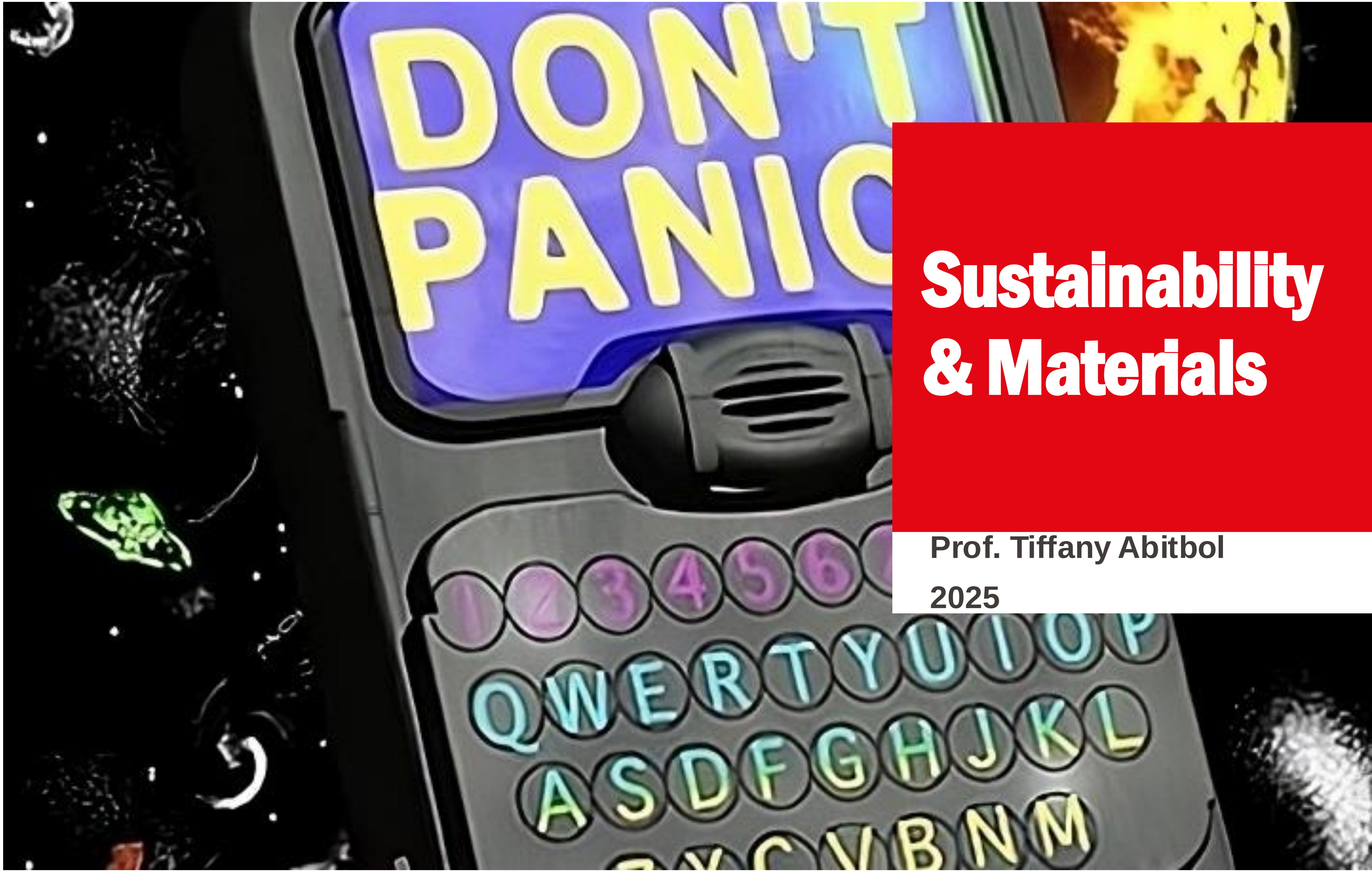


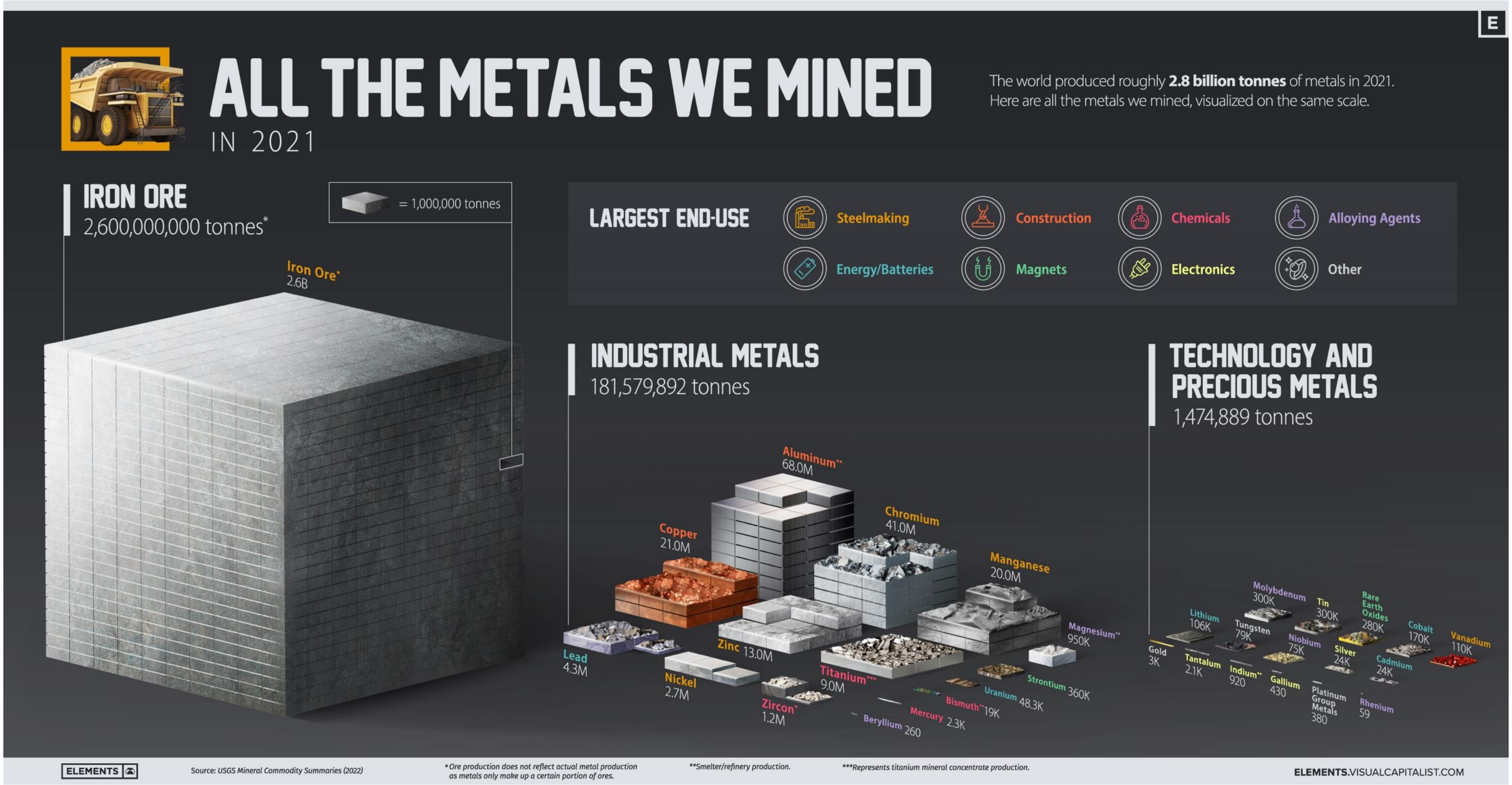
Sustainability & Materials

Prof. Tiffany Abitbol

2025

Resources – Metals

"If you can't grow it, you have to mine it"



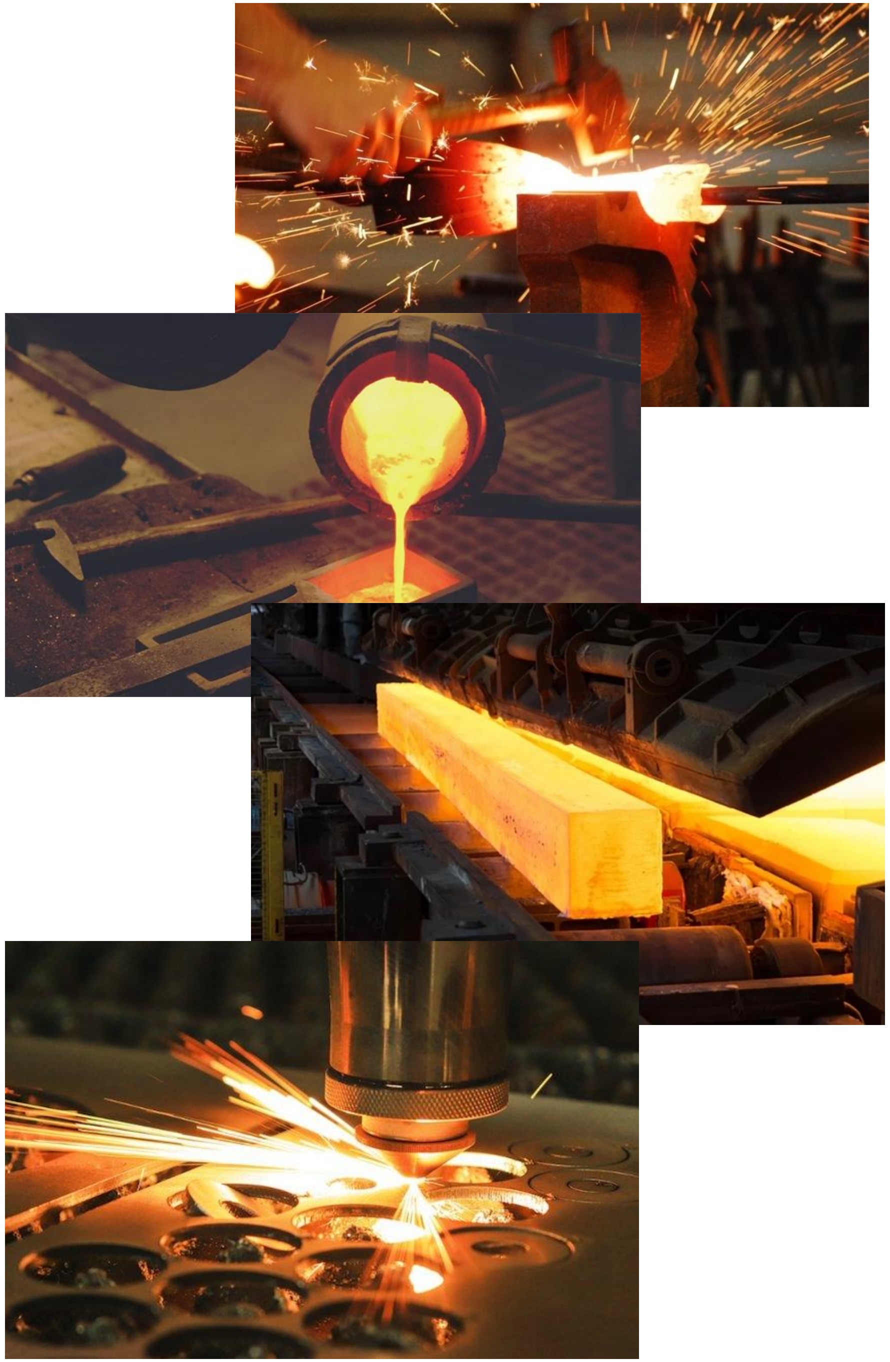
2022 update

Processing – Metals

After ore extraction, metal is refined and prepared for further processing.

Several possible techniques are available to produce metal parts, including:

- **Forging**, metal is heated to the point it can be shaped with the help of a hammer
- **Casting**, molten metal is poured into a mold and let cool down to solidify
- **Drawing**, a tensile force is applied to pull metal through a die (e.g. pipes)
- **Welding**, strong heat is used to join two or more individual pieces together
- **Machining**, subtractive shaping process used to remove unwanted material and refine the final form



Properties & Uses – Metals

Main properties

- Versatility
- Strength
- Toughness
- Machinability
- Recyclability

Main uses

- Construction
- Food packaging
- Electronics
- Automotive
- Luxury goods

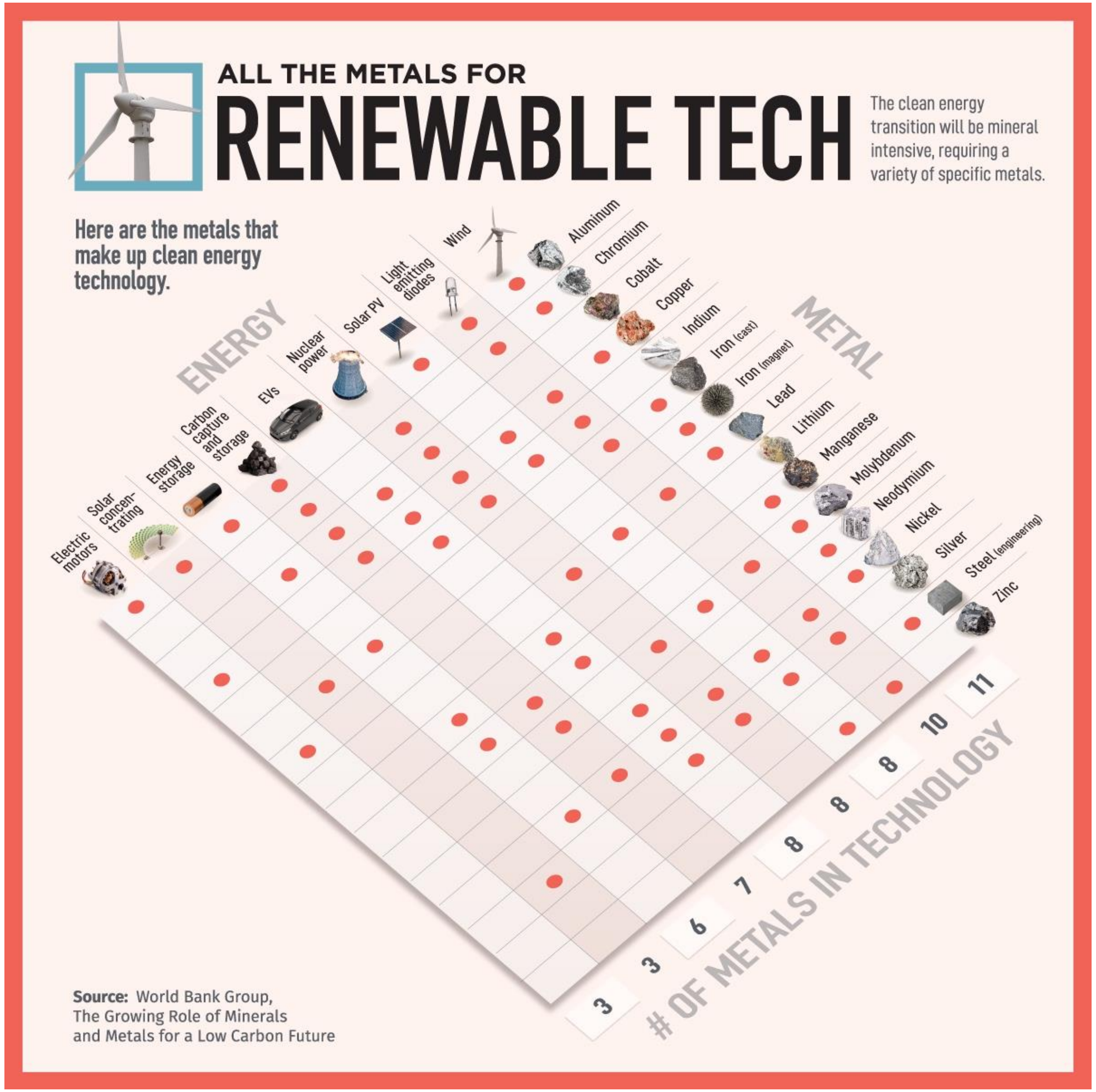
EPFL

Metals and Clean Energy

Clean energy technology is heavily dependent on metals!

- **Electric cars** require 6×more metallic materials than conventional cars
- **Wind turbines** require 9× more metallic materials than gas-fired power plants

Inevitably, more mining will be required to meet the increasing demand of metallic materials for a renewable energy transition



UN SDGs and metals

9 - New tech, product design

INCREASING RESOURCE EFFICIENCY THROUGH INNOVATION

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

New technologies and policies have helped to increase resource-efficiency in the metal packaging industry, cutting CO2 emissions, saving energy and contributing to the circular economy. This includes constant innovation, re-thinking and re-shaping of products to reduce the amount of material required to make them. CO2 emissions from the production of aluminium drink cans, for example, decreased by an average of 31% over a ten year period.

TRANSITIONING TO RENEWABLE ENERGY SOURCES

13 CLIMATE ACTION

The metal packaging industry has put in place a range of initiatives aimed at significantly reducing greenhouse gas emissions, increasing reliance on renewable energy sources, such as wind and solar power, and cutting the carbon footprint across all operations. In addition, the industry continues to support efforts to increase already high recycling rates across Europe.

INCREASING WATER-USE EFFICIENCY

6 CLEAN WATER AND SANITATION

The metal packaging industry is committed to reducing water usage across its operations. It has achieved consistent improvements in water-use efficiency by developing and using new technologies, re-using water, consistently monitoring water data and sharing best practices.

13,6 – Renewable energy, efficient water use

A KEY CONTRIBUTOR TO THE CIRCULAR ECONOMY

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

One way to reduce waste generation is to ensure that resources and materials remain in the economy for as long as possible. As is communicated to the consumer through the Metal Recycles Forever logo, metal is infinitely recyclable without loss of quality, making metal packaging a key contributor to the circular economy. Metal packaging also has one of the highest recycling rates: 74.5% for aluminium cans and 82.5% for steel packaging.

