Towards Low-Carbon Economy: Green Metals/Minerals

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Mining and Minerals - Lifeblood of Economy

Mining and Fuel Production has reached > 17000 Mt

With total value of > 3500 BUS$

Fuel Production →→→ > 14500 Mt, Revenue →→→ > 1000 BUS$

Mining Production →→ → > 2500 Mt Revenue →→ →1000 BUS$

World mining production

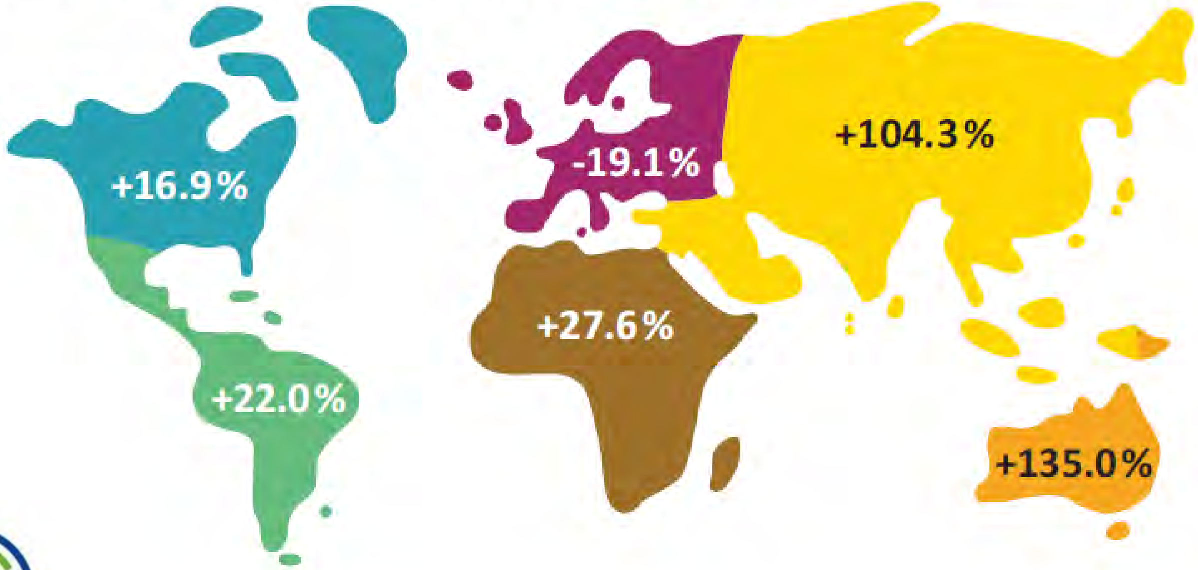
2018
17.7 Billion metric tons

2000
11.3 Billion metric tons

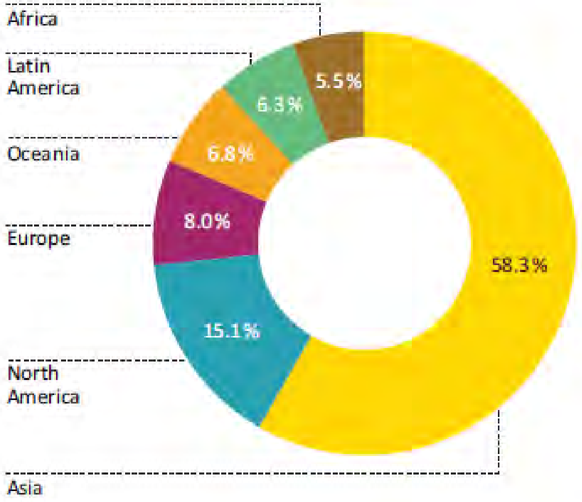
1985
9.6 Billion metric tons

World Mining Data 2020

Declining production rates since 2000 only in Europe – Δ 2000 / 2018



Total production 2018 by continents



eit RawMaterials

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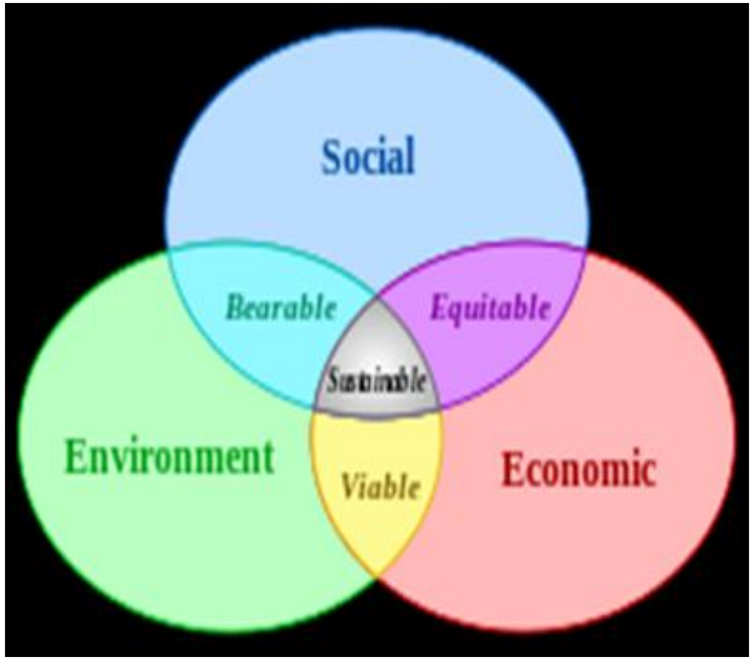
Mining Industry and Sustainability

- ***Sustainability:* development that meets the needs of the present without compromising the ability of future generations to meet their own needs**

- ***Sustainability in Mining is a Paradox?!***

- *Energy: Sector consumes ~7% of the total world energy*
- *Carbon Foot-Print: CO_2 emission in relation with energy consumption*
- *Harder Rocks: Dealing with harder rocks as mining goes deeper*
- *Grade: Decreasing grade and extracting large tonnages*
- *Grind Size: As decreasing grade and liberation size, finer size fractions required in processing*
- *Water: Consumption is considerable, specially in process stage(s)*



