MORE BATTERY MATERIALS OF POSSIBLE INTEREST

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GOALS WERE TO REDUCE CO_2 AND ELIMINATE OIL IMPORTS

But we are again (still?) reliant on imports

- The focus has been on materials that have now become critical
  - Cobalt
  - Nickel
  - Lithium
  - Graphite

> The lack of a substantial lithium battery supply chain in the United States and the lack of secure access to energy materials pose serious threats to U.S. national and economic security. **Li-Bridge Report, February 2023**

CURRENT PATH MAY BE UNREALISTIC

Expert panel evaluated likelihood of achieving projected growth

- Probable
- Possible
- **Improbable**
- Impossible

> Several Li-Bridge participants anticipate a worldwide shortfall in supplies of critical minerals and energy materials within a four-to-twelve-year time frame (before new foreign and domestic sources of supply can be brought online).

Li-Bridge Report February 2023

Future demand requirements for lithium, graphite, cobalt & nickel are staggering

Source: Wood Mackenzie

WHATEVER PATH WE TAKE, USING LESS EASES THE WAY

Technology options can enable sufficient range with less material

- Batteries with higher energy density (*e.g.*, solid-state)
- Plug-in hybrid vehicles
  - Range-extended EV is less complex than dual propulsion system PHEV
  - Supplementary fuel can be biofuel
- In-road charging
- *Battery swapping*
- Modular or hybrid battery design for flexibility
  - Easily available add-ons or vehicle rentals
- Car or ride sharing

MIGHT OTHER PATHS BE MORE PROMISING?

Consider less scarce domestic materials (and more efficient batteries)

- Phosphorus and iron
- Manganese
- Sodium
- Sulfur
- Lithium metal
  - Solid electrolyte materials?
    - Zirconium
    - Yttrium
    - Indium
    - Lanthanum
- Copper

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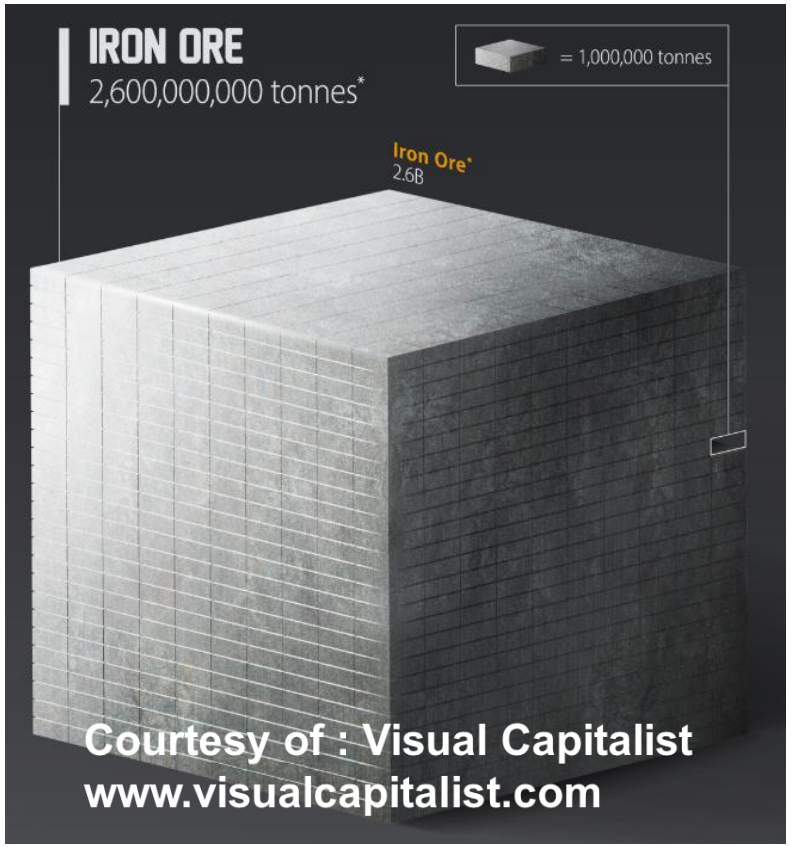
Consider trying to leapfrog instead of playing catch-up.

