BANCA D'ITALIA
EUROSISTEMA

The potential macroeconomic relevance of critical materials: some preliminary evidence

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The views expressed in this presentation may not reflect those of Banca d'Italia

Introduction

- **Aim of the talk:**
  - discuss macroeconomic relevance of critical-material markets
- **Why**:
  - need to understand whether central banks should regularly monitor critical-material markets (e.g., for inflation-forecasting purposes)
- **Main aspects analyzed / discussed:**
  - **1)** market size; **2)** price volatility; **3)** substitutability / elasticity of demand; **4)** criticality / vulnerability to shocks
- **Scope**:
  - Mostly, macro transmission of "normal volatility" (outside war-like scenarios / extreme value-chain disruptions)

Market size

Methodology

- IEA's Global Critical Minerals Outlook 2024 as a starting point
  - Six main minerals: copper, nickel, lithium, graphite, cobalt, rare earths (Nd, Pr, Dy, Tb)
  - Estimates of yearly demand (kt of purified material)
  - 2023 + 2030 NZE scenario
- Cross-check IEA with other sources (+ reverse engineering)
- Own price data and scenarios applied to IEA's quantities

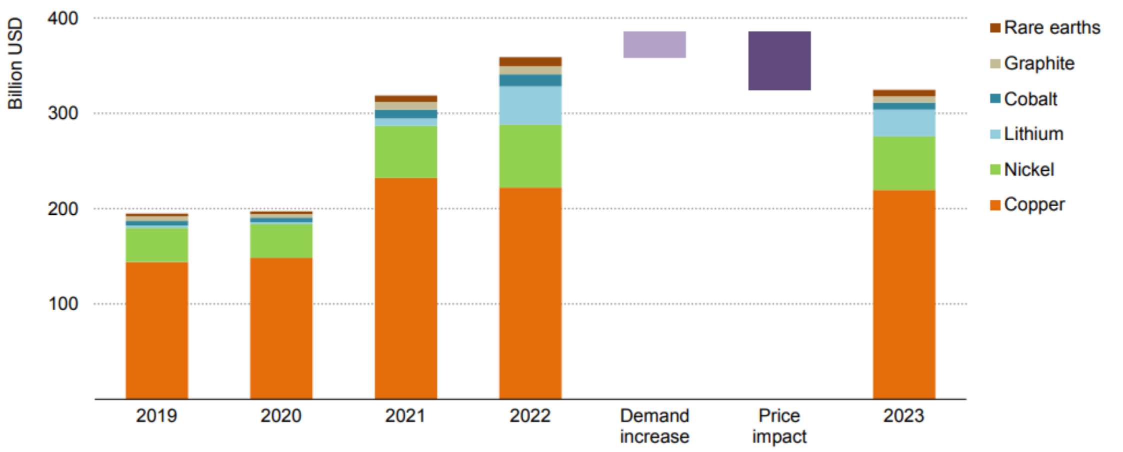
Market value of demand (USD bn; 2023 avg. prices)

	Total	Cleantech
Copper	220.9	54.3
Nickel	67.4	10.4
Lithium	34.1	19.0
Graphite	6.9	1.9
Cobalt	7.5	2.2
Rare earths	13.1	2.3
Total	349.8	90.1

Our estimates of **Total** largely agree with IEA's

Due to falling prices, the market size for key energy transition minerals contracted by 10% to USD 325 billion in 2023, despite demand growth

Market size for key energy transition minerals, 2019-2023



IEA. CC BY 4.0.

