UNIVERSITÀ DEGLI STUDI DI TRIESTE

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Summer School on Energy **Giacomo Ciamician**

Raw materials & the energy transition

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June 13th – 17st, 2022

dipartimento di ingegneria e architettura

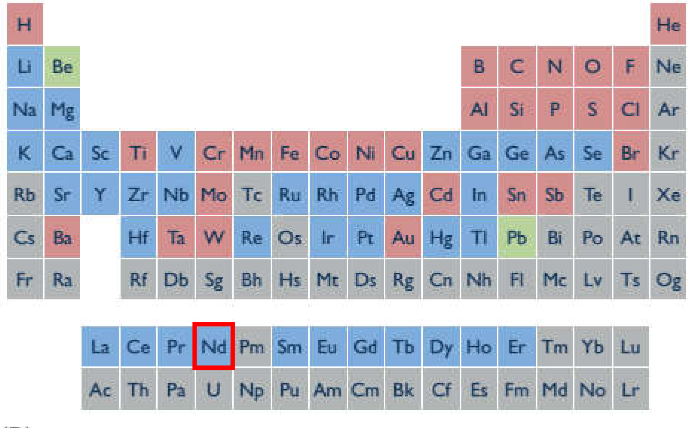
Levi Cases

Centro Interdipartimentale per l'Energia, l'Ambiente e i Trasporti Giacomo Ciamician

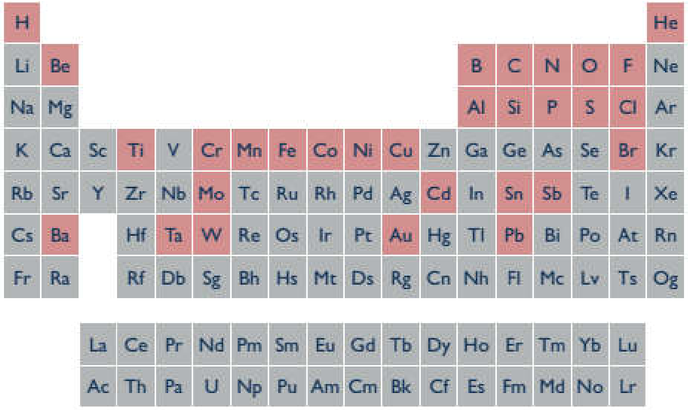
IEEE Industrial Electronics Society IES Italy Chapter

AEIT 1897 Sezione MILANO

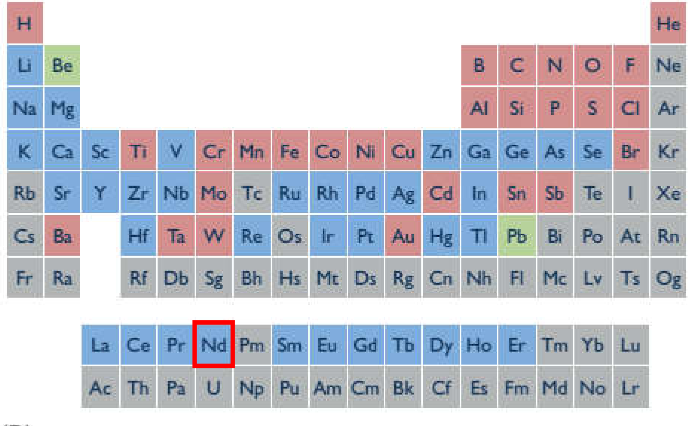
60
Nd
NEODYMIUM
144.242



[figure from: A. King, Critical Materials, Elsevier 2021]



1983

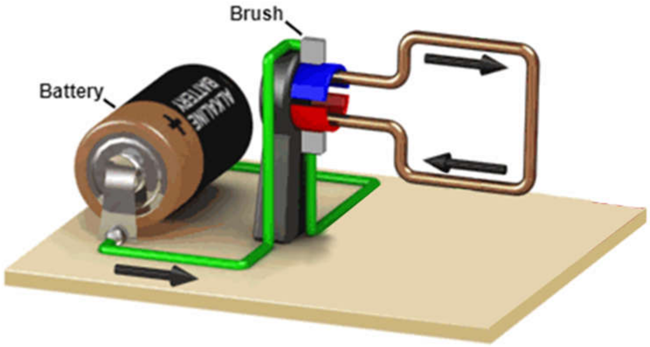


2020

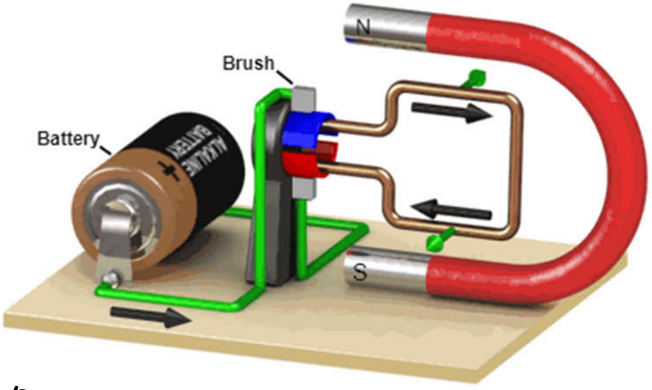
[figure from: A. King, Critical Materials, Elsevier 2021]

