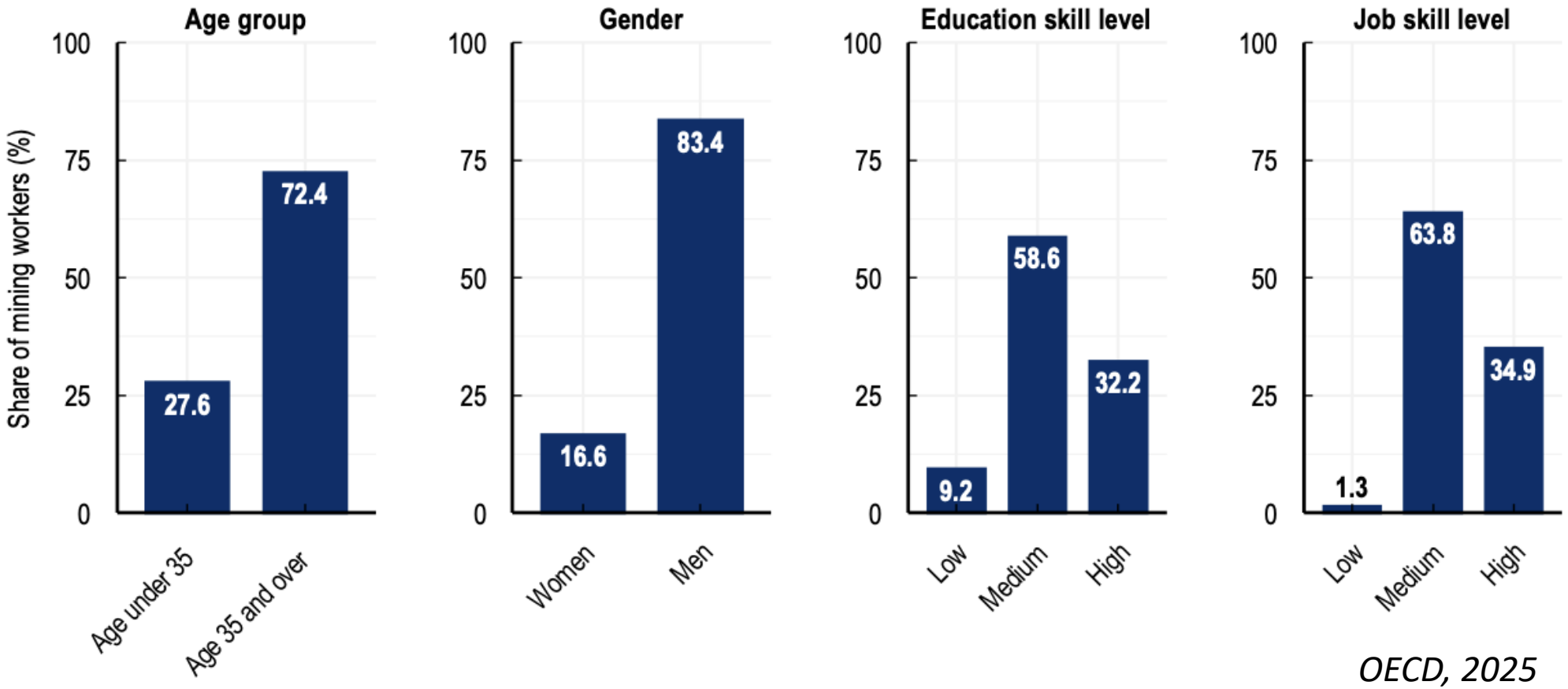
  - **Community relations**
  - …

A large part of the talent pool is being missed!