VITAL TO REDUCING FOOD WASTE

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

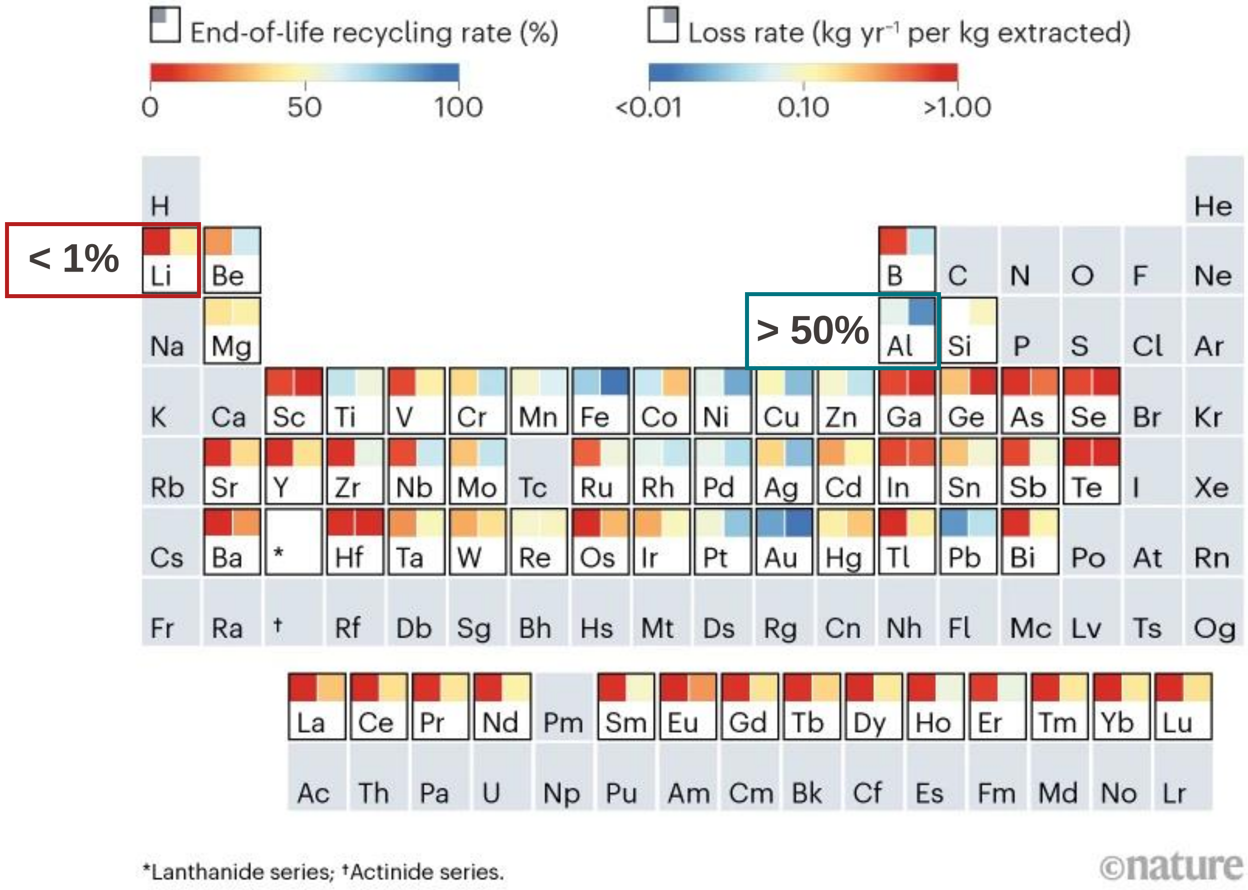
The metal food can has a vital role to play in reducing global food waste and food losses. By using cans, we can reduce individual food waste by almost 30%. Their strength, barrier properties and versatility all help to keep food fresh for longer and minimise product loss during filling and transport.

12 - Metal food packaging to reduce waste, keep metals in circulation, recycle

End of life – Metals

"The longer we use metals, the less we need to mine"

- Reading the graph: color map for recycling rate (upper left) and loss rate (upper right)
- Loss can happen across life cycle, but usually lost at end of life to landfill or environment
- Strategic metals (e.g., lithium) have low rates of recycling (< 5% due to cost and complexity) and high rates of loss; compare to Al
- Poor end of life management can result in accumulation in the environment (ex. heavy metal pollution)



https://www.nature.com/articles/d41586-022-01467-8

End of life – Metals

- Toxic metals, like mercury, can contaminate soil and water through natural events, like weathering or volcanic activities, or through manmade sources, such as improper waste disposal, industrial activities such as mining, agriculture, etc.,

- These metals can "bioaccumulate" up through the food chain

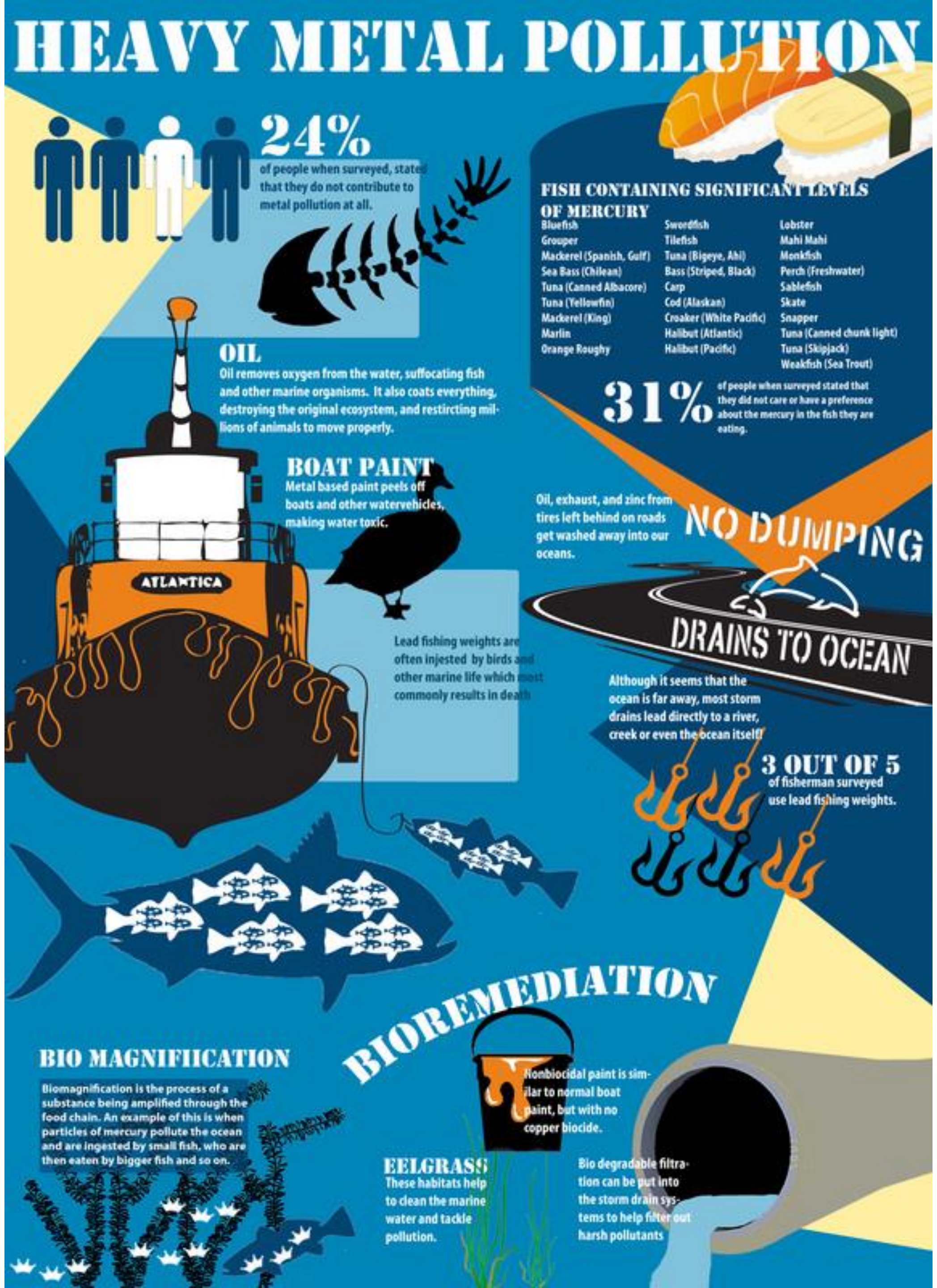
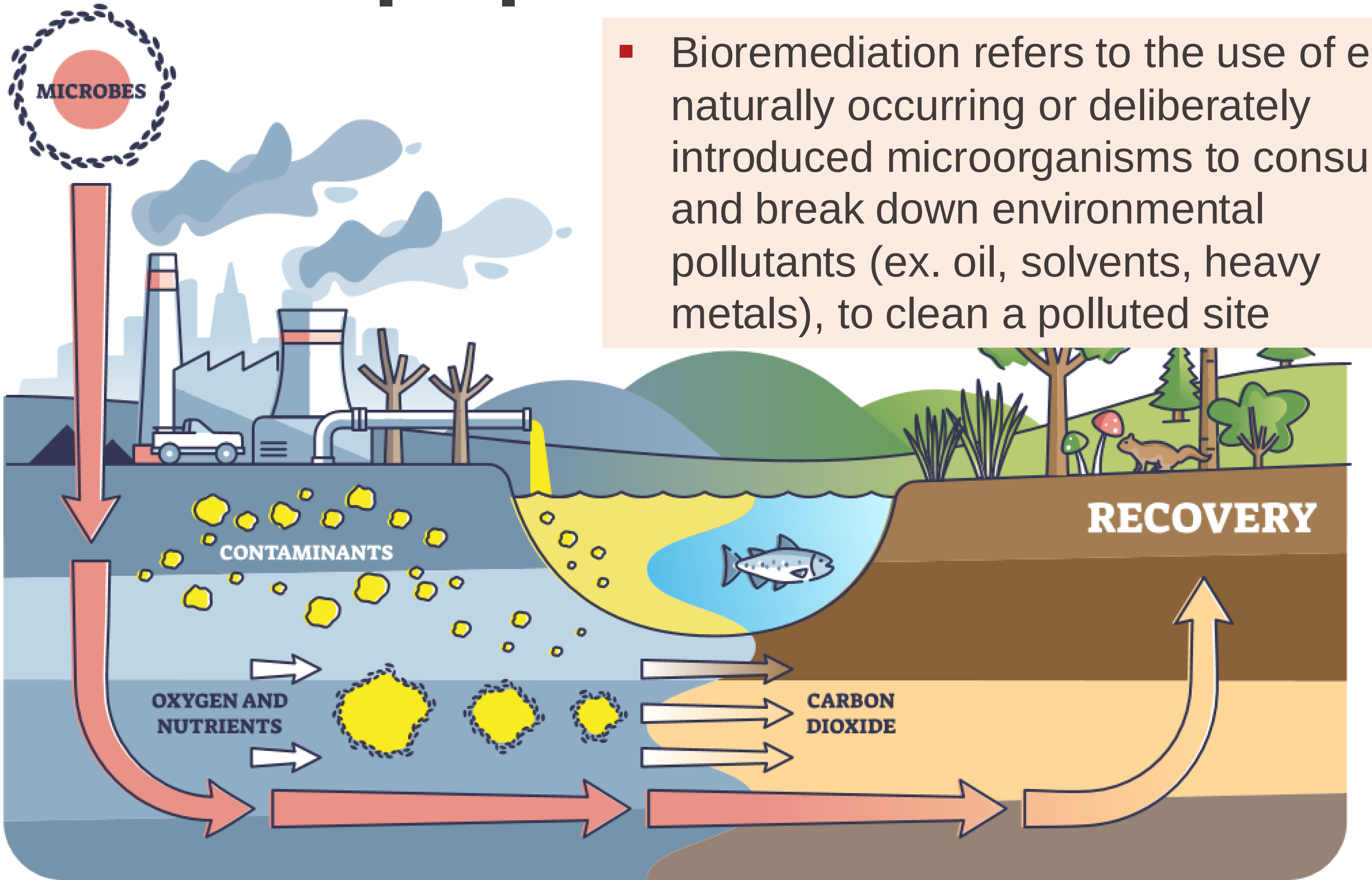


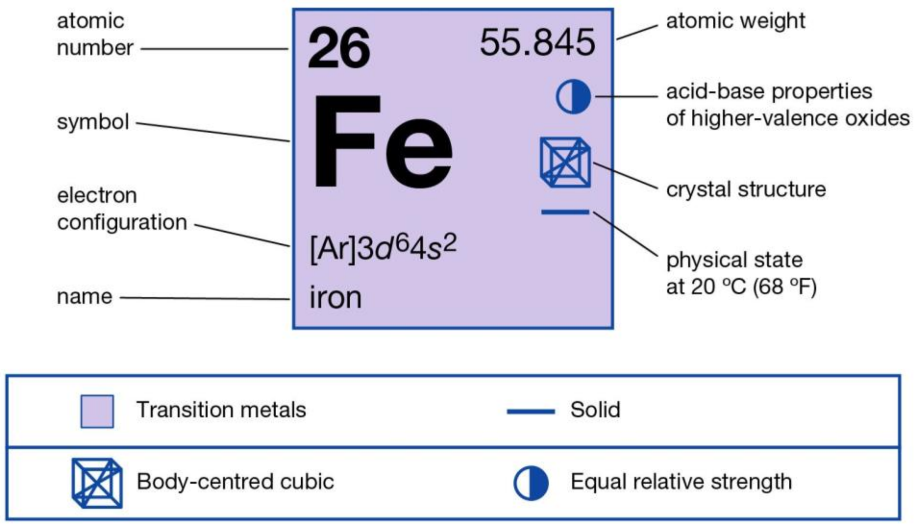
Image from San Diego Oceans Away Project

Sustainable perspectives – Bioremediation

- Bioremediation refers to the use of either naturally occurring or deliberately introduced microorganisms to consume and break down environmental pollutants (ex. oil, solvents, heavy metals), to clean a polluted site



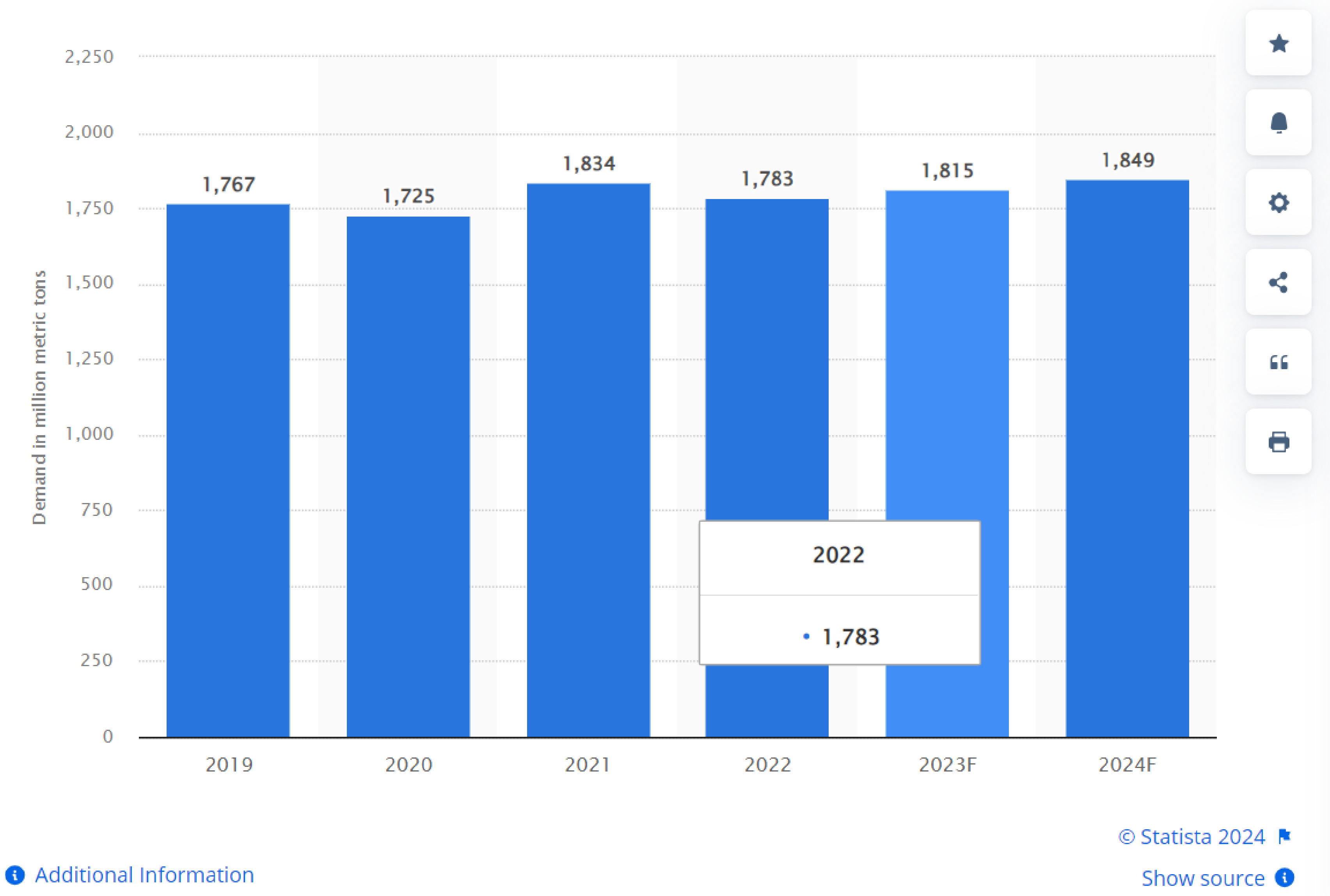
Focus on steel



- Iron is the 2nd most abundant metal in the crust (after aluminum)
- Iron ore makes up 93% of total metals mined (2021)
- First traces of iron objects were found in Egypt dated around 3400 BC
- Roughly 98% of iron ore goes into steelmaking
- Steel is an alloy of carbon and iron
- Critical to building infrastructure – key to urbanization and growth