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World’s Energy Consumption

- ✓ ***World’s Energy Consumption is~ 584*10^{18} Joules (1.62*10^{14} kWh), i.e., increasing rate of 1.6% (last 10 years)***
- ✓ ***By 2050, the consumption will reach 2.6*10^{14} – 3.0*10^{14} kWh***

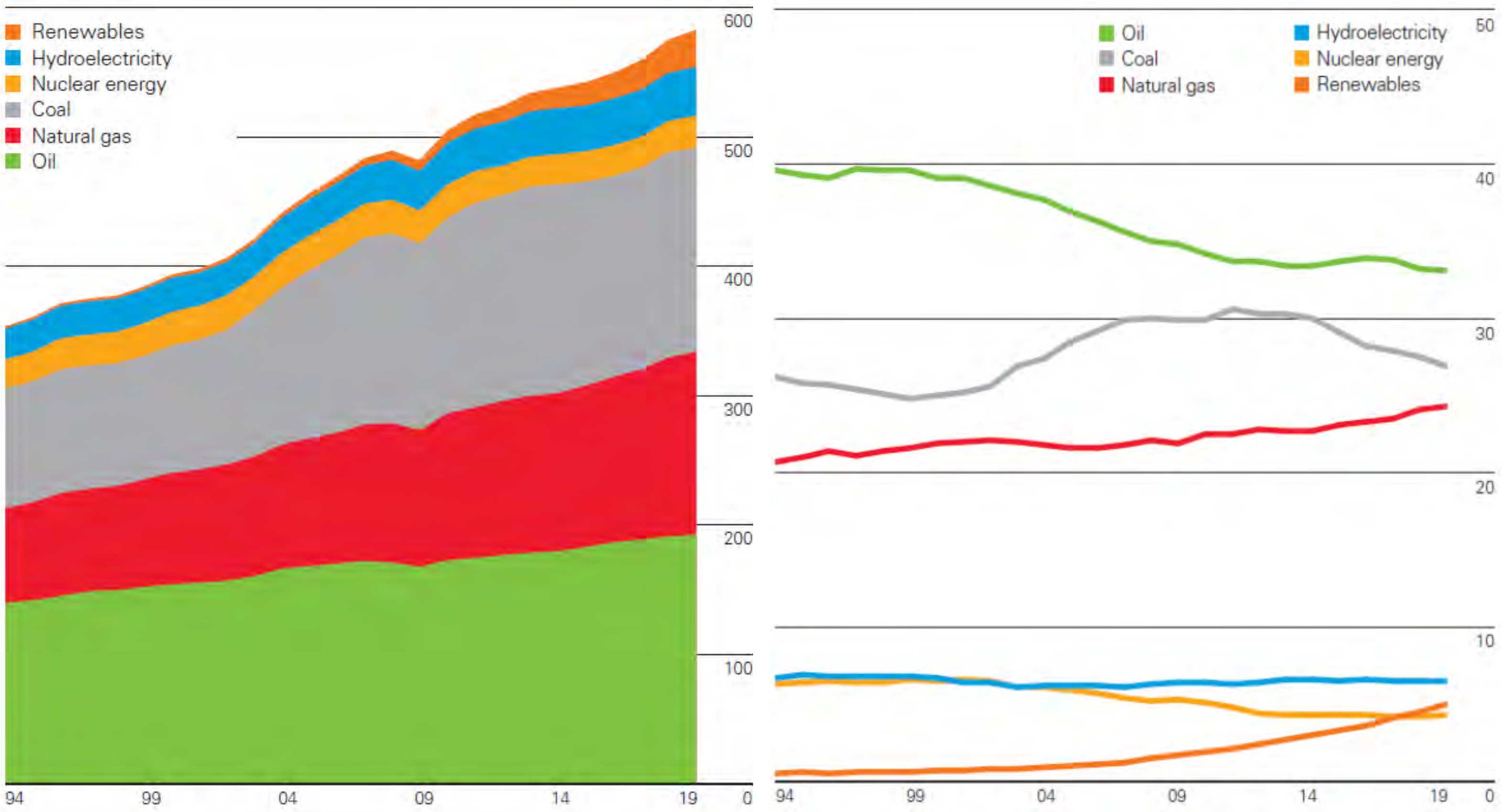


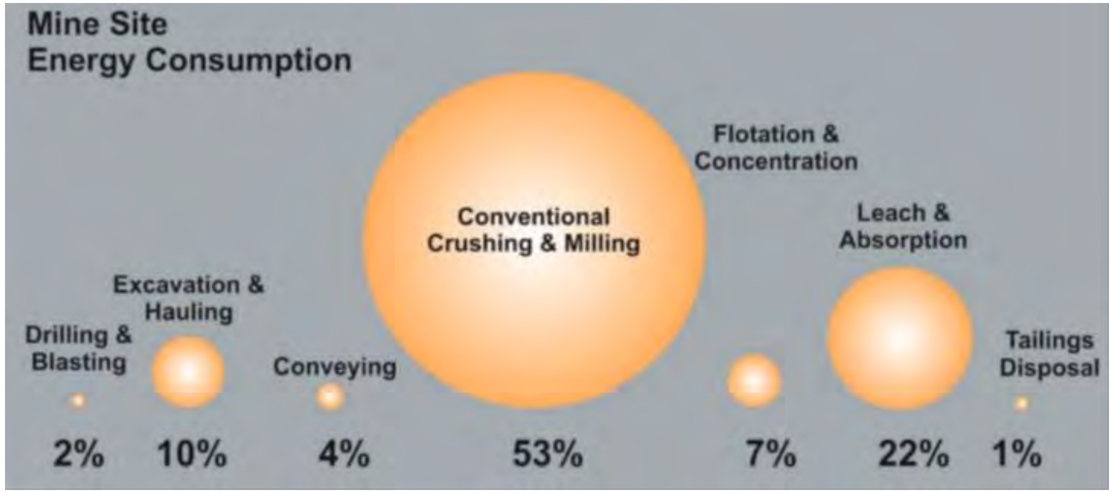
Fig.1- World energy consumption (left) and global primary energy share (right): 1994-2019