60
Nd
NEODYMIUM
144.242

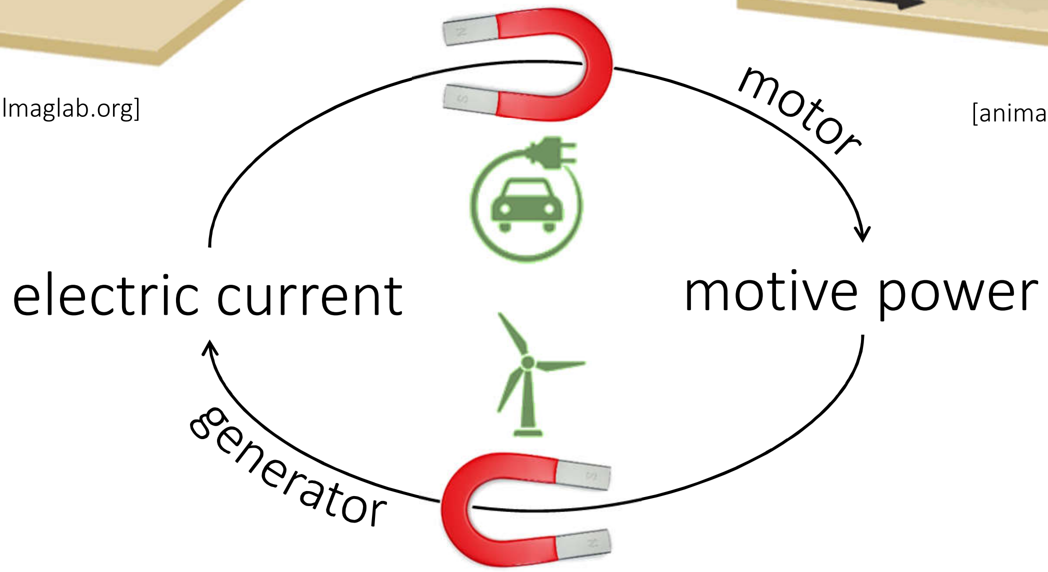
magnets
NdFeB

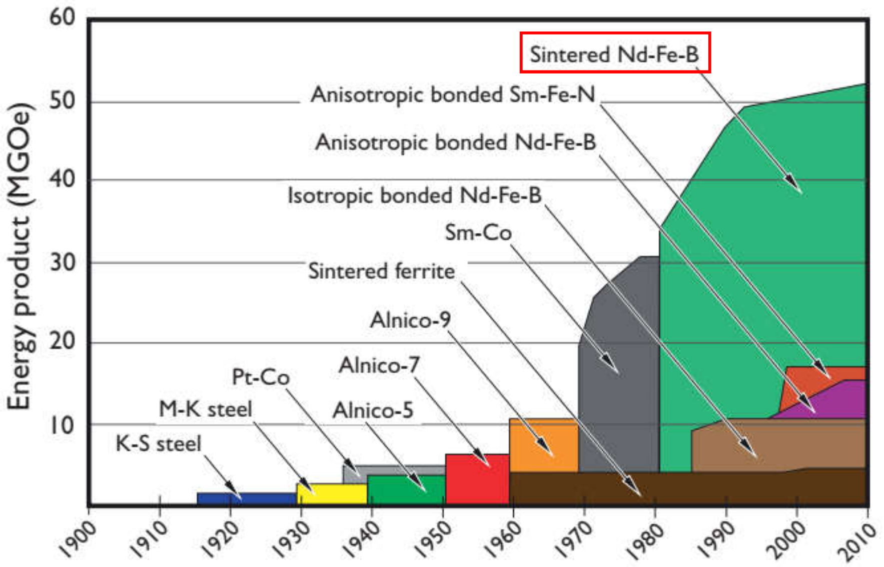


[image adapted from: nationalmaglab.org]

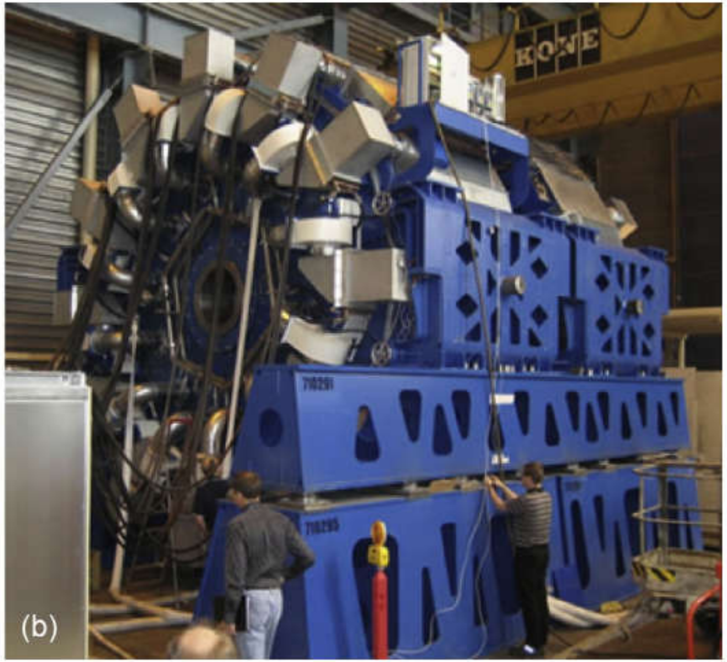


[animation from: nationalmaglab.org]