EPFL

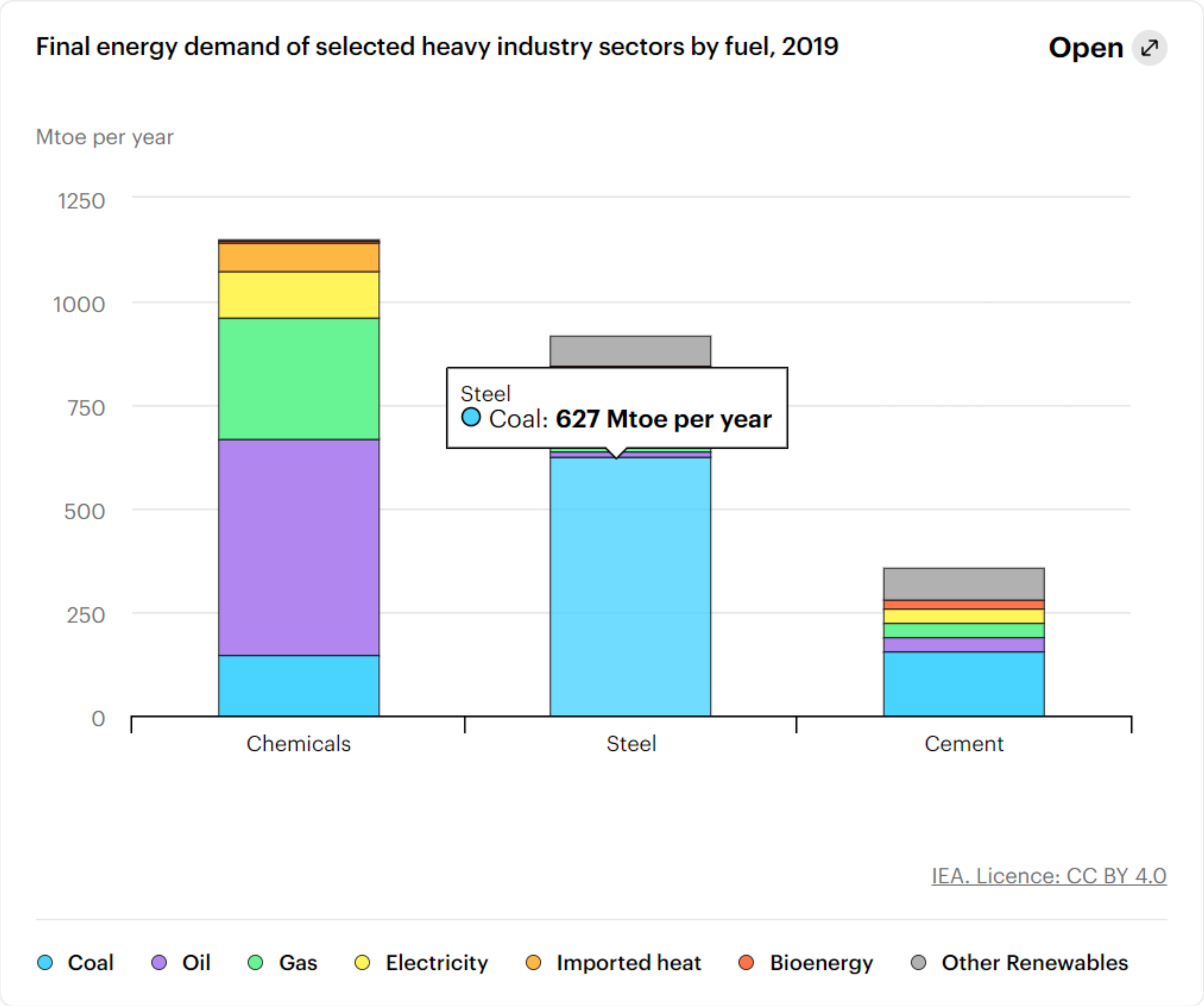
Global steel demands



- Global steel demand is projected to increase by 1/3 by 2050 (from ca. 1.8 million metric tons now)

Steel stats

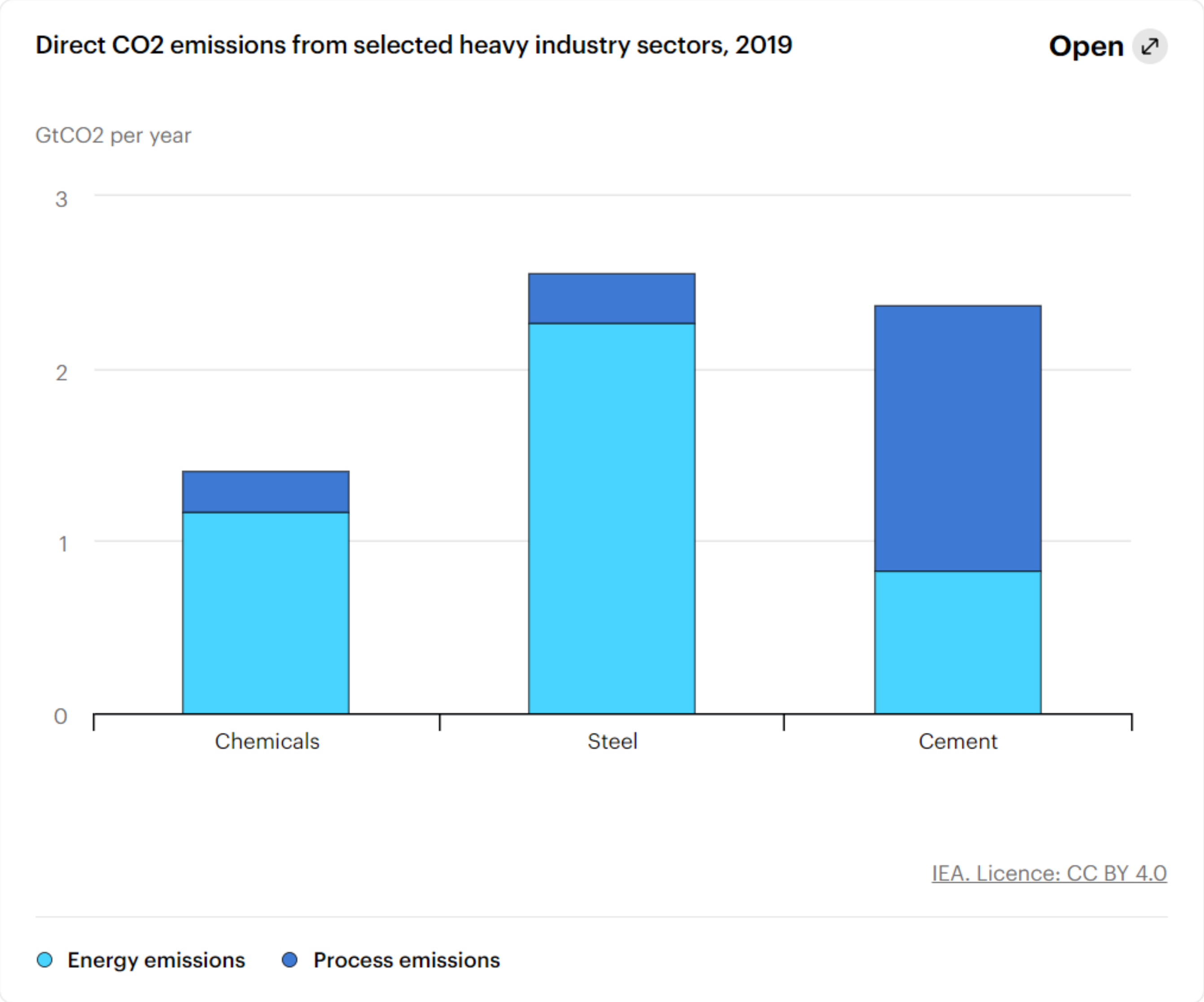
Environmental impact of steel, 2019



- The steel sector is currently the largest industrial consumer of coal, which provides around 75% of its energy demand.
- Coal is used to generate heat and to make coke, which is instrumental in the chemical reactions necessary to produce steel from iron ore.
- *Mtoe?* million tonnes of oil equivalent; unit used to compare energy sources; 1 toe is the amount of energy released by burning 1 tonne of crude oil, about 42 GJ or 12 MWh

Iron and steel roadmap

Environmental impact of steel, 2019



- The iron and steel sector directly accounts for 2.6 gigatonnes of carbon dioxide (Gt CO_2) emissions annually
- This is about 7-9% of all anthropogenic CO_2 emissions
- Steel decarbonization strategies are critical!

Iron and steel roadmap

Steel production

- Starts with resources: mining (ca. 0.25 tCO_2e/t) and recycled
- Next step is smelting to convert iron ore to pig iron, usually in a **blast furnace (BF)**, with hot CO as the reducing agent
- Next step is refining usually in **basic oxygen furnace (BOF)** – oxidation to remove excess carbon and other impurities to get steel
- Alternatively, can use **direct reduced iron (DRI)** instead of blast furnace, with hot H_2 and CO gases as reducing agents + **electric arc furnace (EAF)** to refine (DRI is lower carbon than BF – natural gas or hydrogen alternatives instead of coal)
- EAF instead of BOF (refining alternative)! DRI instead of BF (smelting alternative)!

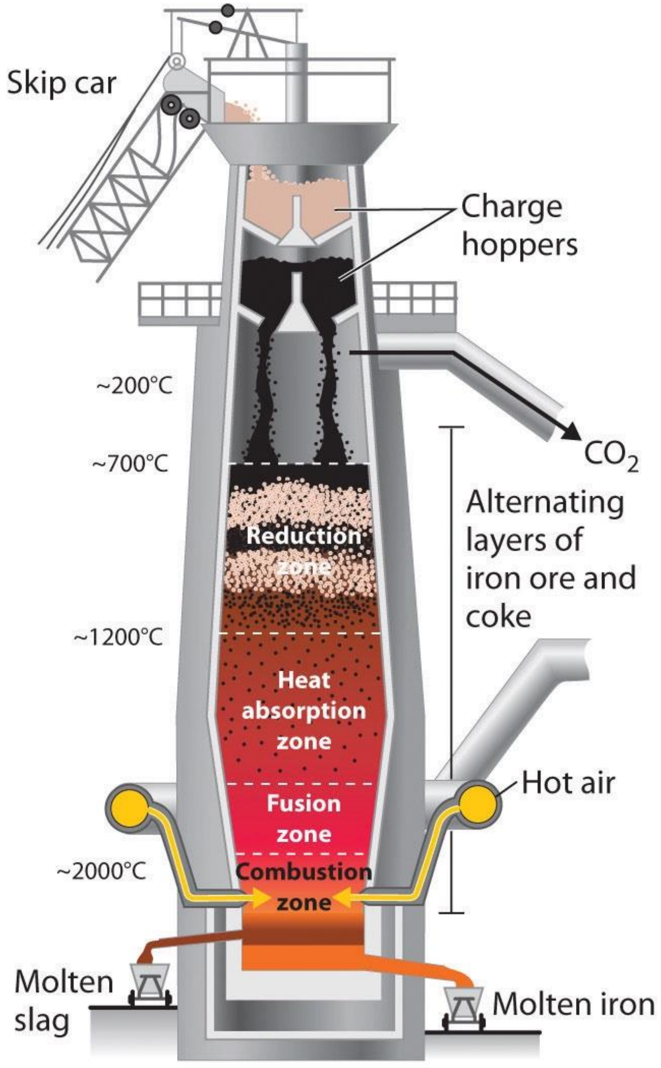
Steel emissions

Steel production

- **BF-BOF emits an average of 2.2 tCO_2e**
- **DRI+EAF emits an average of 1.2 tCO_2e**
- We will briefly explore both approaches

Steel emissions

Iron production in a blast furnace



(a) Blast furnace

The furnace is charged with alternating layers of iron ore (largely Fe_2O_3) and a mixture of **coke (C)** and limestone ($CaCO_3$).

Blasting hot air into the mixture from the bottom causes it to ignite, producing CO and raising the temperature of the lower part of the blast furnace to about 2000 °C.

As the CO that is formed initially rises, i**t reduces Fe_2O_3 to form CO_2 and Fe**, which absorbs heat and melts as it falls into the hottest part of the furnace.

Decomposition of $CaCO_3$ at high temperatures produces CaO (lime) and additional CO_2, which reacts with excess coke to form more CO.

Steel making

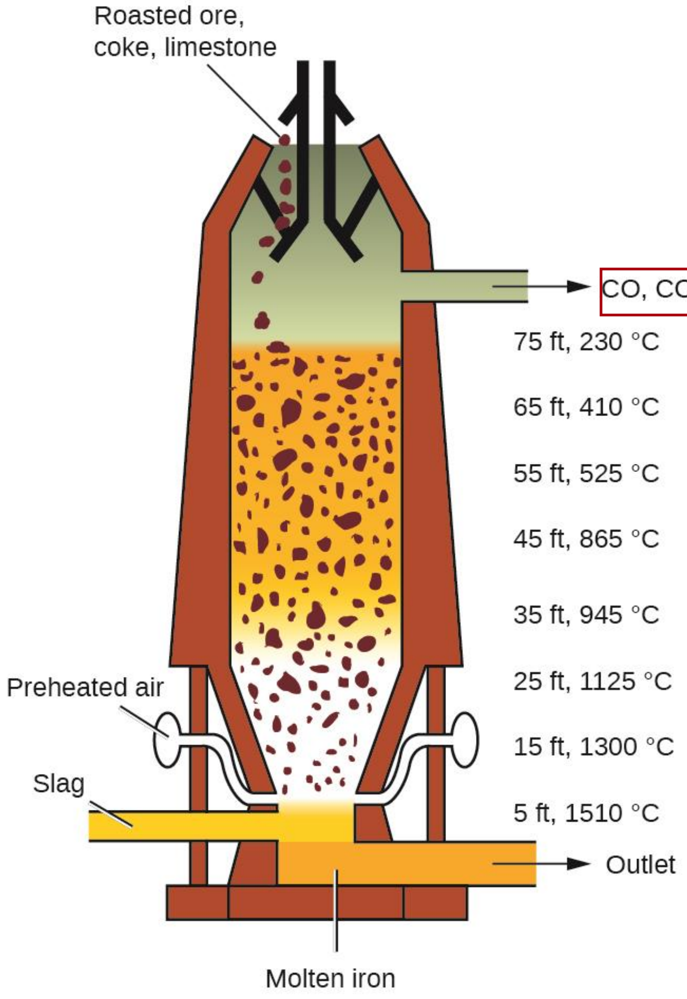
Smelting = iron ore → pig iron

Iron production making in a blast furnace

1. Furnace is charged up!

$$Fe_2O_3(s) + 3C(s) \xrightarrow{\Delta} 2Fe(l) + 3CO(g)$$

Overall reaction



CO, CO_2, N_2 *7. Pollution and nitrogen*

$3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2$

$Fe_3O_4 + CO \longrightarrow 3FeO + CO_2$

$FeO + CO \longrightarrow Fe + CO_2$

4. Iron oxides are reduced by CO (reducing agent) generating Fe and CO_2

$C + CO_2 \longrightarrow 2CO$

3. Hot CO_2 is reduced to CO by reaction with coke

$CaCO_3 \longrightarrow CaO + CO_2$; $C + CO_2 \longrightarrow 2CO$

$CaO + SiO_2 \longrightarrow CaSiO_3$; $C + CO_2 \longrightarrow 2CO$

5. Limestone decomposes to CaO (lime), which reacts with silicates to form slag ($CaSiO_3$)

$C + O_2 \longrightarrow CO_2$

2. Coke (C) reacts with hot air to produce CO_2 and heat

*6. Slag and Fe are molten, denser slag protects Fe from oxidation; Fe and slag are removed (referred to as **pig iron** – impure)*

[Steel making](#)

What is "coke" ? Coal that is heated in the absence of air to remove impurities

What is the reducing agent that converts iron ore to iron in a blast furnace?

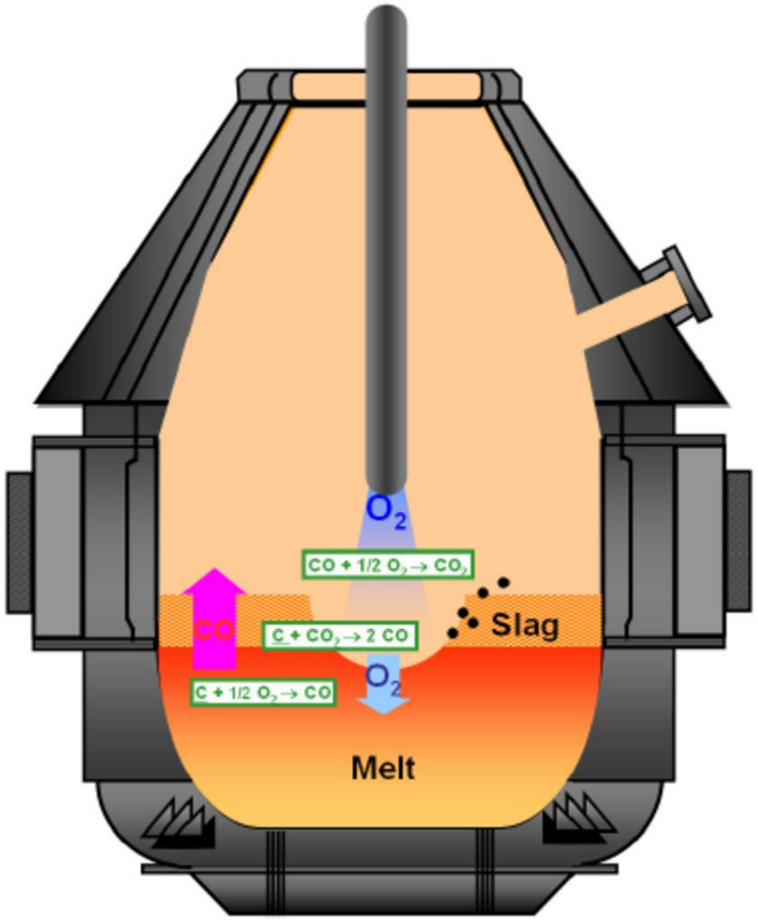
A. Hot air
B. Carbon dioxide
C. Carbon monoxide
D. Coke

How the molten Fe is converted to steel

- Molten pig iron is refined, usually in a Basic Oxygen Furnace (BOF)

In BOF:

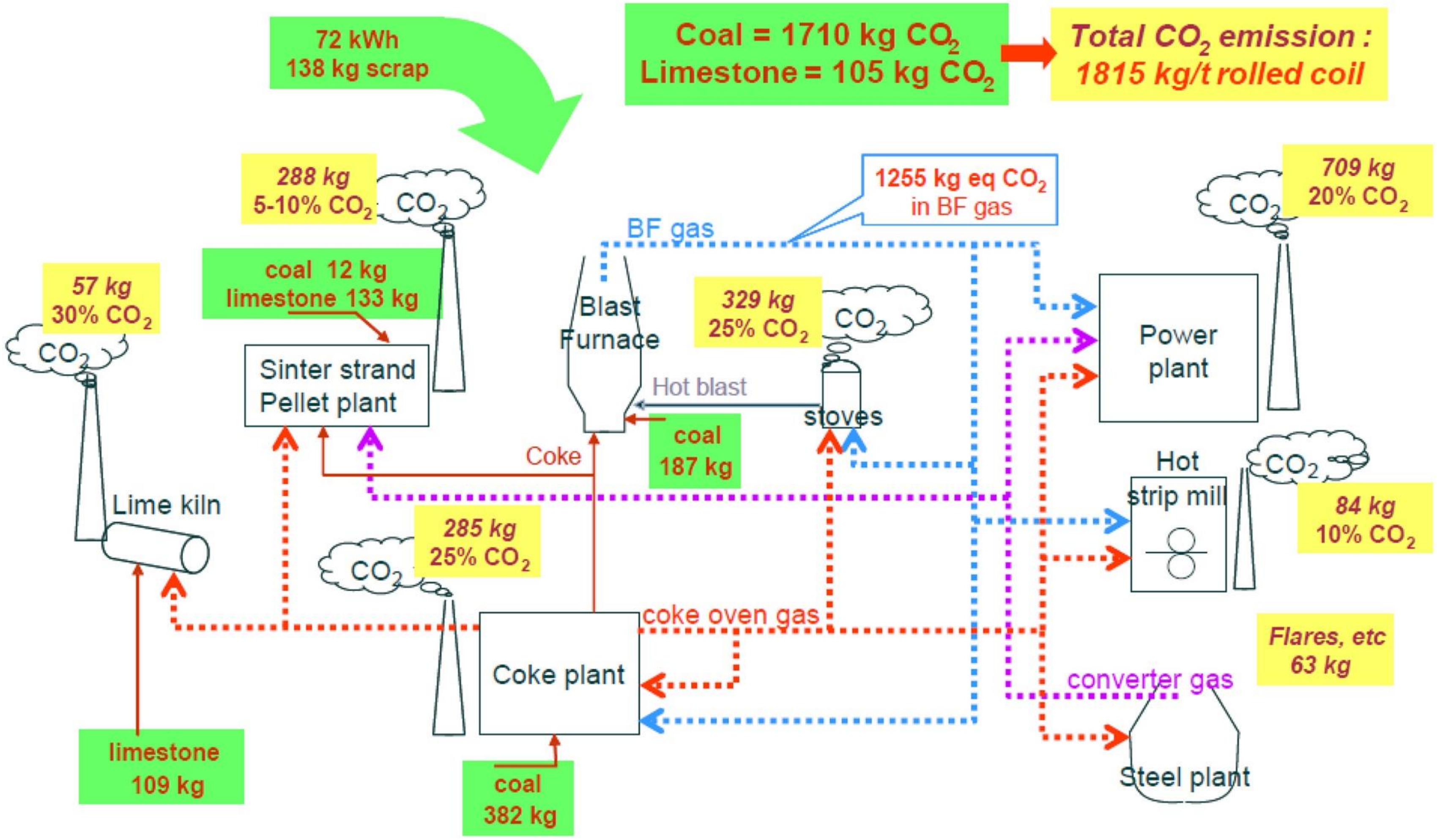
- Molten iron, containing high amounts of carbon, is fed into furnace
- Oxygen blown through at high pressure to oxidize the excess carbon and other impurities to get product known as steel



Refining = pig iron → steel

Decarbonizing steel

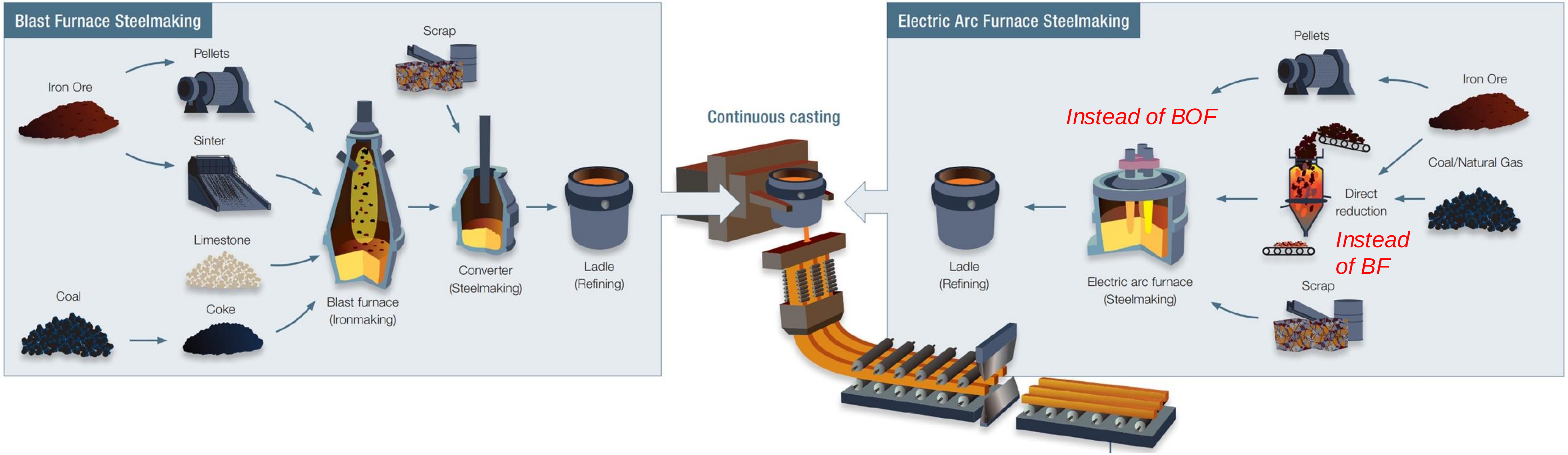
Emissions from typical steel mill (blast furnace)



- BF/BOF – blast furnace/basic oxygen furnace
- Primary emission source is raw materials and fuel combustion
- 1.8 t CO_2 emissions per t rolled coil, With 1.7 t from coal use and 0.1 t from lime use*

* Some source-related discrepancies

Decarbonizing steel

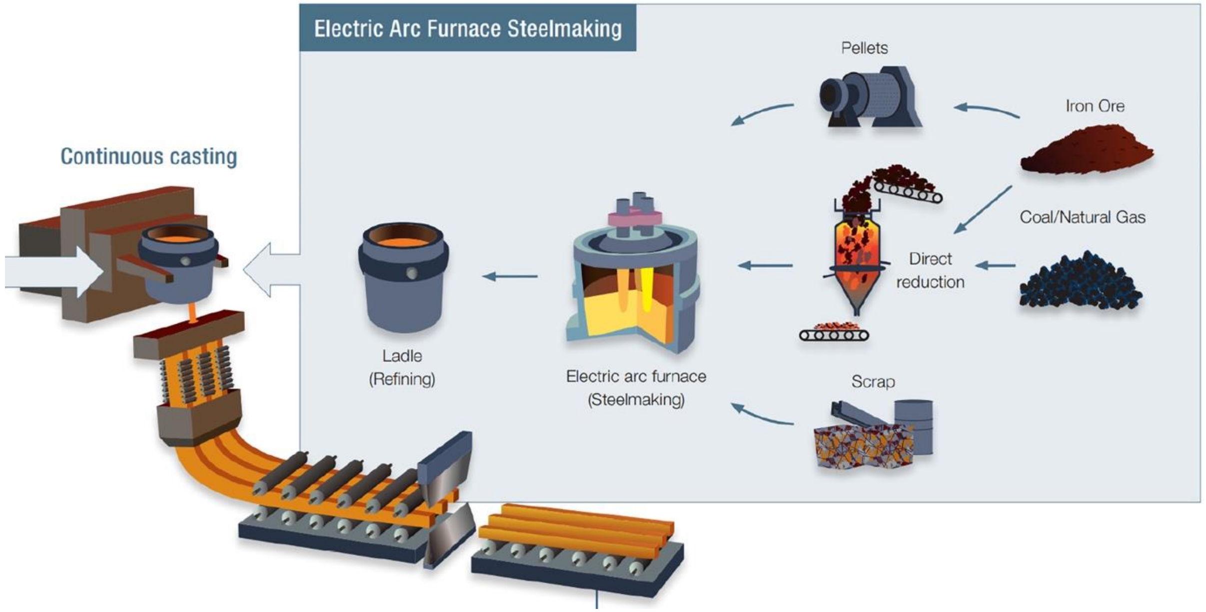


- BF to remove oxygen from ore to get pig iron (smelting)
- BOF to remove excess carbon and remove impurities to get steel
- Coal for energy
- ***Best suited for steel from ore***

- DR removes oxygen from ore to get a usable form of iron (natural gas, syngas, hydrogen for energy)
- EAF is fed with pig iron (“pellets”), DRI, and scrap steel (removal of impurities) – ***best suited to steel from scraps***
- EAF uses electricity for energy

Decarbonizing steel

Steelmaking in electric arc furnace



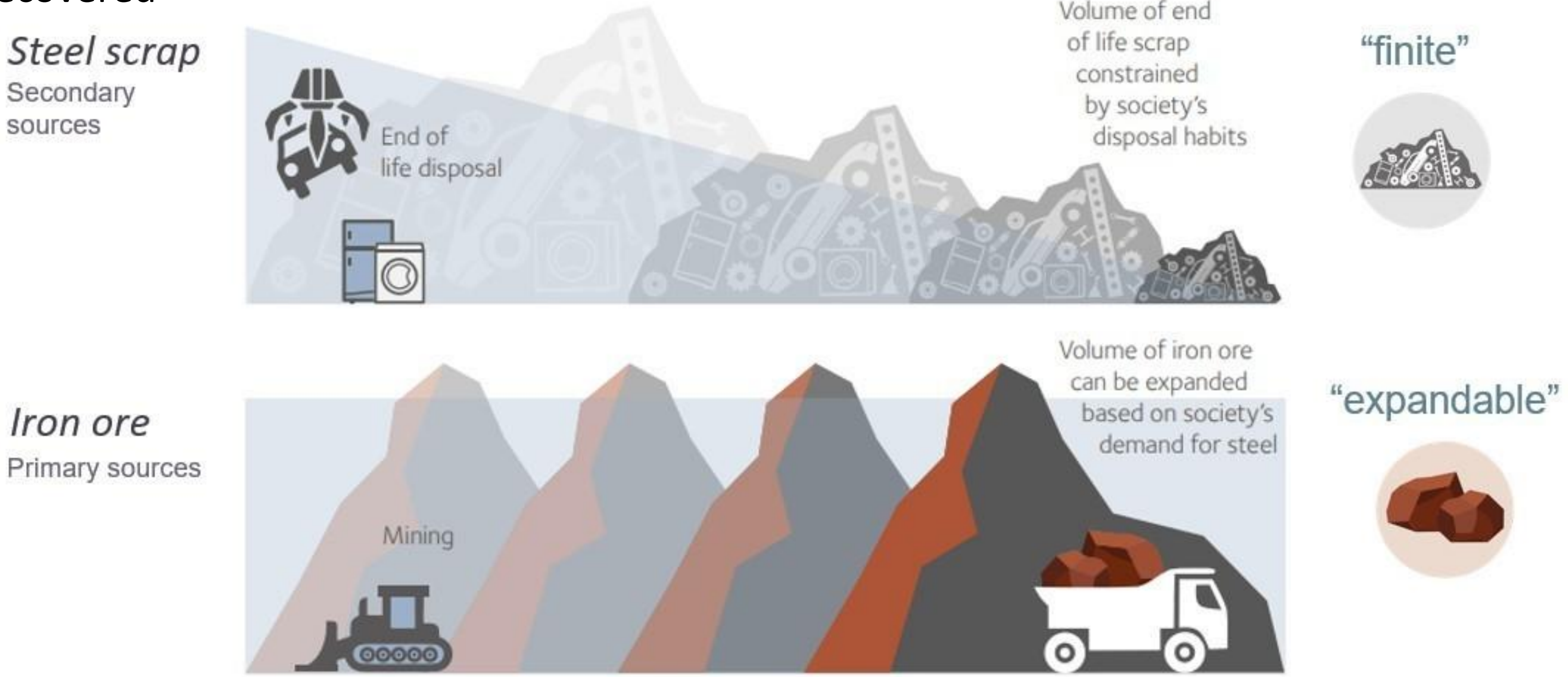
- DRI – iron reduced in **solid state**, without melting; lower temperatures (<1000 °C), less carbon, less energy
- In EAF, high voltage arcs are generated, heating and melting scrap steel, DRI and pig iron; less CO_2
- Compared to BF/BOF, more efficient and better for environment (if renewable energy, scrap steel), can be flexible with raw materials (DIR, scrap)

[Decarbonizing steel]

Two sources of metallics to make steel

Steel scrap decarbonization

Approx. 85-90% of steel scrap potential is recovered

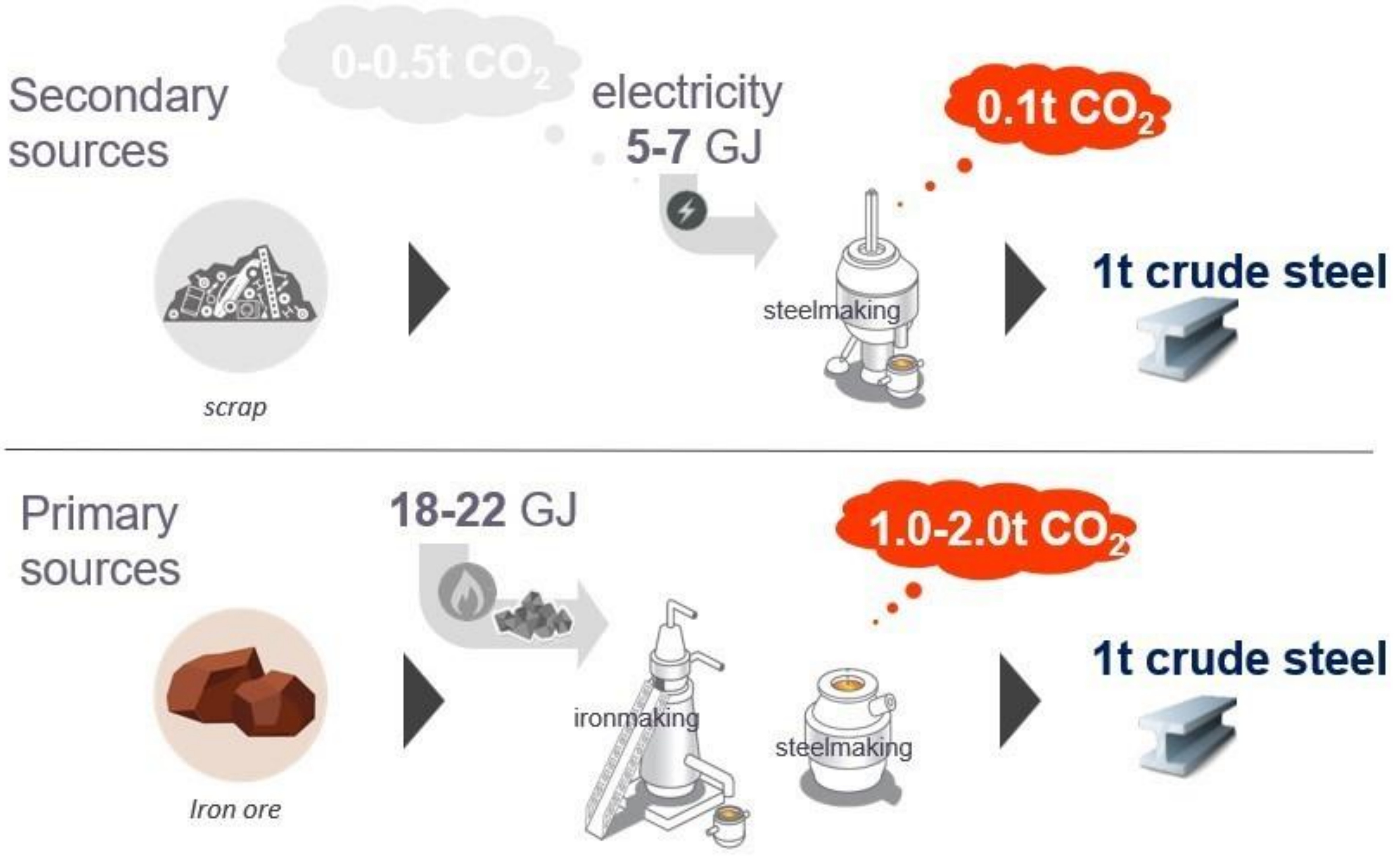


Click to add text

ArcelorMittal

Steel's CO_2 challenge, it's all about primary steel

Steel scrap decarbonization

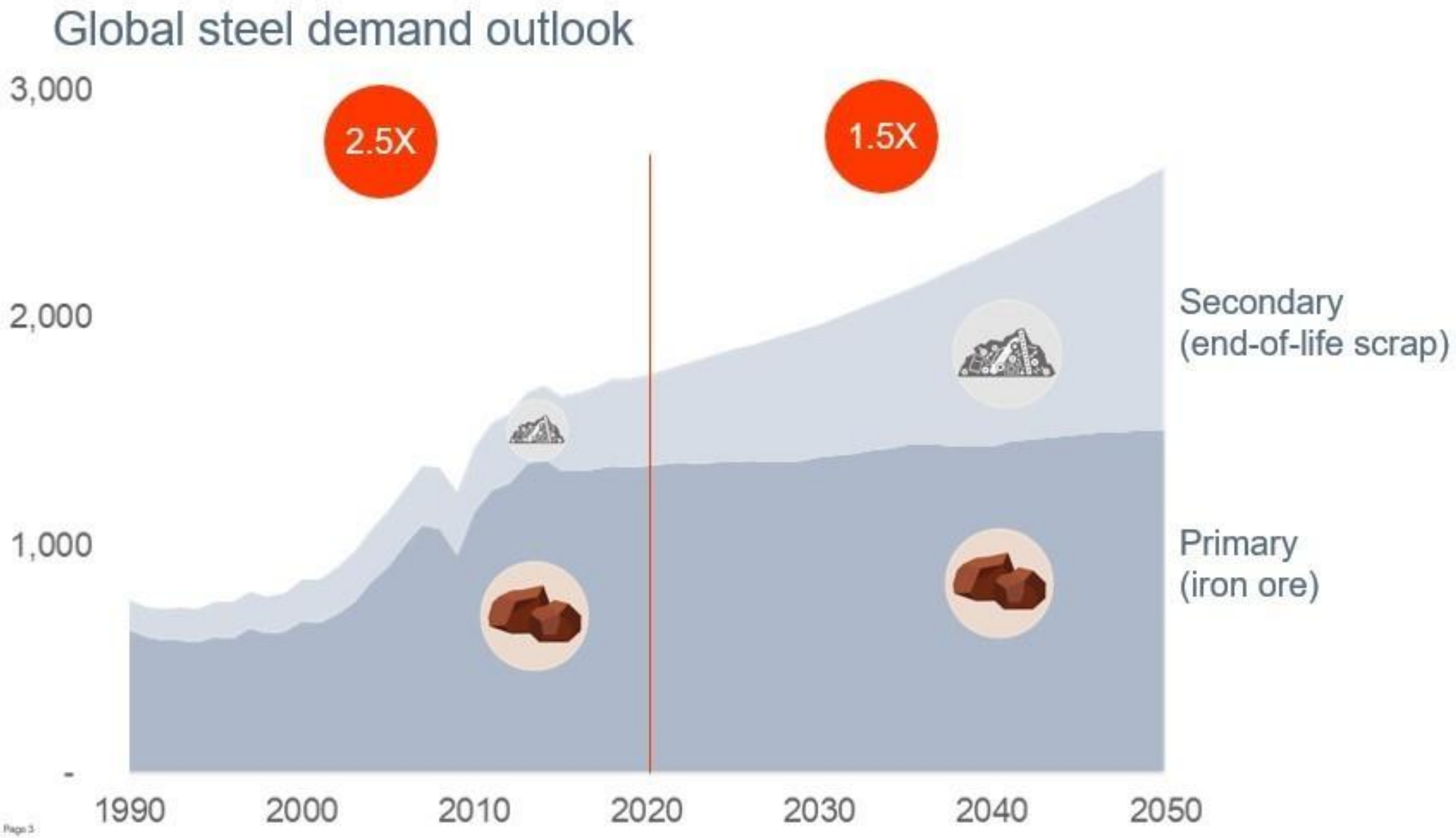


Source: ArcelorMittal Corporate Strategy

ArcelorMittal

We cannot escape it, primary steel will be needed over the long term

Steel scrap decarbonization



Source: ArcelorMittal outlook

Key drivers of steel demand growth

- Developing world convergence to developed world standards
- Transition to clean energy economy
- Partially neutralised by material efficiency