Notes: The market size for rare earth elements is based on the aggregate size of four magnet materials. In this year's assessment, rare earth elements and refined copper based on secondary scrap were included in the calculation, which raised the 2022 market size to USD 360 billion (up from USD 320 billion in the Critical Minerals Market Review 2023).

iea

For comparison: market value of fossil-fuel demand (USD bn; 2023 avg. prices)

	Total
Crude oil	2973
Natural gas	1268
Coal	939
Total fossil fuels	**5180**

Market value by technology (USD bn; 2023 avg. prices)

	EVs	Wind	Solar	E storage	E network	Other	Total
Copper	3.4	4.3	10.3	0.3	35.3	0.7	54.3
Nickel	6.5	1.0	0.0	0.3	0.0	2.6	10.4
Lithium	17.1	0.0	0.0	1.9	0.0	0.0	19.0
Graphite	1.7	0.0	0.0	0.2	0.0	0.0	1.9
Cobalt	2.1	0.0	0.0	0.1	0.0	0.0	2.2
Rare earths	0.9	1.3	0.0	0.0	0.0	0.0	2.3
Total	31.8	6.6	10.3	2.8	35.3	3.3	90.1
% of sales or investments	6.5	3.8	3.3	49.3	10.9	NA	6.9

2030 NZE scenario + stressed prices

	Total	Cleantech
Copper	364.2	163.8
Nickel	267.8	134.3
Lithium	330.8	289.0
Graphite	39.1	25.2
Cobalt	39.1	23.1
Rare earths	30.6	12.8
Total	1071.6	648.4

Highlights

- Size of main energy-critical materials markets still small (350 USD bn in 2023, of which 90 bn are energy-related)
- In NZE scenario, under additional hypothesis of price stress, size could surpass 1 tn mark in 2030 (similar to natural gas market)
- Does size similar to that of natural gas market imply similar macroeconomic relevance?
- <u>Need to consider other characteristics beyond size</u> (rest of the presentation)

Volatility

Need to assess volatility

- Size alone is not sufficient to assess macroeconomic relevance
- Price volatility needs to be taken into consideration
- Conceptual experiment: imagine the price of a commodity were completely stable (no volatility). Would it have macro impacts?

Annual price volatility of critical materials and fossil fuels (per cent)

Critical materials	Volatility		Fossil fuels	Volatility
Copper	19.5		Oil (Brent)	38.0
Nickel	37.4		Natural gas (TTF)	78.0
Lithium	49.6		Coal (API2)	37.5
Graphite	15.2			
Cobalt	33.4			
Rare earths	28.6			
CM Index 2023	18.6			
CM Index 2030	19.6			

- Sample: 2016-2024 (but results do not change materially on 2020-2024 sample)

Reasons for relatively low volatility

- Theory of storage (strong empirical evidence): commodities that have high (low) **storage costs** have high (low) volatility
  - high storage cost -> small stockpiles -> stockpiles are unable to absorb shocks, which are absorbed almost entirely by prices
  - storage costs for main critical materials between 0.5-2% per annum (vs. 5-20% for natural gas)
- For CM index, **diversification effects**
  - strong empirical evidence that idiosyncratic factors play a major role
- Volatility also related to **elasticity of demand** (in general, higher for intermediate goods, such as CM, used to produce durables and investment goods)

Highlights

- Even if the size of critical material markets reaches the size of the natural gas market, their lower volatility (especially as a complex) may limit their impact on macro variables
- There are structural reasons for lower volatility (storage costs!)
- But volatility may increase. IRENA (2023):
  - More speculation / market manipulation
  - More frequent disruptions of mining activities because of climate stress
  - Higher cartelization (? ambiguous effect according to literature ?)

Substitutability

The role of substitutability

- **How likely is it that we end up in a price-stress scenario** due to increasing demand?
- **Much will depend on substitutability**.
- By definition, critical materials are difficult to substitute
- But substitutability can improve due to technological progress
- Substitutability is usually difficult to assess because it is application-dependent, but energy applications relevant for green transition are few (batteries, wires, motors/generators), so something can be said

