The Geology of Climate Change

How we're going to dig ourselves out

BBC

www.sapphiregassolutions.com

Polleverywhere

True / False

Climate change is real and humans are causing a very significant increase in that change.

Polleverywhere

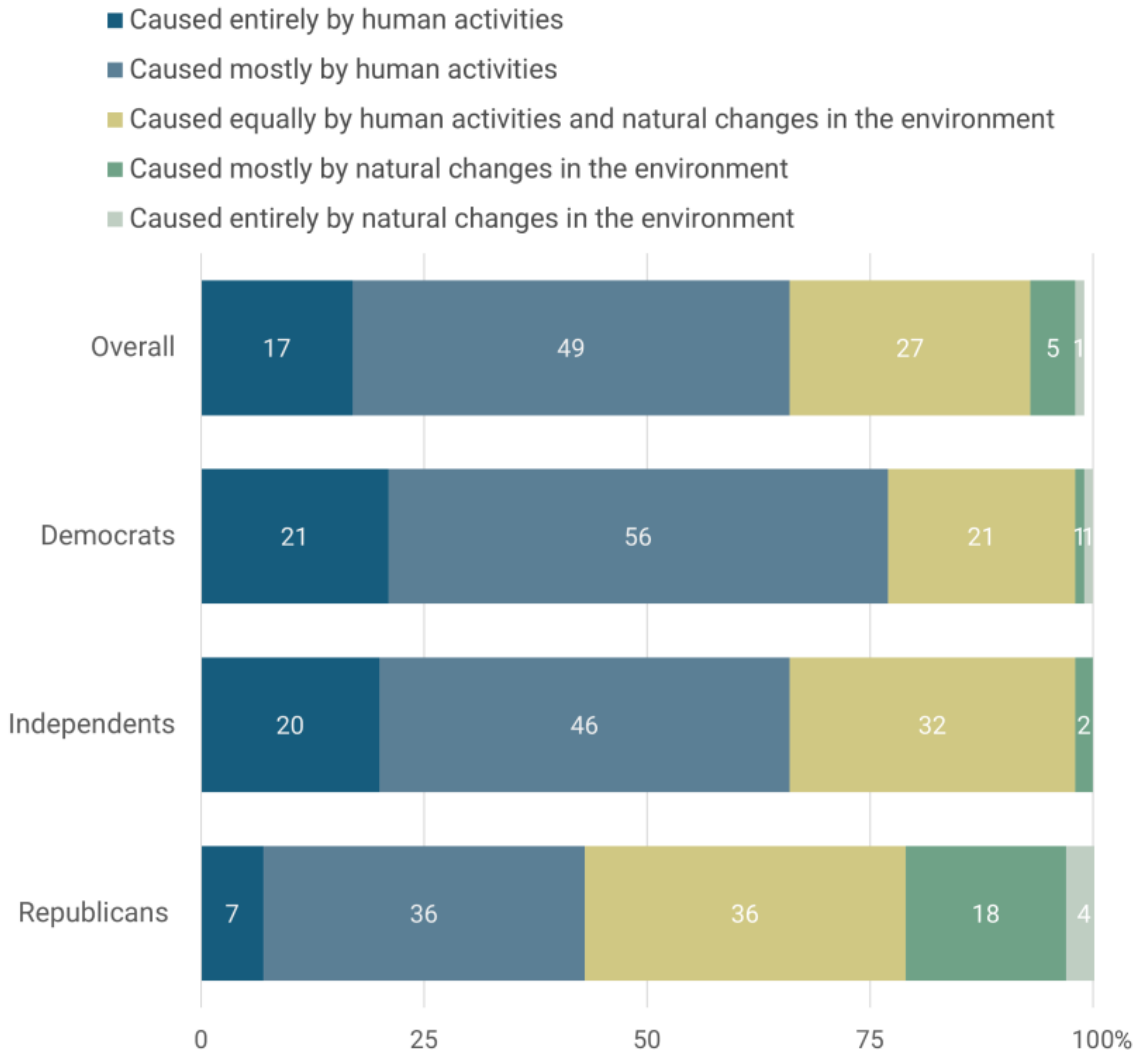
True / False

Mining is old, dirty, problematic, and we don’t need it.

Outline

- The geology of climate change
- Geologist's role
- An important part of the solution is... more mining???

A majority of Americans believe climate change is caused by human activity.
Percent of adults who believe climate change is happening



Question: Do you think climate change is caused entirely by human activities, caused mostly by human activities, caused about equally by human activities and natural changes in the environment, caused mostly by natural changes in the environment, or caused entirely by natural changes in the environment?
Source: AP-NORC Poll conducted June 23-27, 2022 with 1,053 adults nationwide.

AP | NORC

APNORC.org

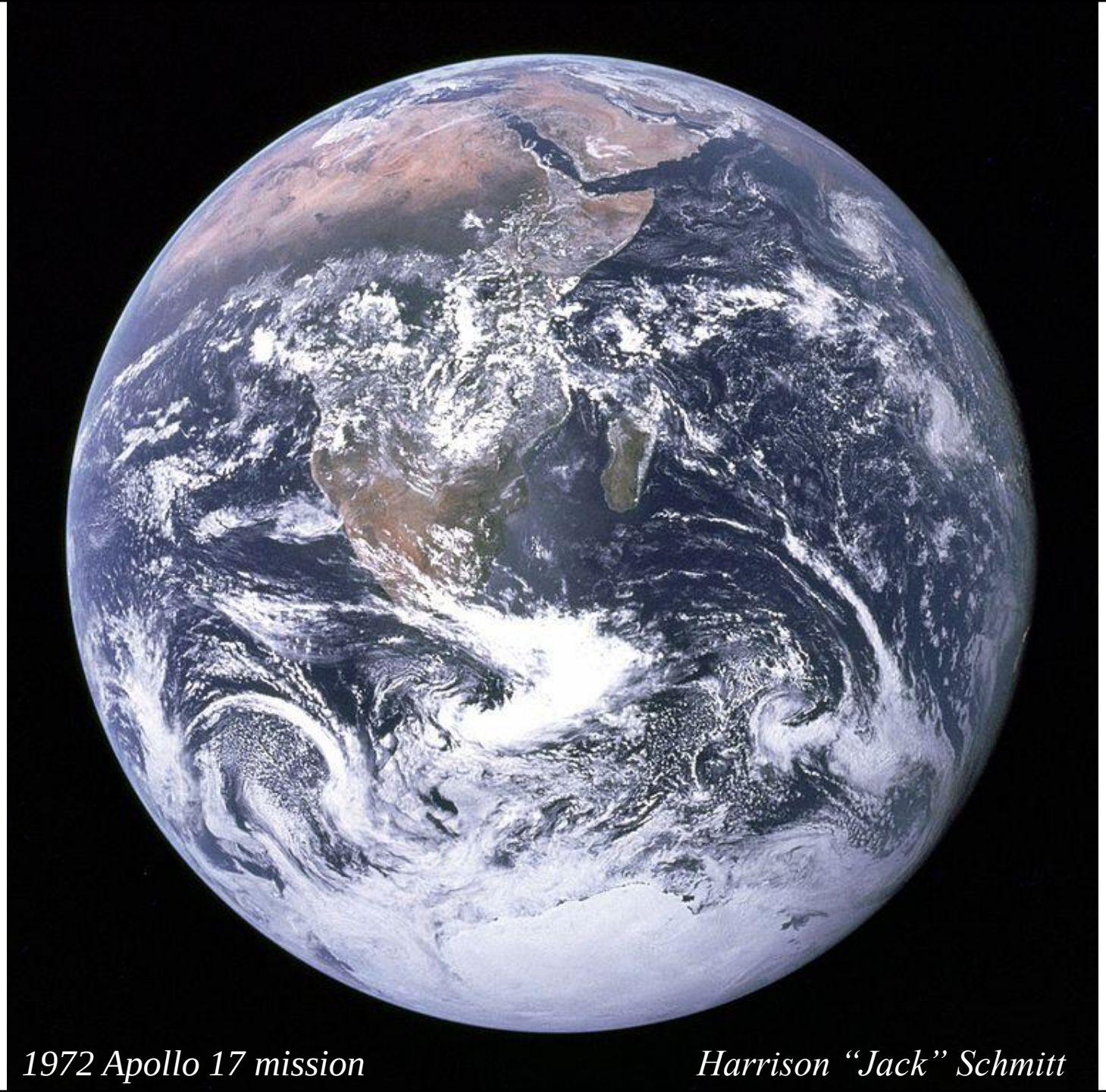

cnn


New York Times


BBC


Princeton

The Blue Marble



1972 Apollo 17 mission

Harrison “Jack” Schmitt

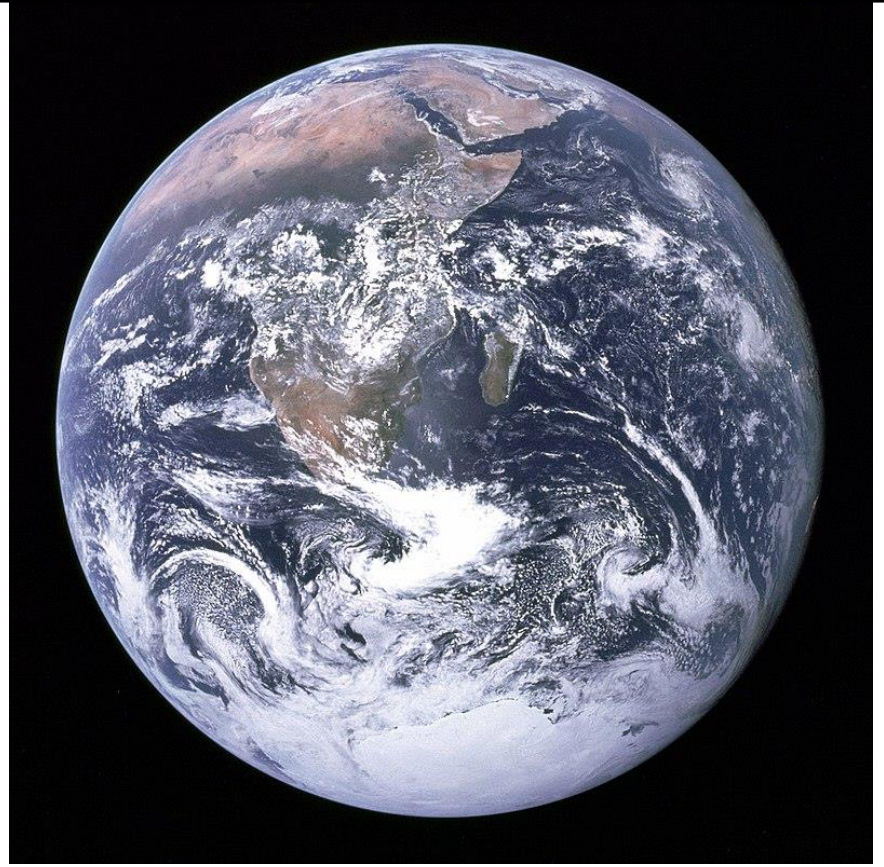
Atmosphere:

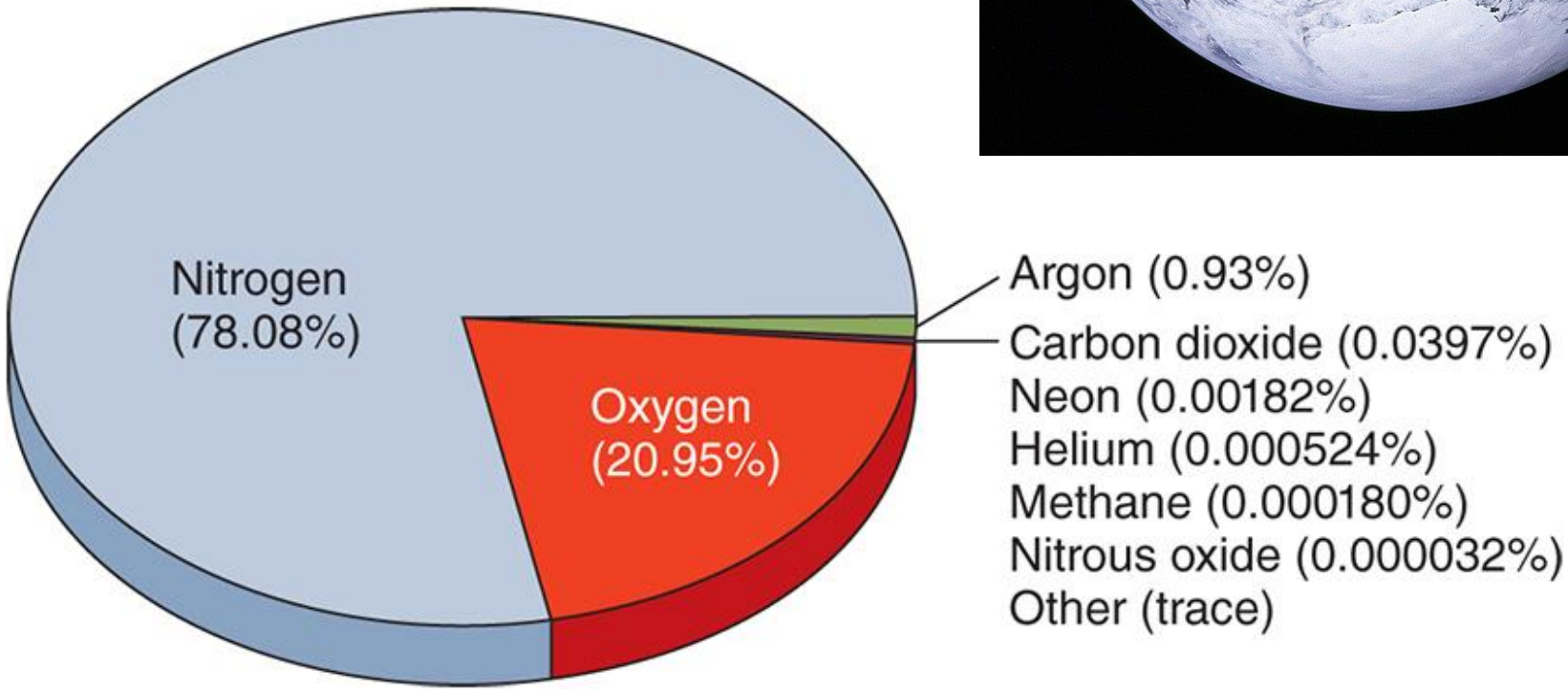
78.1 % N_2

20.9 % O_2

0.9 % Ar

0.04 % CO_2





Think

Pair

Share

Where does the atmosphere come from?