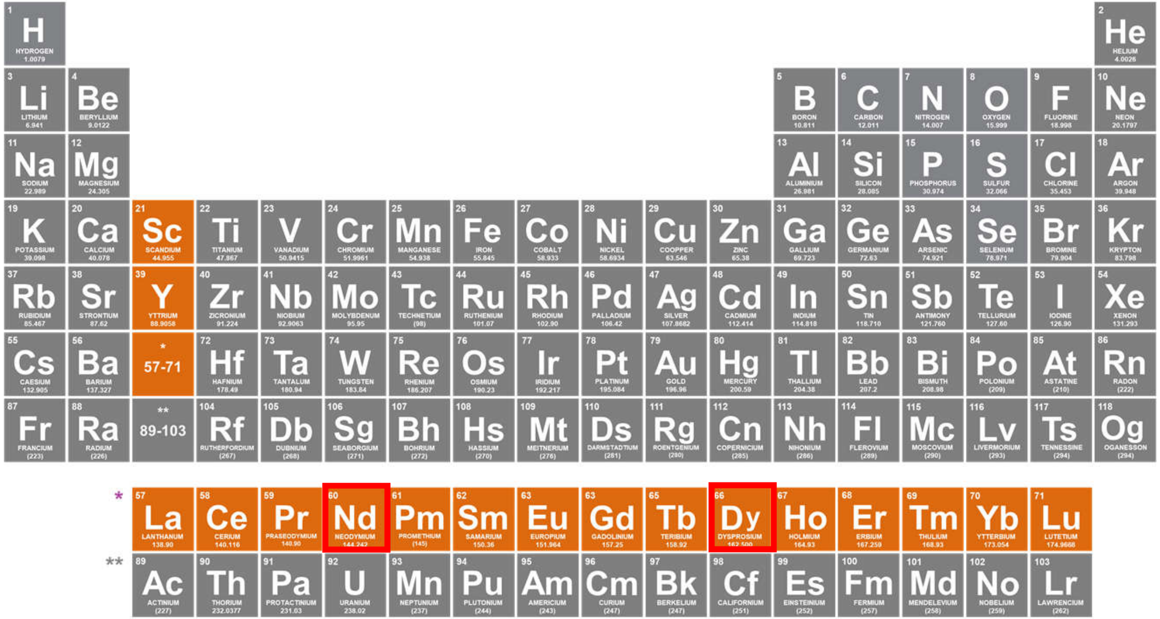


[figure from: A. King, Critical Materials, © Elsevier 2021]



[figure from: J. Lucas, ed., Rare Earths, © Elsevier 2015]

~2t **NdFeB** magnets (> **500 kg** of Nd)



RE: rare earths

REE: rare earths elements

REO: rare earths oxides

in **2040** we will need from **3** to **7** times more the amount of REE used in **2020**

(source: IEA)

Stated Policies Scenario (STEPS) → 3

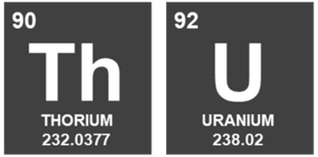
Sustainable Development Scenario (SDS) → 7

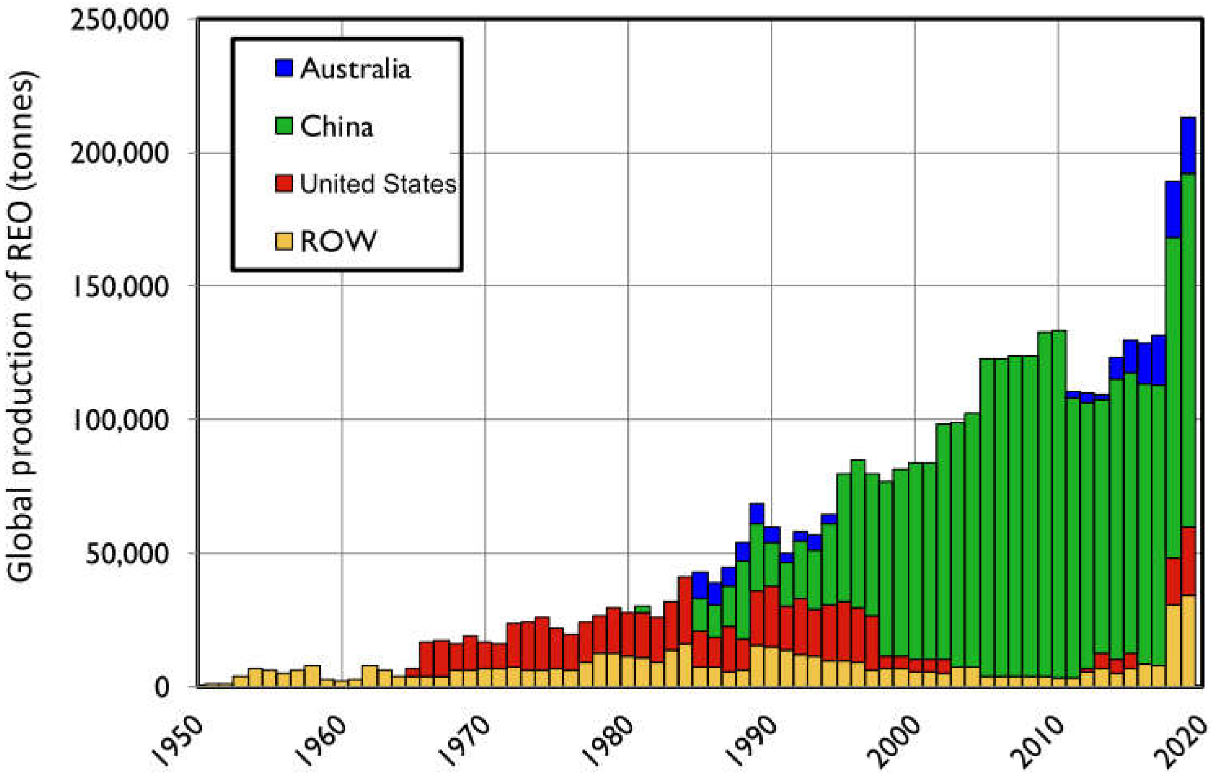
[figure from: www.japantimes.co.jp, © Reuters]

[figure from: https://www.bbc.com/future/article/20150402-the-worst-place-on-earth]

Baotou tailing dam, China (inner Mongolia)

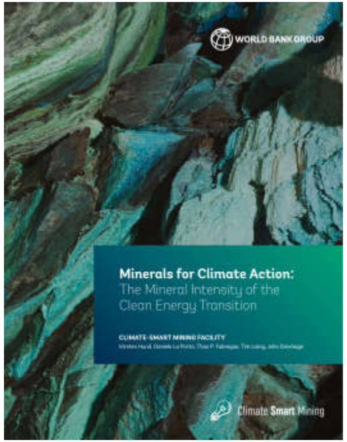
Bayan Obo mine,
China (inner Mongolia)