Aluminum is often (almost always?) a good substitute for copper

Copper scarcity will not materially slow down the energy transition

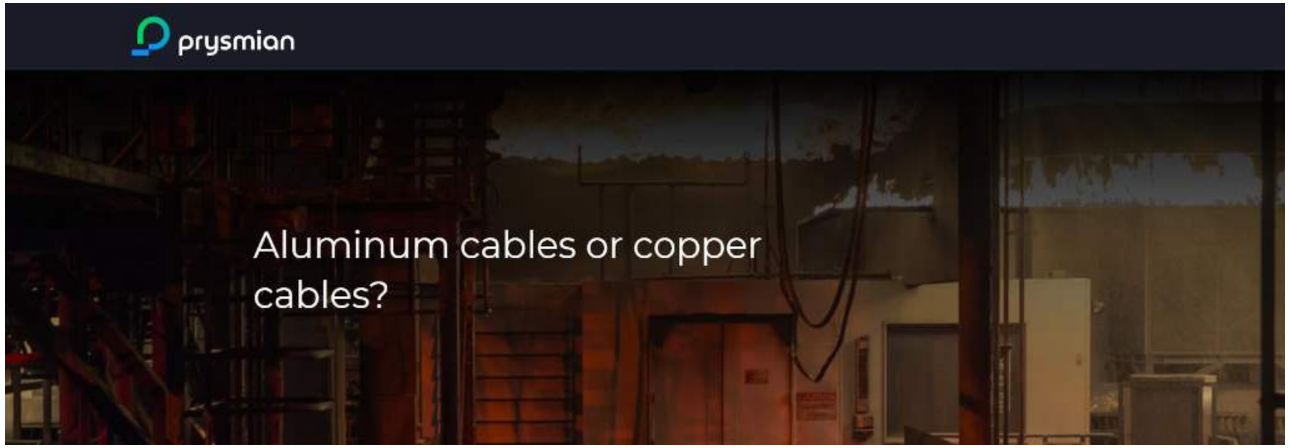
May 6, 2023 — by Auke Hoekstra in Renewable energy, Uncategorized

Auke Hoekstra, director of NEONresearch, a.e.hoekstra@tue.nl, @aukehoekstra

Abstract

Many scientific publications assert copper scarcity is a roadblock on the way to renewable energy, but almost none take substitution into account. Although copper demand could increase about 30% because the transition to renewable energy, substitution with aluminum is possible for almost all applications. Therefore, it is implausible that copper scarcity will hamper the transition to renewable energy.

Nexans
ELECTRIFY THE FUTURE



Lithium is being replaced by sodium (in low-density applications)

Volkswagen-backed EV maker rolls out first sodium-ion battery powered electric car

Peter Johnson | Dec 27 2023 - 11:10 am PT | 66 Comments

Iberdrola

Sodium-ion batteries

Sodium-ion batteries: the revolution in renewable energy storage

Battery

CATL gears up for next-gen SIBs and global licensing

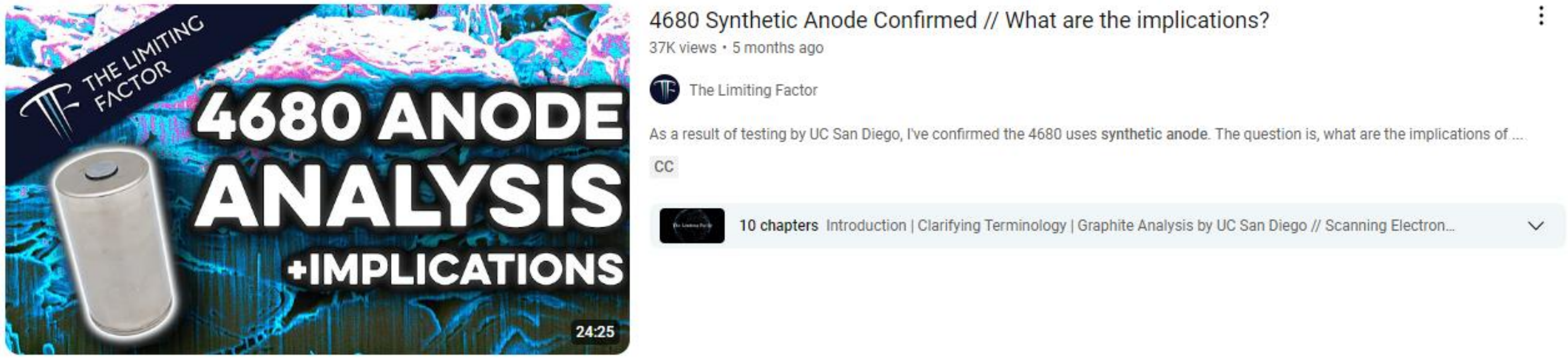
CATL is developing second-generation sodium-ion batteries with an energy density of 200 Wh/kg. The Chinese battery leader is also talking with a dozen car manufacturers about licencing partnerships that could allow OEMs to build their own batteries with CATL technology.