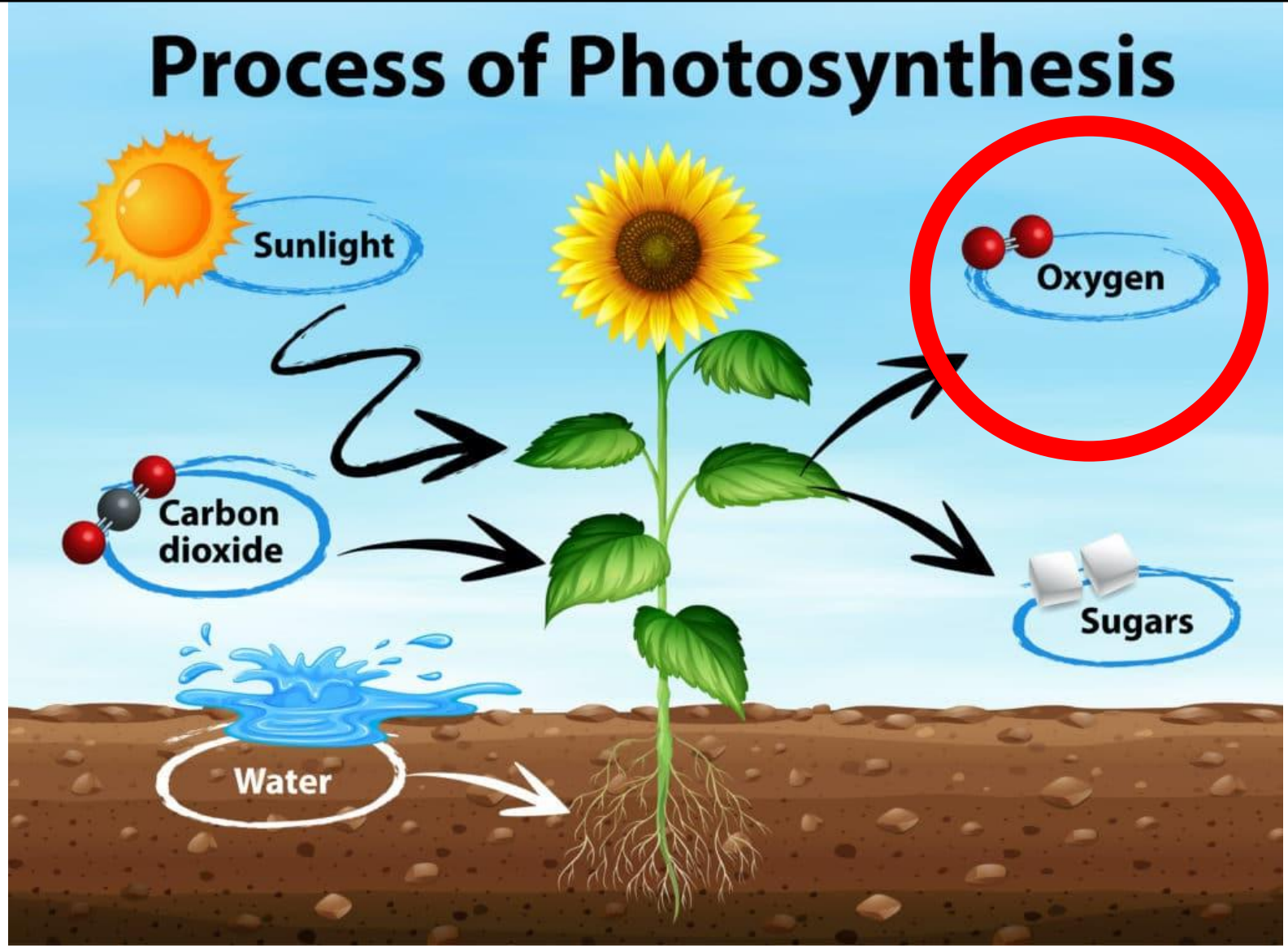
Volcanic Gases:

~60% H_2O

~40% CO_2

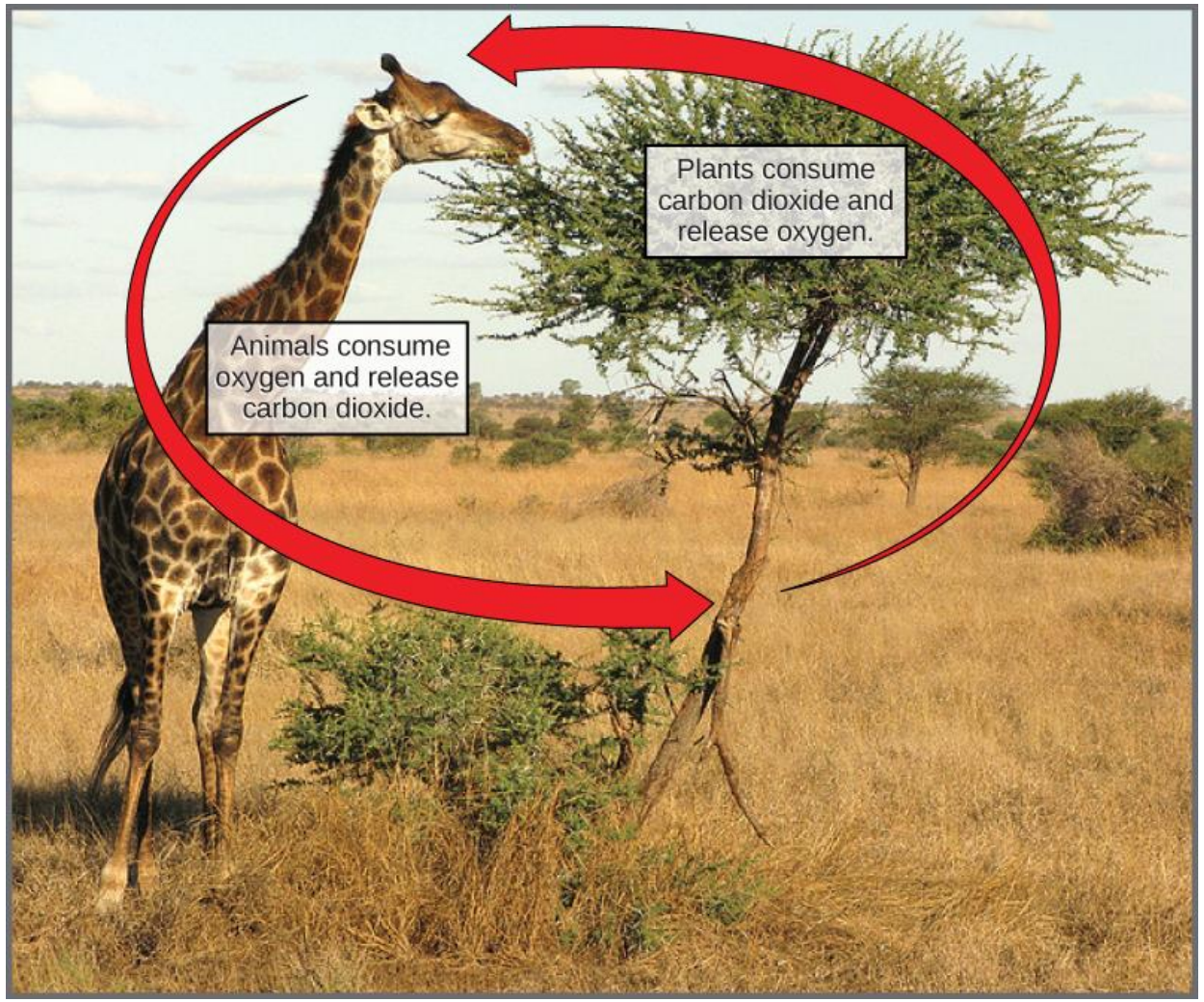
Trace SO2, N2, Ar, He

Photo Credit: The New York Times



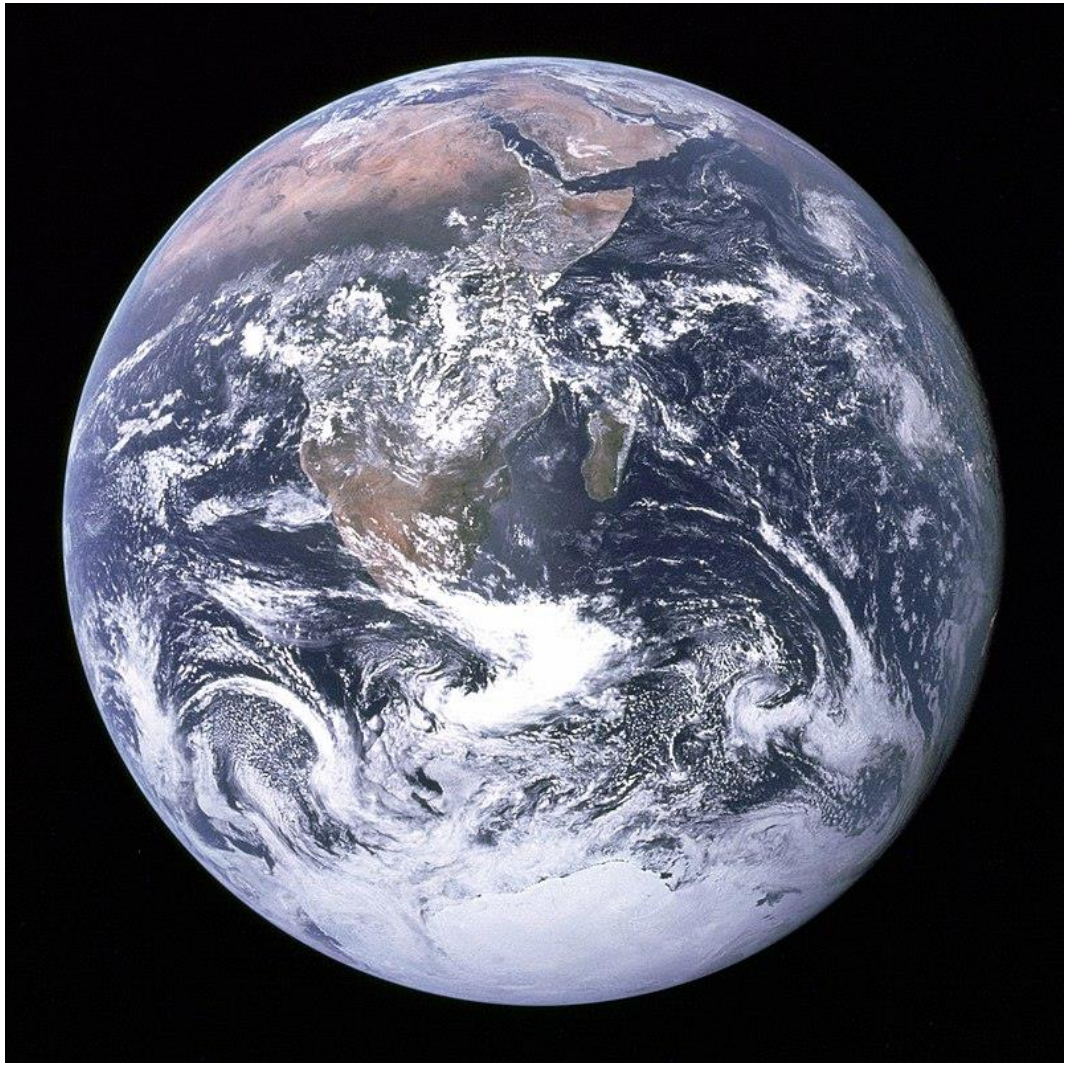
$$6H_2O + 6CO_2 + Energy \rightarrow C_6H_{12}O_6 + 6O_2$$

Biosphere consumes oxygen



$$6H_2O + 6CO_2 + Energy \text{ <-> } C_6H_{12}O_6 + 6O_2$$

Thought Experiment: What if we combusted every living cell on Earth?