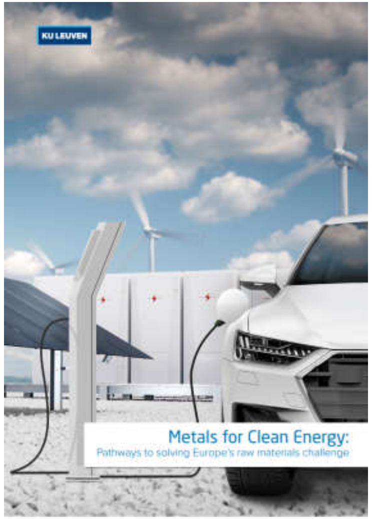


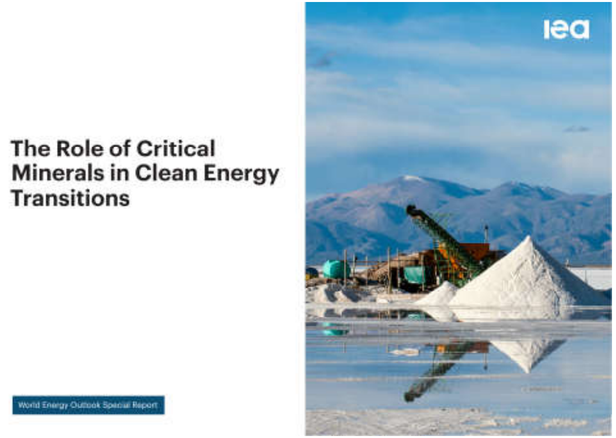
[figure from: A. King, Critical Materials, © Elsevier 2021]

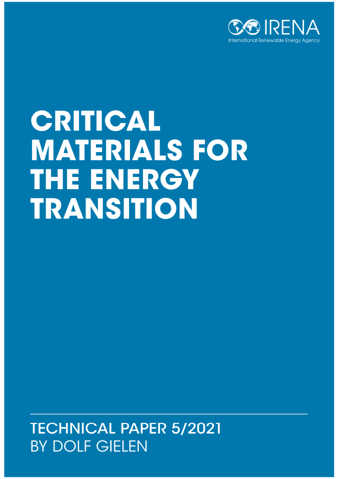

Critical Raw Materials for Strategic Technologies and Sectors in the EU
A Foresight Study


WORLD BANK GROUP
Minerals for Climate Action:
The Mineral Intensity of the Clean Energy Transition
CLIMATE-SMART MINING FACILITY
Climate Smart Mining


ROYAL SOCIETY OF CHEMISTRY
Decarbonisation: materials and circularity challenges for clean technologies
August 2021


KU LEUVEN
Metals for Clean Energy:
Pathways to solving Europe's raw materials challenge

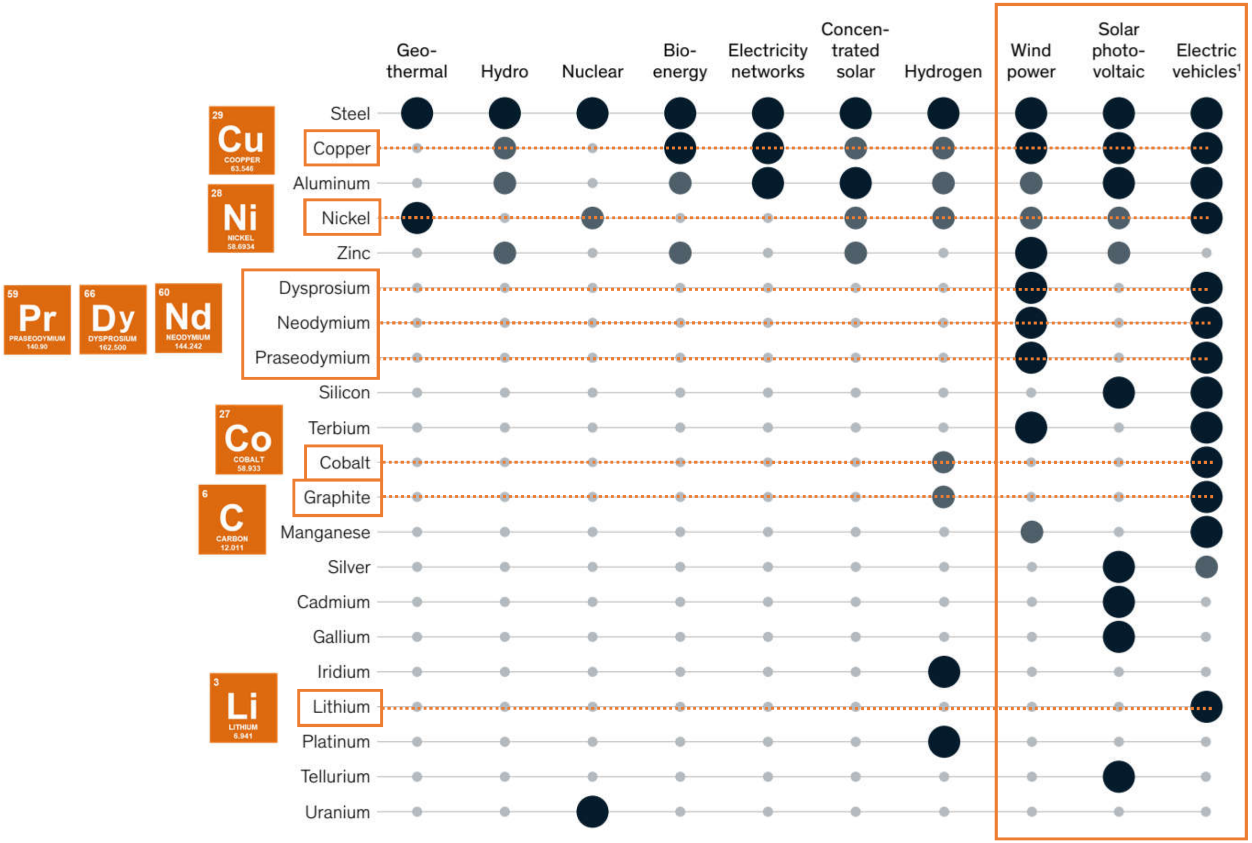

The Role of Critical Minerals in Clean Energy Transitions
World Energy Outlook Special Report
iea


