THE ESSENCE OF THE ENERGY TRANSITION

JUST CHANGING THE STUFF WE ARE MINING

FOSSIL FUELS

- **Large mining quantities** — In 2021, 15 billion tonnes of fossil fuels were extracted.[1]
- **Generate huge rents** — Oil and gas exports alone represented a value of USD 2 trillion in 2021.[3]
- **Combusted as fuel** — Fossil fuels are primarily burned as fuel, accounting for approximately 94% of their usage.[5]
- **Energy security risk** — A disruption in the supply of fossil fuels can lead to immediate energy shortages and price spikes.
- **Not recyclable** — Fossil fuels are primarily consumed through combustion and cannot be recovered or repurposed.

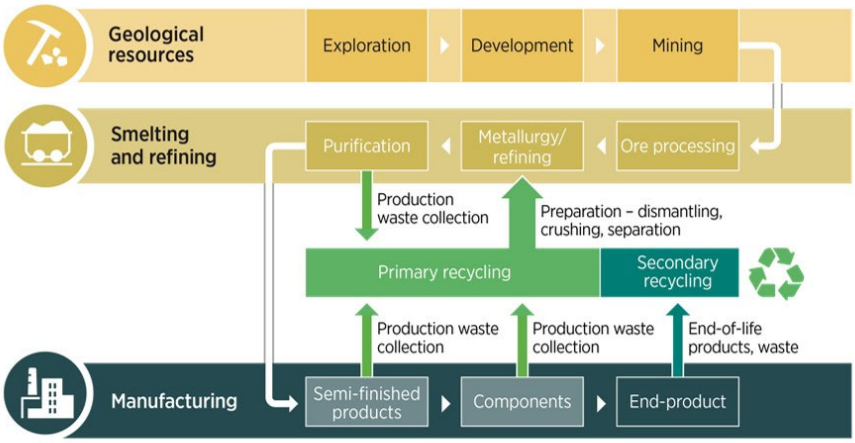
CRITICAL MATERIALS

- **Low mining quantities** — Some 10 million tonnes energy transition minerals were produced in 2022 for low-carbon technologies.[2]
- **Generate smaller profits** — Exports of copper, nickel, lithium, cobalt and rare earths generated 96 billion in 2021.[4]
- **Input to manufacturing** — Critical materials are housed within energy assets that typically have a 10–30 year lifespan.
- **Energy transition risk** — Disruptions in the supply of critical minerals can delay the construction of new clean energy assets, but do not affect current energy prices or supply.
- **Reusable and recyclable** — High potential for reducing use, reusing and recycling.

Source: Geopolitics of the Energy Transition: Critical Materials (irena.org)

THE SUPPLY CHAIN OF CRITICAL MATERIALS

SCHEMATIC OVERVIEW

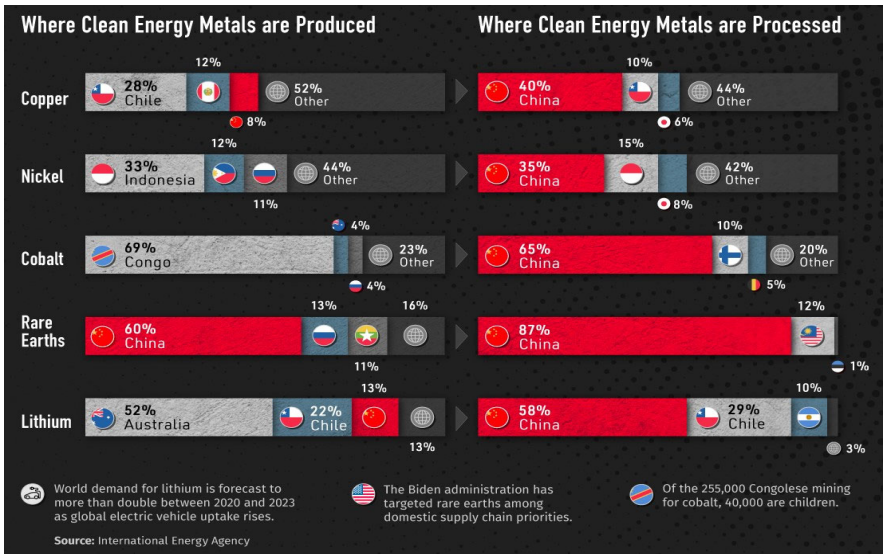


Source: (Ayuk *et al.*, 2020).