Atmosphere Now:

78.1 % N_2

20.**9** % O_2

0.9 % Ar

0.0**4** % CO_2

Combust Everything:

78.1 % N_2

20.**4** % O_2

0.9 % Ar

0.0**9** % CO_2

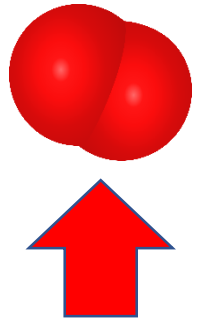
Photosynthesis is
necessary
but not
sufficient
to create the
atmosphere we have
today

Think

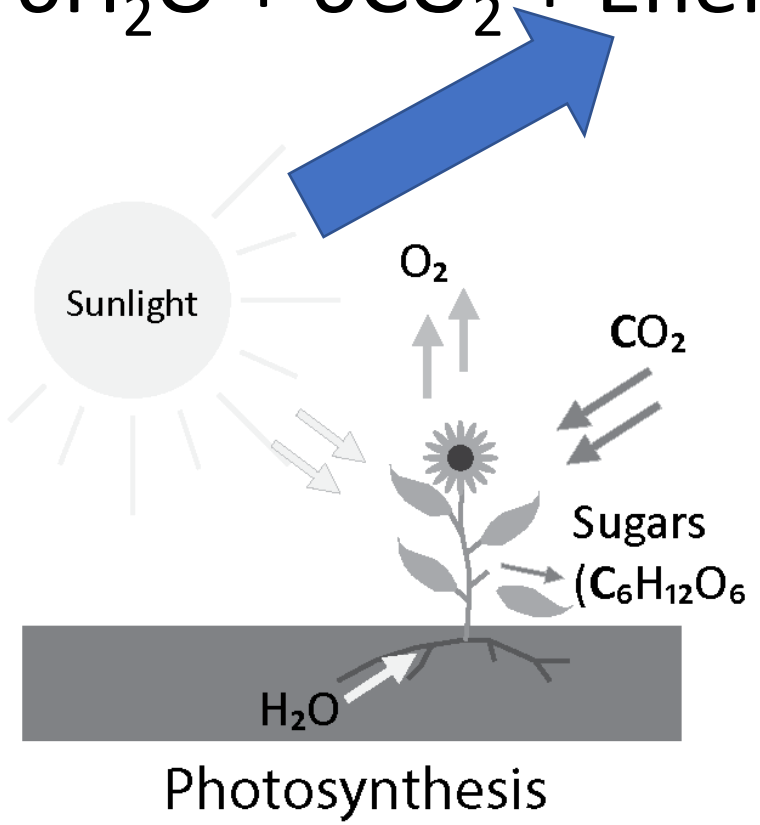
Pair

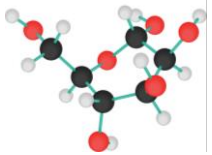
Share

What Shifts the reaction to the right?

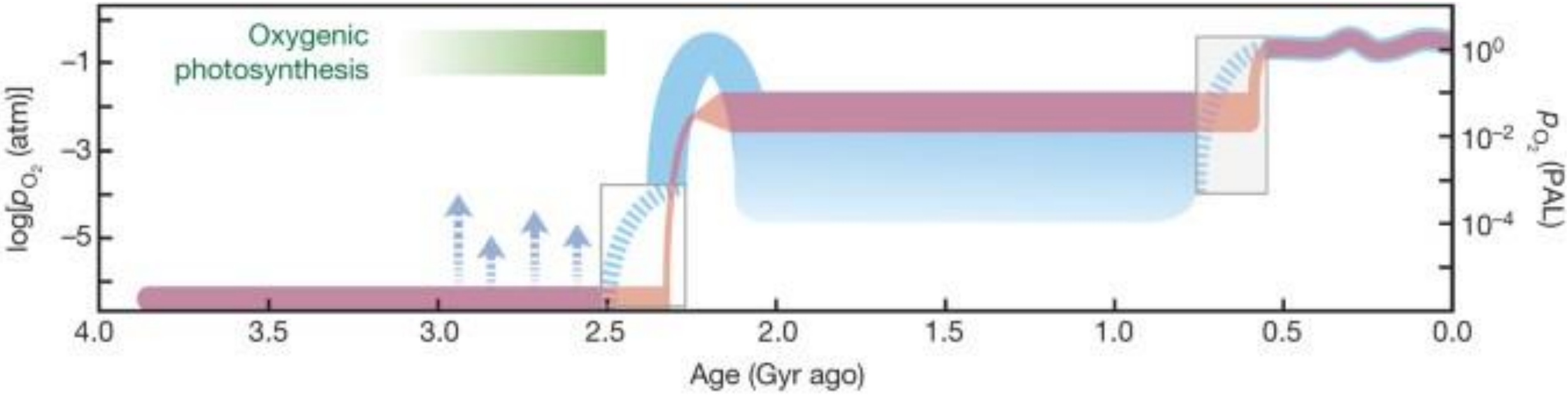


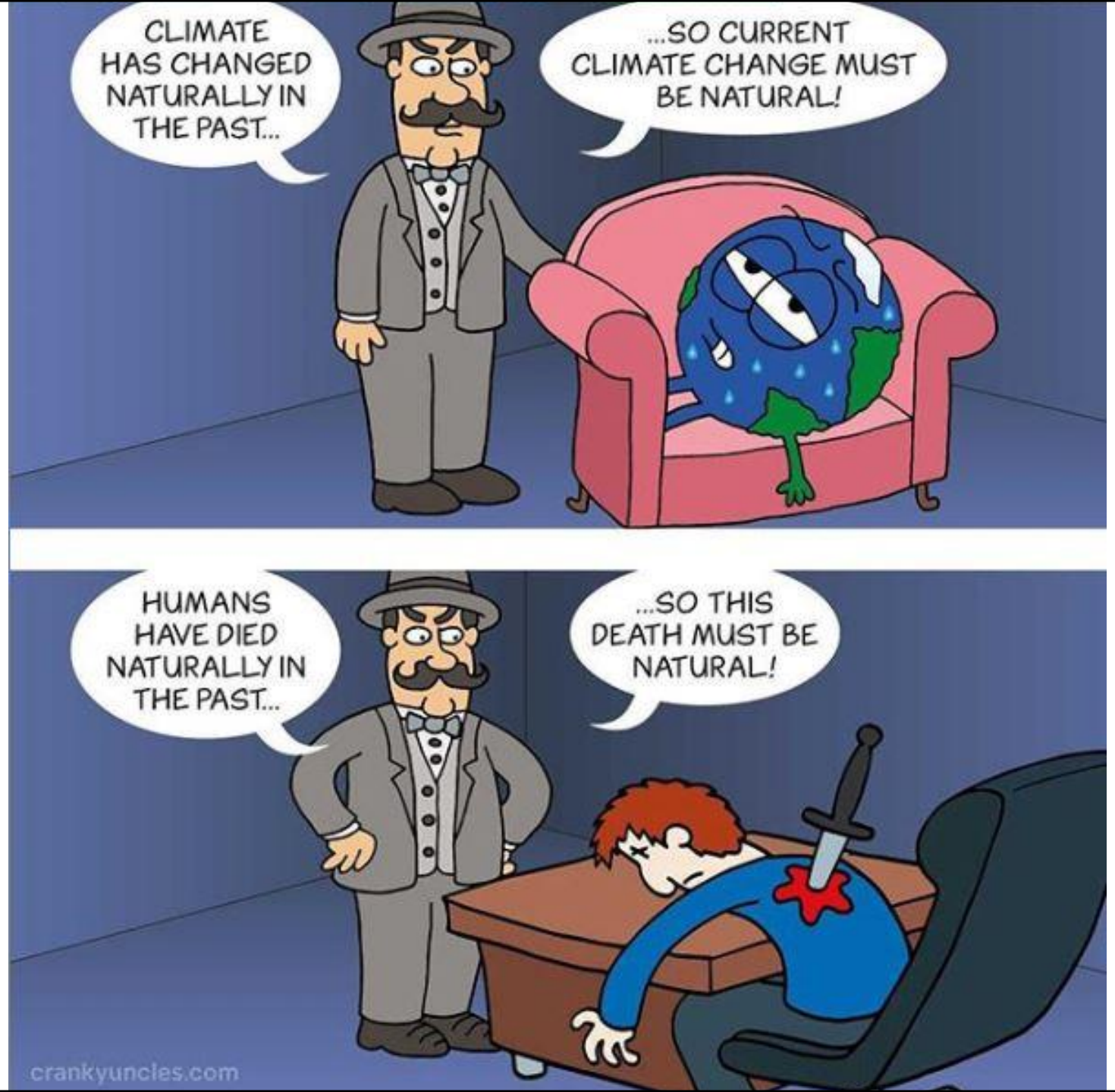
$$6H_2O + 6CO_2 + Energy \rightarrow C_6H_{12}O_6 + 6O_2$$

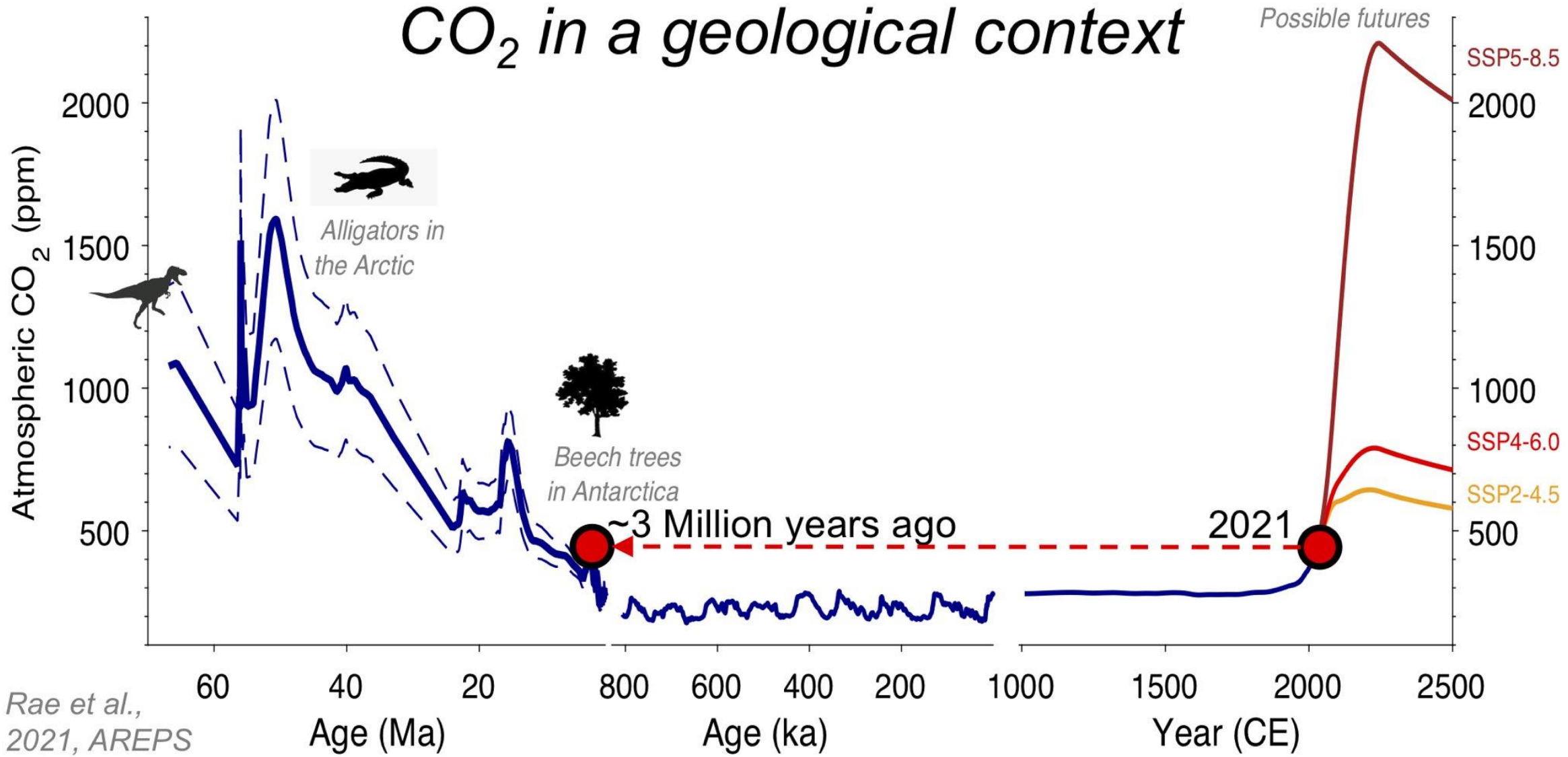




Oxygen in the atmosphere through time




CLIMATE HAS CHANGED NATURALLY IN THE PAST...
...SO CURRENT CLIMATE CHANGE MUST BE NATURAL!
HUMANS HAVE DIED NATURALLY IN THE PAST...
...SO THIS DEATH MUST BE NATURAL!
crankyuncles.com


CO_2 in a geological context
Possible futures
SSP5-8.5
SSP4-6.0
SSP2-4.5
Atmospheric CO_2 (ppm)
2000
1500
1000
500
Alligators in the Arctic
Beech trees in Antarctica
~3 Million years ago
2021
60
40
20
800
600
400
200
1000
1500
2000
2500
Age (Ma)
Age (ka)
Year (CE)
Rae et al., 2021, AREPS

Outline

- The geology of climate change (carbon cycle)
- **Geologist's role in this**
- An important part of the solution is... more mining???

