

What Makes a Material Critical? What Makes a Supply Chain Resilient?

Rod Eggert

July 14, 2022

DOE Critical Materials Workshop

Golden, Colorado



COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT



Critical Materials Institute
AN ENERGY INNOVATION HUB

Critical

Vital

Essential

Indispensable

Most of the 1st 83 elements in the periodic table are vital to someone

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57 - 71 La-Lu	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 - 103 Ac-Lr	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

A narrower definition

Essential functionality (i.e., indispensable)

Difficult substitution

Supply-chain risks

US list 2022 – not much of a narrowing!

- Gallium
- Niobium
- Cobalt
- Neodymium
- Ruthenium
- Rhodium
- Dysprosium
- Aluminum
- Fluorspar
- Platinum
- Iridium
- Praseodymium
- Cerium
- Lanthanum
- Bismuth
- Yttrium
- Antimony
- Tantalum
- Hafnium
- Tungsten
- Vanadium
- Tin
- Magnesium
- Germanium
- Palladium
- Titanium
- Zinc
- Graphite
- Chromium
- Arsenic
- Barite
- Indium
- Samarium
- Manganese
- Lithium
- Tellurium
- Nickel
- Beryllium
- Zirconium
- Cesium
- Erbium
- Europium
- Gadolinium
- Holmium
- Lutetium
- Rubidium
- Scandium
- Terbium
- Thulium
- Ytterbium

Note: In rank order from top to bottom and then left to right; elements starting with cesium were not rank ordered.

Source: Nassar and Fortier 2021 (USGS Open-File Report 2021-1045)

“What is ‘critical’ depends on
who you are, where you are,
and when you ask”

- Alex King

World, national, company, technology

Something important is at risk

Each material has its own story

Lack of supply chain diversity

Geopolitical risks

Co-production risks and opportunities

Technology risks

Entry barriers

Opaque markets

Etc.

The time dimension often is ignored

Short- to medium-term risks

v.

Medium- to long-term availability

Short- to medium-term risks

Fragility due to:

Existing geography of production & use

Existing technologies

Specific risks:

Physical availability

Price volatility

Reputation

Medium- to long-term availability

- Demand
 - Will increase quickly and substantially for some materials, although at what rate and by how much is uncertain
- Supply
 - Is characterized by supply chains that often are fragmented, concentrated (insecure), small, opaque
 - May not grow ‘appropriately’ to meet growing demands (sufficiently, securely, affordably, sustainably, responsibly)
- The Fear
 - Lack of appropriate availability will become an obstacle to clean energy transitions