IRENA
CRITICAL MATERIALS FOR THE ENERGY TRANSITION
TECHNICAL PAPER 5/2021
BY DOLF GIELEN

elements involved in the *energy transition*

1 H HYDROGEN 1.0079																	2 He HELIUM 4.0026
3 Li LITHIUM 6.941	4 Be BERYLLIUM 9.0122											**5 B BORON 10.811**	**6 C CARBON 12.011**	7 N NITROGEN 14.007	8 O OXYGEN 15.999	9 F FLUORINE 18.998	10 Ne NEON 20.1797
11 Na SODIUM 22.989	12 Mg MAGNESIUM 24.305											**13 Al ALUMINIUM 26.981**	**14 Si SILICON 28.085**	15 P PHOSPHORUS 30.974	16 S SULFUR 32.066	17 Cl CHLORINE 35.453	18 Ar ARGON 39.948
19 K POTASSIUM 39.098	20 Ca CALCIUM 40.078	21 Sc SCANDIUM 44.955	22 Ti TITANIUM 47.867	23 V VANADIUM 50.9415	**24 Cr CHROMIUM 51.9961**	**25 Mn MANGANESE 54.938**	**26 Fe IRON 55.845**	**27 Co COBALT 58.933**	**28 Ni NICKEL 58.6934**	**29 Cu COOPPER 63.546**	**30 Zn ZINC 65.38**	31 Ga GALLIUM 69.723	32 Ge GERMANIUM 72.63	33 As ARSENIC 74.921	34 Se SELENIUM 78.971	35 Br BROMINE 79.904	36 Kr KRYPTON 83.798
37 Rb RUBIDIUM 85.467	38 Sr STRONTIUM 87.62	39 Y YTTRIUM 88.9058	40 Zr ZICRONIUM 91.224	41 Nb NIOBIUM 92.9063	**42 Mo MOLYBDENUM 95.95**	43 Tc TECHNETIUM (98)	44 Ru RUTHENIUM 101.07	45 Rh RHODIUM 102.90	46 Pd PALLADIUM 106.42	**47 Ag SILVER 107.8682**	48 Cd CADMIUM 112.414	49 In INDIUM 114.818	50 Sn TIN 118.710	51 Sb ANTIMONY 121.760	52 Te TELLURIUM 127.60	53 I IODINE 126.90	54 Xe XENON 131.293
55 Cs CAESIUM 132.905	56 Ba BARIUM 137.327	* 57-71	72 Hf HAFNIUM 178.49	73 Ta TANTALUM 180.94	74 W TUNGSTEN 183.84	75 Re RHENIUM 186.207	76 Os OSMIUM 190.23	77 Ir IRIDIUM 192.217	78 Pt PLATINUM 195.084	79 Au GOLD 196.96	80 Hg MERCURY 200.59	81 Tl THALLIUM 204.38	82 Bb LEAD 207.2	83 Bi BISMUTH 208.98	84 Po POLONIUM (209)	85 At ASTATINE (210)	86 Rn RADON (222)
87 Fr FRANCIUM (223)	88 Ra RADIUM (226)	** 89-103	104 Rf RUTHERFORDIUM (267)	105 Db DUBNIUM (268)	106 Sg SEABORGIUM (271)	107 Bh BOHRIUM (272)	108 Hs HASSIUM (270)	109 Mt MEITNERIUM (276)	110 Ds DARMSTADTIUM (281)	111 Rg ROENTGENIUM (280)	112 Cn COPERNICIUM (285)	113 Nh NIHONIUM (286)	114 Fl FLEROVIUM (289)	115 Mc MOSCOVIUM (290)	116 Lv LIVERMORIUM (293)	117 Ts TENNESSINE (294)	118 Og OGANESSON (294)
	*	57 La LANTHANUM 138.90	58 Ce CERIUM 140.116	**59 Pr PRASEODYMIUM 140.90**	**60 Nd NEODYMIUM 144.242**	61 Pm PROMETHIUM (145)	62 Sm SAMARIUM 150.36	63 Eu EUROPIUM 151.964	63 Gd GADOLINIUM 157.25	65 Tb TERIBIUM 158.92	**66 Dy DYSPROSIUM 162.500**	67 Ho HOLMIUM 164.93	68 Er ERBIUM 167.259	69 Tm THULIUM 168.93	70 Yb YTTERBIUM 173.054	71 Lu LUTETIUM 174.9668	
	**	89 Ac ACTINIUM (227)	90 Th THORIUM 232.0377	91 Pa PROTACTINIUM 231.03	92 U URANIUM 238.02	93 Mn NEPTUNIUM (237)	94 Pu PLUTONIUM (244)	95 Am AMERICIUM (243)	96 Cm CURIUM (247)	97 Bk BERKELIUM (247)	98 Cf CALIFORNIUM (251)	99 Es EINSTEINIUM (252)	100 Fm FERMIUM (257)	101 Md MENDELEVIUM (258)	102 No NOBELIUM (259)	103 Lr LAWRENCIUM (262)	