Geologist's Role in Climate Change

We found the fossil fuels

We found the climate record

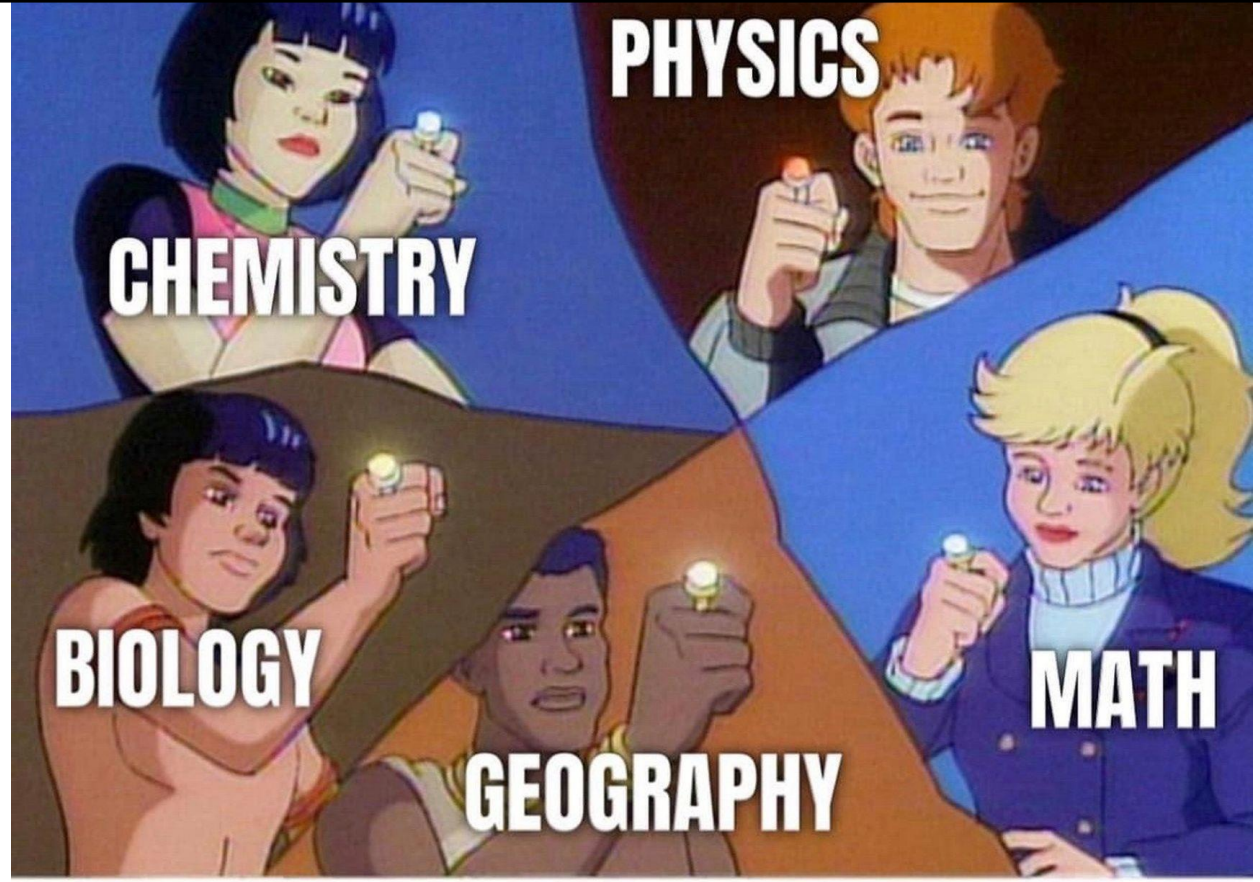
We're "finding" the solution

Geo-

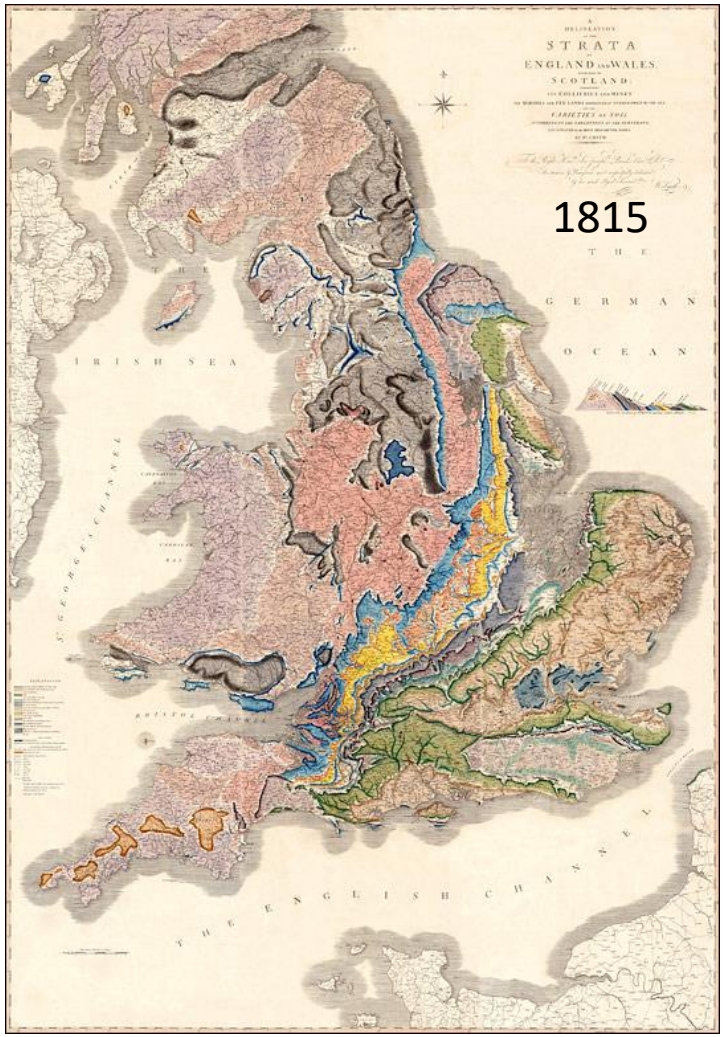
Greek *geō-,* combining form of *gê* - "the earth"