Mining Industry – Energy and Carbon Emission

- ✓ ***World's Energy Consumption is ~ 584*10^{18} Joules (1.62*10^{14} kWh), i.e., increasing rate of 1.6% (last 10 years)***
- ✓ ***By 2050, the consumption will reach 2.6*10^{14} – 3.0*10^{14} kWh***

Mining Energy Consumption Share is 6-7%:
*e.g., 9.7 – 11,3 * 10^{12} kWh*

- ➢ *Responsible for 4-7% Carbon Emission :*
  (1% by Energy and 3-6% by Fugitive CH_4)
  (~ 28% Emission is by Coal Combustion)
- ➢ *There are indirect energy consumption adding embodied energy in media production (6-7 MWh/t), with media consumption of 0.5-1 kg/t*
- ➢ *Wear, an important part which consumes almost 40% of total energy used in mining*



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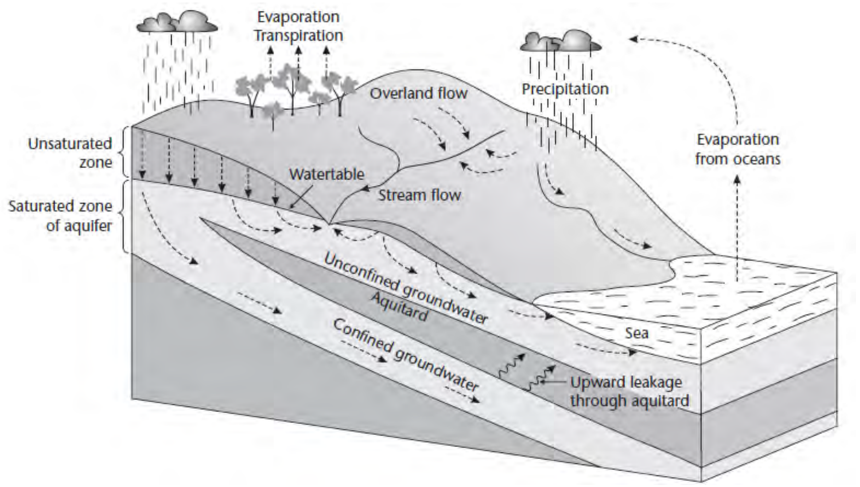
Earth (Water and Energy)

✓ *Hydrosphere consists of water (ocean 69%, fresh surface water, rain, under ground, ice, and atmospheric vapor)- average depth of oceans 3800 m, the ocean total water*

$$4\pi r^2 h = 4\pi(6.375x10^3)^2 x3,8 = 1.34x10^9\ km^3$$



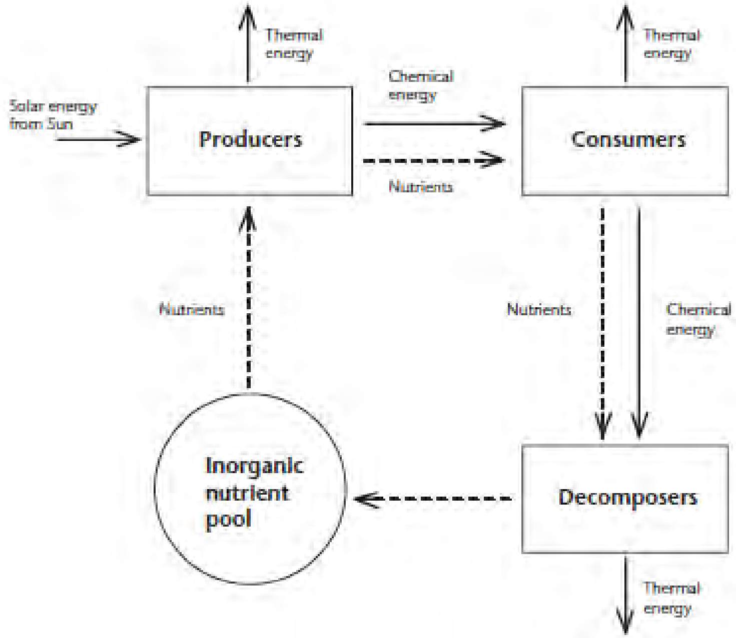
Water Cycle

✓ *Energy captured from the Sun estimated: 1366 Wm^{-2} per annum (measured at the outer edge of atmosphere in a plan perpendicular to the radiation - Mizutani, 1995) and the total quantity of energy is*

$$E = \pi r^2 x1366\ Wm^{-2} = \pi(6375)^2 x1366 = 1.77x10^{17}\ W$$

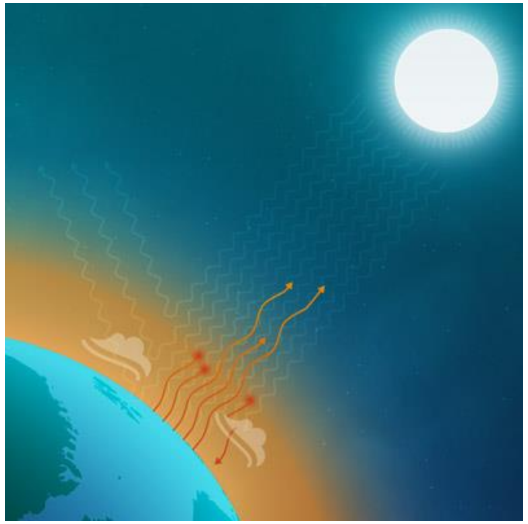
✓ *About 70% of the Sun's energy is absorbed by the Earth*

$$E_{aborbed} = 70\% * 1366\ Wm^{-2}$$



Energy and nutrient flows in the biosphere

Earth Energy and Temperature



- ✓ *Black bodies are capable to absorb and/or emit electromagnetic radiation (Stefan-Boltzmann law : J, radiation or flux emitted by the body Wm^{-2}, T temperature in Kelvin σ is $5.67x10^{-8}$ $Wm^{-2}K^{-4}$)*

$$J=\sigma T^4$$

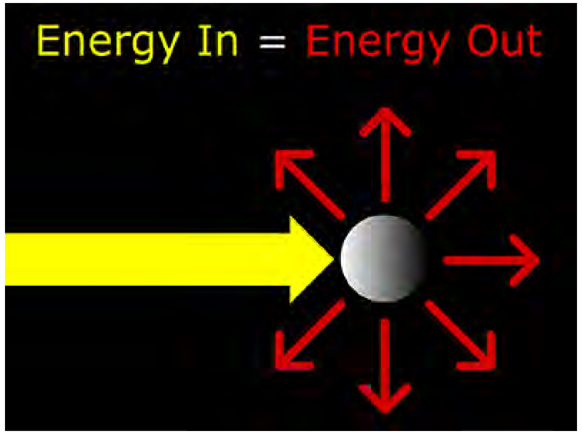
$$E_{emitted} = \sigma T^4 * 4\pi r^2 J$$