Financial Times, May 5, 2021

Commodities

+ Add to myFT

High metal prices could delay transition to clean energy, warns IEA

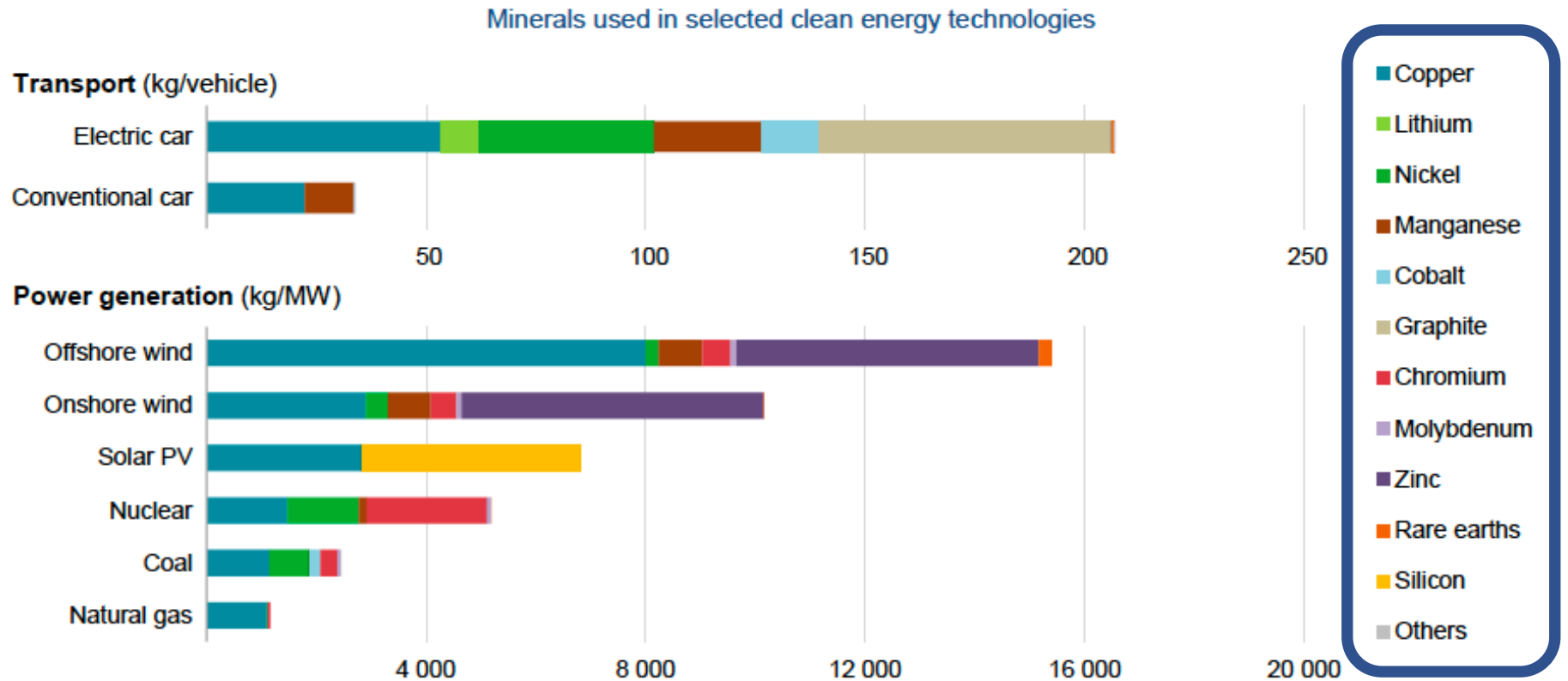
Paris agreement climate goals to 'turbocharge' demand for minerals amid lack of investment in mining



Prices for commodities — from lithium to cobalt — have rallied as demand for clean energy technologies has increased and governments have rolled out green stimulus packages © REUTERS