-ology

Any science or branch of knowledge

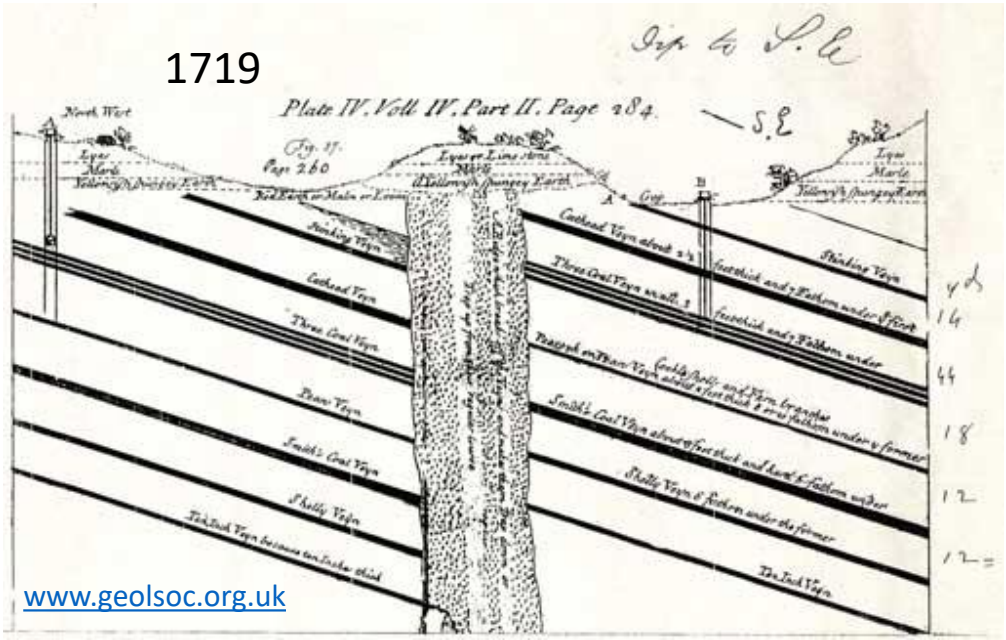


Coal



www.geolsoc.org.uk

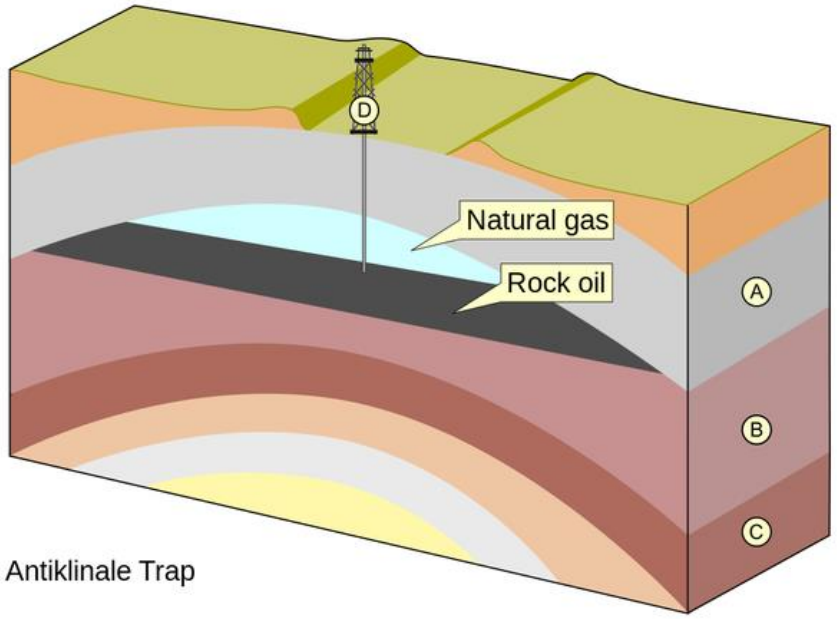
1719



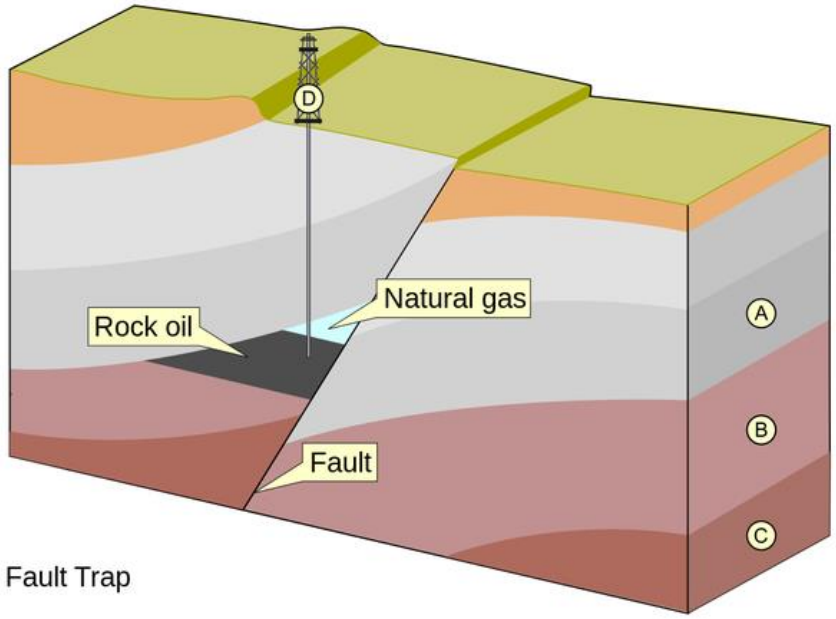
www.geolsoc.org.uk

www.greenamerica.org

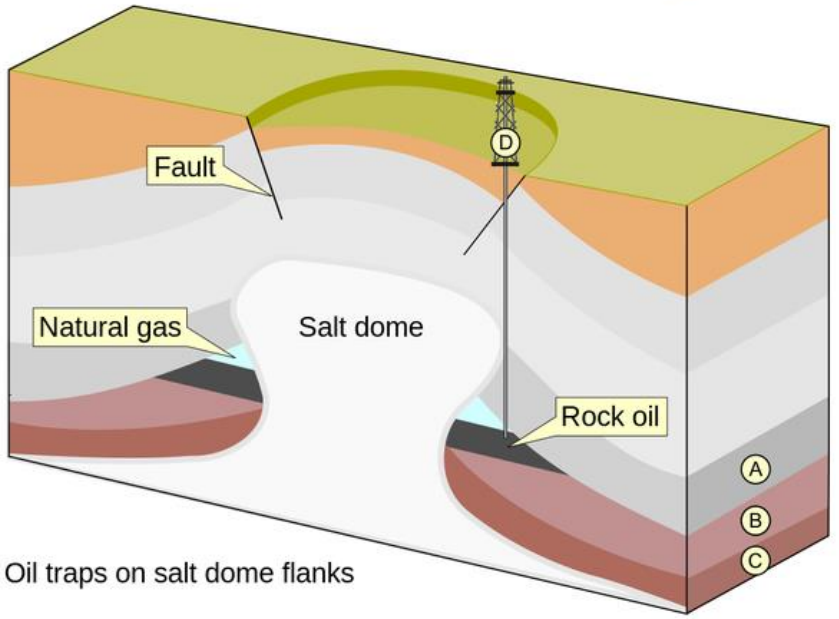
Oil and Natural Gas



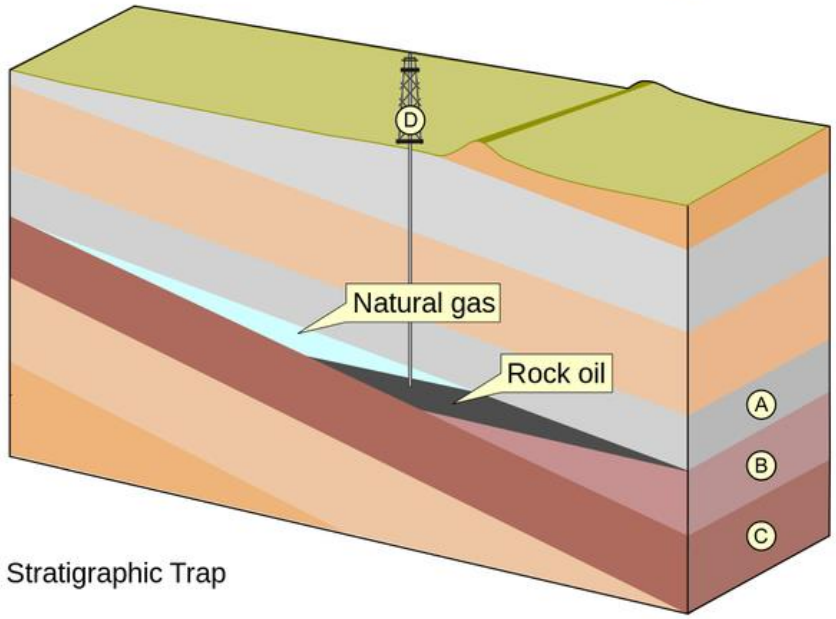
Antiklinale Trap



Fault Trap



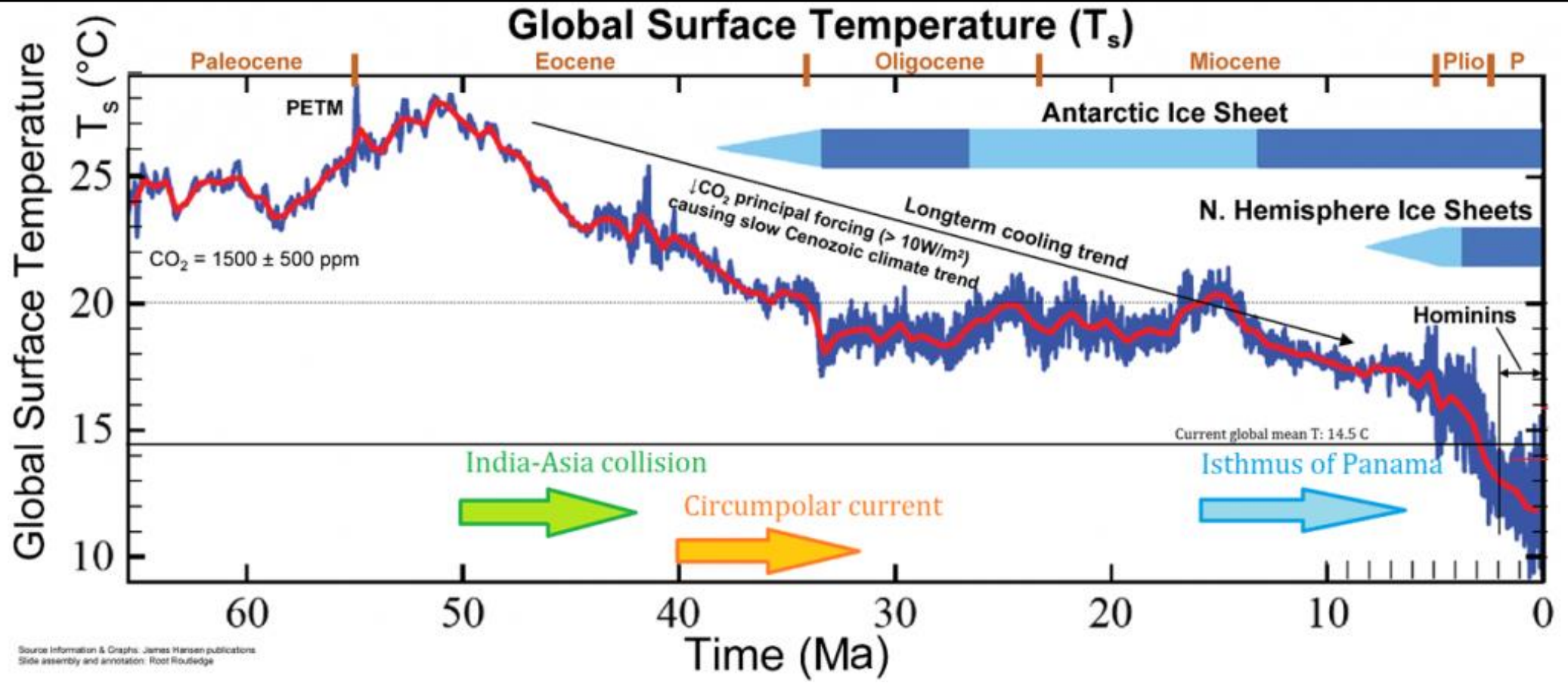
Oil traps on salt dome flanks

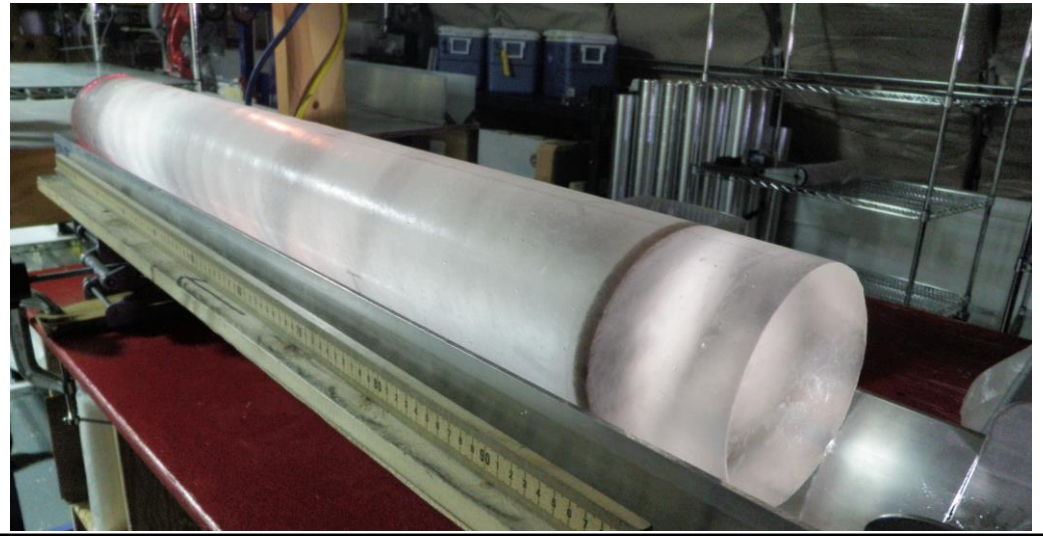


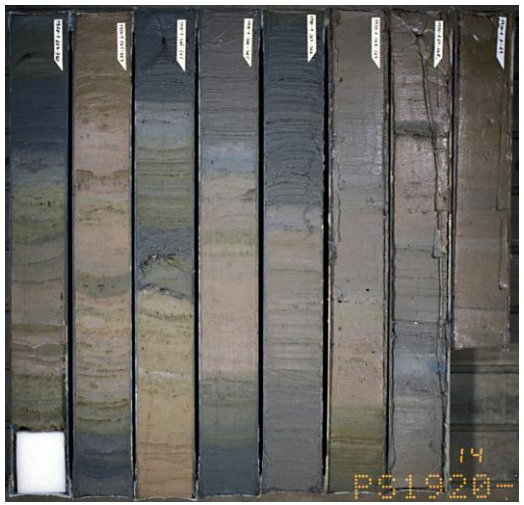
Stratigraphic Trap

Ⓐ = Impermeable Shale clay Ⓑ = Porous Reservoir rock Ⓒ = Source rock Ⓓ = Oil well

https://energyeducation.ca/encyclopedia/Oil_and_gas_traps


Global Surface Temperature (T_s)
Paleocene
Eocene
Oligocene
Miocene
Plio
P
PETM
Antarctic Ice Sheet
↓CO_2 principal forcing (> 10W/m²)
causing slow Cenozoic climate trend
Longterm cooling trend
N. Hemisphere Ice Sheets
CO_2 = 1500 ± 500 ppm
Hominins
Current global mean T: 14.5 C
India-Asia collision
Circumpolar current
Isthmus of Panama
Global Surface Temperature
T_s (°C)
25
20
15
10
60
50
40
30
20
10
0
Time (Ma)
Source Information & Graphs: James Hansen publications
Slide assembly and annotation: Root Routledge