In Perfect situation:

$$E_{emitted} = E_{absorbed} ,$$

$$1366*70\% * \pi r^2 = \sigma T^4 * 4 \pi r^2$$

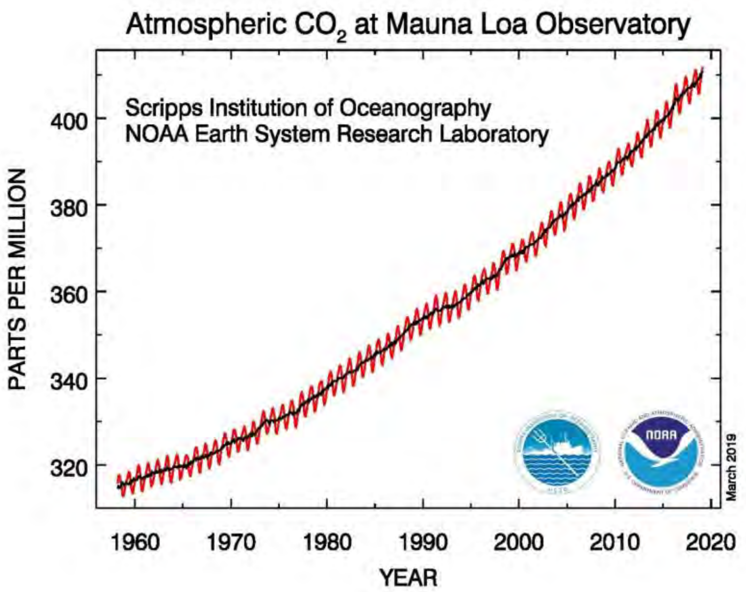
$$T = \sqrt[4]{\frac{1366*70\%}{4*5,670*10^{-8}}} \approx 254 \text{ Kelvin (i.e., about -19°C)}$$

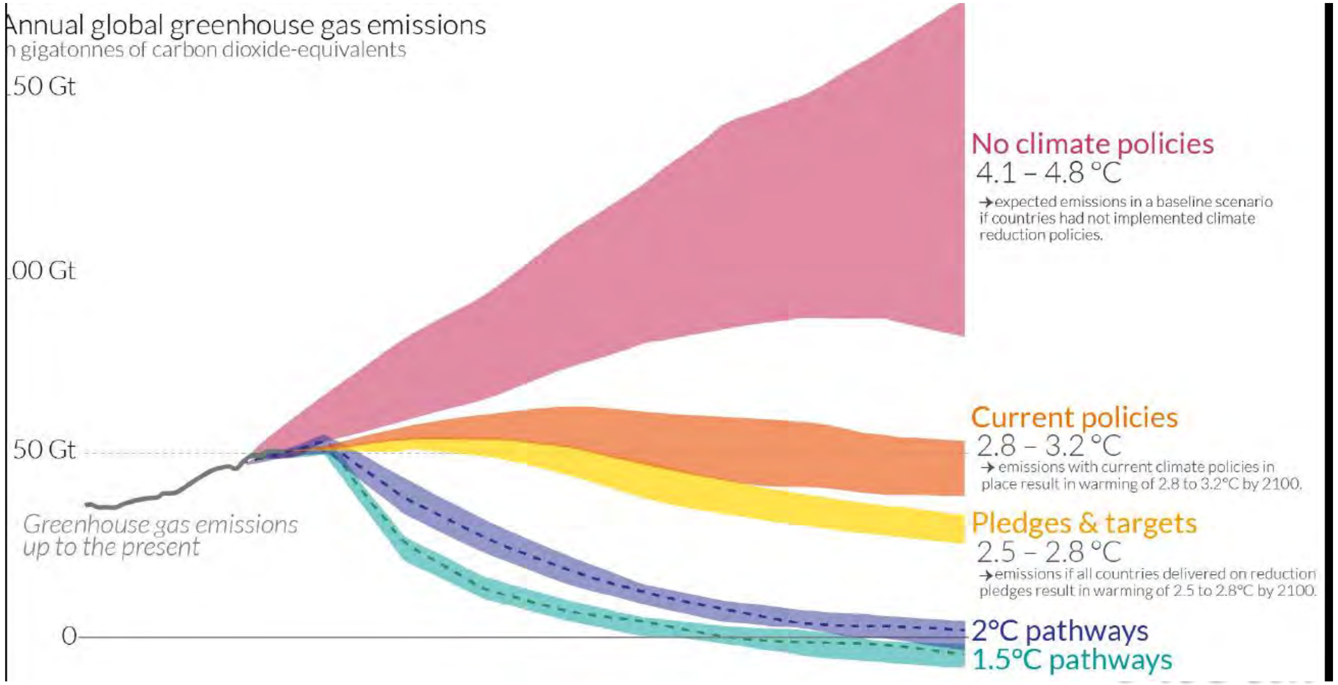


- ✓ *However, the Earth's actual average temperature is about 15°C*
- ✓ *The Earth's temperature is higher than calculated value because of "Green-House Effect"*
- ✓ *Gases like CO_2, H_2O, CH_4, and N_2, etc., have strong absorption capability, therefore, absorb energy and re-radiate the energy in all direction to cause increasing the Earth's temperature by more than 30°C*

GHG Emission and Global Warming

- ✓ GHG emissions have grown exponentially, reaching the value of 413.95 ppm in December 2020.
- ✓ IPCC's/Paris Agreement goal is to limit the global warming < 1.5°C - 2 °C to avoid the most serious climate consequences.
- ✓ To achieve the goal, about 10 billion tons of CO_2 per year must be sequestrated by mid-century, and roughly twice of that amount each year by 2100.
- ✓ The goal can be achieved in part by making different strategies including:
  - *renewable energy,*
  - *energy efficiency programs,*
  - *capturing and sequestering,*
  - *etc.*
- ✓