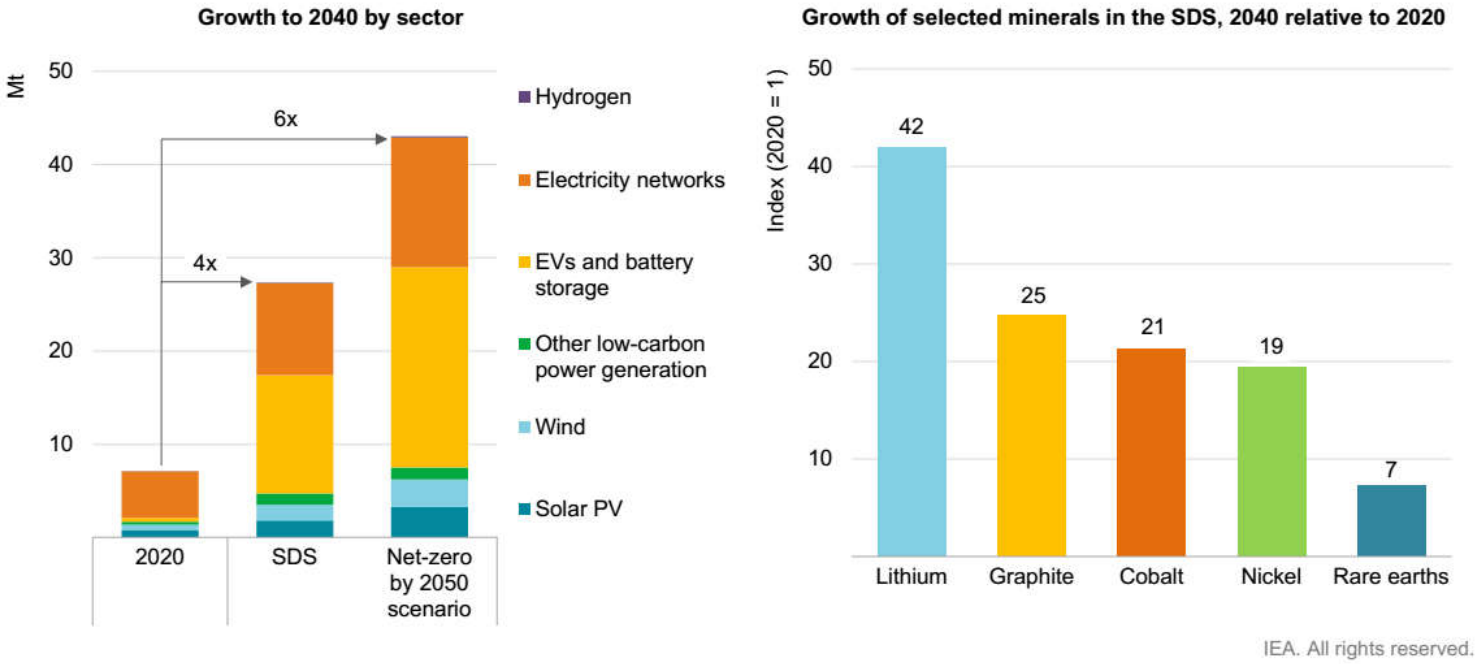
materials **critical for the energy transition**, by technology type



[figure from: The raw-materials challenge - McKinsey © 2022]

[1]Includes energy storage.
Source: *Critical raw materials for strategic technologies and sectors in the EU*, A foresight study, European Commission, Mar 9, 2020; *The role of critical minerals in clean energy transitions*, IEA, May 2021; McKinsey analysis

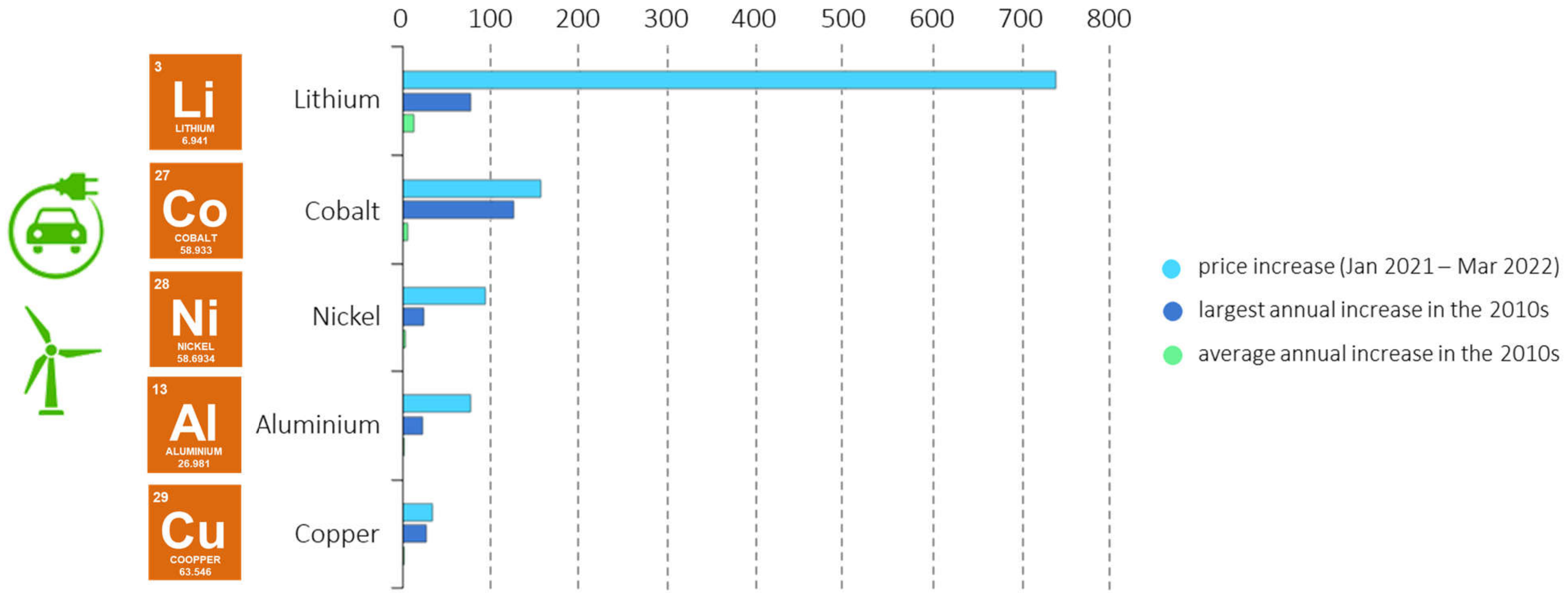
mineral demand for clean energy technologies by scenario



Notes: Mt = million tonnes. Includes all minerals in the scope of this report, but does not include steel and aluminium. See Annex for a full list of minerals.

