CRITICAL MINERALS AND MATERIALS FOR ENERGY TRANSITION

INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH, KOLKATA
SUSTAINABILITY AND CHEMISTRY: A SYSTEMS APPROACH
CH 5106 – LECTURE 11
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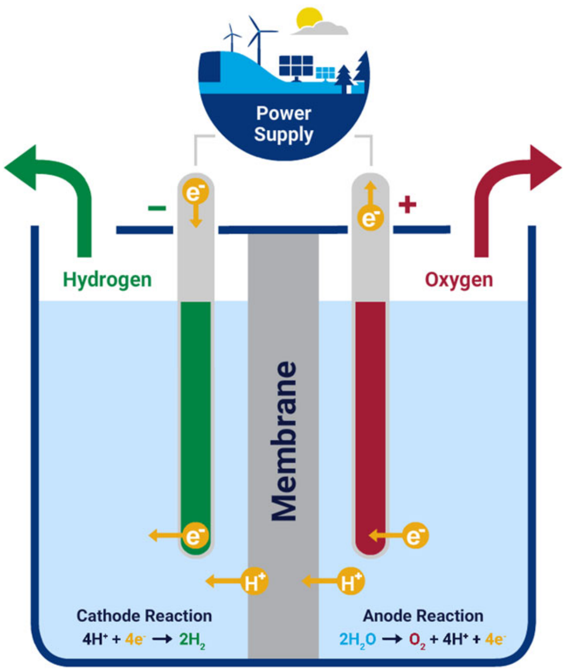
LOW CARBON ENERGY TECHNOLOGIES

MATERIALS CRITICALITY

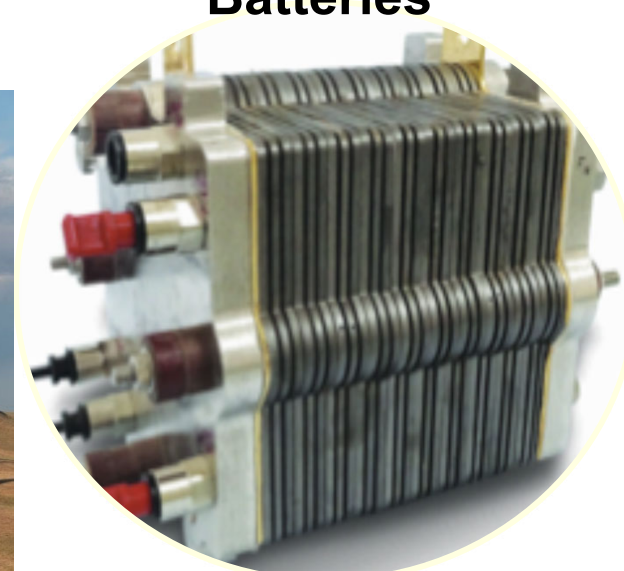


Electrolysers (Water)

Solar

Batteries

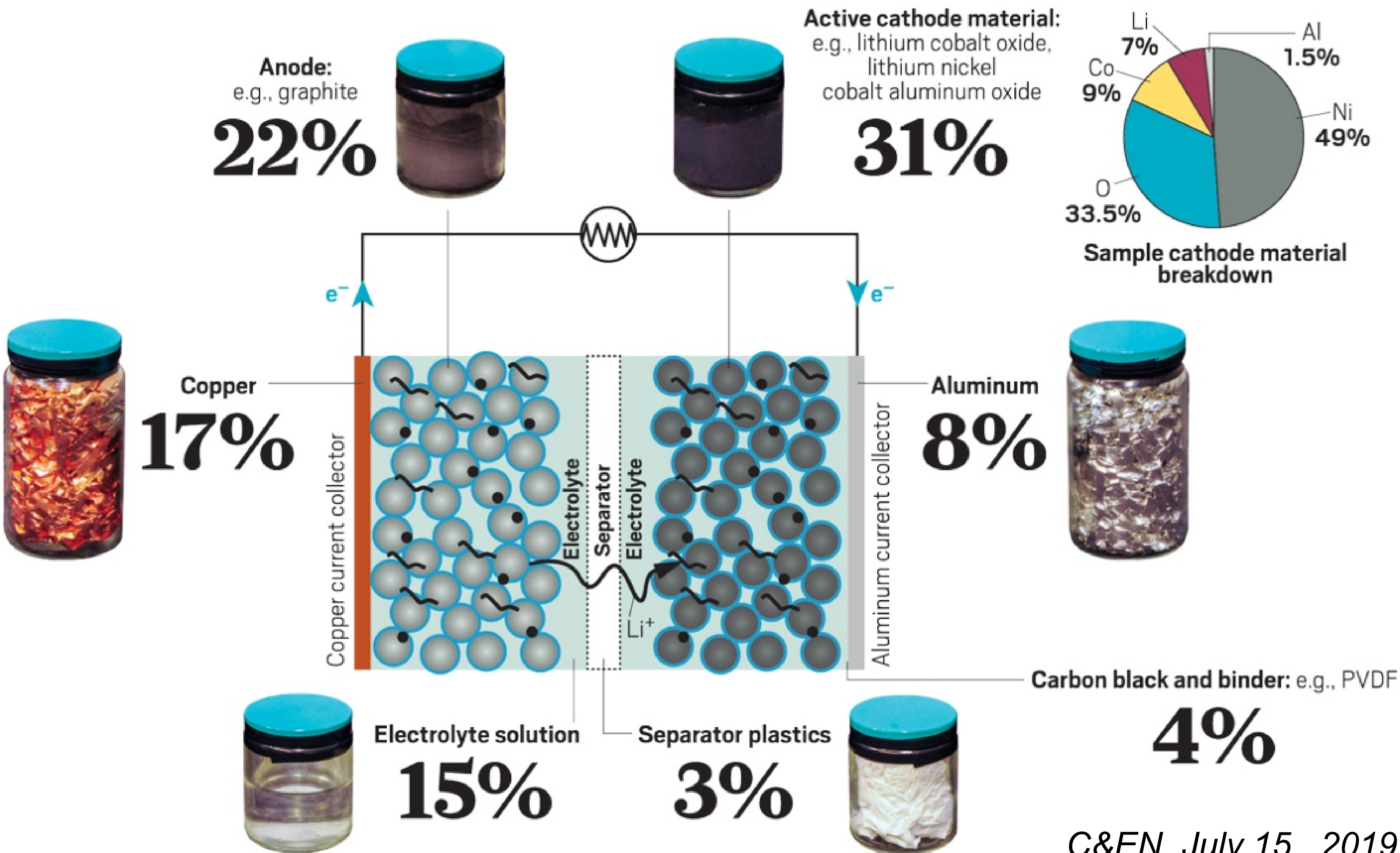
Wind



Fuel Cells (water)


design by toonitopia
Raw materials in your laptop
Dozens of resources mined on planet Earth
curiosity odyssey
toonitopia
345 grams
Plastics
6.2 grams
Lithium
386 grams
Magnesium
83 grams
Copper
330 grams
Glass
71 grams
Iron
46 grams
Graphite
52 grams
Cobalt
102 grams
Aluminium
48 grams
Steel
structural components
battery
electrical components and wiring
chips
thermal management
source — hp product material content (2019) based on a 1.7 kg notebook
note — 27 materials that each contribute less than 1% to the laptop's weight are excluded