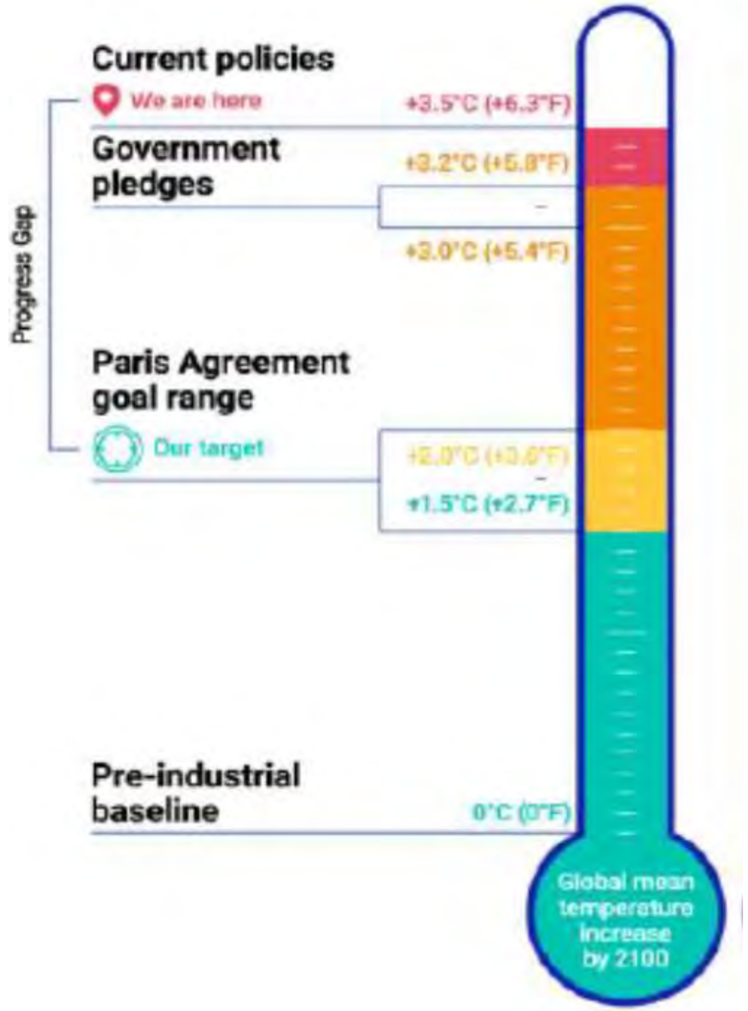




GHG Emission and Global Warming (Consequences)

Paris Agreement goal is to limit the global warming < 1.5°C - 2 °C by 2030 to avoid the most serious climate consequences, if not consequences will be:

- ✓ Low-lying areas become uninhabitable
- ✓ Increasing species extinction
- ✓ Food and water become more scarce
- ✓ Increasing mortality rates (possible additional deaths of 250.000/yr between 2030-2050)
- ✓ Equatorial regions becomes uninhabitable
- ✓ Increasing "Economic Losses" (e.g., 2% of US GDP, $400B, could be lost at temperature increasing by 4 °C) .



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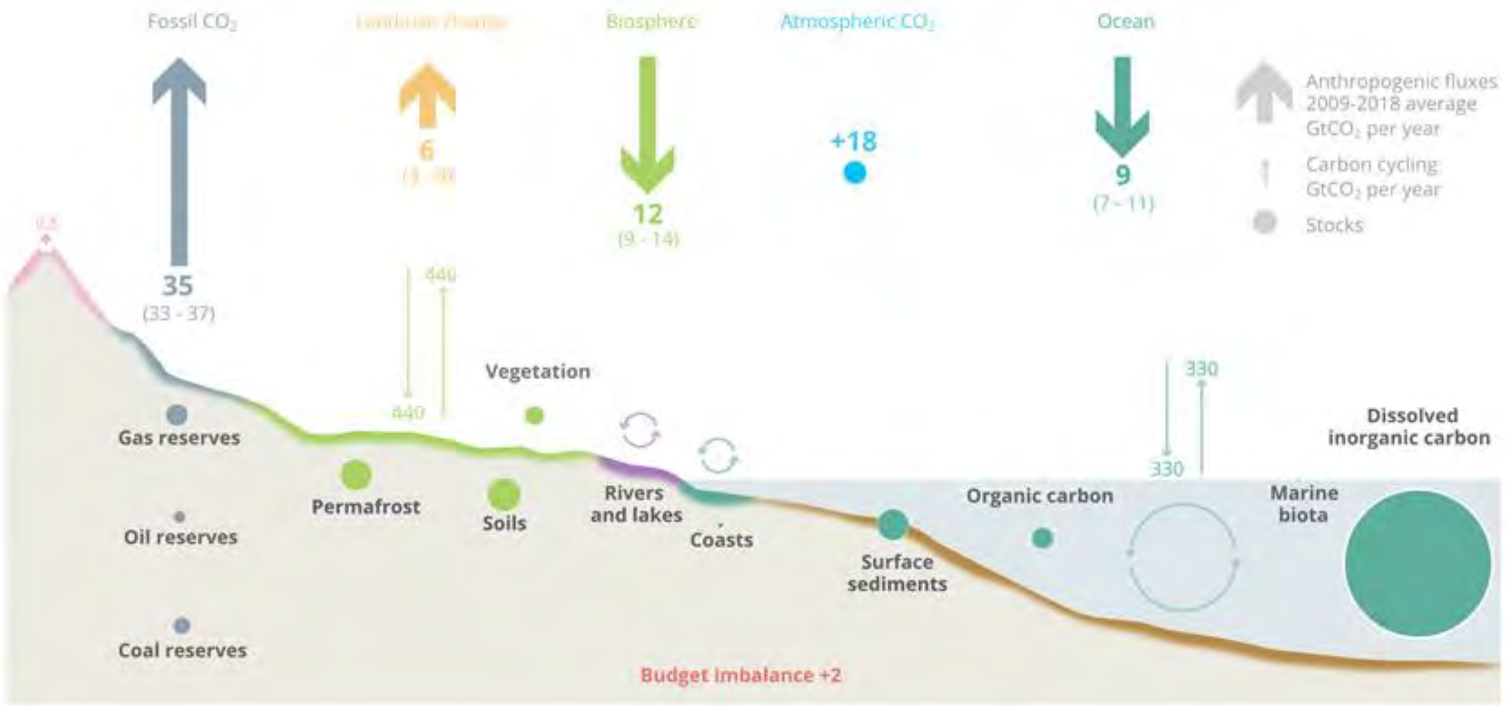
World's GHG Emission