[figure from: The role of critical minerals in clean energy transitions, © IEA 2021]

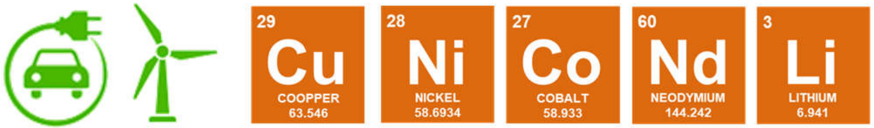
price increase (%) for selected energy transition materials



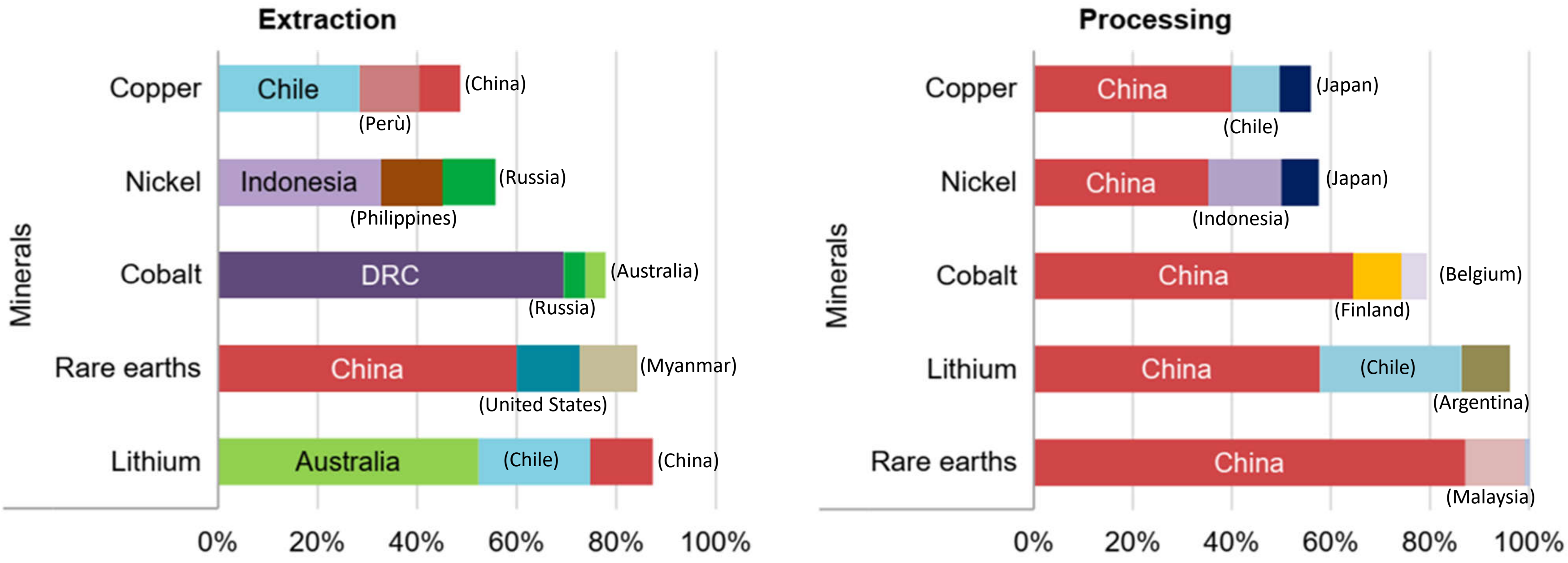
[figure adapted from: IEA (2022), www.iea.org/commentaries/critical-minerals-threaten-a-decades-long-trend-of-cost-declines-for-clean-energy-technologies. Licence: CC BY 4.0]

Not In My Backyard (NIMBY)

[Belgrade 2021, demonstration against Li mine opening – source: bloomberg.com – © Oliver Bunic/Bloomberg]



share of **top three producing countries** in production of selected minerals, 2019

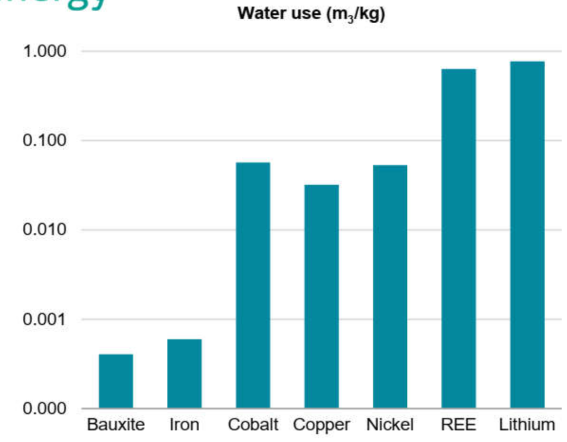


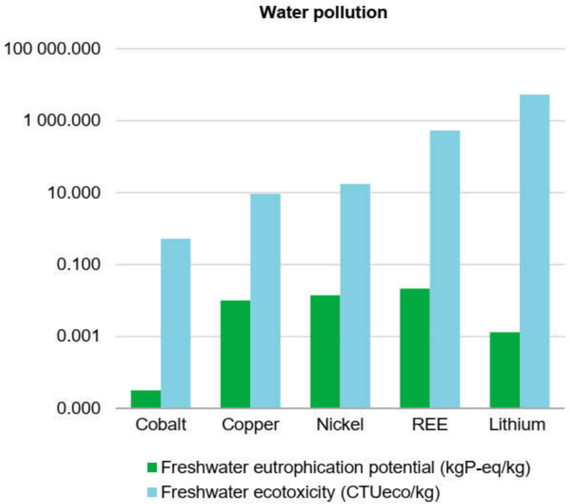
[source: IEA 2021, dati: IEA (2020a); USGS (2021), World Bureau of Metal Statistics (2020); Adamas Intelligence (2020)]

[figure adapted from: The role of critical minerals in clean energy transitions, © IEA 2021]

environmental impacts

- biodiversity loss
- water depletion and pollution
- waste-related contamination
- air pollution

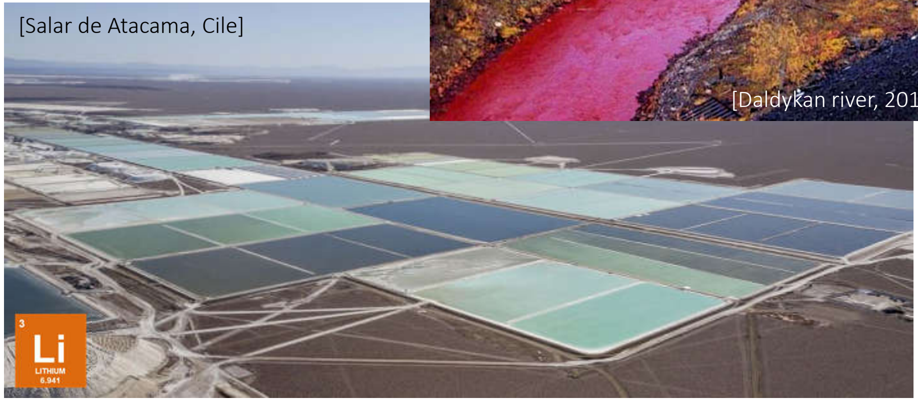




[figure adapted from: The role of critical minerals in clean energy transitions, © IEA 2021]