MATERIALS IN A Li-ION BATTERY



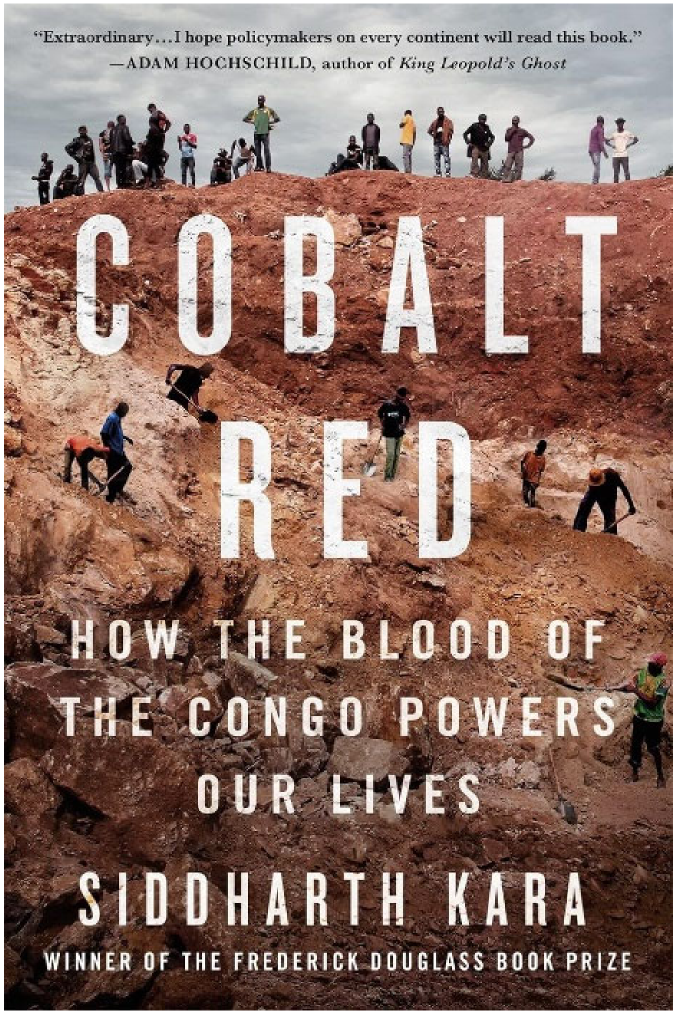
C&EN, July 15, 2019

CLEAN ENERGY MATERIALS : LITHIUM AND COBALT

- Current battery technology for mobile applications uses 20 % cobalt, 50 % nickel, 20 % manganese and 10 % lithium

- The world demand for lithium for battery application is about 100,000 tpa in 2021. Supply of lithium is from four countries, Chile (52% of global reserve), China (22%), Argentina (14%) and Australia (11%) and is controlled by four MNC's. The global reserve of lithium will last only for about 75 to 100 years at today's rate of consumption !

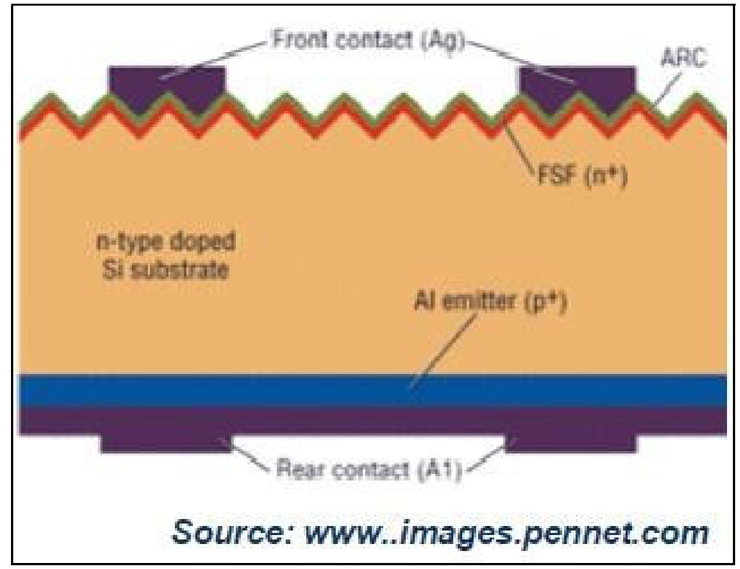
- Congo accounts for greater than 70 % of cobalt production and is controlled by two MNC's, one of them Chinese. Cobalt based NMC is the work-horse battery cathode for electric vehicles and also for the emerging 5G technology for mobile phones



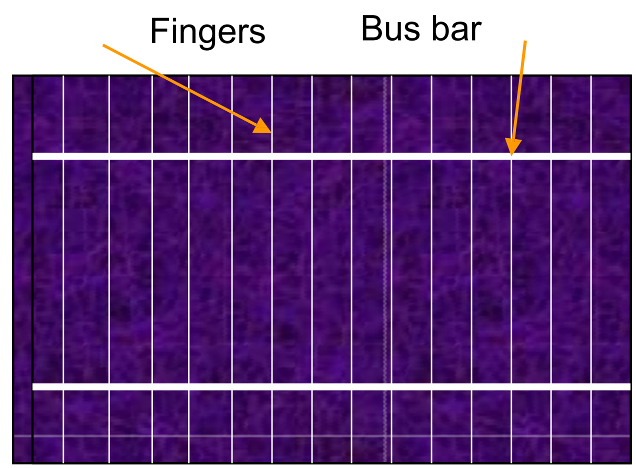
METAL PASTE: SILVER AND ALUMINUM

- Metal pastes are used in crystalline silicon solar cells to improve conversion efficiency. These pastes form a path for the conduction of the generated electricity from the silicon substrate while reducing the effective area exposed to sunlight.
- Metal pastes of silver are applied on the front of the cell in the form of grid contacts (fingers). Thicker bus bars connect the fingers to the external circuit. Silver paste is the dominant variety used in front contacts.
- The solar power industry accounts for more than 10 percent of global silver consumption. Each panel contains about 20 grams of silver.

Front and Rear Contacts in Solar Cells



Front Contacts in Solar Cells



CLEAN ENERGY MATERIALS: SILVER

- Silver used for making solar panels at 5 % of the current power demand will consume 50 % of the silver produced across the world

- 100 GW of solar electricity requires 4000 tons of silver per year. India's silver production is 500 tons per annum, and we import approximately 7,000 tons of silver per year.

- Today's silver price is about Rs 1,65,000 per kg (November 2025); It was Rs 91,555 per kg in November 2024

ELEMENTS USED IN A WIND MILL

Metal	Geared	Direct Drive
Aluminum	x	x
Chromium	x	X
Copper	x	x
Iron	x	x
Lead		x
Manganese	x	x
Rare earths		x
Nickel	x	x
Steel	x	x
Zinc	x	x

Geared wind mills are used on land; direct drive are used in oceans; 30 % of windmill are direct drive and balance is geared. Maintenance costs are higher for geared wind mills

TYPES OF ELECTROLYSERS

There are four generations of electrolysis technology to produce low-carbon hydrogen

Alkaline

Alkaline electrolyzer cells (AECs) consist of two electrodes immersed in an alkaline electrolyte and separated by a diaphragm. AECs are the most mature electrolysis technology and deployed at large scale in industrial applications.