Source: <https://www.ft.com/content/2f709342-3070-4b75-8924-3d9190f5c0c7>

Demand for some mineral-based materials will increase significantly

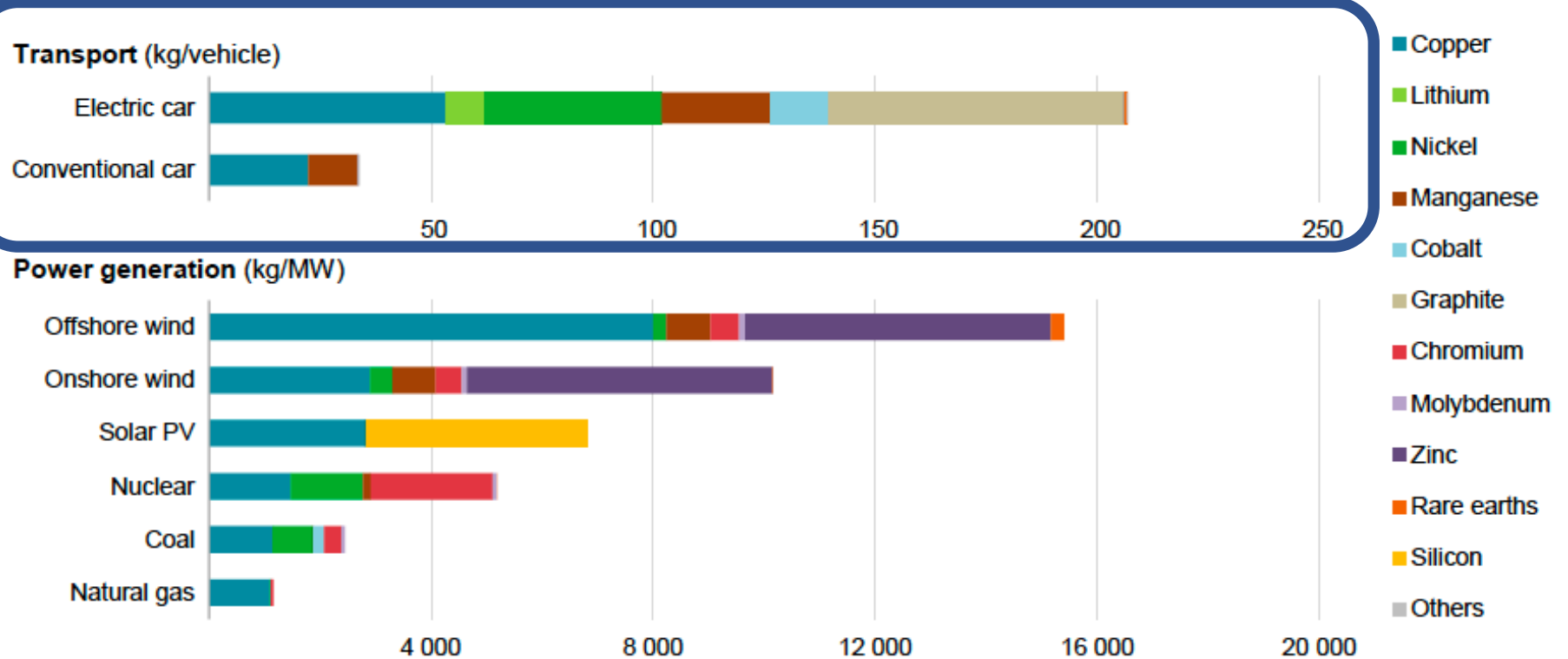


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Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

Demand for some mineral-based materials will increase significantly

Minerals used in selected clean energy technologies



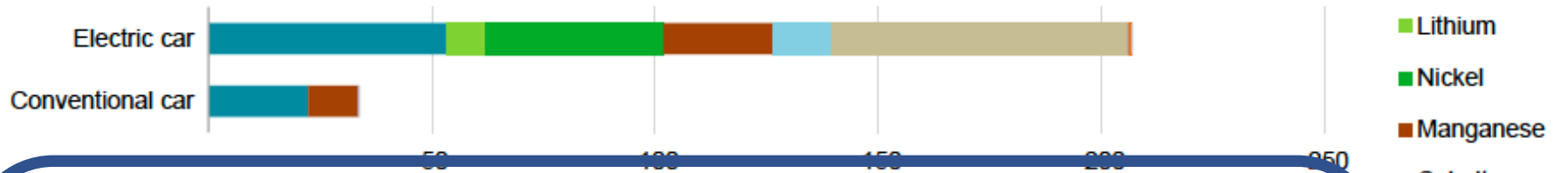
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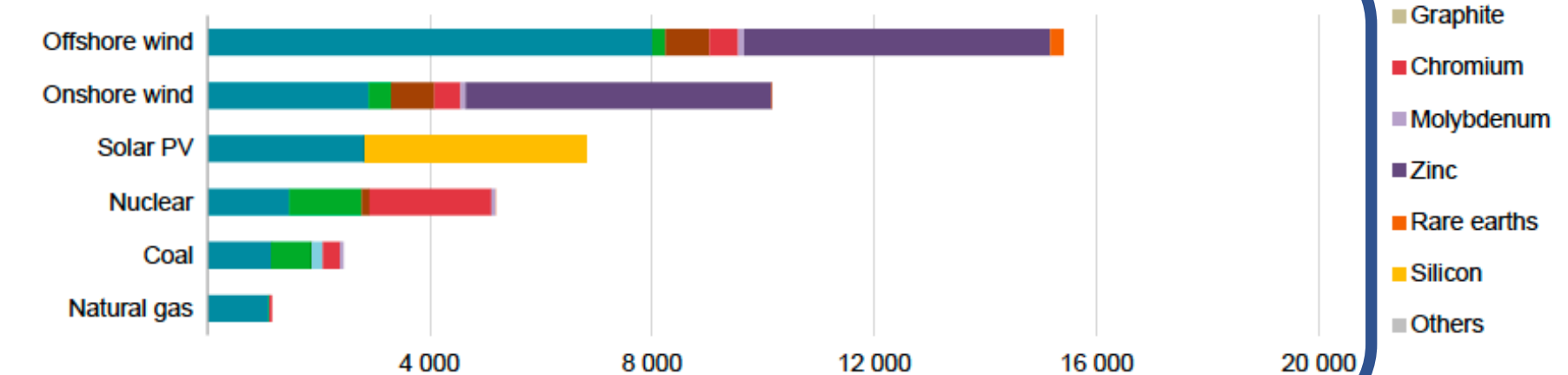
Demand for some mineral-based materials will increase significantly