OECD, 2025

Meeting the challenge means investing in education

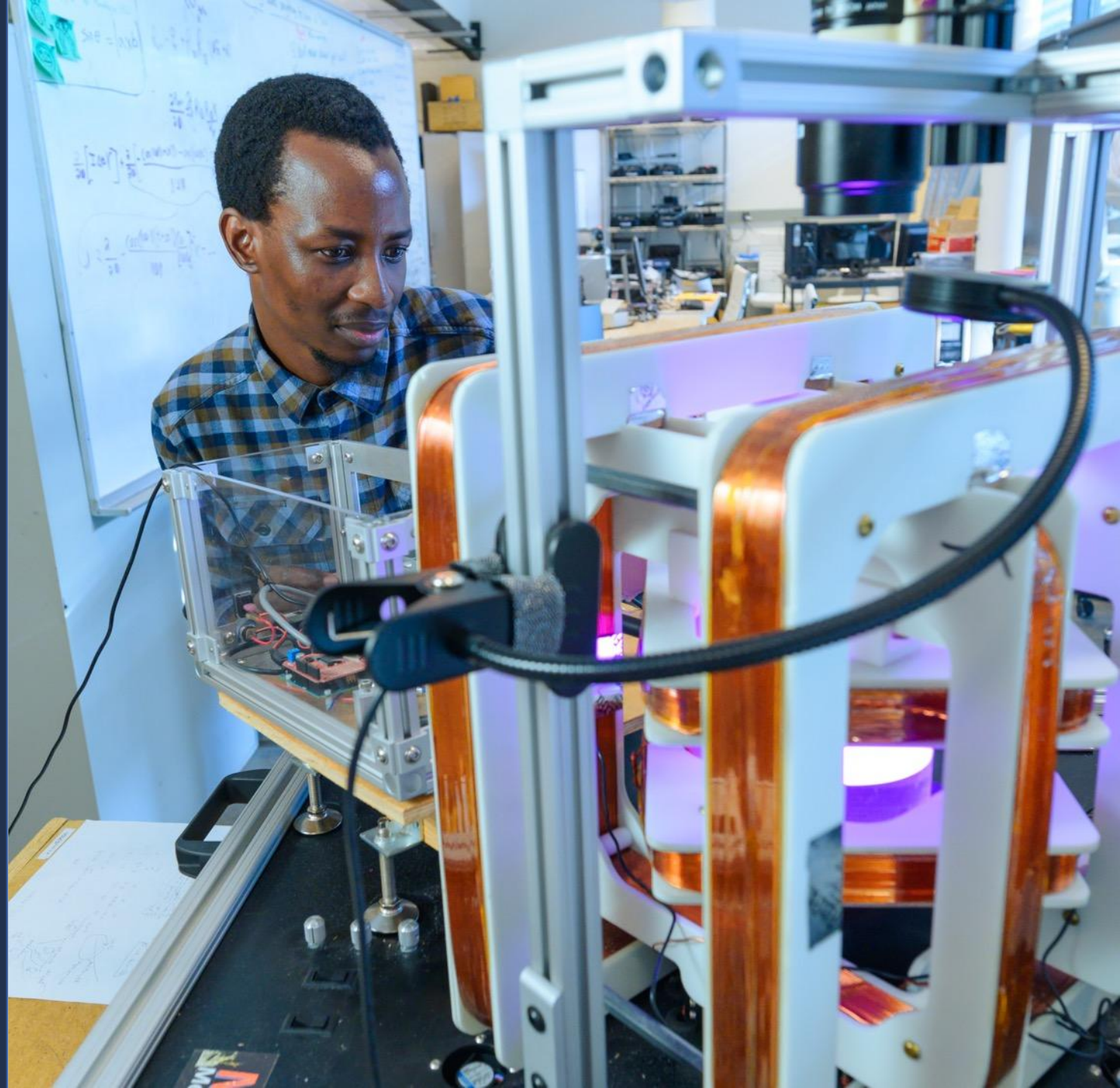
How to solve the most critical challenges as quickly as possible

Professional education to upskill/reskill existing workforce

Invest in modern laboratory facilities and train existing faculty

Build programs that spark innovation

Invest in the youth, the future mining leaders



COLORADO SCHOOL OF MINES