TRL = 9

Proton-exchange membrane (PEM)

PEM electrolyzer cells (PEMECs) consist of two electrodes separated by a solid proton-exchange polymer membrane. PEMECs operate in an acidic environment. PEMECs are currently being scaled up for industrial applications.

TRL = 7

Solid oxide

Solid oxide electrolyzer cells (SOECs) consist of two electrodes separated by a solid ion-conducting membrane. SOECs operate at temperatures above 800 °C. They are currently at the pilot scale with the first industrial deployment expected within five years.

TRL= 6

Anion-exchange membrane (AEM)

AEM electrolyzer cells (AEMECs) consist of two electrodes immersed in an AEC and separated by a solid anion-exchange polymer membrane. AEMECs are currently at the laboratory scale with the first industrial deployment expected within 6–8 years.

TRL = 4

https://www.luxresearchinc.com/wp-content/uploads/2022/07/executive-summary-critical-minerals-for-the-hydrogen-economy.pdf

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THE MATERIAL REQUIREMENT FOR ELECTROLYSIS TECHNOLOGY

	AEC	PEMEC	SOEC	AEMEC
Electrolyte	Aqueous potassium hydroxide	Solid electrolyte	Solid oxide electrolyte	Aqueous potassium hydroxide
Separator / membrane	Zirconium oxide	Fluorinated polymer membranes (Nafion)	Yttria-stabilized zirconium (YSZ)	Aromatic and aliphatic hydrocarbons polymers
Anode catalyst (oxygen side)	Nickel alloy-plated steel/nickel-cobalt	Ruthenium or Iridium oxides/platinum-carbon	Nickel/YSZ	Nonplatinum group metals/nickel-based alloy
Cathode catalyst (hydrogen side)	Nickel-based alloys	Platinum or platinum-palladium	Lanthanum-strontium-manganite/YSZ	Nickel-iron-molybdenum grown on nickel foam
Bipolar plates	Nickel-coated stainless steel	Platinum/gold-coated titanium	Stainless steel/iron- nickel alloy	Nickel-coated stainless steel
Frames and sealing	Sulfonate/ fluorinated polymers	Sulfonate/fluorinated polymers	Ceramics/glass	Silicon/fluorinated polymers

KEY MINERALS FOR ELECTROLYSERS

Nickel

Today, a 1-GW electrolyzer uses anywhere between 800 to 1,000 tonnes of nickel. Nickel has a low supply risk since as many as 25 different countries around the world carry nickel reserves. However, its wide usage across other energy applications such as in fast-growing battery has seen nickel prices soar to a decade high. The IEA estimates that further increase in nickel prices could have significant affects on future battery and electrolyzer supply chains.

Iridium and platinum

iridium usage (criticality score >1) is the biggest bottleneck to meeting projected 2050 PEMEC installations. Iridium is far scarcer than platinum. However, due to its excellent catalytic activity in highly acidic conditions, finding promising alternatives is a challenge. Supply risk is relatively high for both minerals as platinum group metals production is concentrated in South Africa.

Zirconium, yttrium, and lanthanum

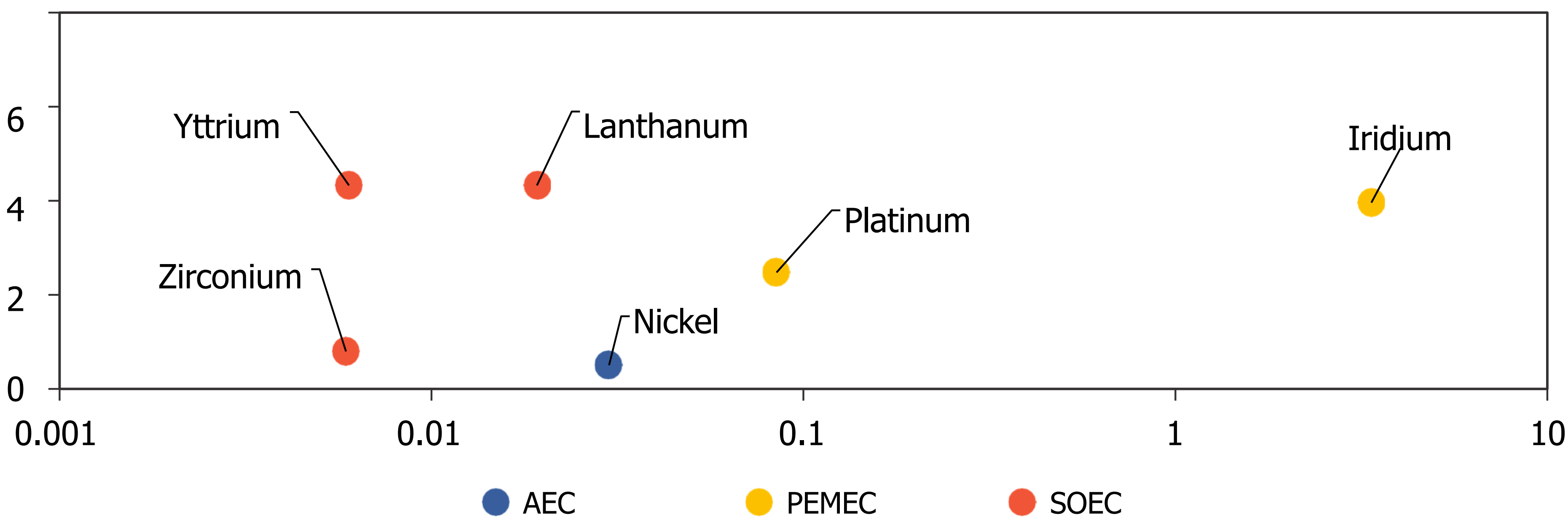
While zirconium is a non-critical mineral, yttrium and lanthanum show up in the high supply risk region of the chart. China produces nearly 4 times the volume of rare earths than the second largest producer, the U.S. Nearly 95% of these mineral reserves are in China, increasing their supply risk as SOEC technology scales up to decarbonize industrial applications. A lack of strong alternatives to these minerals add to the criticality of yttrium and lanthanum.