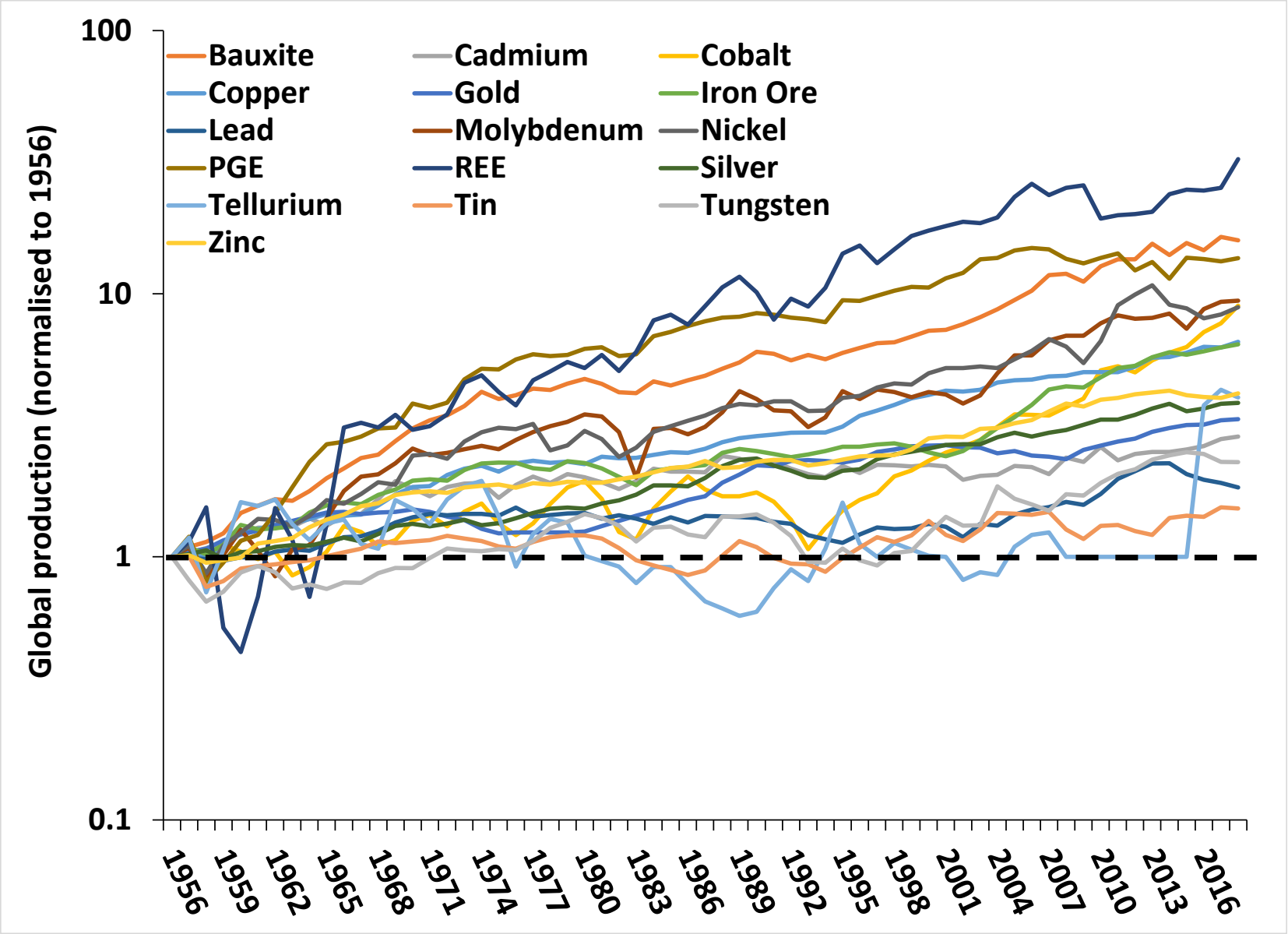




Outline

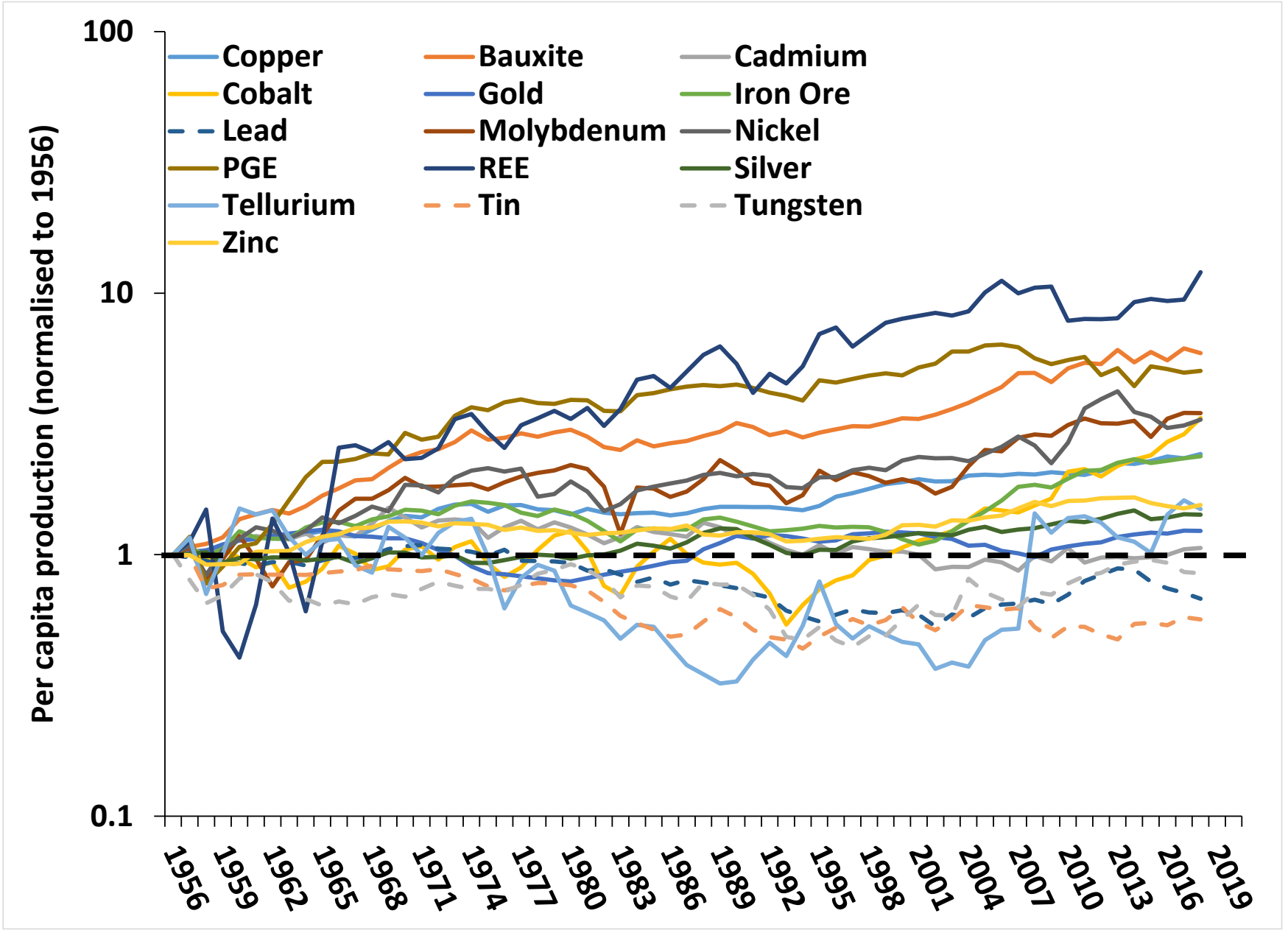
- The geology of climate change (carbon cycle)
- Geologist's role in this
- **An important part of the solution is… more mining???**

We're mining more metals all the time (all while increasing recycling)



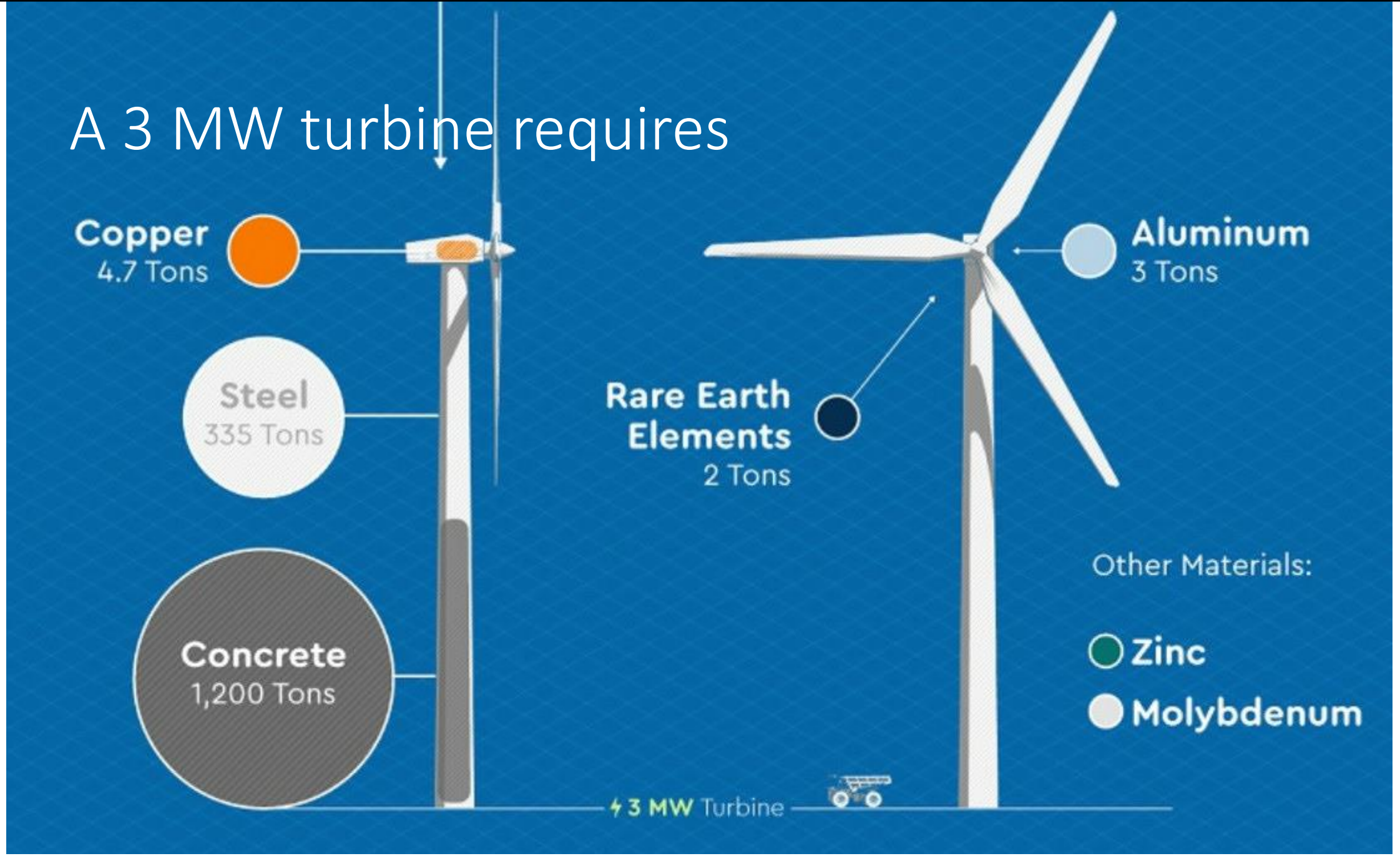
Simon Jowitt

Not just totals but per capita (exceptions are Pb, Sn, W)



Simon Jowitt

A 3 MW turbine requires



World Bank

Copper Development Association Inc.
Copper Alliance

COPPER CONTENT BY VEHICLE TYPE

Internal Combustion Engine (ICE)

48LB

Hybrid Electric Vehicle (HEV)

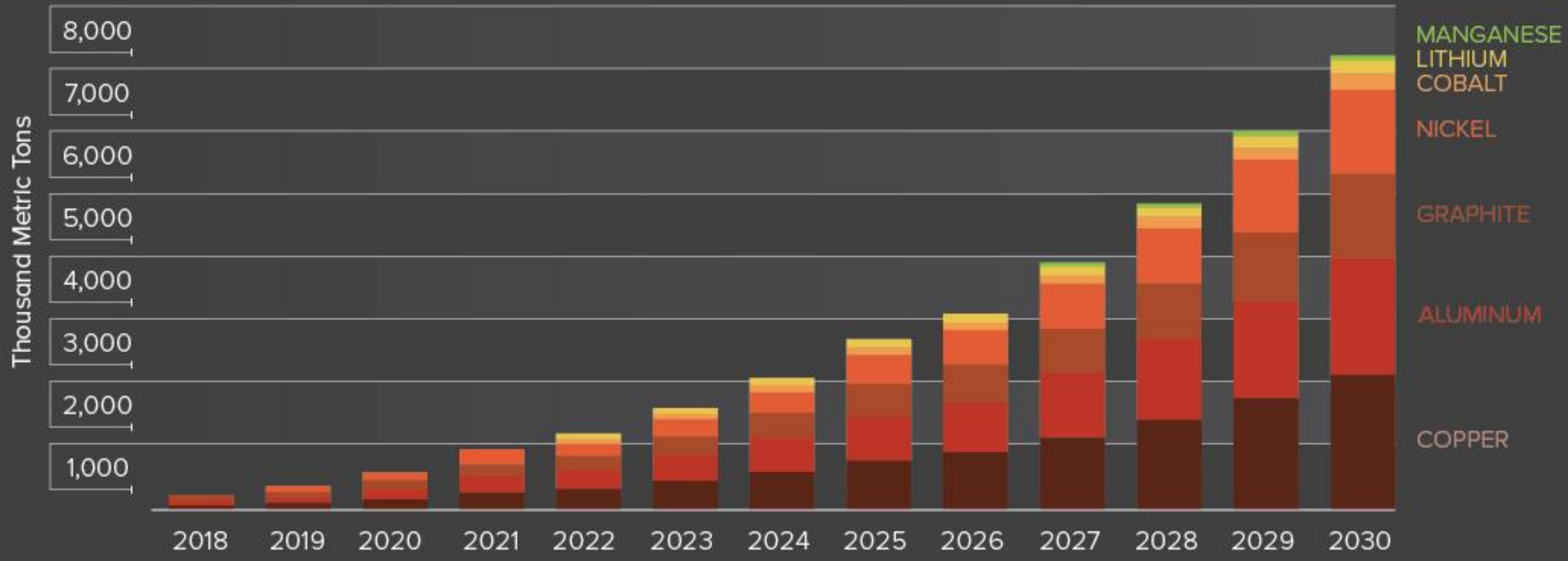
88LB

Battery Electric Vehicle (BEV)