Minerals used in selected clean energy technologies

Transport (kg/vehicle)



Power generation (kg/MW)



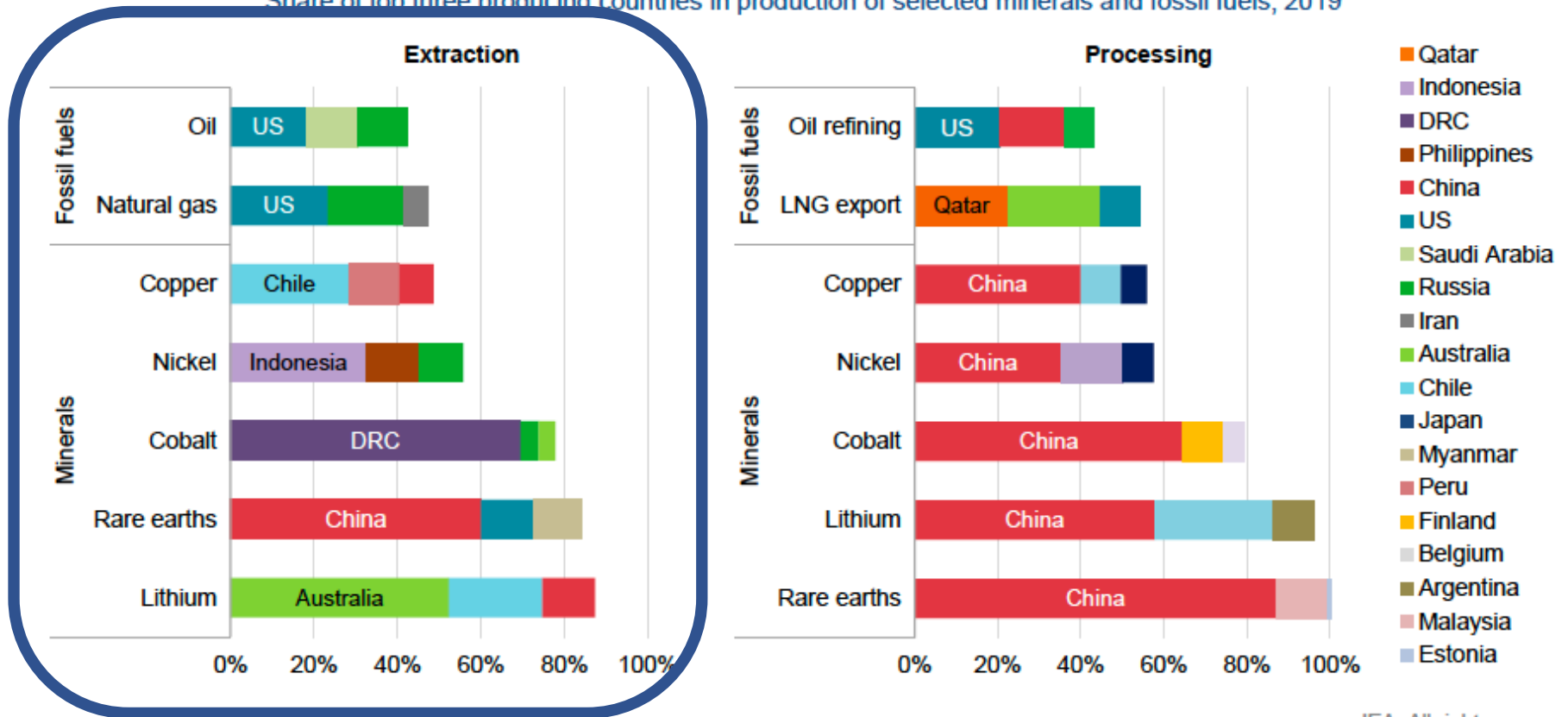
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Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