PHOSPHORUS AND IRON ARE ABUNDANT IN US

US has a head start for producing lithium iron phosphate (LFP)

- LFP plants planned in St. Louis (ICL) and Quebec (First Phosphate)
- US has onshore:
  - Phosphate rock
  - Chemical grade phosphoric acid capacity
    - Might require expansion
  - Unlimited iron supply and refining capacity
  - Sufficient lithium for a few years
  - Resources for a complete domestic supply chain
- About 110 kg Fe and 70 kg P (including electrolyte salt) needed per car
  - Tighter constraint is P (~2 million T/y mined in US)
  - Enough for ~30 million cars annually



IRON SUPPLY WILL NOT BE AN ISSUE

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MANGANESE IS ABUNDANT GLOBALLY

Several Mn-based cathodes are under consideration

- US reserves are poor
  - Ore containing 20% or more Mn not mined domestically since 1970.
  - Last USGS estimate 230 MT (enough for 34B 100 kWh batteries)
  - Too expensive to mine in US
- Ore and ferromanganese are imported from Gabon (67%), South Africa (19%), Mexico (12%)
  - Mn content ranges from 35-54% for Mn and from 74-95% for ferromanganese
  - Reserve 1.5 BT, resources larger

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SODIUM SUPPLY IS NOT AN ISSUE

Sodium-ion batteries could relieve the lithium supply crunch

- US produces 42 million T/y salt (NaCl)
  - 94% from Kansas, Louisiana, Michigan, New York, Ohio, Texas, and Utah
  - 39% used by chemical industry
- Potential for extraction from seawater is practically unlimited

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SULFUR IS A WASTE PRODUCT

From petroleum refining and copper smelting

- The incentive for recycling Li-S batteries could be low
  - Depends on Li price and whether any valuable structure can be recovered
- 2022 production 8 million T
  - 1.6 MT exported
  - 1.9 MT imported
- Main use is as sulfuric acid
  - Phosphoric acid is produced from phosphate rock and sulfuric acid
  - So S is needed for LFP as well as Li-S
- And don't forget about Li-air!

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WHAT WOULD BE NEEDED FOR SOLID-STATE BATTERIES?

Anode and electrolyte are different

- Lithium metal needed for the anode
- SSB expert identifies 3 major contenders for solid electrolyte
  - Li argyrodites (Li_6PS_5Cl, Li_6PS_5Br)
  - Li garnets ($Li_7La_3Zr_2O_{12}$ with either Ta, Al, or Ga dopants)
  - Li halides (Li_3YCl_6, Li_3AlF_6, Li_3InCl_6, etc.)
- Halide elements not scarce
- Dopants only needed in trace quantities

Elements to look at:
Zirconium
Indium
Yttrium
Lanthanum

US ALREADY PRODUCES LITHIUM METAL

Rapid expansion could enable US to be a long-term leader as market grows

- Li metal capacity would be needed for solid-state batteries
- US is a player in this arena
- US does have Li reserves
  - Can supply our own needs, but cost uncertain
  - Geothermal brine coproduction lab call issued
- 100's of 1000's of tons may be needed, vs. current 5000 T (Li^0) market*
- Need better production technology, on large scale
- **US has potential to get ahead of the curve on Li metal**
  - Can control our entire Li metal supply chain

	2020 BG Li Metal Capacity	2050 BG Li Metal Demand
US	0.55	--
World	2.5	1,000

Units: 1000 metric tons

* Half of Li metal is battery grade

ONLY ZR IS A COMMODITY CHEMICAL

US has significant production and reserves

Element	Production (T)	Imports (T)	Import sources	Exports (T)	Reserves (T)	kg per EV
Zirconium	<100,000 (ore)	35,000	various	14,000	500,000	50
Indium	--	170	China (31%), Canada (23%), ROK (20%)	--	--	?
Yttrium	--	1000	China (74%)	4	.012% of Mt. Pass	?
Lanthanum	--	--	China (74%)	--	~25 % of RE	

Zr Import sources: Zirconium ores and concentrates: South Africa, 51%; Senegal, 25%; Australia, 21%;. Zirconium, unwrought, including powder: China, 89%; Germany, 8%. Zirconium, wrought: France, 62%; Germany, 19%; Belgium, 6%.