183LB

Source: Reuters

Metals and materials demand from lithium-ion battery packs in passenger EVs



Source: Electric Vehicle Outlook 2018, Bloomberg New Energy Finance

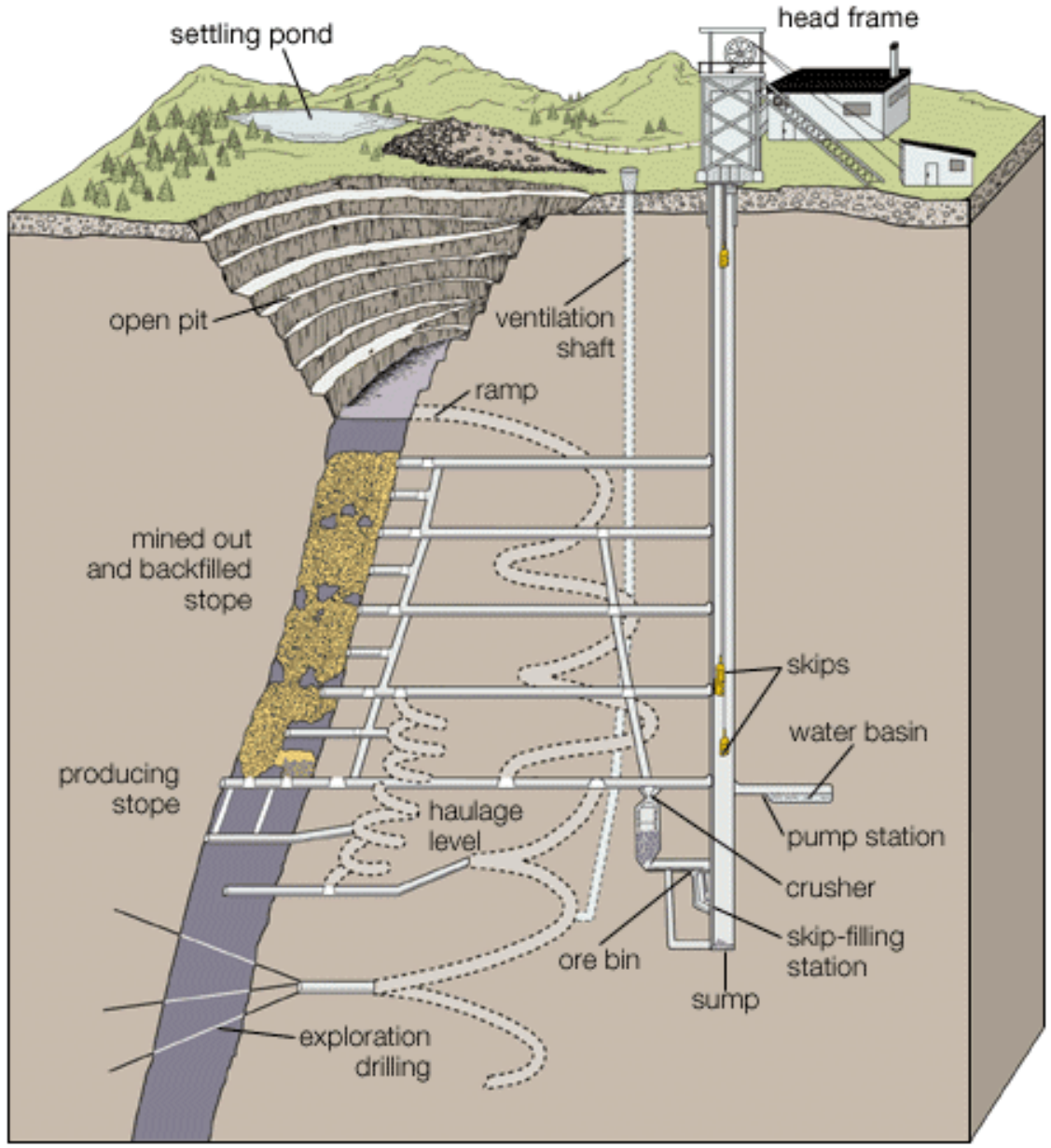
Modern technologies have become more mineral intensive

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp		Fl		Lv		

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp		Fl		Lv		

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



Source: H. Hamrin, *Guide to Underground Mining Methods and Applications* (Stockholm: Atlas Copco, 1997)

b

Building Canada’s green future through mining

MINE EVOLUTION

www.mineevolution.ca

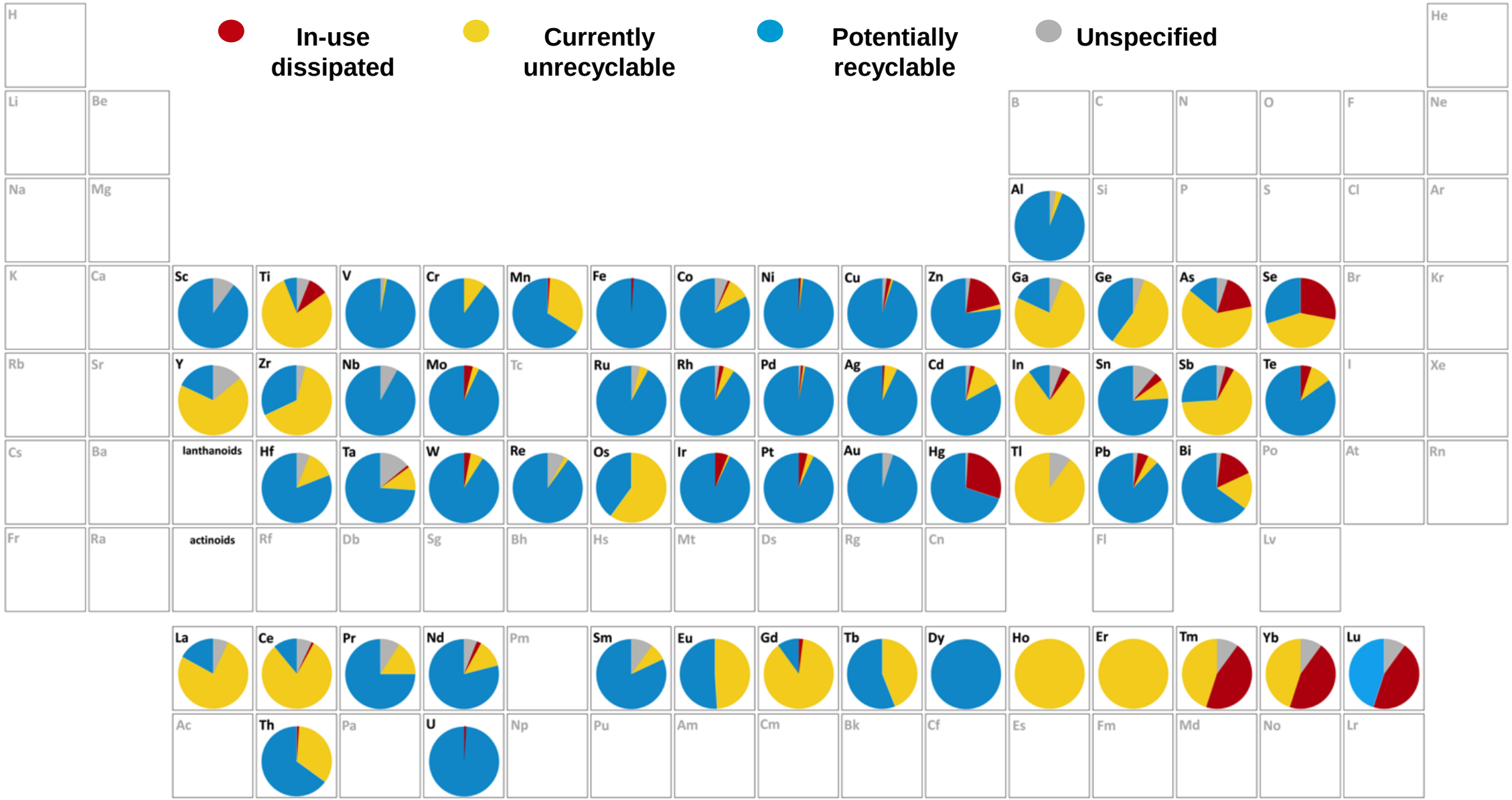
Can we recycle our way out?

Typical end-of-life recycling ra

1 H																	
3 Li	4 Be												5 B	6 C			
11 Na	12 Mg												13 Al	14 Si			
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge				
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn				
55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb				
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq				

* Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
** Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

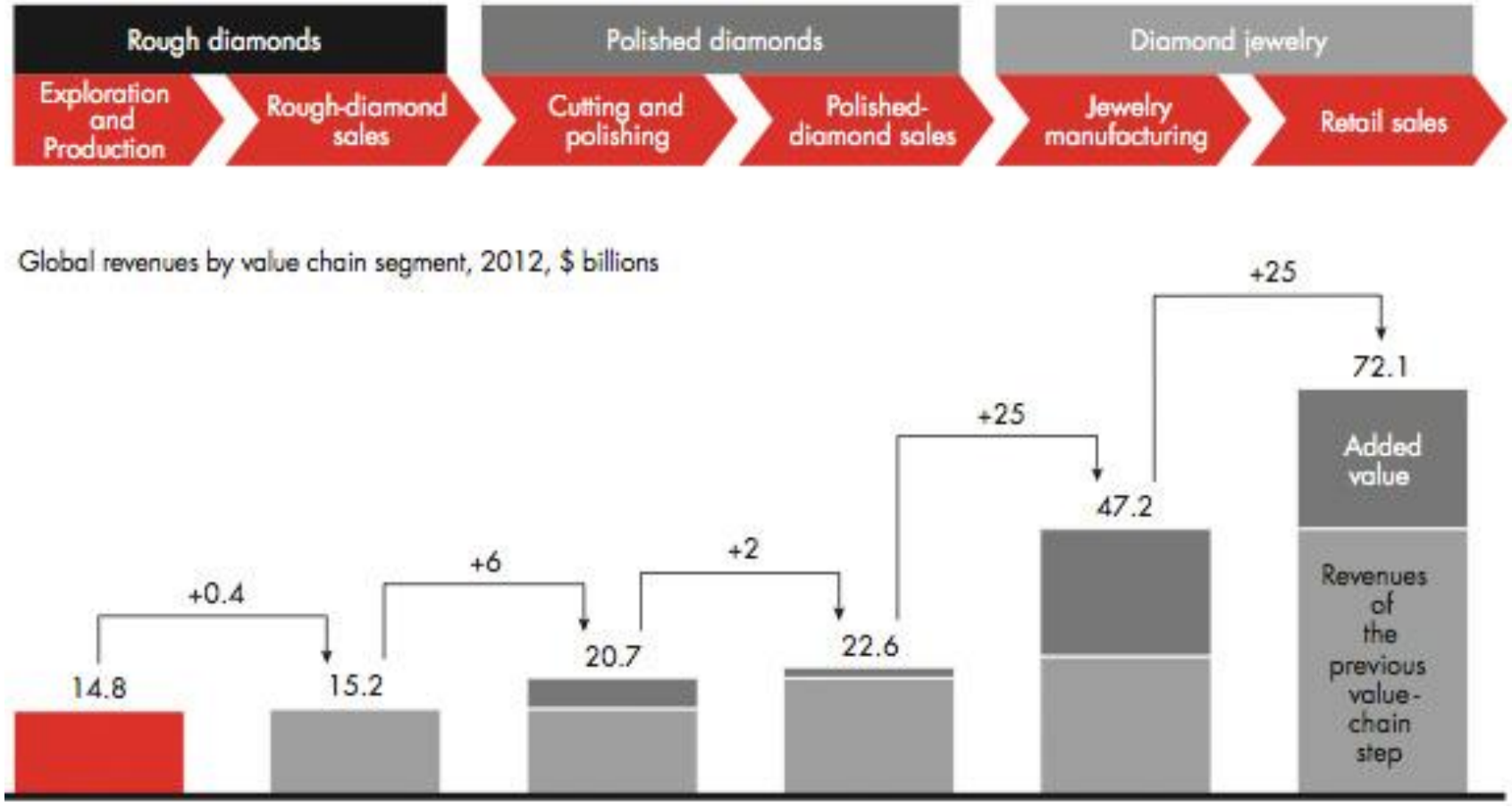
Recycling Potential of Metals



Ciacci, et al., 2015. *Environmental Science & Technology* 49(16): 9443-9451.

What about mining value chains?