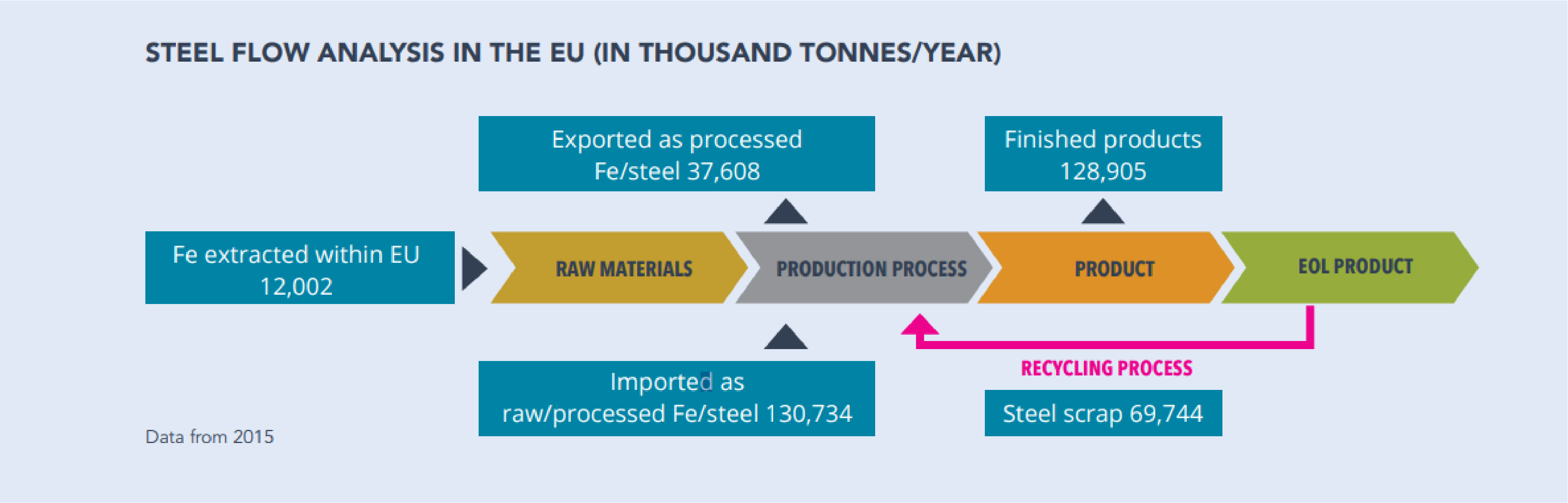
ArcelorMittal

Further steel decarbonization

Some strategies	Characteristics
Improve energy efficiency	• Exactly as it sounds
Reduction with hydrogen	• Instead of carbon-intensive coke (coal derived) used hydrogen as a reducing agent
Carbon capture, utilization and storage	• Exactly as it sounds (will discuss in a later class)
Material efficiency and recycling	• Maximize the use of scrap steel, design more efficiently to use less steel
Biomass	• Replace fossil fuels with biomass

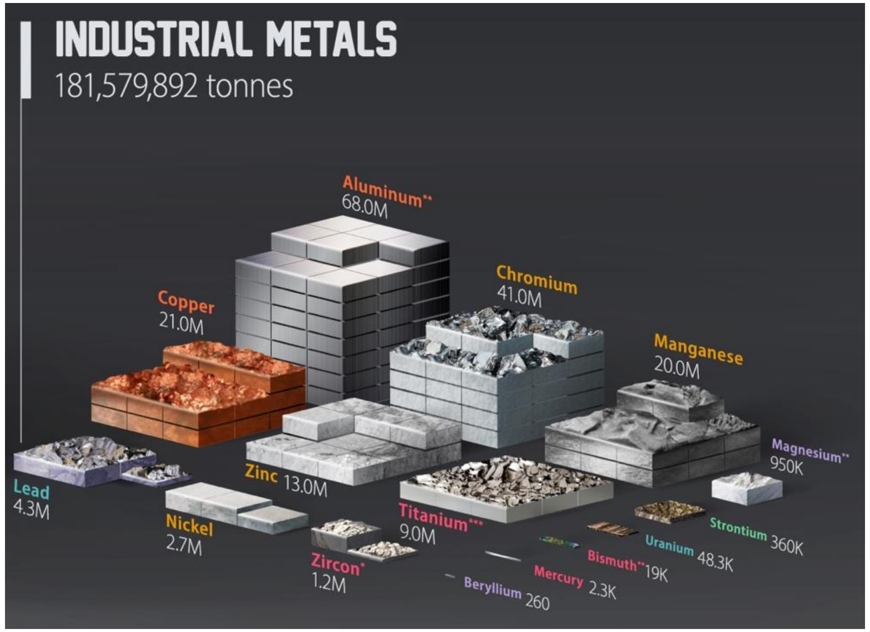
Steel flow in the EU –recycling

EU metal recycling factsheet



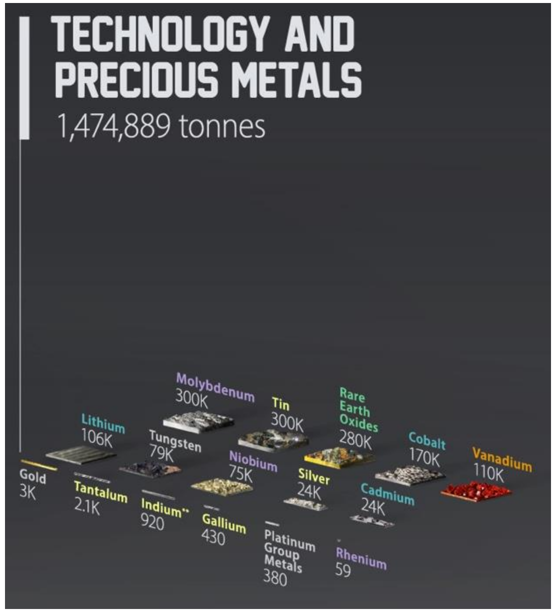
- Using steel scrap reduces CO_2 emissions by 58%.
- Recycling steel saves 72% of the energy needed for primary production.
- Recycling one tonne of steel saves 1.4 tonnes of iron ore, 0.8 tonnes of coal, 0.3 tonnes of limestone and additives, and 1.67 tonnes of CO_2.
- In 2018, 157 million tonnes of CO_2 were saved in the EU by recycling 94 million tonnes of scrap, an equivalent amount to all automobiles circulating in France, Great Britain and Belgium.
- Using recycled steel to make new steel reduces air pollution by 86%, water use by 40%, and water pollution by 76%.

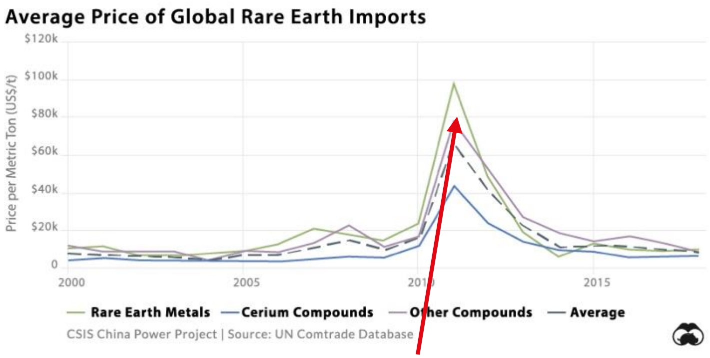
Other metals



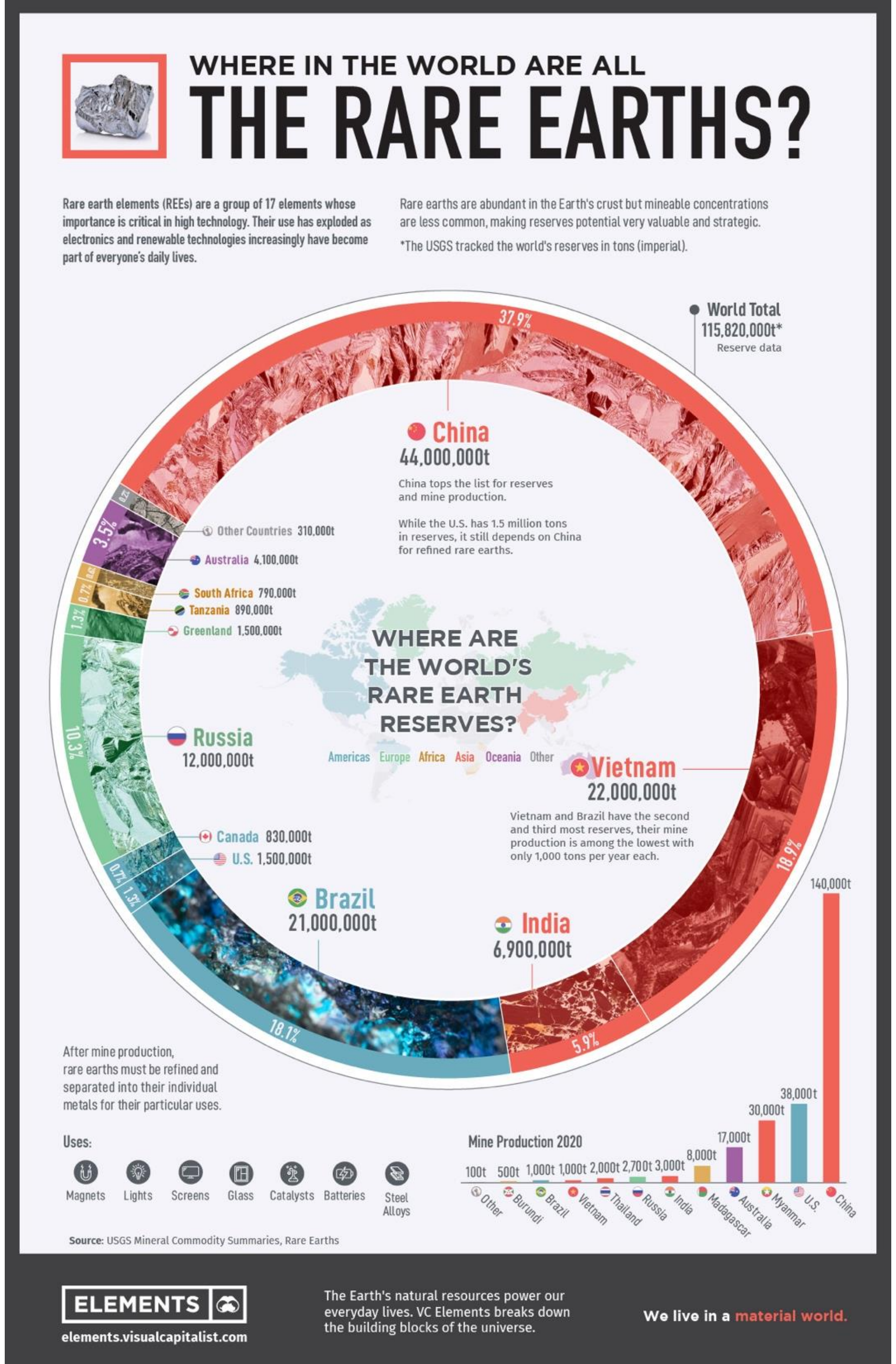
- **Aluminum**, most abundant metal in the Earth's crust (8% by weight)
  - Around 75% of the 900 million tons ever produced is still in use
  - Found in electronic devices, vehicles, and aircrafts
- **Copper**, used in many applications ranging from wiring to construction due to its durability, malleability, and electrical and thermal conductivity
- **Manganese**, fundamental in steel production and lithium-ion batteries

Rare earth metals





2010, China reduces REM export by 37%



- **Rare Earth Metals**, critical for current high-tech devices (e.g., screens, catalysts, batteries)
- **Lithium and Cobalt**, fundamental for lithium-ion batteries (e.g., electric vehicles)

Periodic Table of the Elements

ELEMENT GROUPS

- Non Metals
- Halogens
- Noble Gases
- Metals
- Metalloids
- Alkali Metals
- Alkali Earth Metals
- Transition Metals
- Lanthanides
- Actinides

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
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 Aluminium	14 Si Silicon	15 P Phosphorous	16 S Sulphur	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 Lan.	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 Act.	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

Lanthanides	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
Actinides	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

How many rare earth elements in an iPhone?

A. 3

B. 6

C. 8

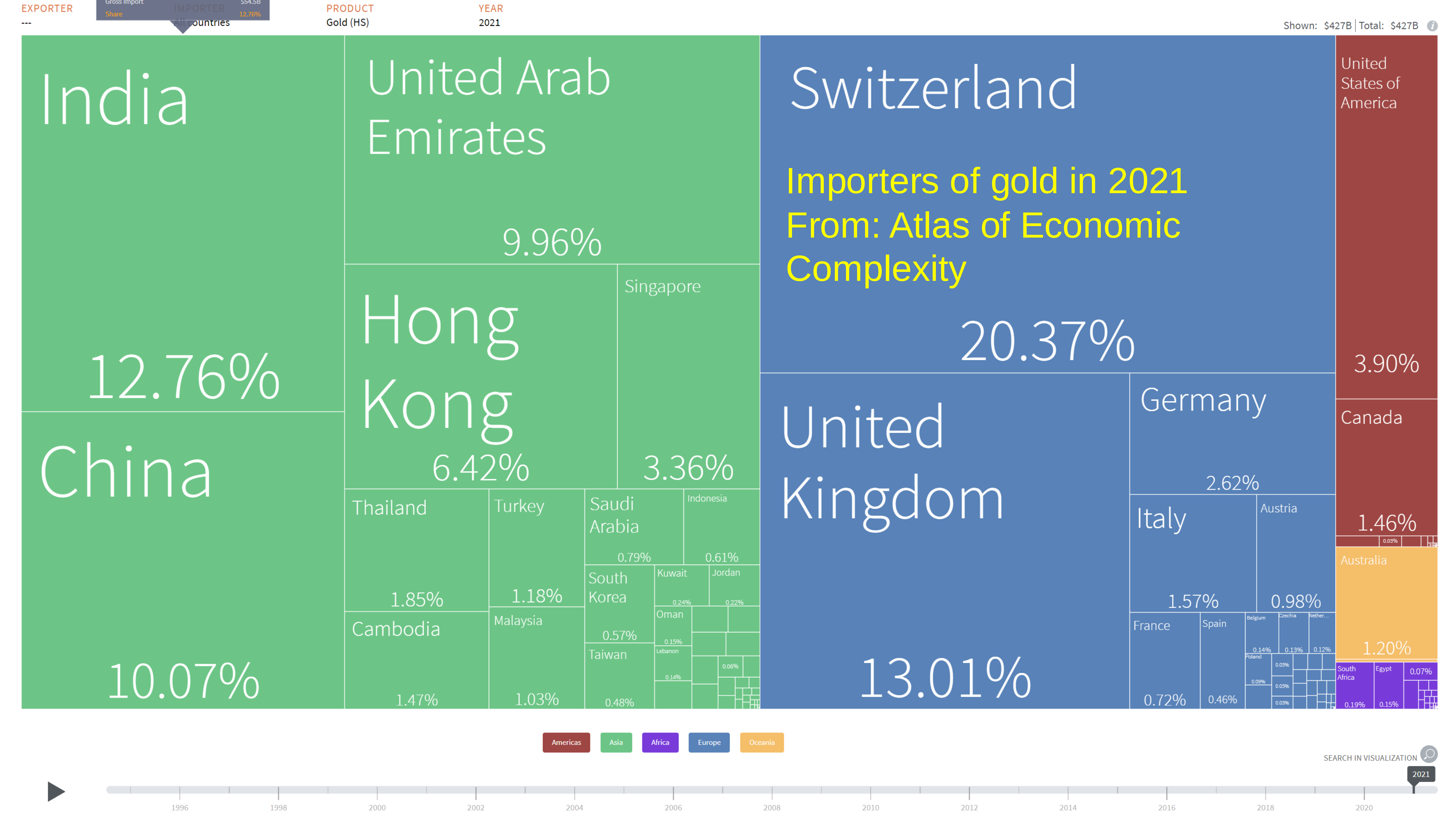
D. 17

Smartphone chemistry_2014

Switzerland and Gold

- 4/7 global gold refineries their Switzerland
- **Watches**, **jewelry**, and **investments** are by far the main uses of gold, and Switzerland is a world leader in all 3 areas
- Demand for new mining operations – due to growth in investment sector
- Lack of transparency in sourcing – most watch companies were not able to trace their supply chain to understand where their raw materials were sourced (2018 WWF study)

From: The impact of gold Sustainability aspects in the gold supply-chains and Switzerland's role as a gold hub – 2021 WWF report