THE MINERAL CRITICALITY OF ELECTROLYZERS

https://www.luxresearchinc.com/wp-content/uploads/2022/07/executive-summary-critical-minerals-for-the-hydrogen-economy.pdf

Critical minerals for electrolysis

Supply risk (y-axis); Criticality (x-axis)



Note: The analysis does not include AEMECs as the technology is still at the laboratory scale with sparse data on mineral consumption and unclear

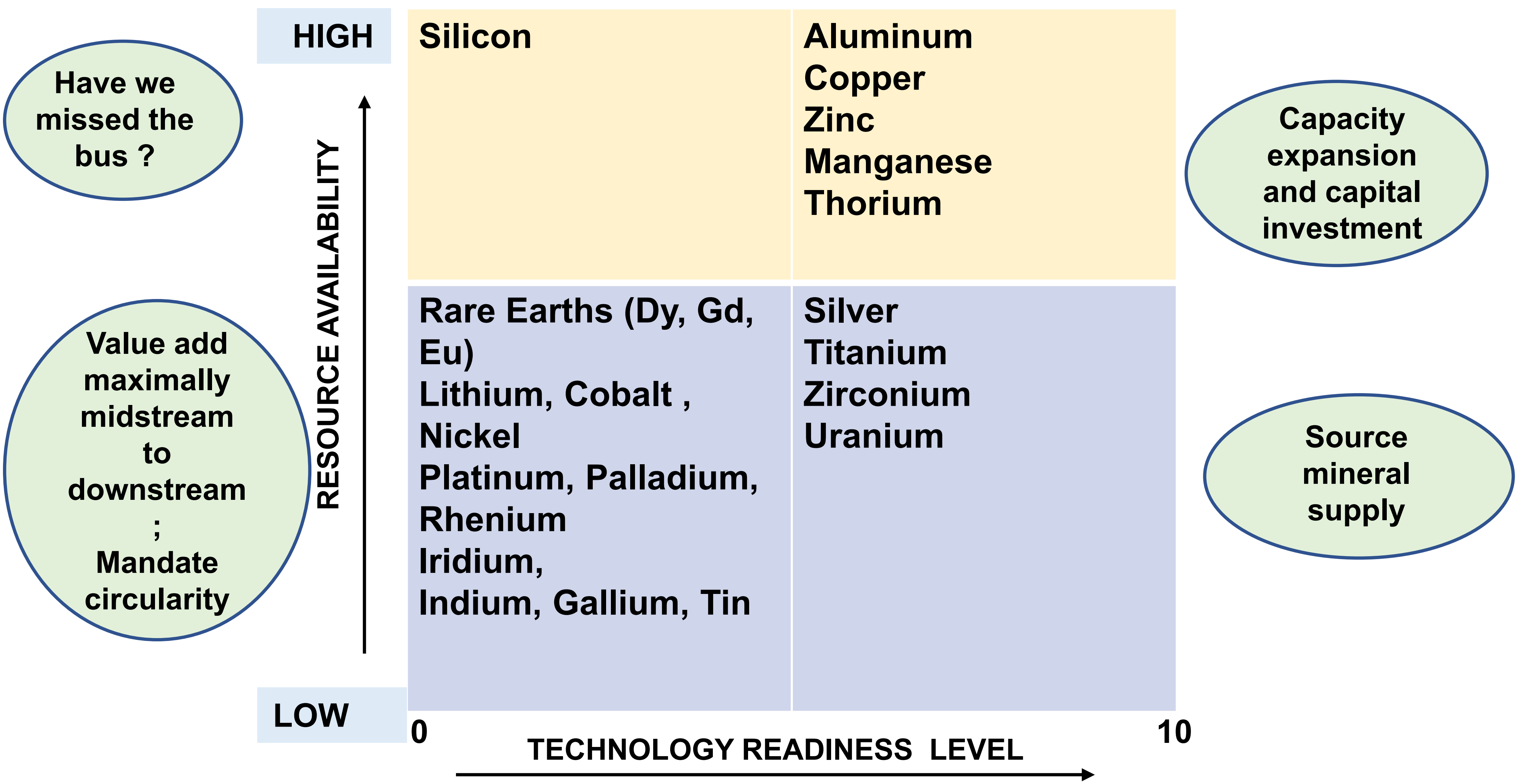
CLEAN ENERGY MATERIALS : RARE EARTHS

- Global production of RE elements : 125,000 tons per year (2015); 85 % from China
- World reserves of RE elements : 125 million tons; more than 50 % found in China and Brazil
- India produced 1600 tons of RE in 2015. To keep pace with projected increase in wind power, India will need 30,000 to 60,000 tons of RE elements by 2050
- Mining of rare earths is beset with problem of dealing with associated radioactive wastes in effluent water, gaseous emissions and tailings. Plants in USA and Malaysia were closed down due to rising public awareness and concerns of radioactive contamination in water
- Additionally good technology for reducing rare earth oxides to metals is still elusive