It's about supply chains not just mining

Production of many energy transition minerals today is more geographically concentrated than that of oil or natural gas

Share of top three producing countries in production of selected minerals and fossil fuels, 2019



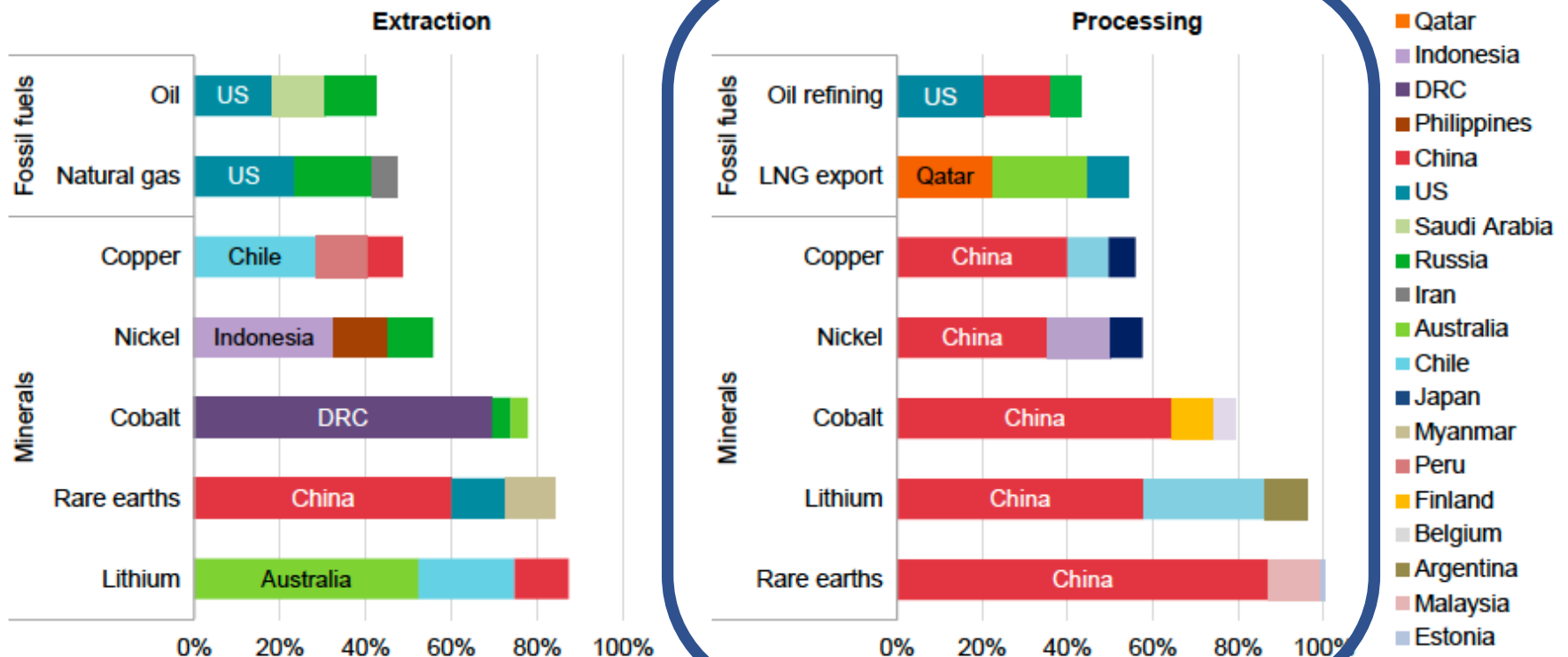
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Notes: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations.
Sources: IEA (2020a); USGS (2021), World Bureau of Metal Statistics (2020); Adamas Intelligence (2020).