Source: Geopolitics of the Energy Transition: Critical Materials (irena.org)

GEOPOLITICS

CHINA DOMINATES THE PROCESSING OF CRITICAL MATERIALS



Source:Visualizing China's Dominance in Clean Energy Metals (visualcapitalist.com)

TOWARDS A SUSTAINABLE EU ENERGY SYSTEM

MATERIALS DEMAND FOR THE EU SUSTAINABLE DEVELOPMENT SCENARIO (SDS)

PV	+10,000 GW +1400 %	low Ga x4	Gallium	med Ge x4	Germanium	low In x1.5	Indium	low Si x4	Silicon metal				
Wind	+1000 GW +410 %	med B x5	Borate	high Dy x5	Dysprosium (HREE)	high Nd x5	Neodymium (LREE)	high Pr x5	Praseodymium (LREE)	high Tr x5	Terbium (HREE)		
Hydrogen	+580 GW	med Ir x9	Iridium (PGM)	low Pt x9	Platinum (PGM)	low Ti x90	Titanium						
Hydro	+48 GW +19 %	med Mg x10	Magnesium	low Ti x90	Titanium								
CSP	+23 GW +920 %	med Mg x10	Magnesium	med Nb x2	Niobium	low Ti x90	Titanium	low V x1.5	Vanadium				
Geo	+5.5 GW +170 %	med Nb x2	Niobium	low Ta x2	Tantalum	low Ti x90	Titanium						
Nuclear	-11 GW -9 %	low Hf x1	Hafnium	low In x1.5	Indium	low W x1	Tungsten	low V x1.5	Vanadium	med Yt x1	Yttrium (HREE)		
Batteries*		med Co x21	Cobalt	low Li x42	Lithium	low C x25	Natural graphite						

low Ga x4 — Supply risk indicator (EC): Low = 0-2.5; med = 2.5-5; high = 5+ / Chemical element / Increase in demand 2020-2050 (TNO): Total demand for energy technologies deployed in Europe, SDS scenario; for batteries: IEA

Deployed capacity of energy technologies in Europe in 2050 under the SDS scenario compared to 2020 and the required CRMs. Data: TNO (forthcoming), *SWOT analysis – Critical raw materials for the European energy transition*; EC (2020), *Study on EU's list of Critical Raw Materials*; IEA (2021), *The Role of Critical Minerals in Clean Energy Transitions.*
* Not included in study TNO. The demand increase shown is a global estimate for 2040 (IEA) rather than a European estimate for 2050 (TNO).

SUSTAINABILITY IMPACT OF MINING

EXAMPLE FOR RARE EARTH OXIDES (REOs)

REOs	Primary Energy MJ/kg	GHG kg CO_2-e/kg	Water kL Water/kg	Toxicity *DALY/kg
La	177	9.3	0.33	1.65×10^{6}
Ce	157	8.3	0.30	1.46×10^{6}
Pr	798	41.4	1.32	7.36×10^{6}
Nd	743	38.5	1.23	6.86×10^{6}
Sm, Eu, Gd (mixed oxide)	1,074	55.6	1.75	9.89×10^{6}

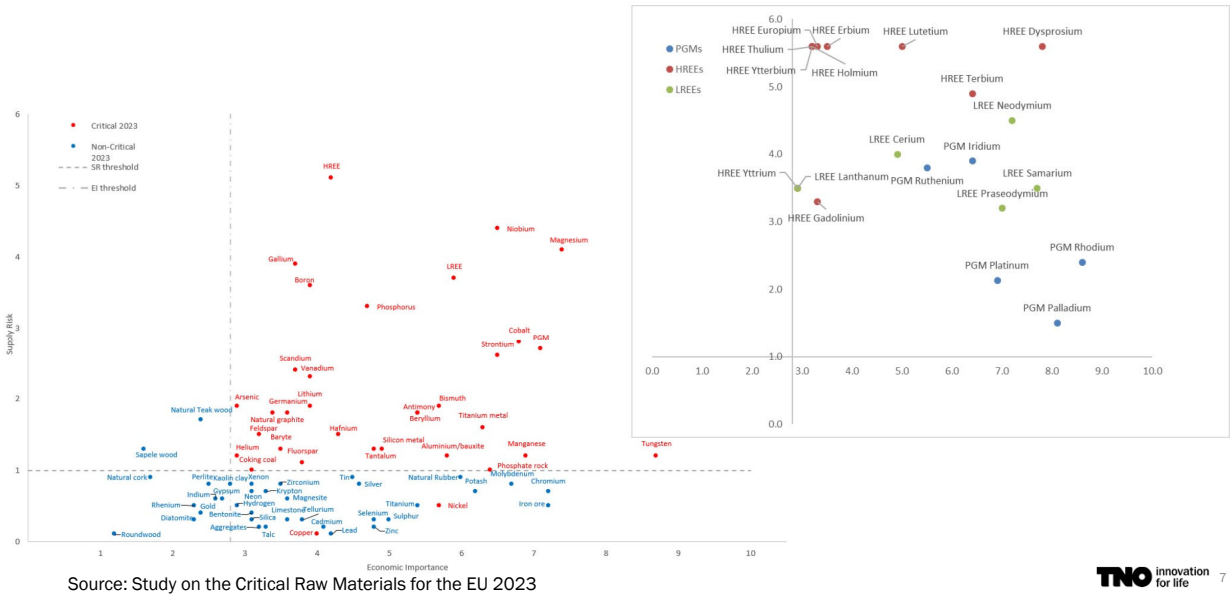
Note: *DALY—Disability adjusted life years (metric to determine toxicity on human health developed by World Health Orgnisation [64].