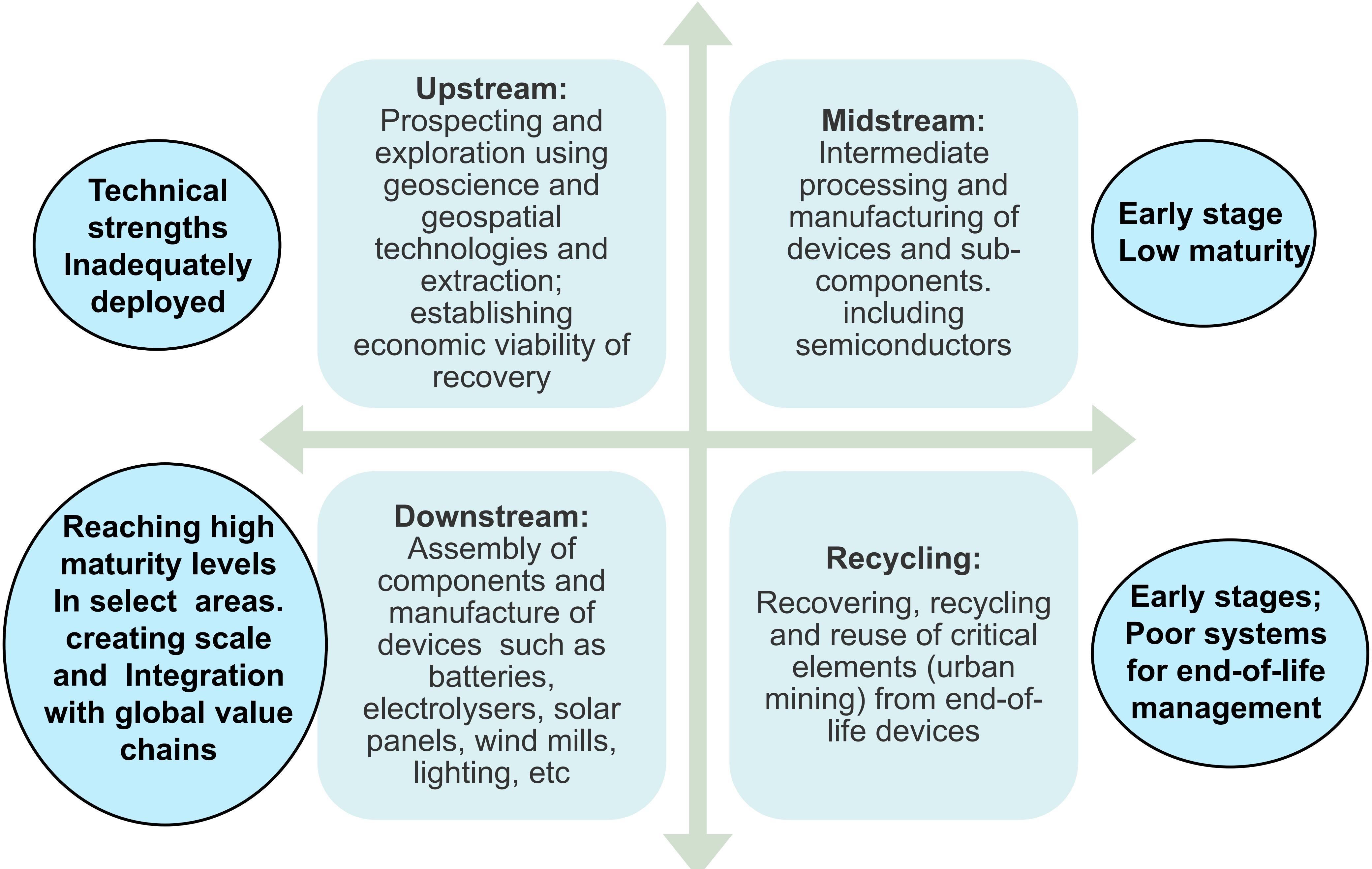
LIST OF CRITICAL MINERALS FOR INDIA IDENTIFIED BY THE GOVERNMENT OF INDIA

India currently imports 80 % of its critical minerals and metals		
Antimony	Lithium	Strontium
Beryllium	Molybdenum	Tantalum
Bismuth	Niobium	Tellurium
Cobalt	Nickel	Tin
Copper	Platinum Group of Elements	Titanium
Gallium	Phosphorous	Tungsten
Germanium	Potash	Vanadium
Graphite	REE	Zirconium
Hafnium	Rhenium	Selenium
Indium	Silicon	Cadmium

RESOURCE SECURITY AND TECHNOLOGY READINESS LEVELS FOR INDIA

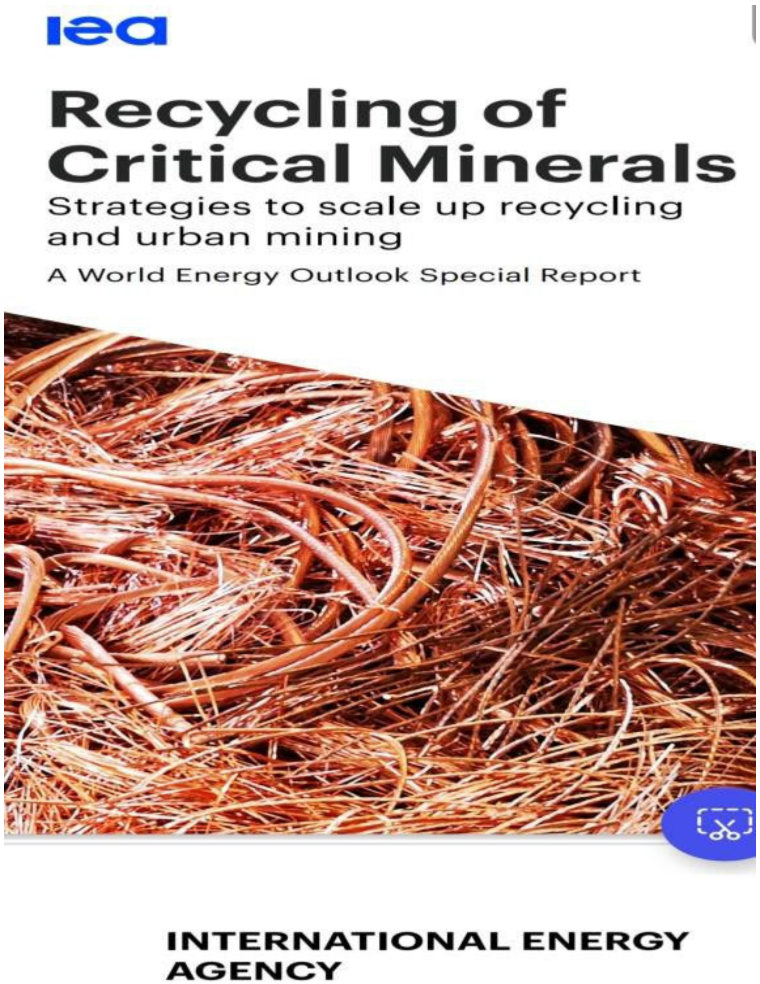


CRITICAL MINERALS SUPPLY CHAIN: STRENGTHS AND WEAKNESSES



THE IMPACT OF RECOVERY & RECYCLING CRITICAL MATERIALS

Recycling reduces the need for new mines, enhancing security and sustainability



- A successful scale up of recycling can lower the need for new mining activity by 25-40% by 2050
- Recycling reduces a new mine development need by 40 % for copper and cobalt and close to 25 % for lithium and nickel by 2050

REPORT / JANUARY 2023 TRANSPORTATION & MINING

Achieving Zero Emissions with More Mobility and Less Mining

by Thea Riofrancos, Alissa Kendall, Kristi K. Dayemo, Matthew Haugen, Kira McDonald, Batul Hassan and Margaret Slattery

In partnership with the University of California, Davis

Key Findings

- **Lithium demand can be reduced by up to 92 percent in 2050 in comparison to the most lithium-intensive scenarios.** This can be done by employing three key policy interventions: decreasing car dependency, right-sizing EV batteries, and creating a robust recycling system.

HOW ARE WE DOING?

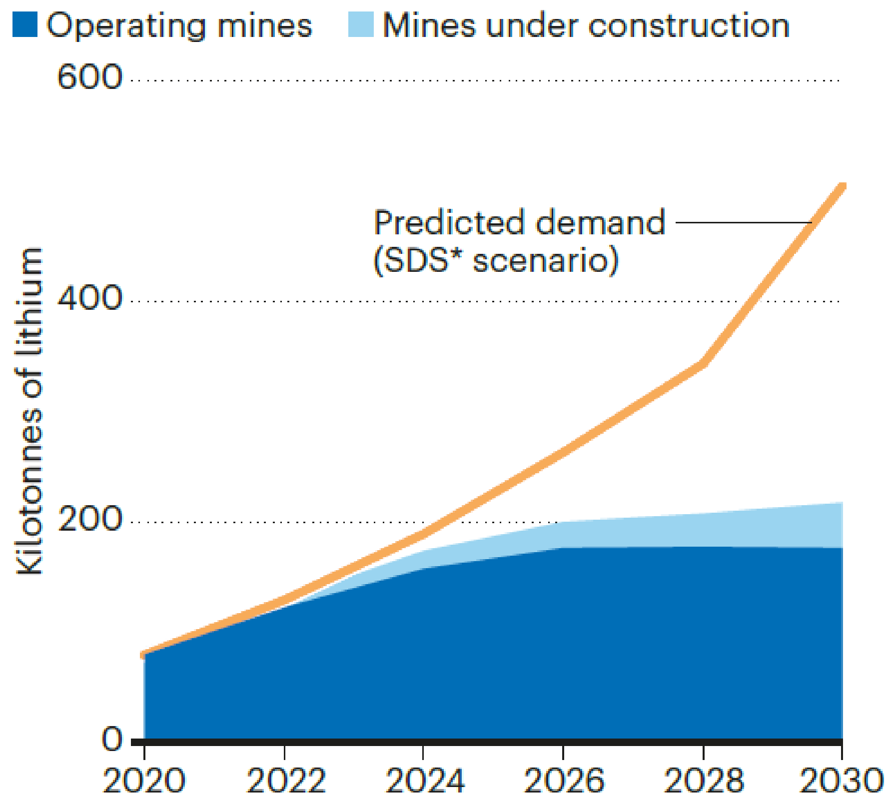
Workers in a lithium evaporation pond in the Atacama Desert in Chile.