[picture from: siberiantimes.com - © Vkontakte]

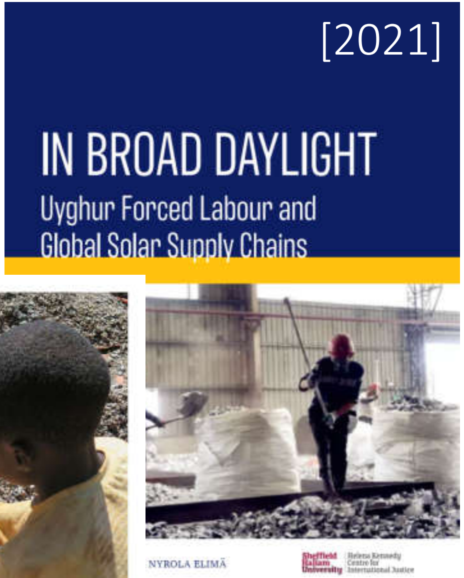
[Daldykan river, 2016, Russia]



[Salar de Atacama, Cile]

[picture from: bloomberg.com - © Cristobal Olivares/Bloomberg]

[2017]



[2021]

[2016]

HUMAN RIGHTS WATCH

"We are concerned about the impacts of extracting minerals [...] for renewable energy technologies on communities, workers and ecosystems around the world"

[Declaration on Mining and the Energy Transition, HRW, Oct **2021**]

sustainability ⟷ *responsibility*

sustainable price

e.g. REE extraction costs in Ganzhou: **4.500 USD/ton**, including environmental remediation: **30.000 USD/ton**

[source: www.chinawaterrisk.org]

energy transition heavily relies on many **raw materials**

issues of concern

- the **demand** for these materials will greatly **increase** in the near future
- mining/processing of these materials is **concentrated** in few countries
- mining/processing of these materials can have big **environmental & social impacts**

solutions

- increase production & investments in mining
- plan for the long term
- increase **research/innovation**
- scale up **recycling** for specific materials

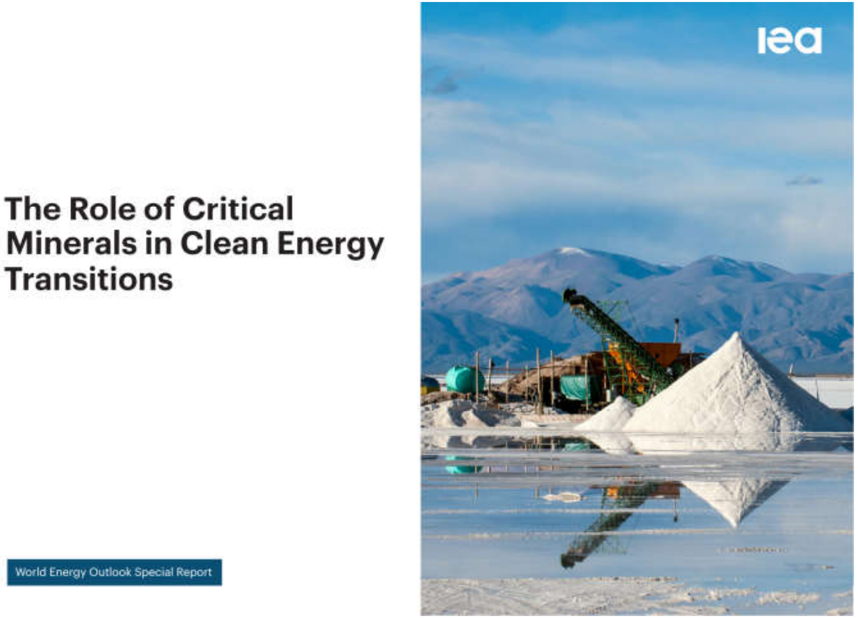
- **diversify supply**
- promote **awareness / social consensus** on mining activities (*no NIMBY*)

- foster **corporate responsibility & accountability**
- promote **certified / transparent supply chains**
- promote **sustainable mining / processing** (*use of renewables, environmental remediation*)
- promote awareness about **real costs** (*environmental, social*) & critical consumption

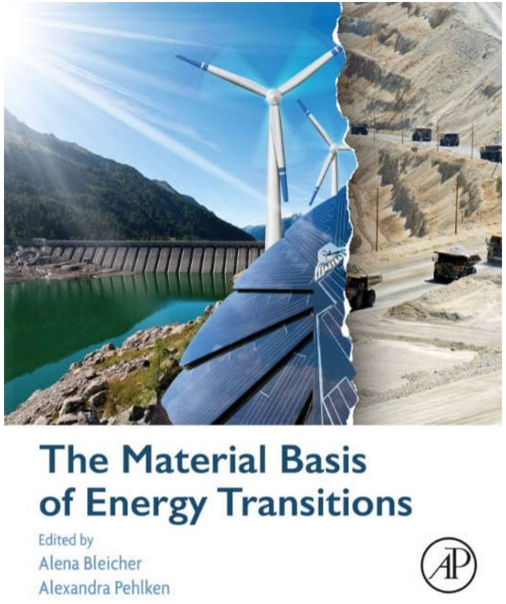
"A truly clean, **just** and **equitable** energy economy will require not just a transition to cleaner sources of energy, but transformation on an individual and collective level. We urge you to join us and ensure that the move to clean energy […] helps to build climate change solutions that put **communities**, **workers** and **the environment** first."

[Declaration on Mining and the Energy Transition, Human Rights Watch, Oct 2021]

essential readings



[2021]



[2021]

popular books