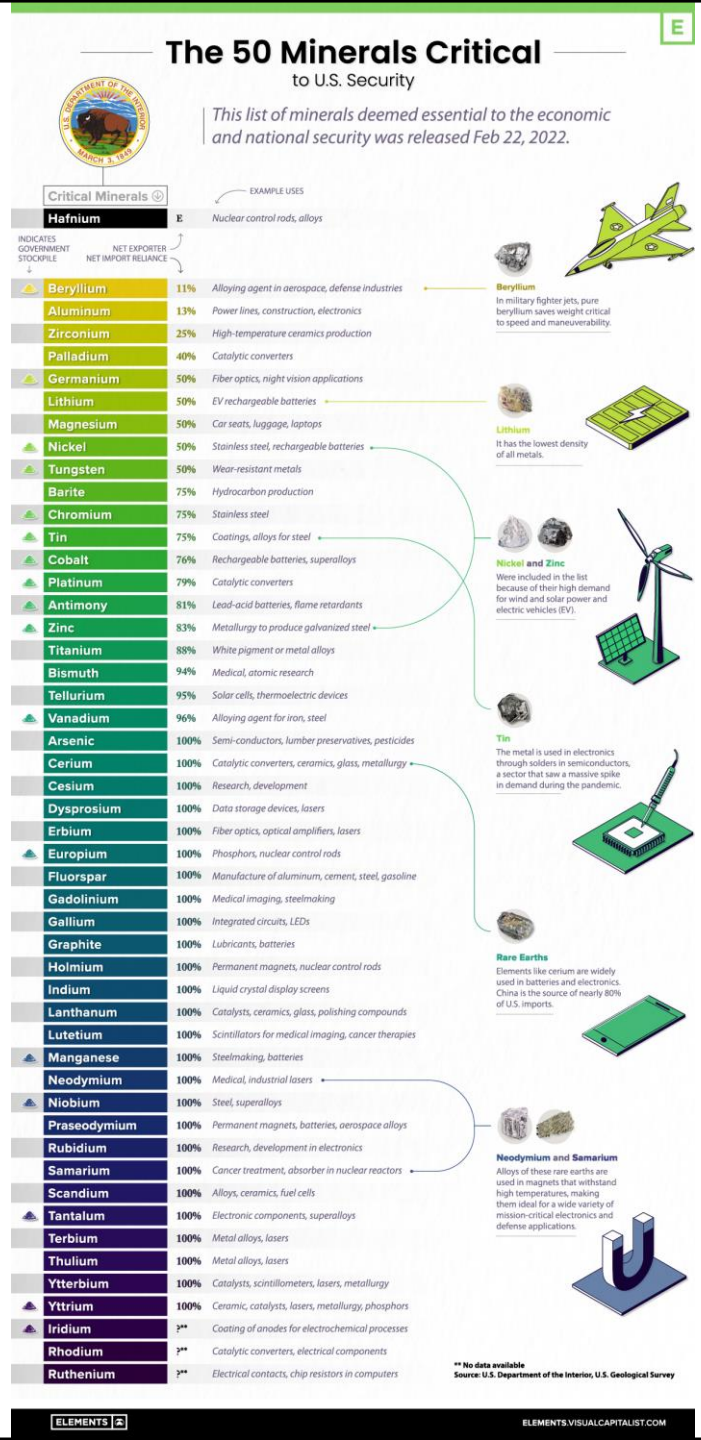
- Rare Earth Metal concentrates from Mountain Pass in CA are processed in China
- Rare Earth Metal concentrates from Mt Weld in Australia are processed in Malaysia



US Critical Metals

List is dynamic and updated periodically

Aluminum, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, cobalt, dysprosium, erbium, europium, fluorspar, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, and zirconium



Think

Pair

Share

The Nyrstar zinc plant (in Clarksville) recently announced an upgrade of it's facilities to better process what two metals?

Gallium:

-Semiconductors

-LEDs

-Electric circuits

Germanium:

-Camera Lenses

-Metal Alloys

-Fluorescent Lamps

China export curbs choke off shipments of gallium, germanium for second month

Reuters

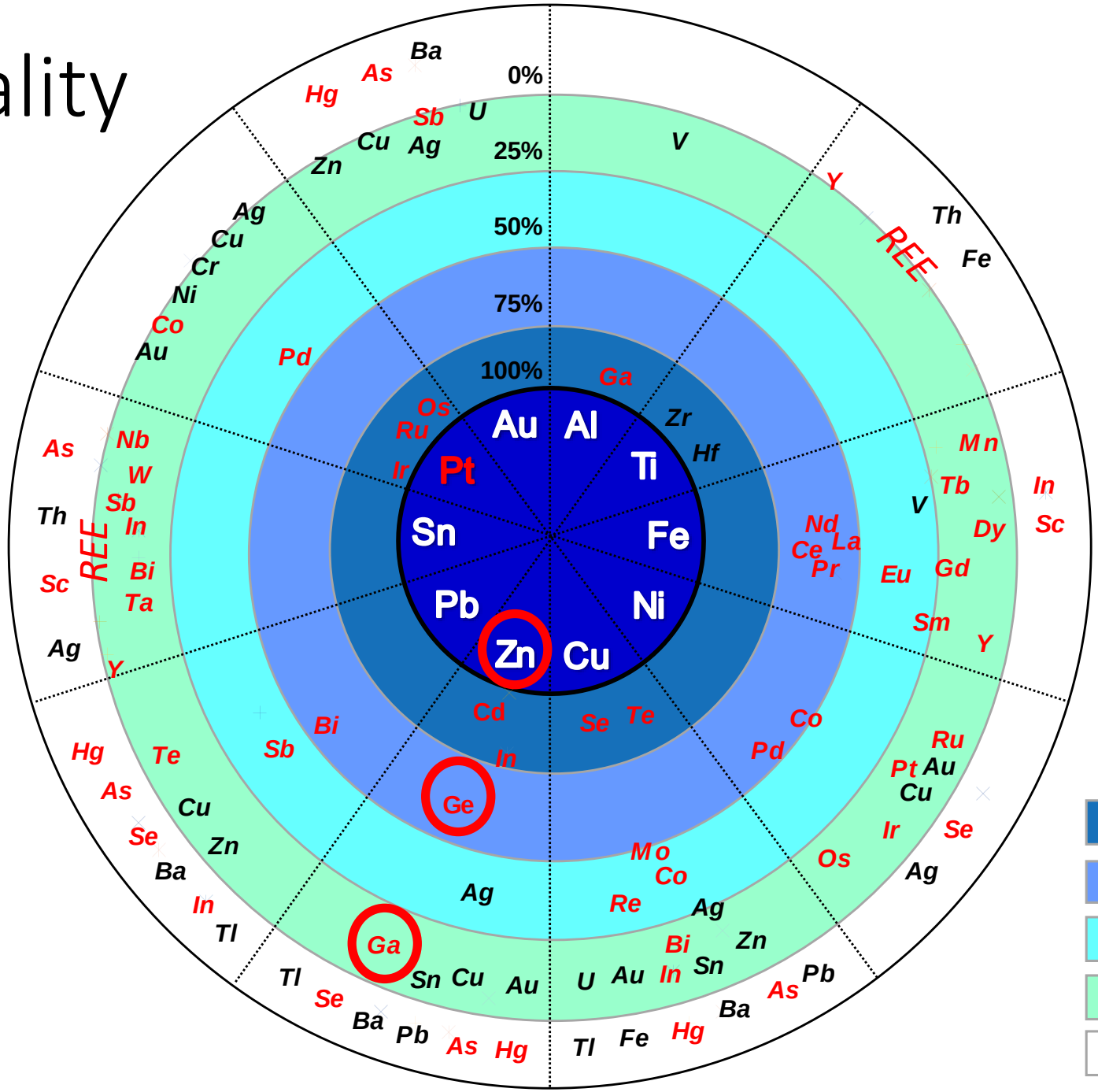
October 19, 2023 10:16 PM CDT · Updated a month ago

Nyrstar plans expansion of Clarksville plant with $90 million germanium, gallium processing facility

By Casey Williams July 7, 2022 3:06 pm

Companionality

Sphalerite



What happens if say zinc demand and production drops for some reason;

we lose production of In, Ge, Cd…

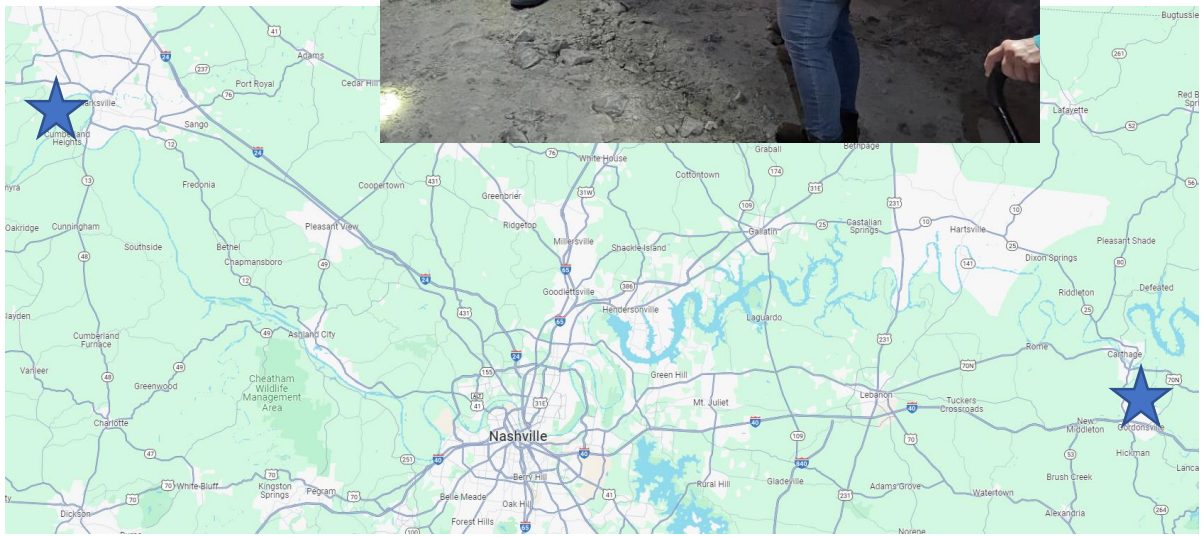
would limit production of touch screens, LEDs, fiber-optic cables, semiconductors, CdTe solar panels…

- 75-100% By-product
- 50-75% By-product
- 25-50% By-product
- 0-25% By-product
- Unquantified

Nyrstar to suspend operations at two U.S. zinc mines

By **Eric Onstad**

November 1, 2023 9:50 AM CDT · Updated a month ago



Price of zinc is down

MINING AND CLIMATE CHANGE

- So if you've not already been convinced, I emphasize that **every single person listening to this talk needs mining**
- **Any sustainable future** with reduced anthropogenic climate change and lower CO2 emissions **will be built on the back of the mining industry**
- **If your immediate attitude is "climate change doesn't exist"**, then the world is moving towards renewable energy and electric vehicles anyway; **this is the chance for the US to be a world leader.**

SO WHAT NOW?

- We need more conversations and discussion of this, rather than just saying we need to reduce CO_2 emissions
- **Need more research, education, outreach**, and consideration of these things during policy development
- The public needs to know the cost of “being green” and the role of mining…

Questions?

CRITICAL MINERALS:
WHY WE NEED A DOMESTIC SUPPLY

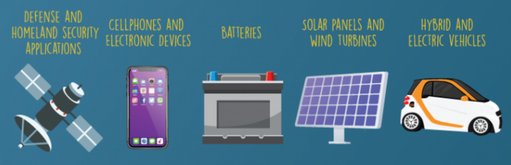
Developing a domestic supply of critical minerals is a national priority, relevant not only to climate change but to economic and national security.

WHAT ARE CRITICAL MINERALS?

Critical minerals, which include rare earth elements, are a group of 50 chemical elements in the periodic table of elements. These critical minerals form the building blocks for many modern technologies and clean energy technologies.

WHAT ARE CRITICAL MINERALS USED FOR?

Critical minerals are integral to the way we live and to America's economic growth and national security. They have unique magnetic, heat-resistant, and phosphorescent properties unlike any other elements. They are essential components in:



Demand for critical minerals is increasing as the world transitions to a clean energy economy. In fact, the global demand for critical minerals is set to skyrocket by 400-600 percent over the next several decades. The need for some minerals, such as lithium and graphite used in electric vehicle batteries, will increase even more—by as much as 4,000 percent.

WHERE ARE CRITICAL MINERALS PRODUCED AND SUPPLIED?

Up until the mid-1980s, the United States was the leading global producer of critical minerals. But these elements are often found in low concentrations, mixed together in other mineral deposits, which can be challenging and expensive to separate.

The United States is increasingly dependent on foreign sources for many of the processed versions of critical minerals. Globally, China controls most of the market for processing and refining lithium, rare earth elements, cobalt, and other minerals.

Because these elements are essential to our everyday lives and will help us achieve the nation's climate goals, the U.S. Department of Energy's Office of Fossil Energy and Carbon Management is supporting the development of the United States' own supply of critical minerals.

MAJOR U.S. SOURCES FOR KEY CRITICAL MINERALS

Lithium	*Chile*	*Argentina*	*China*	
Rare Earth Elements	*China*	*Estonia*	*France*	*Japan*
Cobalt	*Norway*	*China*	*Japan*	*Finland*
Graphite	*China*	*Mexico*	*Canada*	*Brazil*
Gallium	*China*	*Germany*	*United Kingdom*	*Ukraine*

View more data on U.S. critical minerals import reliance.

WHERE ARE CRITICAL MINERALS FOUND IN THE UNITED STATES?

A vast quantity of critical minerals exist as trace elements within the United States' large supply of natural resources. Critical minerals can also be found in "unconventional and secondary" sources, such as wastes from fossil fuel and other industries, including mine tailings, refuse piles, acid mine drainage, fly ash, and water produced by oil and gas supply chains. Initial estimates suggest these unconventional and secondary sources currently contain, for example, more than 10 million tons of rare earth elements.

WHAT ARE THE BENEFITS OF DEVELOPING A DOMESTIC SUPPLY OF CRITICAL MINERALS?

In addition to supporting our national security and economic prosperity, developing a domestic supply of critical minerals will:

REDUCE U.S. DEPENDENCE ON FOREIGN SOURCES

SUPPORT THE CREATION OF NEW MANUFACTURING JOBS

SECURE DIVERSE, RESILIENT, AND DOMESTIC CRITICAL MINERAL SUPPLY CHAINS

SUPPORT ENVIRONMENTAL STEWARDSHIP AND CLEAN UP OF LEGACY WASTE

SUPPORT THE TECHNOLOGICAL DEVELOPMENT OF A CLEAN ENERGY FUTURE

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June 2022

U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management