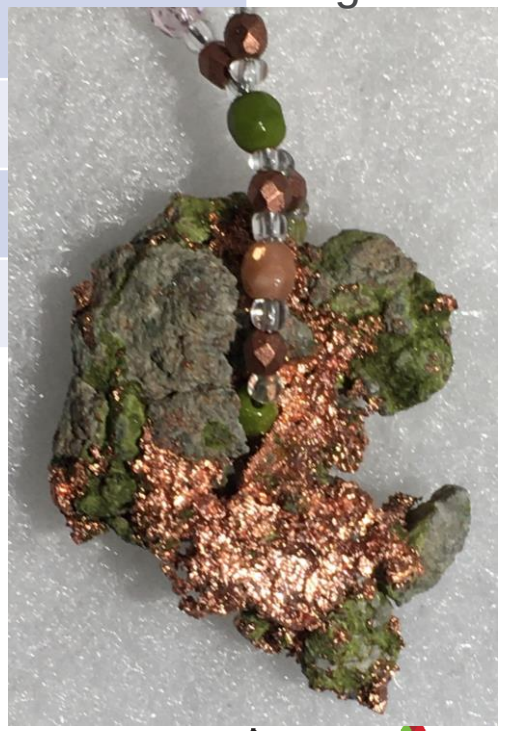
COPPER WILL NOT LIMIT GROWTH

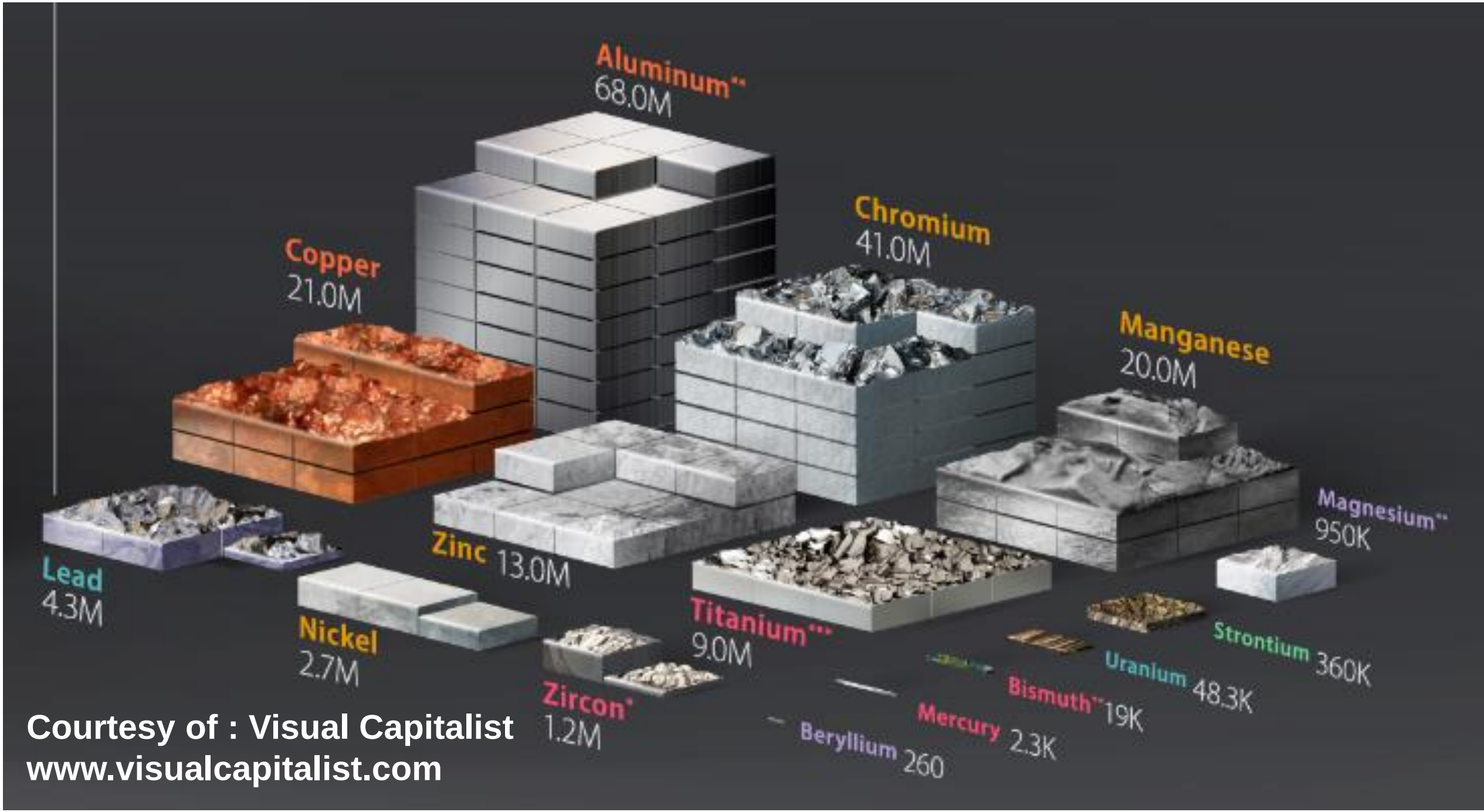
EV does use more copper than ICE

Component	Cu required (lb)	# needed per vehicle	Total Cu (lb)	% of total Cu
Vehicle body	288.9	1	288.9	71.5
Battery	111.0	1	111.0	27.5
Home charger	4.4	0.8	3.5	0.9
Level 2	15.4	0.04	0.6	0.1
DCFC	48.4	0.0017	0.08	0.02
TOTAL			404.08	100

- One million tonnes refined in US in 2022.
- Enough for 5 million cars annually
- Clean energy will dominate use, but US reserves 44 million T
- So domestic supply is not a major issue.