- ✓ ***The total carbon emission has reached 55.3 $GtCO_2e$***
- ✓ ***Carbon emission by energy consumption would be about 37.5 $GtCO_2e$***
- ✓ ***GHG emissions causing global warming which must be reduced***



The global carbon cycle ($GtCO_2$/annum) caused by anthropogenic activities, averaged globally for a decade 2009–2018 (Global Carbon Budget, 2019)

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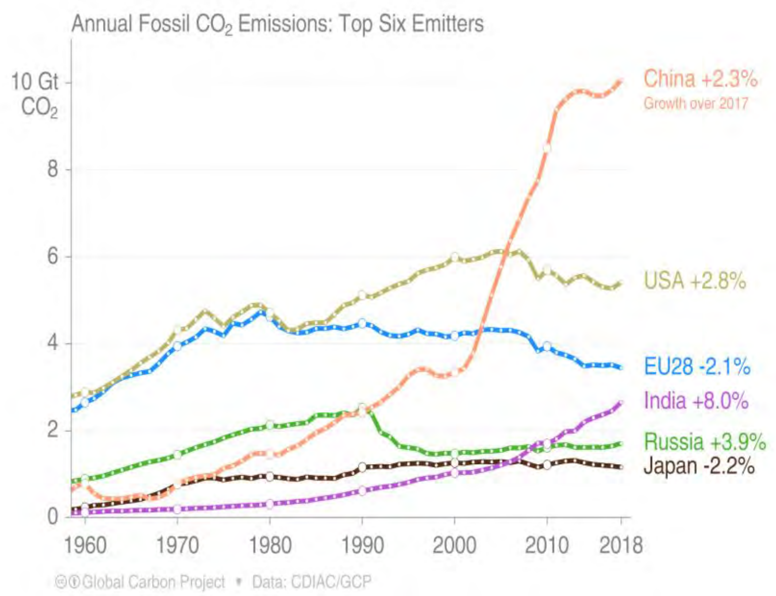
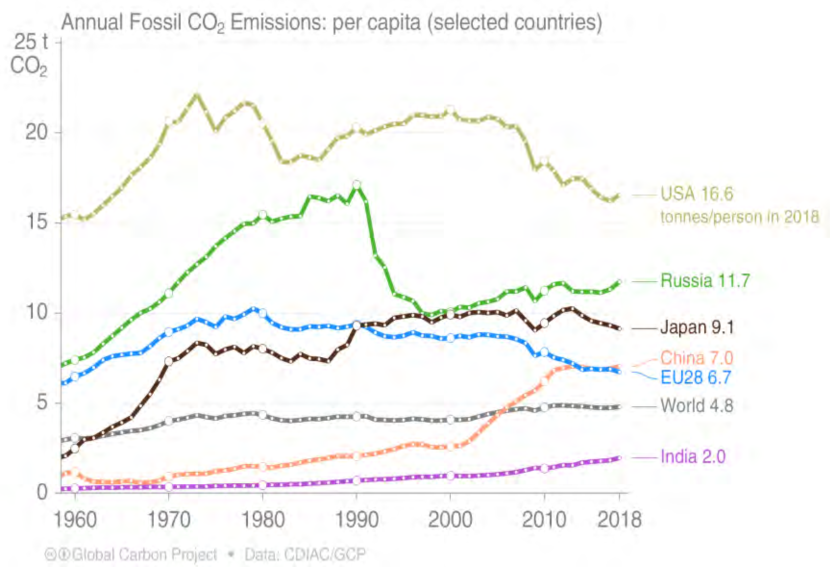
World’s GHG Emission

- ✓ According to Paris Agreement (2015), the global warming must be set at well below 2.0°C, ideally not more than 1.5°C.
- ✓ The world’s emission in 2030 needs to be lowered at least by 25% of its value in 2018
- ✓ Global warming causing water stress affecting all activities, including mining industry





Annual GHG emissions by top six emitters (left) and annual emission per capita for the six emitters in comparison to total world (right) (Global Carbon Budget, 2019)

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Mining Industry – Global Warming Risks

✓ ***Vulnerability of Mining Industry to Water Stress:***

- *Nowadays, 30% to 50% of the mining activities producing Cu, Au, Fe and Zn ores/resources are located in the areas with high water risk (in 2017, these mining sites, accounted for roughly $150 billion in total annual revenues).*
- *Considering the current trends in global warming, the situation will be worsened and more mines will be under water stress, particularly in Australia, South Africa and South America.*

✓ ***Operational Disruption and Other Issues:*** *Harsh climate changes would also cause mine closure, washed-out roads, and unsafe water levels in tailing dams, etc.,*

- *Extreme weather can damage processing or transportation infrastructures*
- *Extreme heat in already hot places can decrease productivity and raise cooling costs and put the workers' health and their lives at risk.*
- *Affects the political and socio-economic environment around the mine.*