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Electrification

- Copper
- Not officially a US 'critical' mineral – but certainly essential with few if any substitutes

Financial Times, July 13, 2022

Opinion **Copper**

'Dr Copper' has a worrying message about the energy transition

The metal has become central to the drive to net zero given its use in electric car batteries and other technologies

DANIEL YERGIN

+ Add to myFT

Image source: pixabay.com



Electronic materials

e.g., solar applications, power electronics

Gallium, indium, selenium, silver, tellurium, tin



Magnets & motors

Wind turbines, EVs, other industrial and household uses

Selected rare earths



Energy storage & batteries

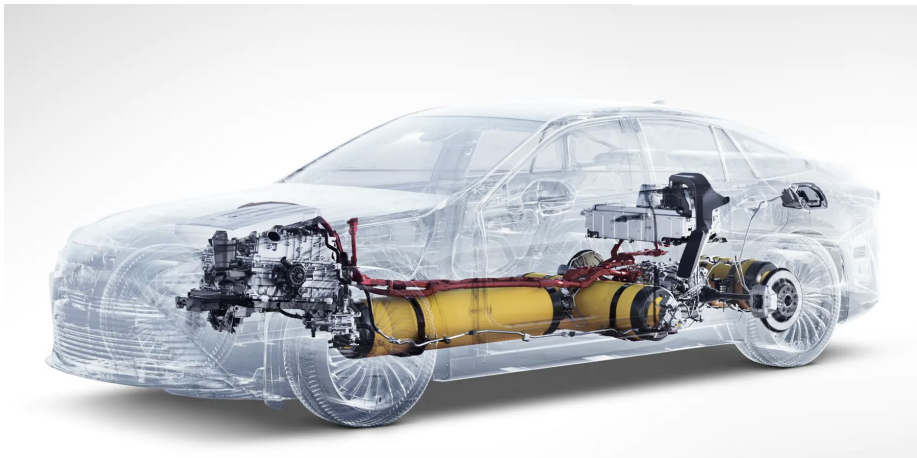
Lithium ion, solid-state lithium, sodium ion, flow, etc.

Lithium, nickel, cobalt, manganese, graphite, vanadium, sodium, lead, etc.



Fuel cells

Platinum-group elements,
selected rare earths



Nuclear

Cobalt, dysprosium,
gadolinium, hafnium,
indium



What makes a supply chain resilient?

Resilient

Able to withstand or recover quickly from
difficult conditions

Options

Short- to medium-term options

- Increase stockpiles/working inventories
- Develop sourcing arrangements
- Adopt off-the-shelf technologies
 - A material or process

Medium- to long-term options

- Diversify and increase primary production
 - Develop supply chains in more places
- Waste less
 - Increase manufacturing efficiency
 - Enhance re-use and recycling
- Use less
 - Develop substitutes

What mix of private initiative and public policy do we want?