First-ever commercial-scale production of sodium-ion batteries in the US

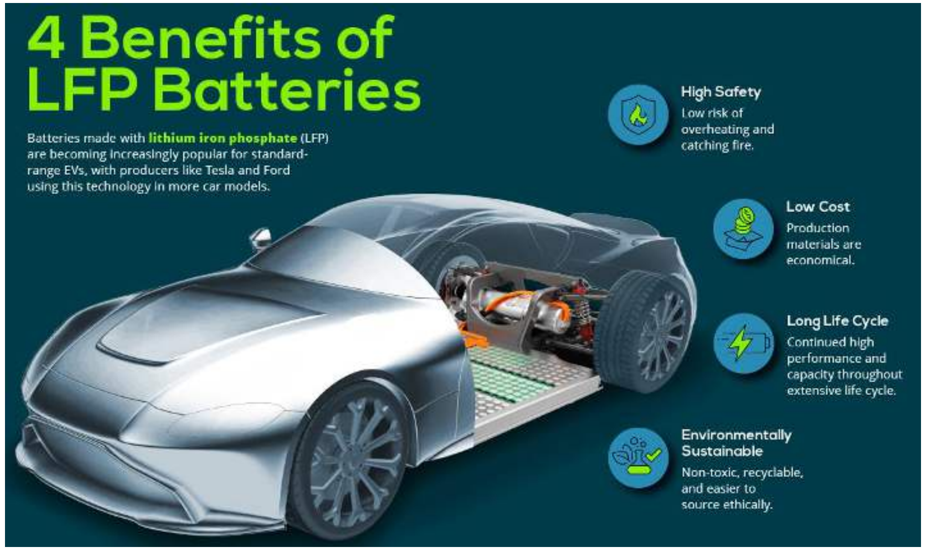
By Michelle Froese | May 3, 2024

Natron Energy, Inc., a global provider of sodium-ion battery technology, announced the commencement of commercial-scale operations at its sodium-ion battery manufacturing facility in Holland, Michigan. Natron's milestone marks the first-ever commercial-scale production of sodium-ion batteries in the US.

Synthetic graphite is a viable substitute for natural graphite



There are production-ready alternatives (e.g., LFP) to cobalt-based chemistries



Forbes

FORBES > LIFESTYLE > CARS & BIKES

Lithium Iron Phosphate Set To Be The Next Big Thing In EV Batteries

Autos & Transportation | ADAS, AV & Safety | Sustainable & EV Supply Chain | EV Battery

Tesla to bring LFP battery supply chain to US - Bloomberg News

By Reuters

January 31, 2024 11:32 PM GMT+1 · Updated 7 months ago

Aa

Electric Vehicles

LFP Becoming the Battery of Choice for Electric Vehicles

June 22, 2023

Technological advances have helped lithium-iron-phosphate batteries edge past EV batteries made of nickel and cobalt, experts say

Several new battery chemistries contain no nickel

Will LFP Undermine the Prospects of Nickel-Based Batteries?

06 March 2024

It has been suggested that batteries made from lithium ferro phosphate (LFP) could erode the prospects of nickel, a commodity that is expected to become Indonesia's mainstay in the future.

Sodium-ion batteries (**NIBs**, **SIBs**, or **Na-ion batteries**) are several types of rechargeable batteries, which use sodium ions (Na^+) as their charge carriers. In some cases, its working principle and cell construction are similar to those of lithium-ion battery (LIB) types, but it replaces lithium with sodium as the intercalating ion. Sodium belongs to the same group in the periodic table as lithium and thus has similar chemical properties. However, in some cases, such as aqueous batteries, SIBs can be quite different from LIBs.