Native copper
From Michigan UP




Aluminum**
68.0M
Copper
21.0M
Chromium
41.0M
Manganese
20.0M
Magnesium**
950K
Lead
4.3M
Zinc 13.0M
Nickel
2.7M
Titanium***
9.0M
Zircon*
1.2M
Strontium 360K
Uranium 48.3K
Bismuth** 19K
Mercury 2.3K
Beryllium 260
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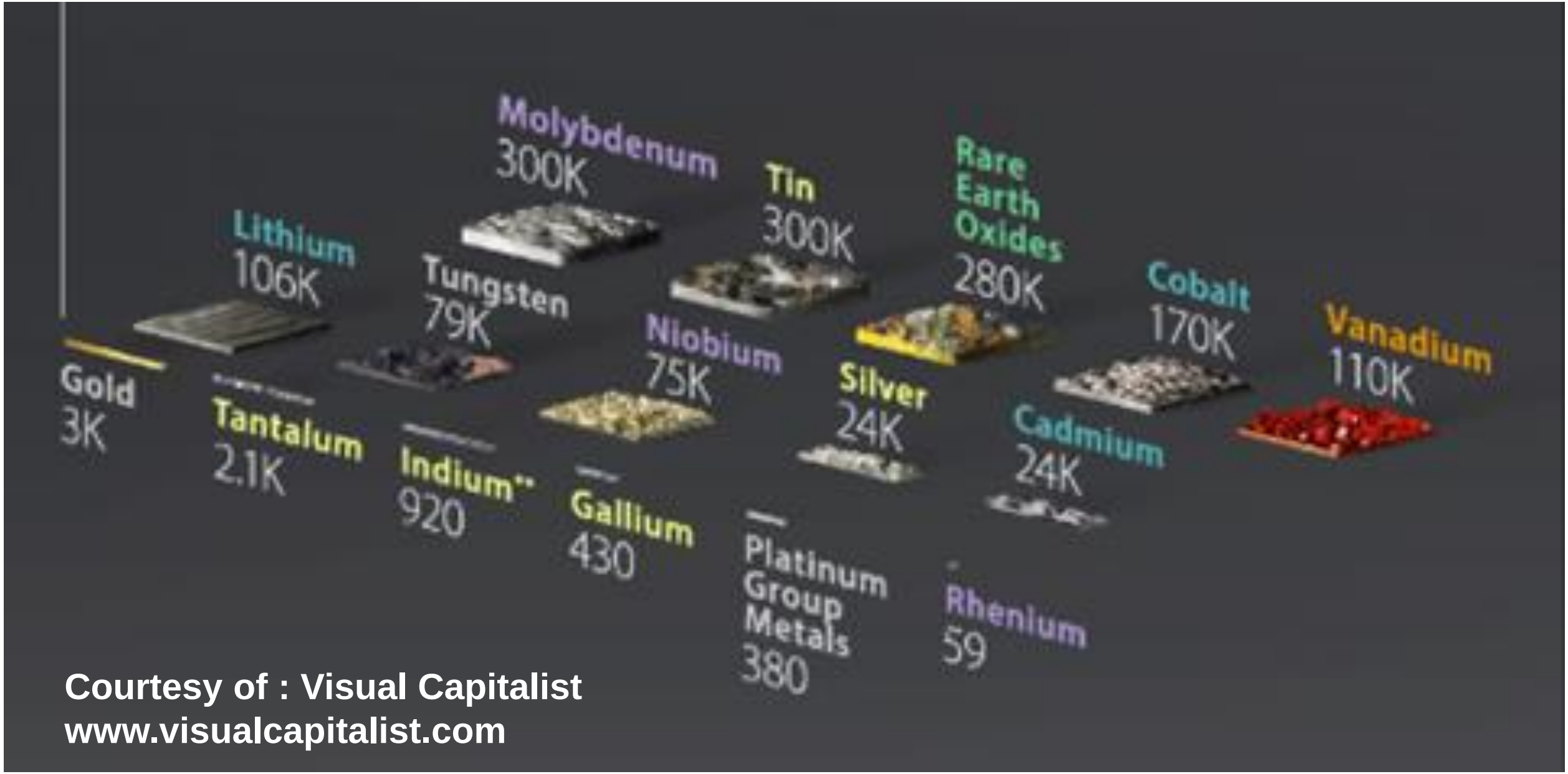

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US IMPORT RELIANCE FOR CRITICAL MINERALS

Figure 9.—20-Year Trend of U.S. Net Import Reliance for Critical Minerals

X= elements usually discussed; # = elements in this presentation