A topic for another time

But a bit of the broader context

After Hyper-Globalization

What should the next trading system be? Can we restore the capacity of the U.S. to produce—and of all nations to regulate capitalism?

BY ROBERT KUTTNER MAY 31, 2022

Reconsideration
of globalization

The Myth of the Global Why Regional Ties Win the Day

By [Shannon K. O'Neil](#) July/August 2022

Businessweek | Remarks

'Onshoring' Is So Last Year. The New Lingo Is 'Friend-Shoring'

The Biden administration recognizes that the U.S. can't go it alone.

By [Peter Coy](#)

June 24, 2021, 3:00 AM MDT

★ ★ ★

Minerals Security Partnership

MEDIA NOTE

JUNE 14, 2022

MAY 24, 2022

Reboot: Framework for a New American Industrial Policy

Reconsideration
of industrial
policy

Protection Without Protectionism
Getting Industrial Policy Right

By [Shannon K. O'Neil](#) January/February 2021

**The New Productivism
Paradigm?**

Jul 5, 2022 | [DANI RODRIK](#)

**President Biden Invokes Defense
Production Act to Accelerate Domestic
Manufacturing of Clean Energy**

JUNE 6, 2022

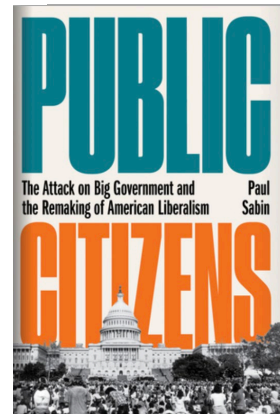
Reconsideration of relative roles of Congress, the Administration, and Civil Society

Supreme Court restricts the EPA's authority to mandate carbon emissions reductions

Updated June 30, 2022 · 10:30 AM ET ⓘ

Government regulation is vital, but it also needs to be efficient

Jimmy Carter had a vision for protecting the environment and consumers — while cutting wasteful regulations



Biden mining order won't change biggest hurdle: Permits

By Jael Holzman, Hannah Northey | 04/08/2022 01:34 PM EDT

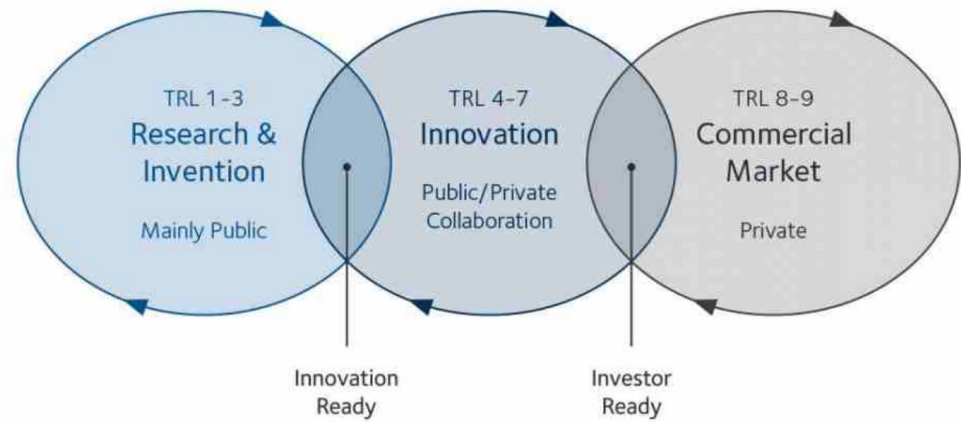
Reconsideration of science and technology policy

The Chinese Way of Innovation

What Washington Can Learn From Beijing About Investing in Tech

By **Matt Sheehan** April 21, 2022

‘Deploy, deploy, deploy’
- DOE, mid to late 2021



Source: <https://www.uk-cpi.com/blog/the-innovation-challenge-and-the-valley-of-death>