SIBs received academic and commercial interest in the 2010s and early 2020s, largely due to lithium's high cost, uneven geographic distribution, and environmentally-damaging extraction process. An obvious advantage of sodium is its natural abundance,[2] particularly in saltwater. Another factor is that cobalt, copper and nickel are not required for many types of sodium-ion batteries, and more abundant iron-based materials (such as $NaFeO_2$ with the Fe^{3+}/Fe^{4+} redox pair) [3] work well in Na^+ batteries. This is because the ionic radius of Na^+ (116 pm) is substantially larger than

Sodium-ion battery

A sodium-ion cell (size 18650)

Specific energy	0.27-0.72 MJ/kg (75–200 W·h/kg)
Energy density	250–375 W·h/L
Cycle durability	"thousands"[1] of cycles
Nominal cell voltage	3.0-3.1 V

Alternatives to rare earths are being developed

Researchers Find Possible Replacement for Rare Earth in Magnets

- New way of making tetrataenite could help produce magnets
- More work is needed to determine if method is suitable

By Bloomberg News

BUSINESS AND INNOVATION | FEATURE

Powering the green economy: the quest for magnets without rare earths

10 Oct 2023 James McKenzie

Rare-earth elements are vital for the magnets found in electric cars, wind turbines and other parts of the "green economy". But with uncertainties over the supply of these materials, **James McKenzie** reports on the importance of magnets that avoid rare earths entirely

ECONOMY & TECH

Japanese Advances in Rare Earth Alternatives Bring Many Advantages

China has a chokehold on access to rare earth minerals used in technologies such as EV engines. These new alternatives will provide welcome supply chain relief.

AI’s impact on materials science is disruptive

Google DeepMind

RESEARCH

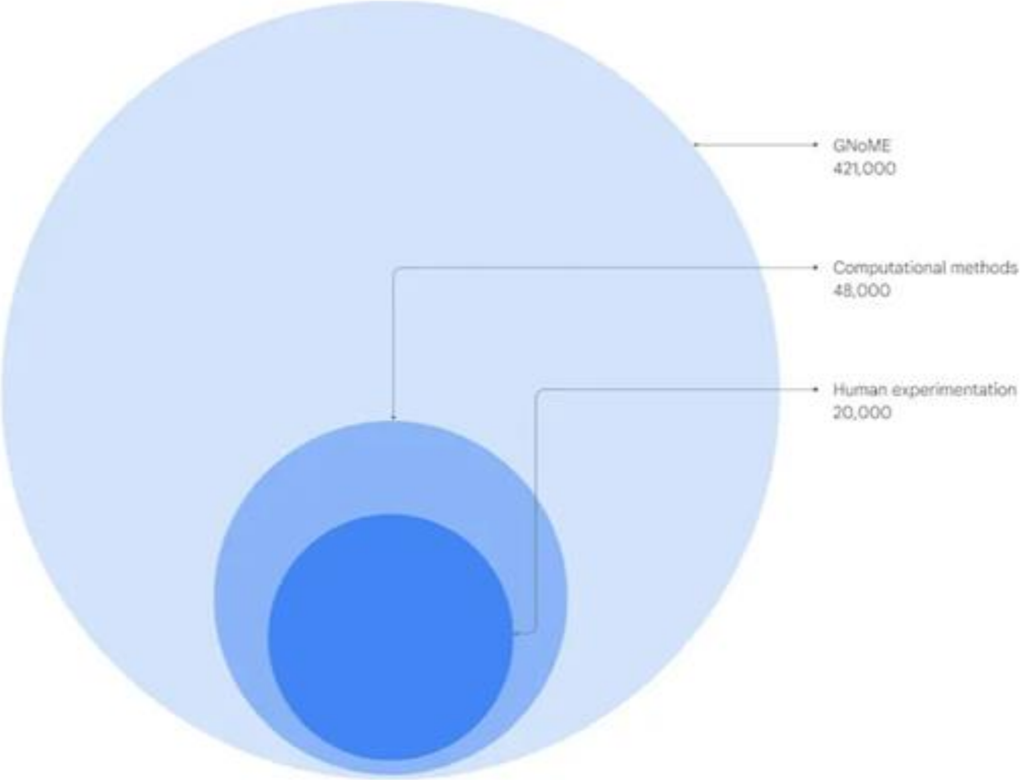
Millions of new materials discovered with deep learning