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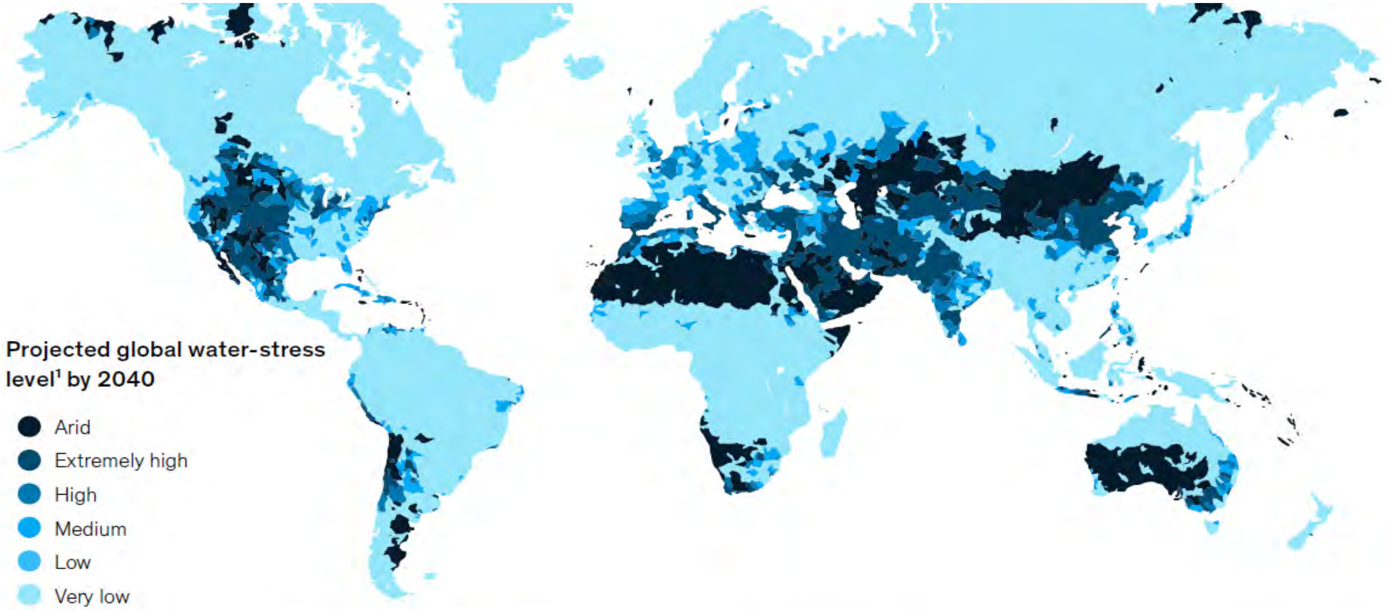
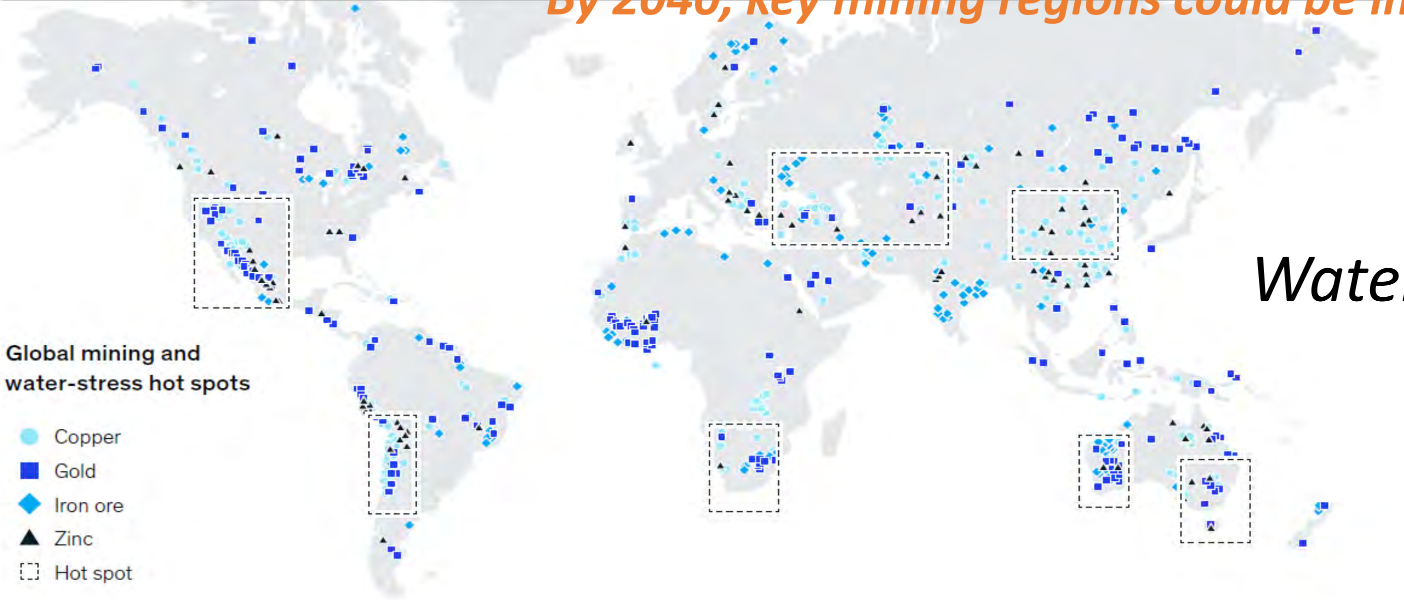
Mining Industry and Sustainability – CO_2 Capturing



- ***Increasing Carbon Foot-Print and Global Warming Result:***
  - *Flooding*
  - *Water Stress*
  - *Decreasing Productivity*
  - *Rising Colling Cost*
  - *Socioeconomic & Political Consequences*

By 2040, key mining regions could be increasingly vulnerable to wáter stress



Water stress affecting metal mining areas

Mining Industry Strategies to Reduce CO2

- ***Carbon Foot-Print and Carbon Capturing:***
  - ***Mining is responsible for 4-7% of GHG emission (~ 1550 t CO_2e /MUS$ Opex)***
  - ***Target by 2030 reducing CO2 emission by 30%***
- ***Strategies for Reducing Carbon Footprint***
  - ***Moving towards renewables (Green Minerals/Metals)***
  - ***Moving towards energy efficient processes***
  - ***Moving towards grade engineering and dry processes***
  - ***Recycling***
  - ***Carbon capturing strategies***

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Moving Towards Renewables (Shifting Demands)

- *Global warming increased by > 1°C since preindustrial level*
- *Sea level has risen by 25 cm*
- *~ 7 million people die every year because of air pollution*