EXPORTER

IMPORTER
All countries
PRODUCT
Gold (HS)
YEAR
2021
Shown: $427B | Total: $427B
India
12.76%
China
10.07%
United Arab Emirates
9.96%
Hong Kong
6.42%
Singapore
3.36%
Thailand
1.85%
Turkey
1.18%
Saudi Arabia
0.79%
Indonesia
0.61%
South Korea
0.57%
Kuwait
0.24%
Jordan
0.22%
Oman
0.15%
Lebanon
0.14%
Cambodia
1.47%
Malaysia
1.03%
Taiwan
0.48%
Switzerland
Importers of gold in 2021
From: Atlas of Economic Complexity
20.37%
United Kingdom
13.01%
Germany
2.62%
Italy
1.57%
Austria
0.98%
France
0.72%
Spain
0.46%
Belgium
0.14%
Czechia
0.13%
Nether...
0.12%
Poland
United States of America
3.90%
Canada
1.46%
Australia
1.20%
South Africa
0.19%
Egypt
0.15%
0.07%
Americas
Asia
Africa
Europe
Oceania
SEARCH IN VISUALIZATION
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2021

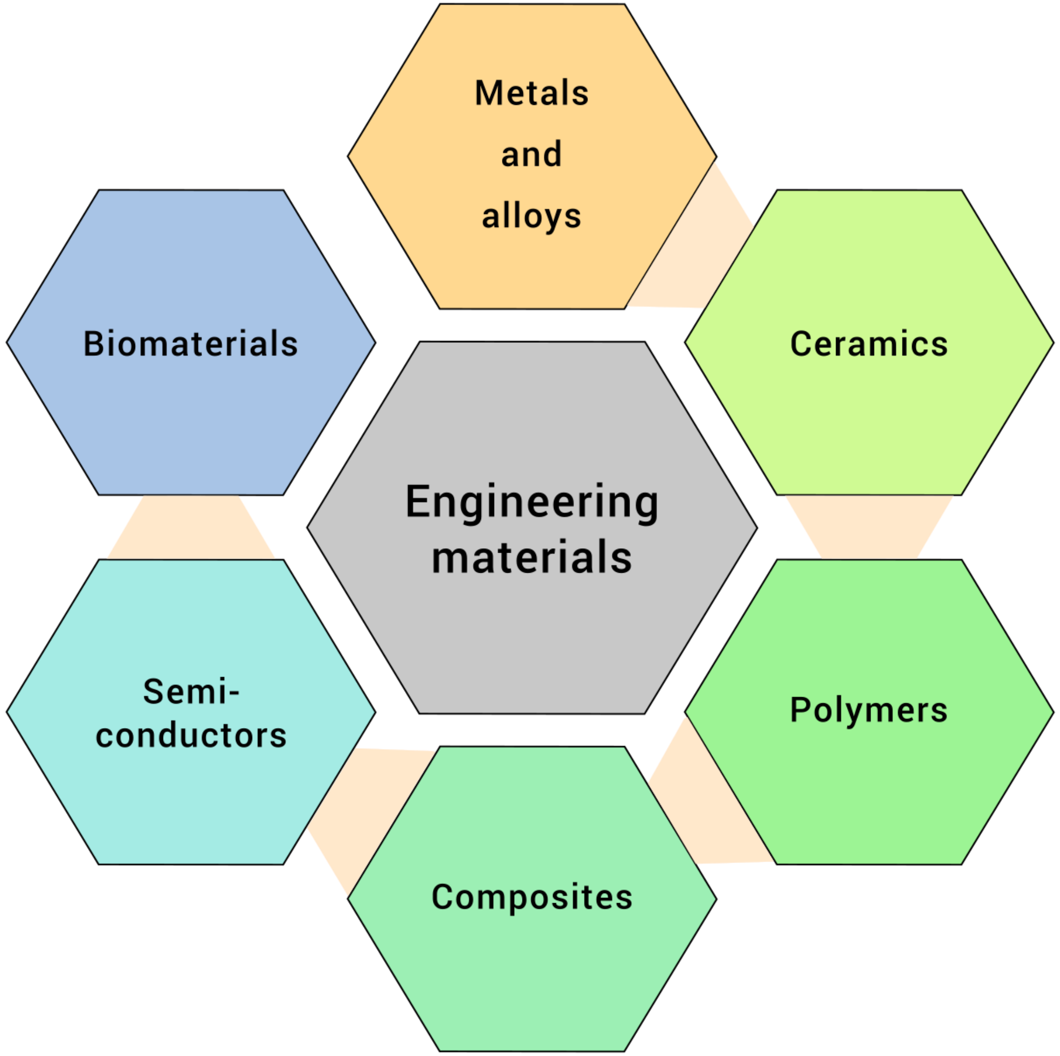
Gold stats – executive summary

- 1 tonne of gold produces 100 000 tonnes of waste rock (or 1000 kg of soil moved for one 10 g ring!)
- 1 kg of gold generates 12 500 kg of CO_2 equivalents (almost 3× Switzerland's transportation emission)
- 38% of worldwide total anthropogenic mercury emissions in 2015 were attributed to artisanal and small-scale mining (focus in Sub-Saharan Africa and South America – 163% increase between 2010-2015)
- Large scale mining (80% of global gold mine production) also challenging with local environmental problems as massive deposits are mined after long periods of time – contaminants, heavy metals, acid mine drainage…

From: The impact of gold Sustainability aspects in the gold supply-chains and Switzerland's role as a gold hub – 2021 WWF report

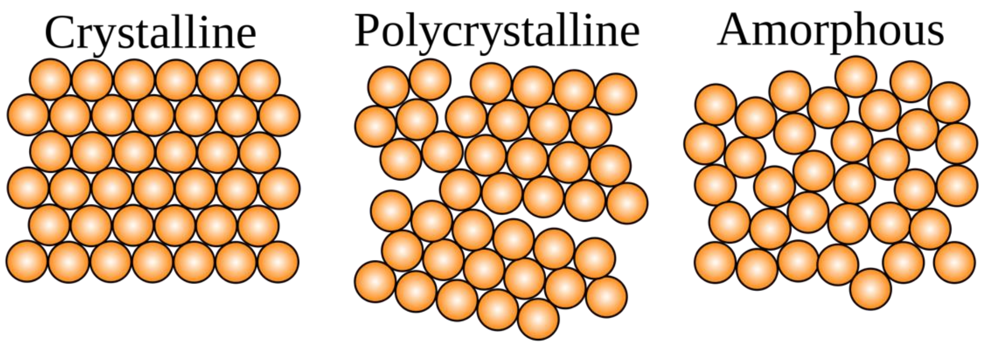
Engineering materials categories (variable)

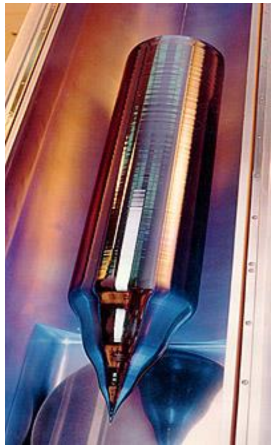
- Metals and alloys
- Polymers
- **Ceramics**
- Composites
- Semiconductors
- Biomaterials

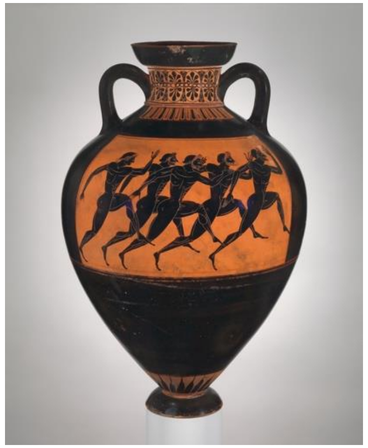


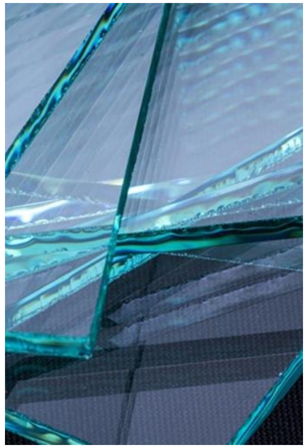
[Materials science classifications]

Ceramics vs. glass



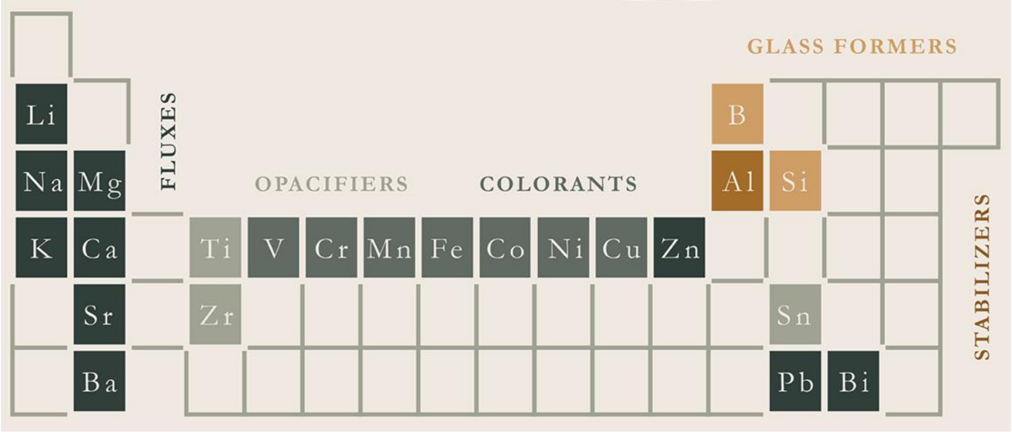






- Ceramics are crystalline, which contributes their almost always high melting temperatures and thermal stability

- Glasses are amorphous and soften/melt upon heating



Ceramics

- Considered one of the greatest and earliest successes of humankind – control of fire
- Among the 1st objects manufactured
- From Greek “keramos” meaning burned earth
- Defined as non-metallic inorganic solids, obtained by firing powders
- Characteristics – long service life, low density, chemically inert, corrosion resistant, electromagnetic response, non-toxic, heat and fire resistant, sometimes electrical resistance or porosity

Decarbonizing ceramics_2022

Ceramics

- 1st pieces reported ca. 24,000 years ago

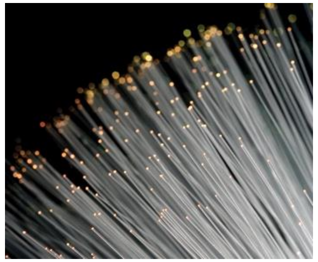
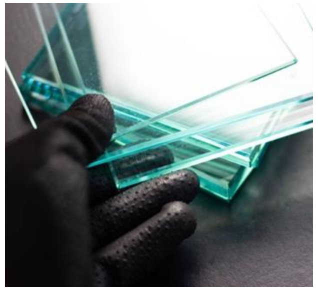
- Many uses today: promising for aerospace and high temperature structural applications, information storage and optical devices, oral prosthetics, water purification, bone void fillers, CO_2 adsorbents, etc.,

- Value of global ceramics market was approx. 230 billion in 2018, and growing due to constant growth in the construction industry, technological advancements in nanotechnology, 3D printing, and ceramics in health

Decarbonizing ceramics_2022

Main uses – Ceramics and Glasses

Ceramics
- Glasses
- Clay products
- Refractories
- Abrasives
- Cements
- Advanced ceramics

Glasses
- Optical fibers
- Glasses
- Household


Clay products
- Pottery
- Whitewares
- Bricks and tiles

Refractories
- Refractory bricks for high T (furnaces)

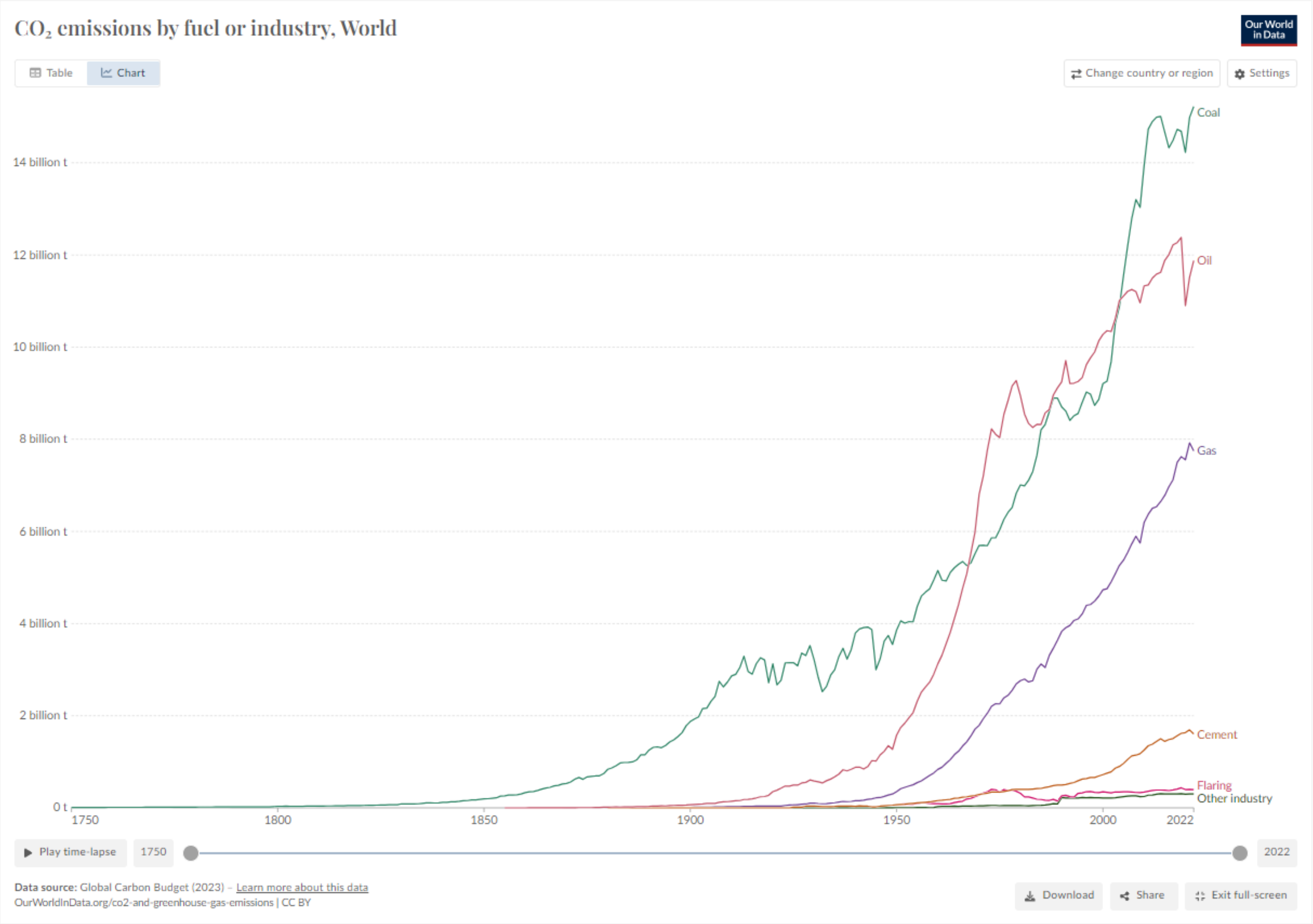

Abrasives
- Sandpaper
- Polishers
- Cutlery

Cements
- Constructions
- Composites

Advanced ceramics
- Electronics
- Turbines

Environmental cost of ceramics

- In EU: production of refractories, wall and floor tiles, and bricks and roof tiles emit around 19 Mt CO_2
- Globally: brick manufacture is responsible for 2.7% of annual carbon emission; cement (considered a ceramic in this course's context) is responsible for 5-8% of annual emissions