How to make lithium extraction cleaner, faster and cheaper — in six steps

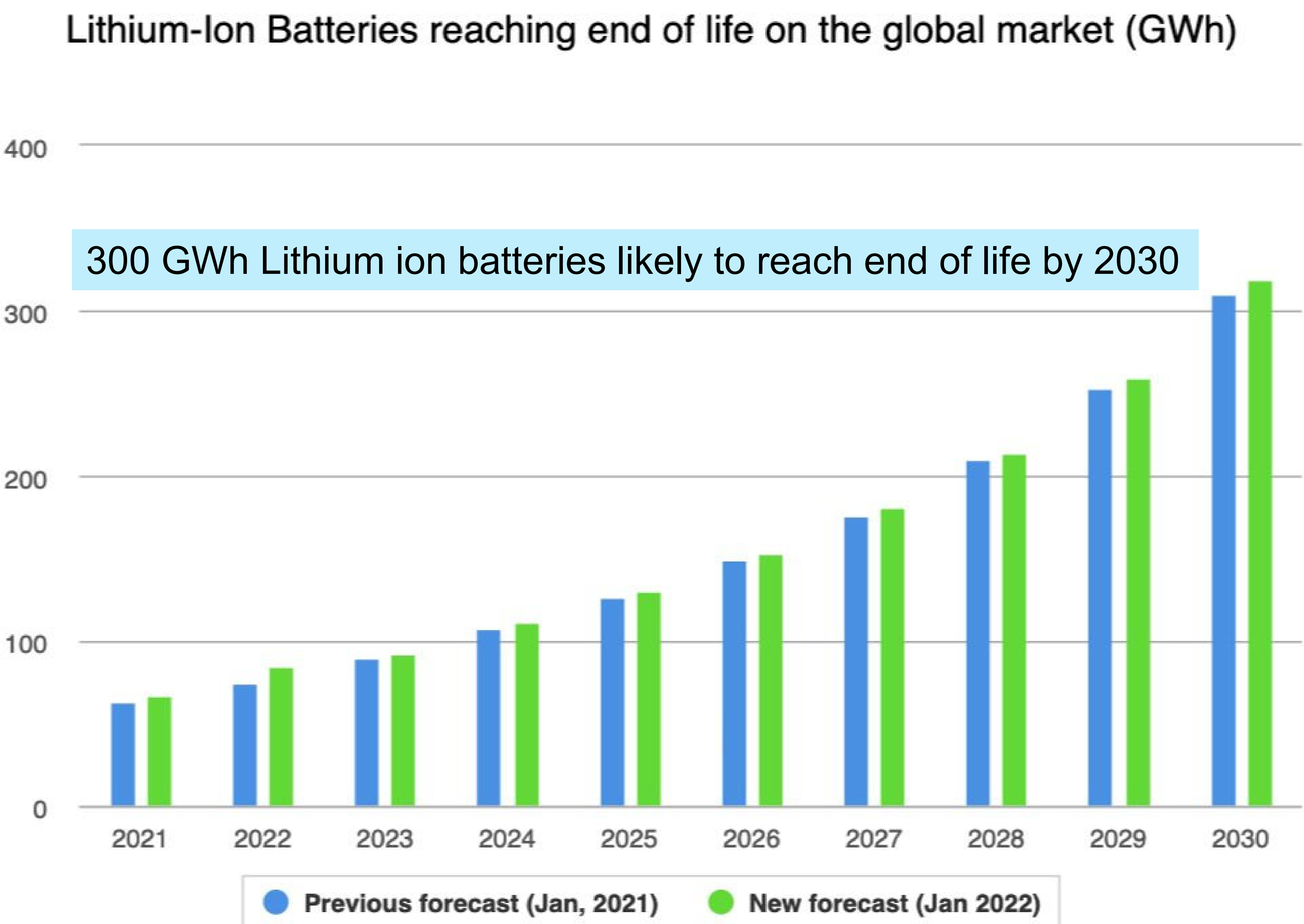
Andrew Z. Haddad, Lukas Hackl, Bilen Akuzum, Garrett Pohlman, Jean-François Magnan & Robert Kostecki

LITHIUM SUPPLY GAP

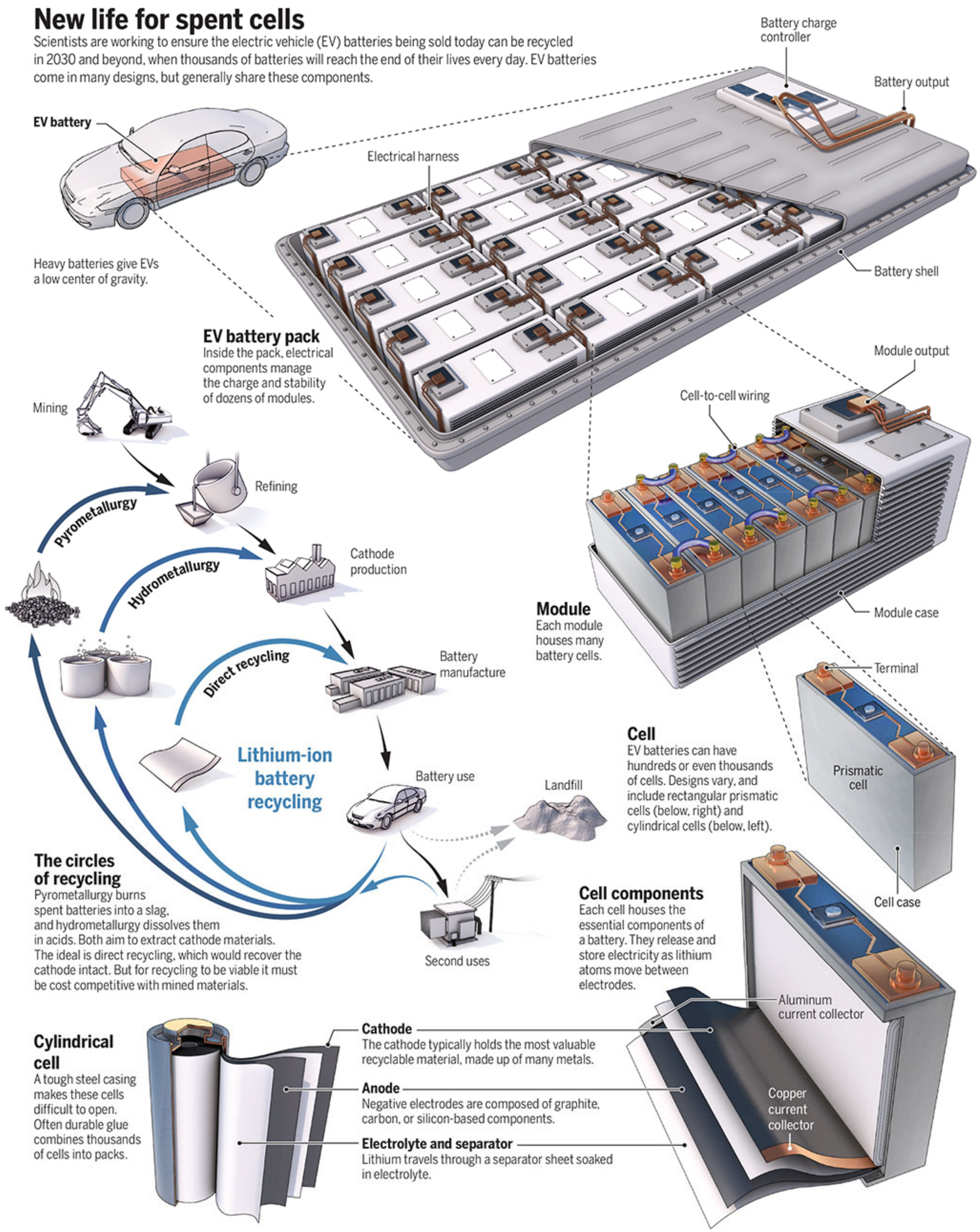
New mines are not opening fast enough to supply the lithium that will be needed for the world to meet sustainability goals through the use of batteries and other green technologies.