29 NOVEMBER 2023

Amil Merchant and Ekin Dogus Cubuk

Share

Accelerating materials discovery with AI



About 20,000 of the crystals experimentally identified in the ICSD database are computationally stable. Computational approaches drawing from the Materials Project, Open Quantum Materials Database and WBM database boosted this number to 48,000 stable crystals. GNoME expands the number of stable materials known to humanity to 421,000.

Highlights

- Decades of investments in green tech and materials science **R&D** are paying off
  - Chinese giants like CATL and BYD are now investing several bn USD / year in battery R&D
- Several cheap and largely available materials are quickly becoming viable substitutes of critical materials in energy applications
- Rare earths seem to be the most problematic materials, as far as the lack of production-ready alternatives is concerned
- AI’s impact on materials science is disruptive
  - DeepMind’s GNoME project increased number of known stable crystals by 10X

Criticality

The role of criticality

- Degree of criticality will be an important determinant of macro impact
- Criticality = Use in strategic sectors + Low substitutability + Significant risk of supply disruptions
- High criticality → High risk of price spikes / extreme volatility → Likely high macro impact
- Very hard to assess and measure. Paper is very nuanced about this topic. Few aspects covered in this presentation.

Risk of extreme supply disruptions

- By definition, large and persistent drops in the availability of a critical material can shut down entire supply chains and seriously harm economies
- Basically never happened since WWII, but Russia-Ukraine war and related natural gas market disruptions have raised concerns that something similar could happen with critical materials
- This tail risk is thoroughly analyzed in BoI paper (Panon et al. 2024)

Geographic concentration + fragmentation

- Number of **export restrictions** on critical materials has increased steadily worldwide (Kowalski and Legendre 2023)
- Mostly export taxes and licensing requirements
- Few export prohibitions
- More export prohibitions could be disruptive, but (luckily) do not align with political incentives:
  - Maintain high tax revenues
  - Avoid harming local businesses
  - Extract benefits from controlling the issuance of licenses

Copper is a heavy-weight in terms of market size, but not very critical

- Criticality is high for most of the IEA’s energy-critical materials, but not (at all?) for **copper**:
  - Large and mature market
  - Production is not highly concentrated
  - Significant portion of demand met by recycling
  - Highly substitutable with aluminum
  - US: not critical for DOI, critical for DOE; EU: strategic but not critical
  - 3 out of 32 surveyed criticality studies deemed copper critical (Hayes and McCullough 2018)

Evolution of criticality is difficult to foretell

- Evolution of criticality difficult to predict because of countervailing forces at play
- Positive factors:
  - Increasing substitutability / technological progress
  - Policymakers’ continued efforts to enhance supply-chain resilience
  - Rapid progress in recycling (which reduces strategic dependences)
- Negative factors:
  - Fast increasing demand in a strategic sector (energy)
  - Increased geopolitical fragmentation

Conclusions

Concluding remarks

- Macroeconomic impact of developments in critical-materials market may become material in the medium term
- Several factors to take into consideration
  - Size, volatility, substitutability, criticality
- Preliminary assessment reveals several knowledge gaps and absence of quantitative frameworks to simultaneously account for all the relevant factors
- Topics worth investigating
  - Elasticity of demand
  - “Transparent” macro models

Thank you for your attention!