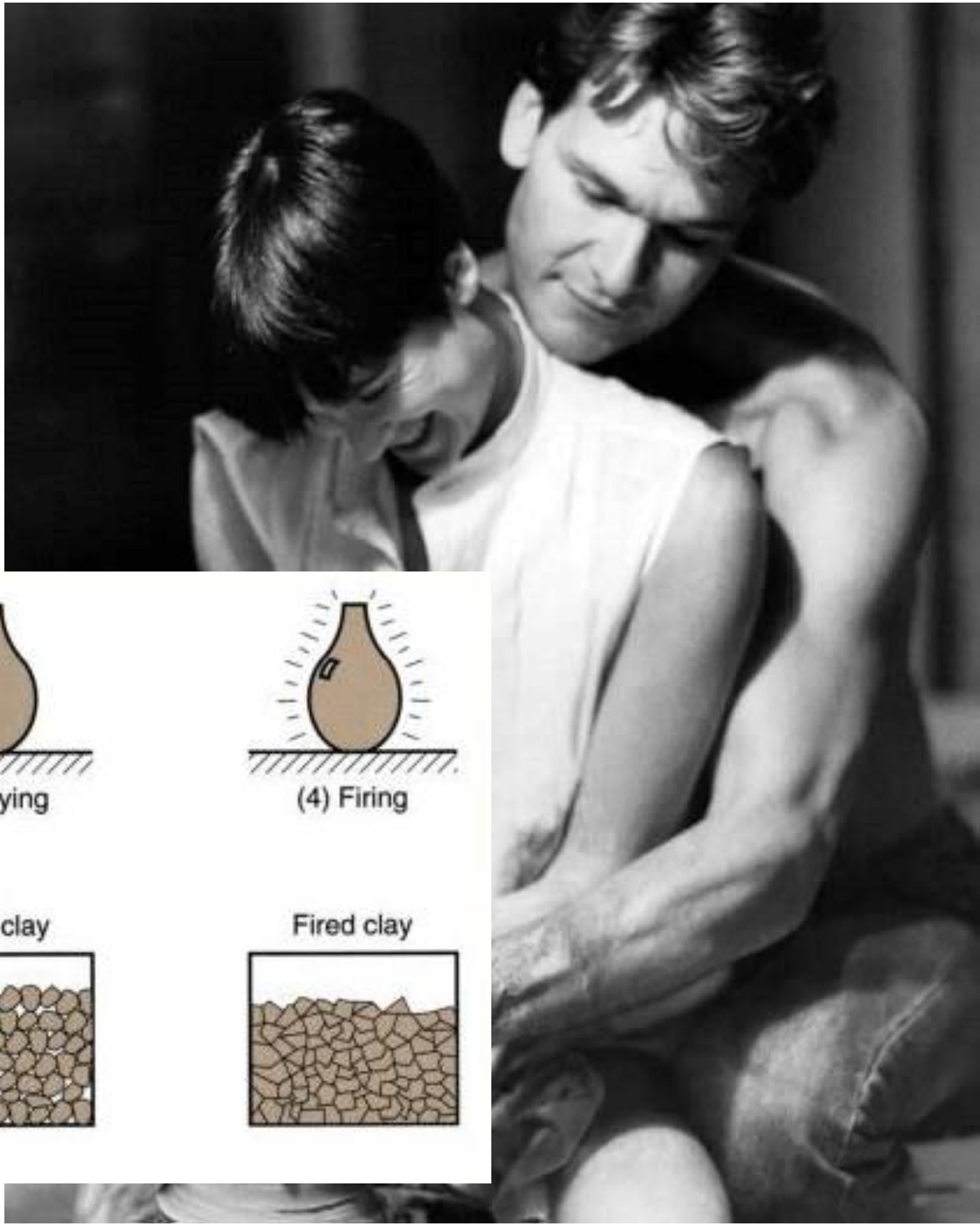
Decarbonizing ceramics_2022

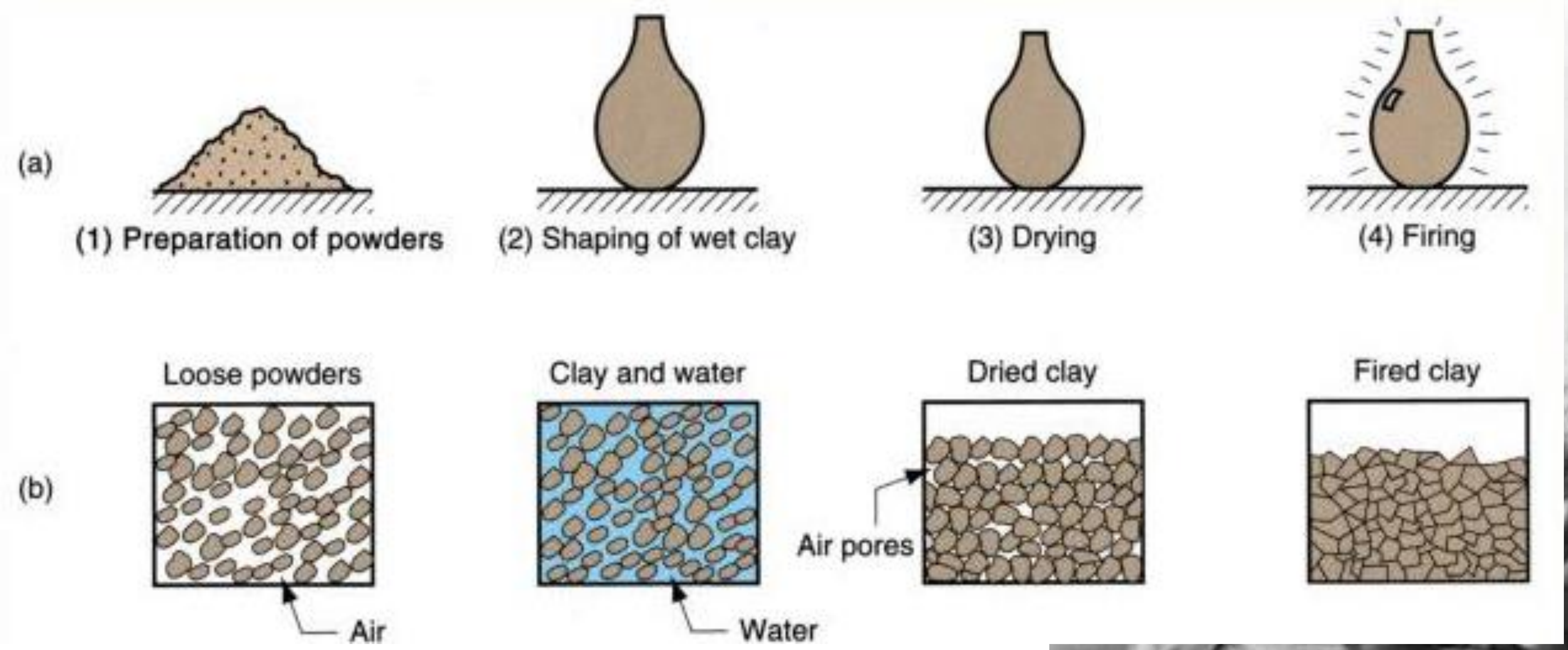
Projecting future carbon emissions from cement_2023

Traditional ceramics

Processing ceramics

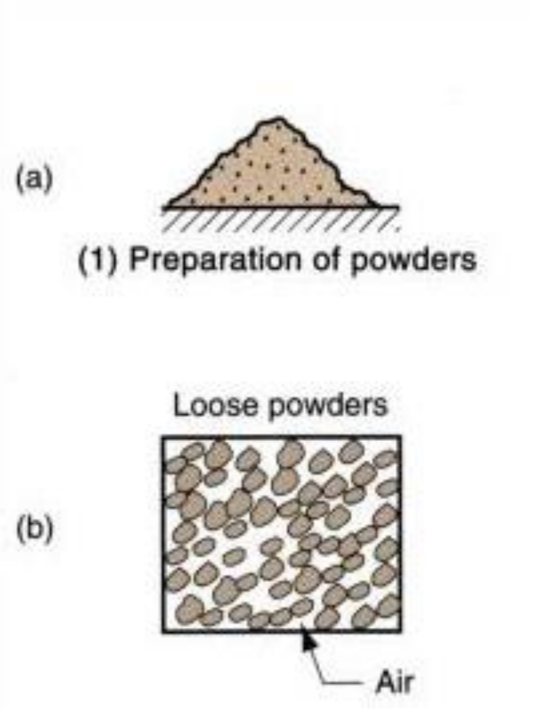
- Traditional ceramics are made from naturally occurring minerals
- Mineral extraction has the usual consequences: habitat destruction, soil erosion, water pollution
- Open pits and quarries common

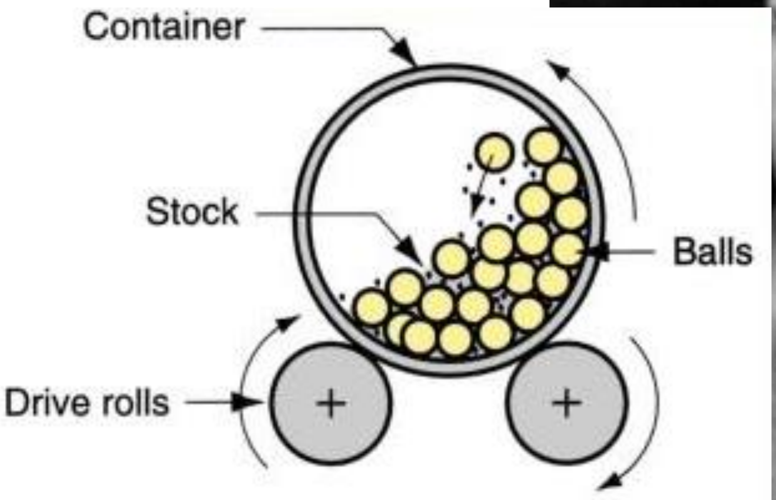




Powders

[Processing ceramics]

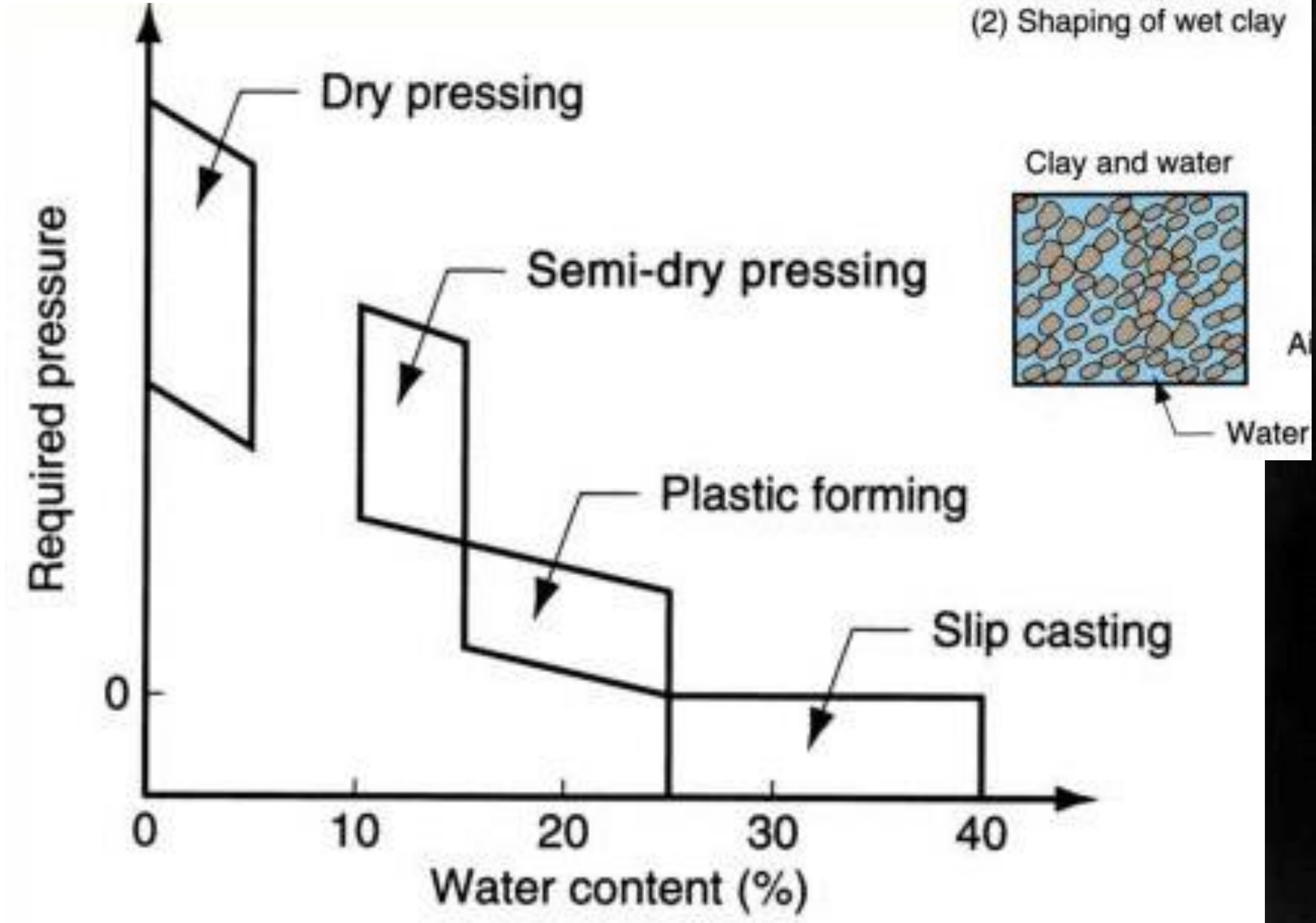


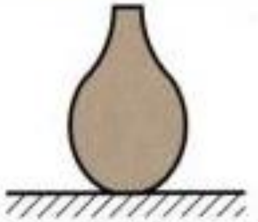


- Starts with a powder
- Powder usually made by ball crushing and then grinding, which is very energy intensive!

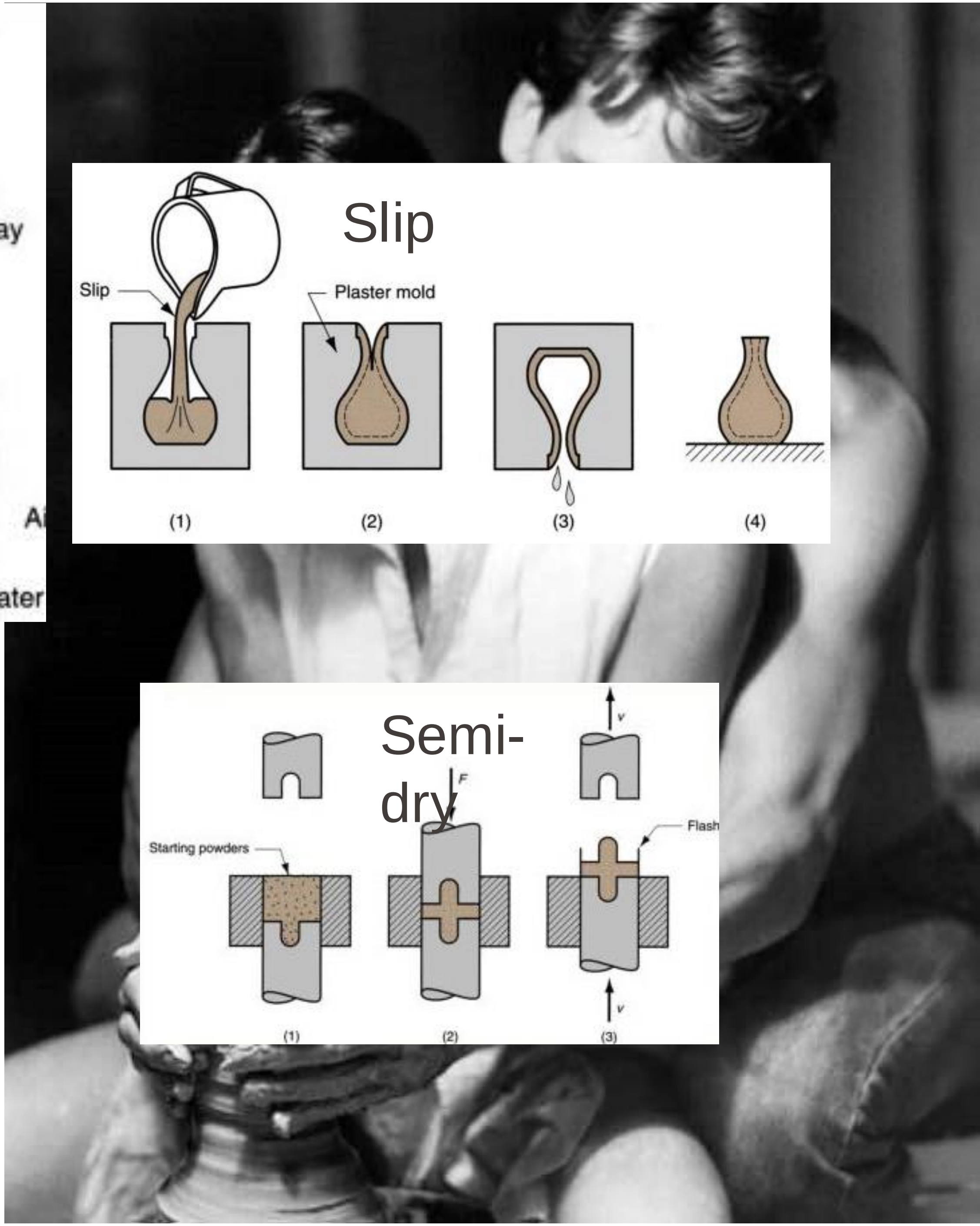
Shaping

Processing ceramics





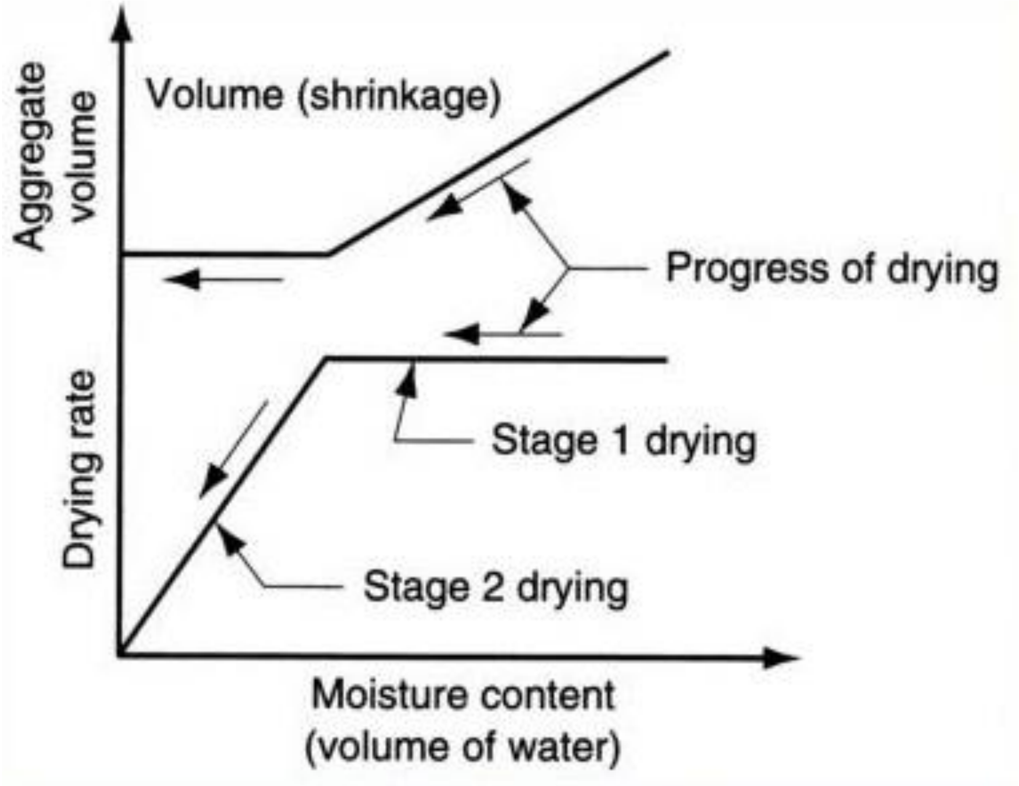
(2) Shaping of wet clay



- Water is needed for shaping only/plasticity
- High pressures required for semi-dry/dry shaping

Drying – 2 stages

Processing ceramics

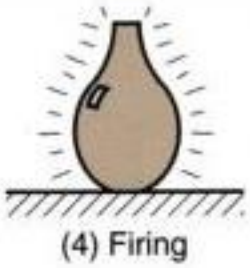


- Stage 1: fast and constant rate to evaporate surface water (prone to shrinkage)
- Stage 2: enough water has been removed so particles are in contact (no shrinkage)

Firing

[Processing ceramics]

- Heat treatment to *sinter* – form bonds between particles, occurring with densification
- Performed in kiln
- Biggest impact to emissions, related to use of fossil fuels to heat the kiln and process emissions from carbonate raw materials which emit CO_2 when heated
- If glaze is applied, the ceramic is fired again!