*The IEA's Sustainable Development Scenario, in which nations transform the energy market to limit climate change.



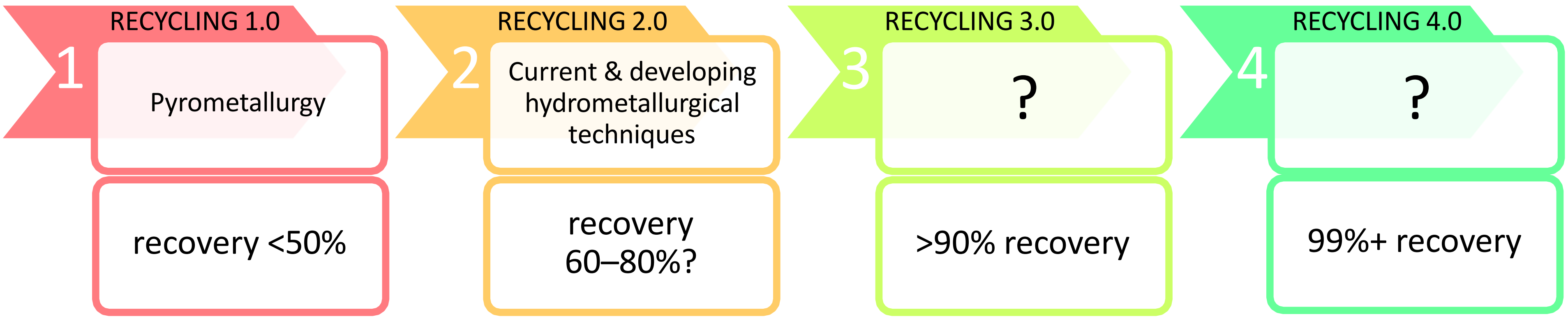
https://circularenergystorage.com/volumes



250,000 tonnes of unprocessed Li ion battery waste will be produced when the electric cars sold now reach the end of their lives

I. Morse, A Dead Battery Dilemma, Science, 2021, 372,780-783

*RECOVERY RATES**



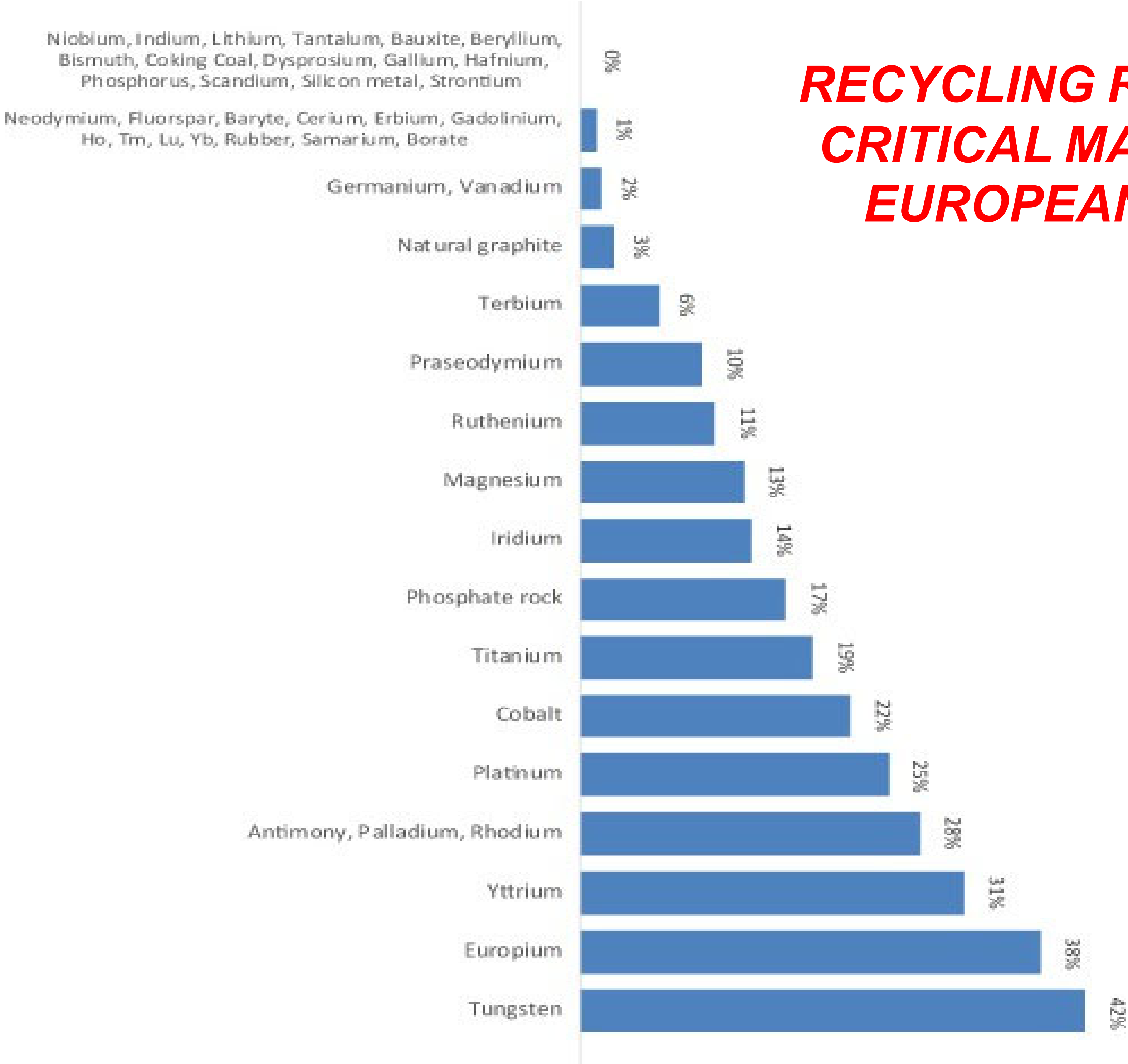
Obstacles to *sustainable* recycling are both economic & technical