Background material

IEA Global Critical Minerals Outlook 2024

- Very interesting and comprehensive report
- Complemented by Critical Minerals Data Explorer (open, but only quantities demanded and supplied)
- Some estimates of market size (unnumbered charts in report, but no dataset)
- Few details about methodology (hence, need for “reverse engineering”)

Critical ~~minerals~~ materials

- Demand estimates and projections (in kt) refer to **purified materials** (in some cases abstract statistical concepts), not to minerals:
  - Grade A copper (99.9% pure)
  - B39-79 nickel (99.8% pure)
  - Pure lithium (6.05 conversion factor to lithium hydroxide monohydrate)
  - Graphite “XL flake equivalents” (natural + synthetic)
  - Standard-grade cobalt (99.8% pure)
  - Mix of pure rare earths (Nd 73%; Pr 21%; Dy 4%; Tb 2%)

IEA’s input data (demand estimates in kt of pure material)

	2023		2030 Announced Pledges	
	Total	Cleantech	Total	Cleantech
Copper	25915	6372		
Nickel	3104	478		
Lithium	165	92		
Graphite	4632	1292		
Cobalt	215	64		
Rare earths	93	16		

United States

- Department of the Interior (USGS) critical "minerals":
  - Commodities analyzed: **65** (54 quantitative assessment + 11 qualitative evaluation)
  - Found critical: **50** (36 exceed quantitative threshold + 3 single-point-of-failure + all 11 evaluated qualitatively)
- Department of Energy critical materials:
  - Commodities analyzed: **38**
  - Found critical: **18** (of which 5 not included by DOI: copper, electrical steel, fluorine, silicon, silicon carbide)

United States

- **Critical materials for energy ("the electric eighteen")**: aluminum, cobalt, copper, dysprosium, electrical steel, fluorine, gallium, iridium, lithium, magnesium, natural graphite, neodymium, nickel, platinum, praseodymium, silicon, silicon carbide and terbium.
- **Critical minerals**: The Secretary of the Interior, acting through the director of the U.S. Geological Survey, published a **2022 final list of critical minerals that includes the following 50 minerals:** "Aluminum, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, cobalt, dysprosium, erbium, europium, fluorspar, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, and zirconium."

European Union

Bauxite	**Coking Coal**	**Lithium**	**Phosphorus**
Antimony	**Feldspar**	Light rare earth elements	Scandium
Arsenic	Fluorspar	Magnesium	Silicon metal
Baryte	Gallium	**Manganese**	Strontium
Beryllium	Germanium	Natural Graphite	Tantalum
Bismuth	Hafnium	Niobium	Titanium metal
Boron/Borate	**Helium**	Platinum group metals	Tungsten
Cobalt	Heavy rare earth elements	Phosphate Rock	Vanadium
		Copper	**Nickel**

- 70 candidates, 29 found critical + 3 groups (light and heavy REE + platinum group)
- Copper and nickel are **strategic**, but not critical

Recycling technology progresses at a fast pace

MIT Technology Review

Featured Topics Newsletters

Recycling facilities can now recover nearly all of the cobalt and nickel and over 80% of the lithium from used batteries and manufacturing scrap left over from battery production—and recyclers plan to resell those metals for a price nearly competitive with that of mined materials. Aluminum, copper, and graphite are often recovered as well.

Owing to technological advancements, a positive market outlook, and an increasing number of discarded batteries, the battery recycling volume has increased annually, from 9 GWh in 2019 to 50 GWh in 2024, with projections estimating a surge of over 230 GWh by 2030, as shown in Fig. Jun 29, 2024

ScienceDirect.com
https://www.sciencedirect.com › science › article › pii

Advances in lithium-ion battery recycling: Strategies, pathways ...

Large-scale use of a critical material incentivizes search for substitutes

“Brains outpace mines. Let’s not let myths outpace truth.”

Lovins, A. (2021) “Reality Check: Greener, Friendlier Alternatives Exist for Rare Minerals in Batteries,” Rocky Mountain Institute.

Your turn to speak

Issues for discussion

- Volatility: *Are there factors that might structurally increase the volatility of critical materials going forward? Or will current moderating factors prevail?*

- Substitutes: *Do you think that the availability of good substitutes will make any of the "big 6 materials" less critical going forward? Which critical materials are most affected by the lack of viable substitutes? In your opinion, do existing analyses properly take substitutes into account?*

- Criticality: *Do you think that copper is a critical material? Why? Are the methodologies currently used to identify critical materials sound? Is criticality increasing or decreasing? Are current policies aimed at keeping criticality in check successful?*