Advanced ceramics

- Made from manmade raw materials
- Developed to meet industrial, technological, and biomedical needs
- Exhibit exceptional properties: high strength, resistance to wear, electrical insulation or conductivity, piezoelectricity, etc.,

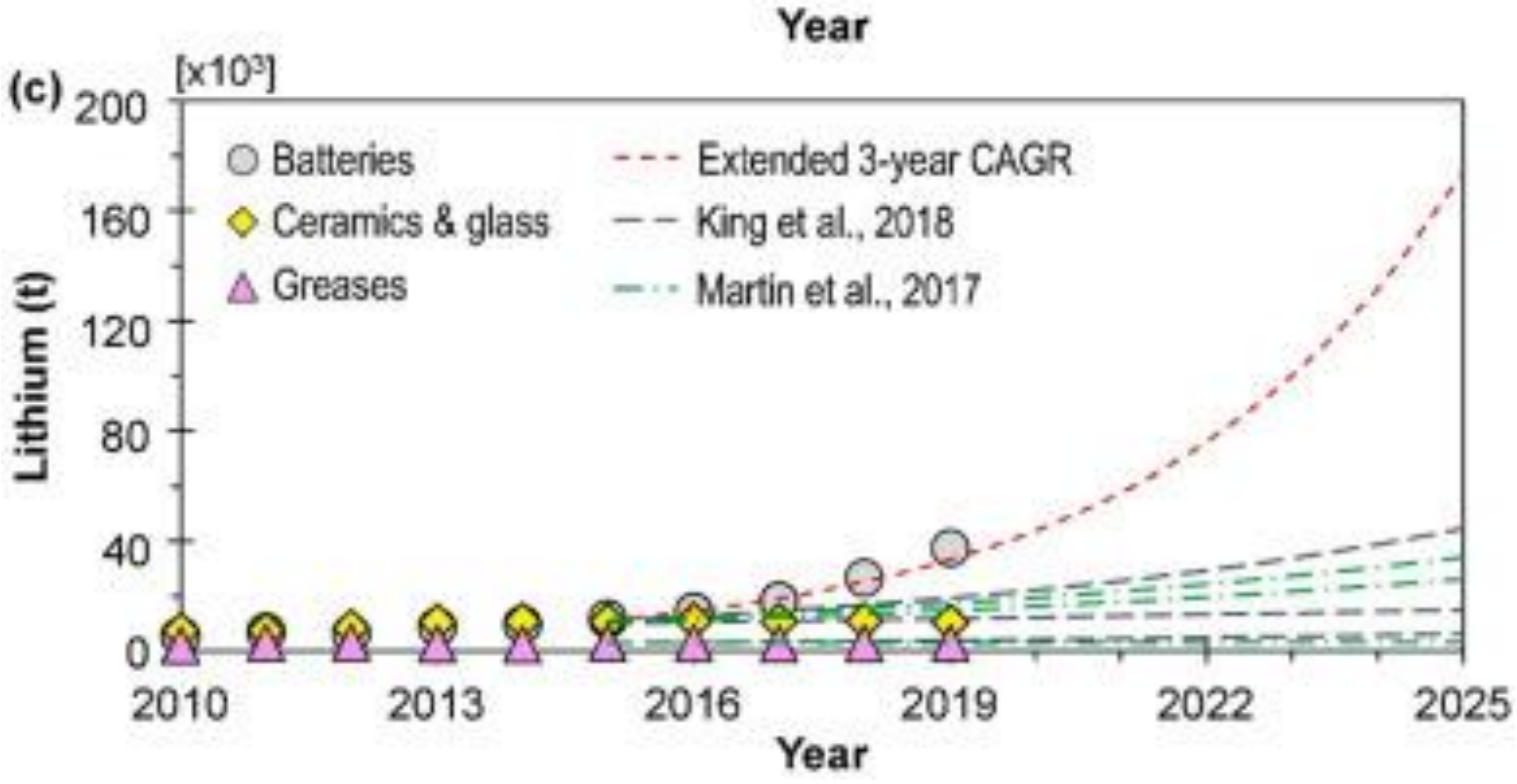
Same general steps:

1. **Starting material preparation** – to satisfy high strength requirements grain size is smaller! Controlled by mechanical and chemical methods
2. **Shaping** – some methods borrowed from powder metallurgy, like hot pressing, which sinters as you press; separate firing step is not needed, or injection molding, where ceramic particles are carried by a polymer that is removed after shaping; lower temperatures need to shape but sintering still needed
3. **Sintering** – plasticity is not usually based on water so drying is not needed, but sintering is still needed
4. **Finishing** – to improve finish or dimensions, usually abrasive

Advanced ceramics roadmap

Lithium connection?

- Lithium is used in new ceramics due to its ability to enhance certain properties: low thermal expansion, high strength and toughness, melting point reduction, improved optical properties, enhanced electrical properties, lightweight

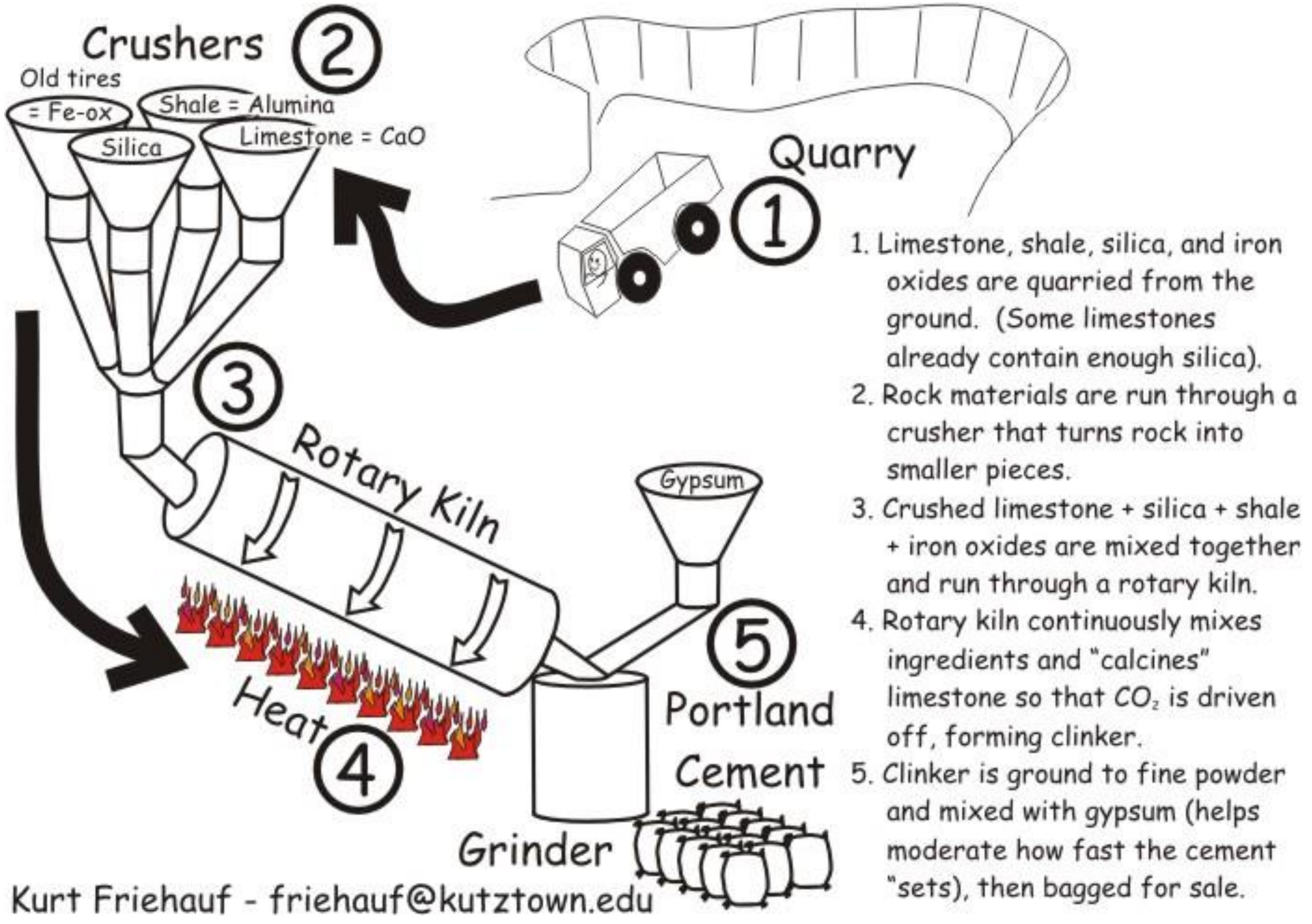


- Now batteries, but before 2015, ceramics and glass was the main industry using lithium

Decarbonizing ceramics_2022

How cement is made

$CaCO_3$ (limestone) + heat -> CaO (lime) + CO_2

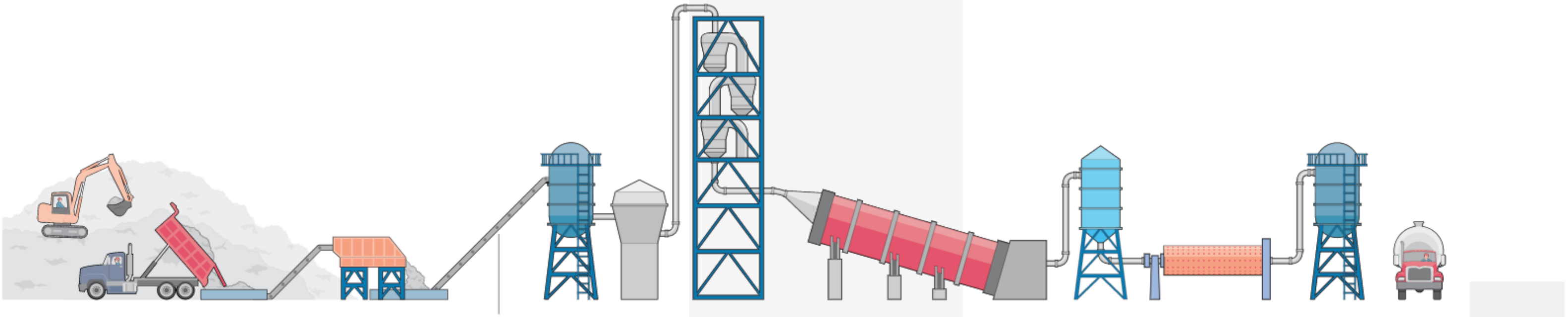


Cement manufacture

Cement

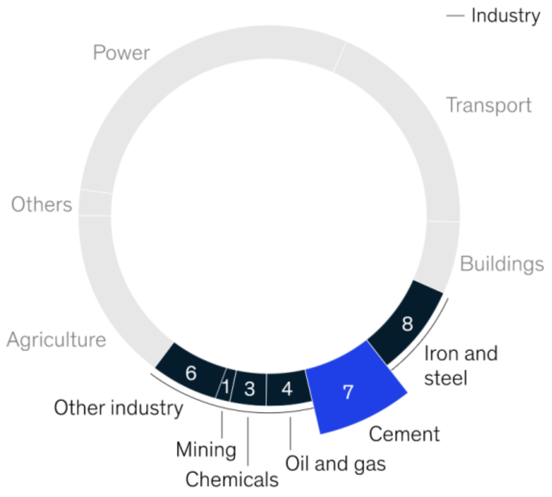
https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

Raw materials, energy, and resources | **Clinker and cement manufacturing**

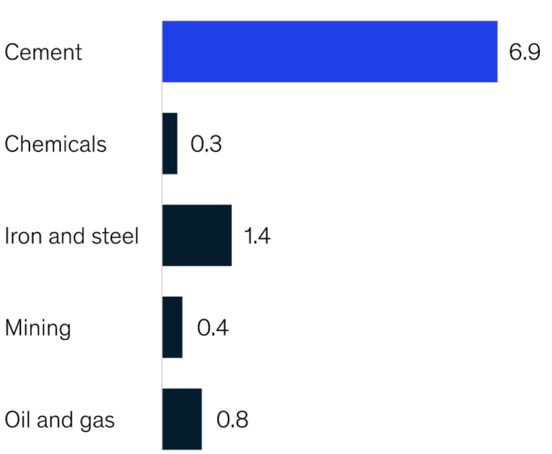


	Quarry	Crusher	Transport[1]	Raw mill	Kiln and preheater/ precalcinator[2]		Cooler[3]	Cement mill	Logistics[4]	**Total**
Energy, mega-joule/ton	40	5	40	100	3,150		160	285	115	3,895
CO_2, kilogram/ton	3	1	7	17	479 Calcination process	319 Fossil fuels	28	49	22	925

Share of global CO_2 emissions, % in 2017

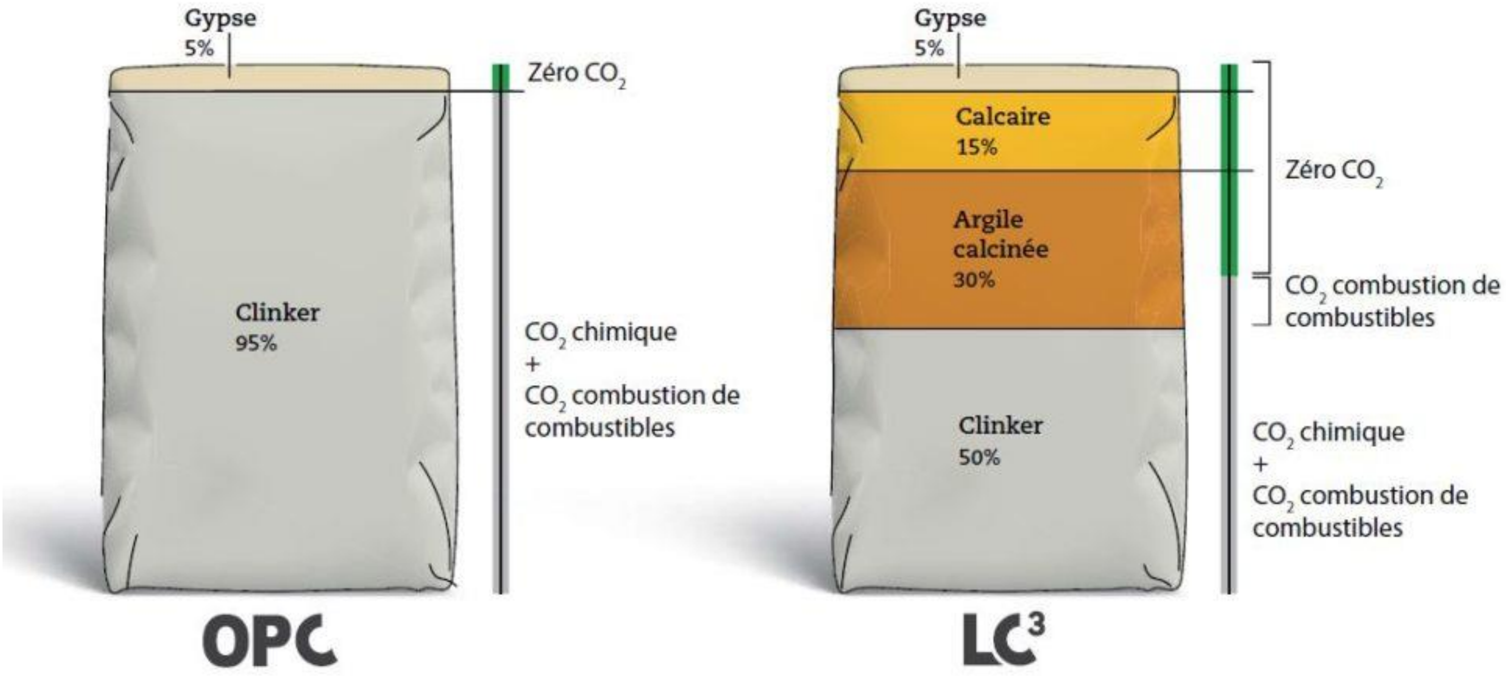


kg of CO_2 per $



- The cement industry alone is responsible for about a quarter of all industry CO_2 emissions, and it also generates the most CO_2 emissions per dollar of revenue
- About two-thirds of those total emissions result from calcination, the chemical reaction that occurs when raw materials such as limestone are exposed to high temperatures.

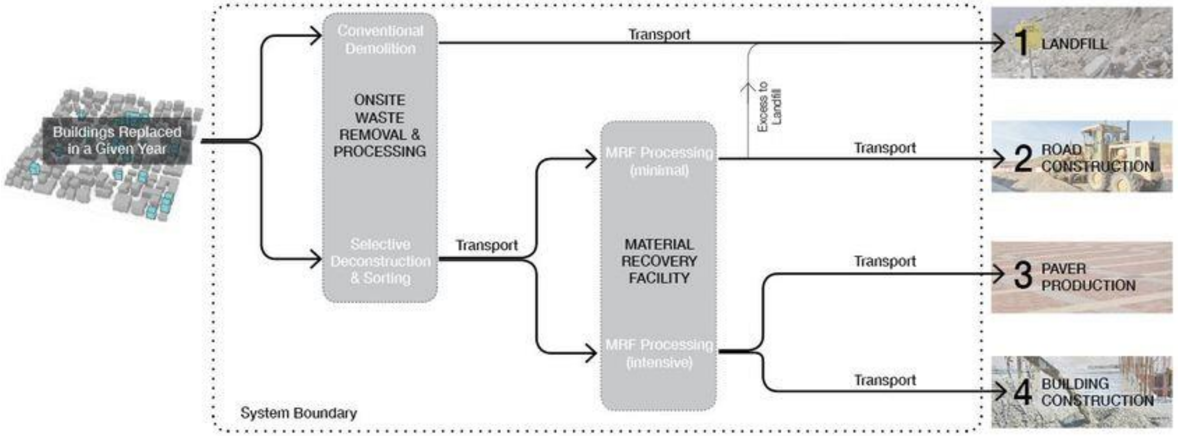
Decarbonizing cement : EPFL connection



- Replaces half of clinker with calcined clay and ground limestone, neither of which releases CO2 when heated the way limestone does
- Clay is heated to lower temperatures, reducing fuel needed and emissions
- Lower temperatures mean that cleaner electricity like clinker can be used

LC3 - more sustainable cement

End of life – Ceramics and Glasses



Concrete

- About 60% of what is crushed can be used for downcycling processes (recovery of materials with a more limited range of uses than the original material).
- These fragments can be used as base materials for structures such as roads.

https://www.archdaily.com/933616/is-it-possible-to-recycle-concrete

Moving on:

- ~~Snapshot of the Swiss economy (recall, less than 7% circular) – why? Economy tracks with carbon footprint~~
- ~~Two important periodic tables, leading into a discussion of CRMs, 3TG~~
- ~~Look for sustainability hotspots: metals and ceramics (two materials classes)~~
- Next meetings: will also consider plastics and composites

Key take aways

- Hotspots in steel making: mining, coal, ore to pig iron using coke
- Hotspots in ceramics: mining, drying, firing, except for glass – downcycling instead of recycling, lithium or other CRMs in advanced ceramics
- Approaches to decarbonize
- Rare earth metals – not rare in terms of abundance
- What's with Switzerland and gold?