- only a few metals (chiefly Co, Ni, Cu) are profitable to recover
  - significant market failure
  - regulation will drive recovery of some others *e.g.* EU targets for lithium
- many materials that are recoverable are not currently recycled *e.g.* graphite, separators
- some materials *e.g.* PVDF are currently regarded as not recyclable

ReLiB is trying to provide *technical* solutions to address both

**pack wt%*

RECYCLING RATES FOR CRITICAL MATERIALS: EUROPEAN UNION



CRITICALITY OF METALS : CONCERNS

- Geological accessibility
- Geo-political risks
- Material substitution difficult
- Recycling rates low
- Demand, supply, costs and prices
- Environmental degradation, changes in land-use pattern and deforestation

Different minerals carry different potential supply risks and demand trajectories which are together reflected in the concept of material criticality

Scenarios for demand growth of metals in electricity generation, cars and electronic appliances, S. Deetman, et.al., Environ. Sci. &Technol., 2018, 52, 4950; future demand for electricity generation materials under different climate mitigation scenarios, S. Wang et.al., Joule, 10.1016/j-joule.2023.01.001

MITIGATION STRATEGIES FOR MATERIALS CRITICALITY

Replace

Basic research to discover and develop materials that can replace critical materials

Reduce

Applied research to reduce the amounts of critical materials required in applications

Recycle

investment in recycling of critical materials to provide a secondary source of supply and help provide greater security security in the future—mid-stream processing is a key component in this and greater circularity in critical materials should also help alleviate waste management issues

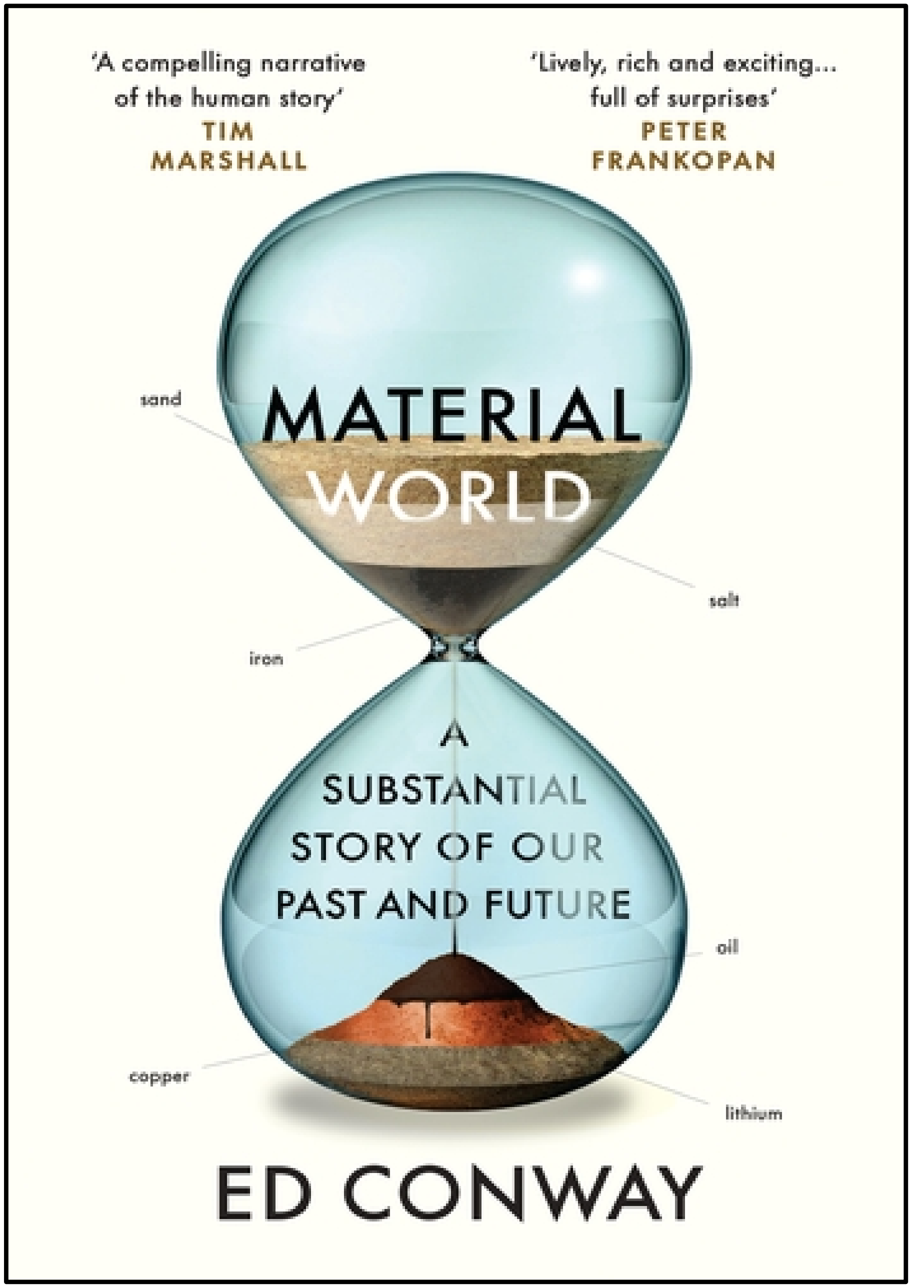
Regulate

Reciprocal trade agreements with friendly nations encompassing not only supply of critical minerals—again mid-stream processing capability which is where the major supply constraint rests in many cases

REDUCING DEPENDENCE ON MINERALS FOR NEW TECHNOLOGIES

Current	Future ?
Silicon (Solar PV)	Perovskites, Organic Photovoltaics (OPVs)
Silver (Solar PV)	Conducting polymer wires
Lithium, Cobalt, Nickel etc (Batteries)	All organic batteries
Neodymium and other rare earth magnets	All organic permanent magnets
Ga (LEDs)	Organic light emitting diodes (OLED), Polymer Light emitting diodes (PLED)

Will a sustainable shift to new energy resources with low or negative carbon intensity depend on the development and deployment of carbon derived resources as advanced materials; in other words, a shift from using carbon based fuels to carbon based devices for energy storage and conversion ?



Penguin Random House, November 2023

- The six materials that make the material world: sand, salt, iron, copper, oil, and lithium

- The intricacy and invisibility of the modern supply chain are causes for both wonder and worry

- Consumers have become disconnected from the importance of the supply chain; it is that lack of knowledge that makes the consumer economies of the world vulnerable

Are world's twin goals of decarbonization and development heading for a collision ?

THANK YOU

If you do not change direction, you may end up where we are heading: Lao Tzu