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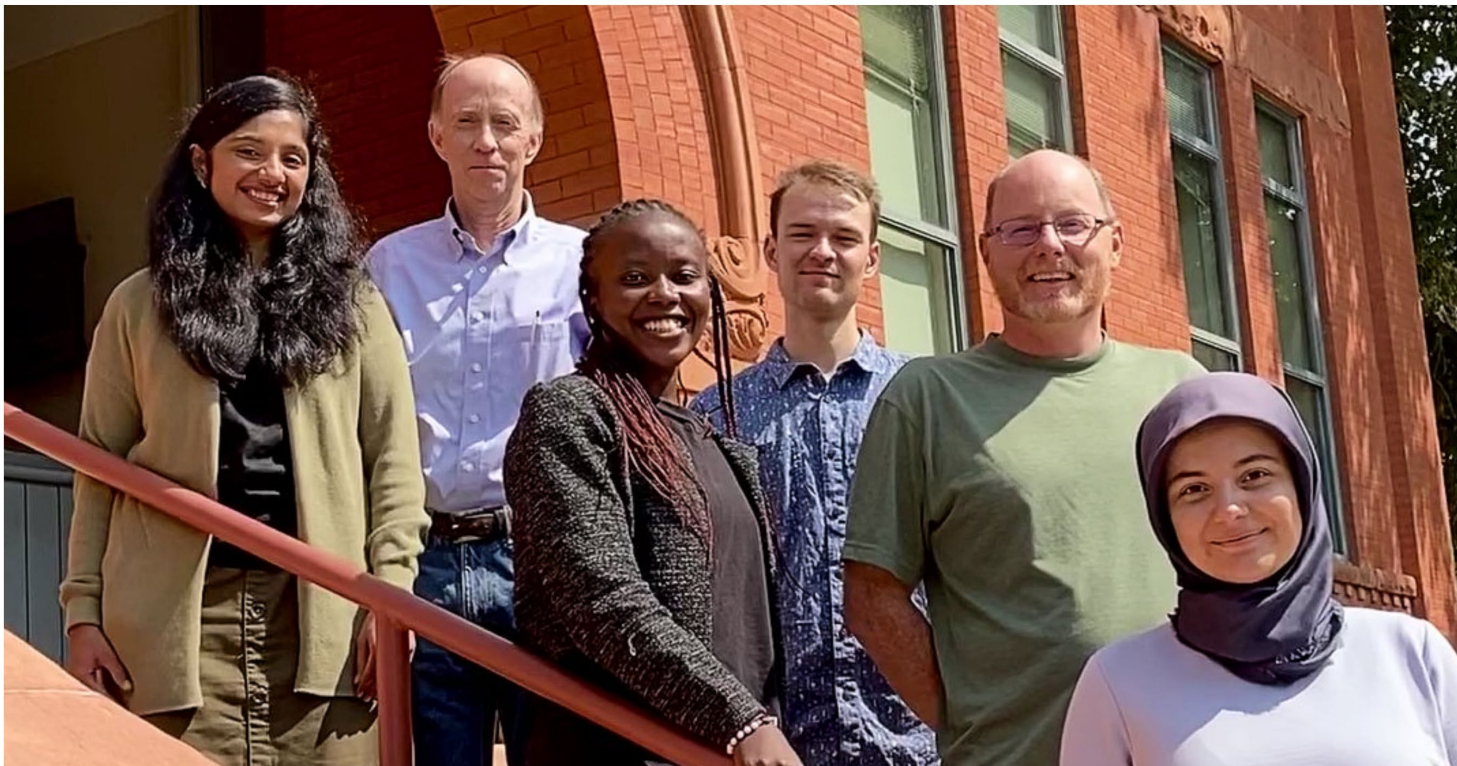
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Spring 2022, Eggert Research Group