The major contributor to total GHG footprint of REE processing is hydrochloric acid (ca. 38%), followed by steam use (32%) and electricity (12%).

Source: Resources 2014, 3, 614-635; doi:10.3390/resources3040614

CRITICALITY OF RAW MATERIALS FOR THE EU

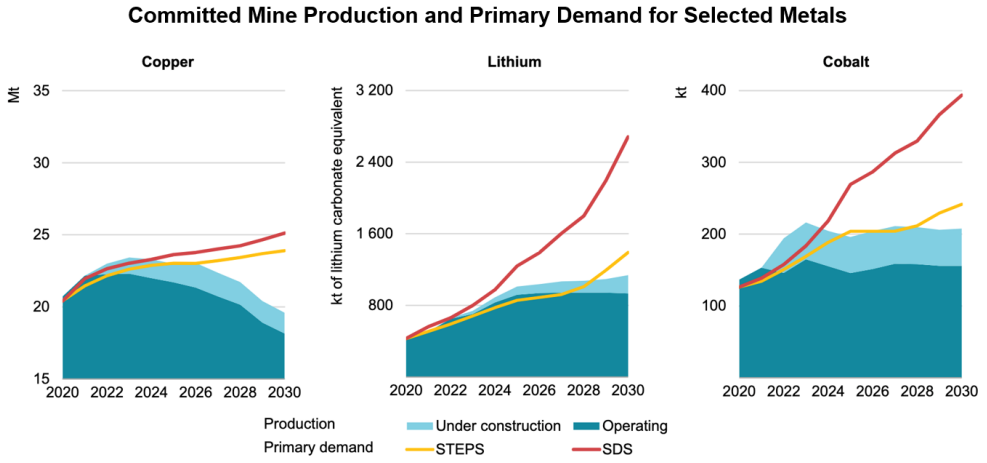
SUPPLY RISKS AND ECONOMIC IMPORTANCE OF CRITICAL MATERIALS



Source: Study on the Critical Raw Materials for the EU 2023

SUPPLY DEMAND GAP

WILL CRITICAL MATERIAL SUPPLY SLOW DOWN THE EU ENERGY TRANSITION?



HISTORIC LEAD TIME FOR DEVELOPING A NEW MINE IS 15-20 YEAR

Source: IEA

DISRUPTION

THE FUTURE OF "MADE IN EUROPE" WITHOUT ACCESS TO CRITICAL MATERIALS?

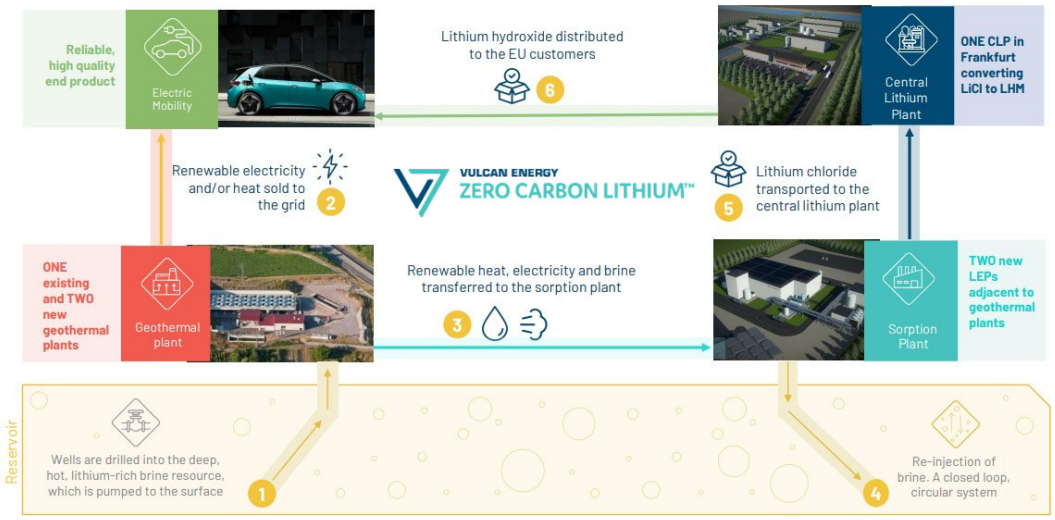
Vestas → GE Renewable Energy → Goldwind

RECOM TECHNOLOGIES → MISSION SOLAR ENERGY → YINGLI SOLAR

Volkswagen → TESLA → BYD

...BUT OPPORTUNITIES ARE ALSO EMERGING

SUSTAINABLE LITHIUM MINING IN GERMANY BASED ON ELECTROCHEMISTRY



Note: LEP = Lithium Extraction Plant, CLP = Central Lithium Plant

HOW TO REDUCE THE SUPPLY RISKS FOR CRITICAL MATERIALS?

"BECOME THE GLOBAL SOLUTION PROVIDER FOR SUSTAINABLE MINING, REFINING AND RECYCLING OF CRITICAL MATERIALS"

ChemistryNL

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