- *According to Paris Agreement the goal is to:*
  - ✓ *Reducing annual global warming to 1.5°C or even 1°C by minimizing CO_2e emission*
  - ✓ *By 2030 CO_2e emission must be reduced to 45% below its 2010 level and must be zero by 2050*
  - ✓ *Accordingly, a radical change in energy generation and its transportation, as well as pulling Gt of CO_2 from atmosphere*

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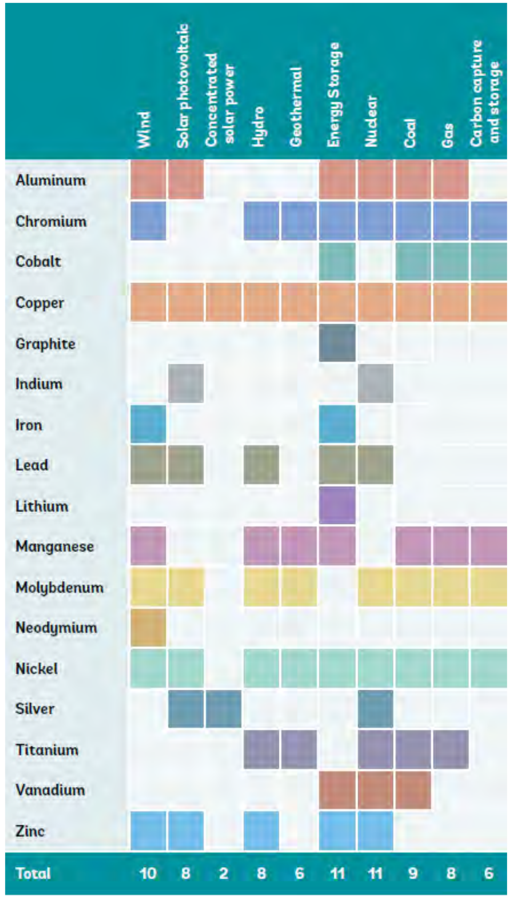
Mining Industry Strategies to Reduce CO_2

- *By moving towards the renewables, the need for metals/minerals will be increased significantly, accordingly:*
  - *Attempts must be made to limit the emission from extraction of the mining and processing of the* ***"Green Minerals/Metals"*** *which is a win-win scenario.*



Minerals/Metals needed for Low Carbon Energy Generating Technologies (except REEs)

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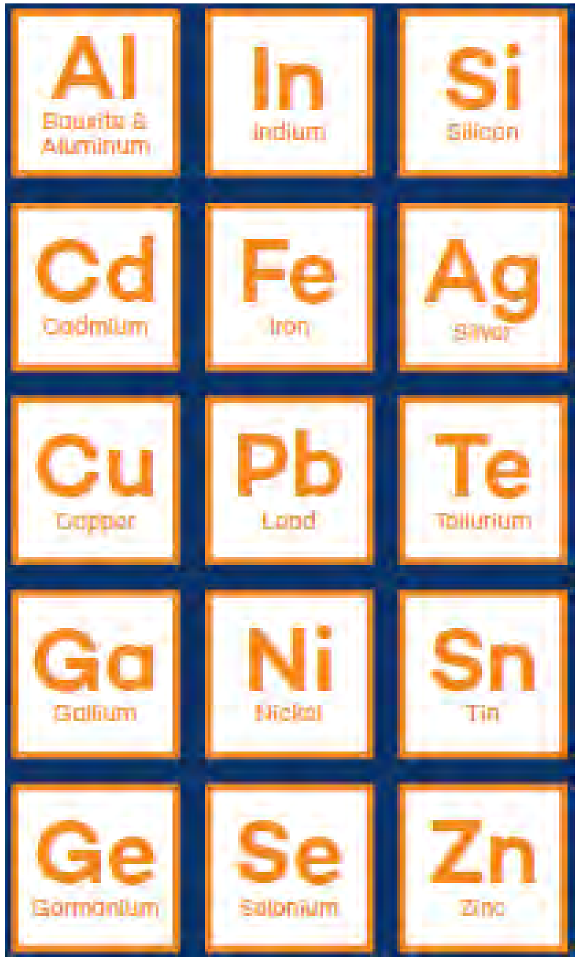
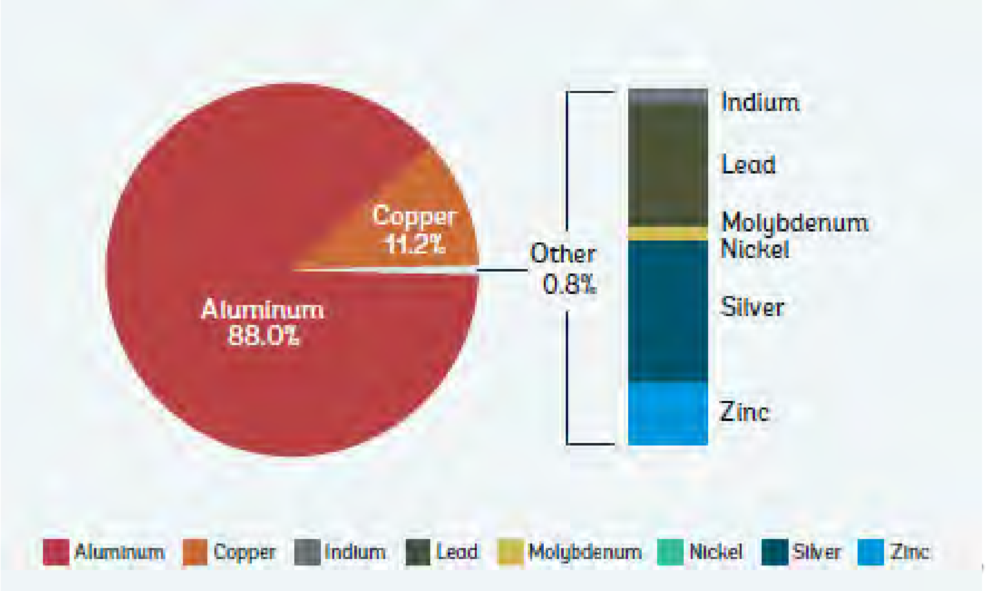
Moving Towards Renewables (Shifting Demands)

➢ *Minerals/Metals for PV Solar Energy Technology*



➢ *Interstingly Al is the major metal/mineral for the technology*

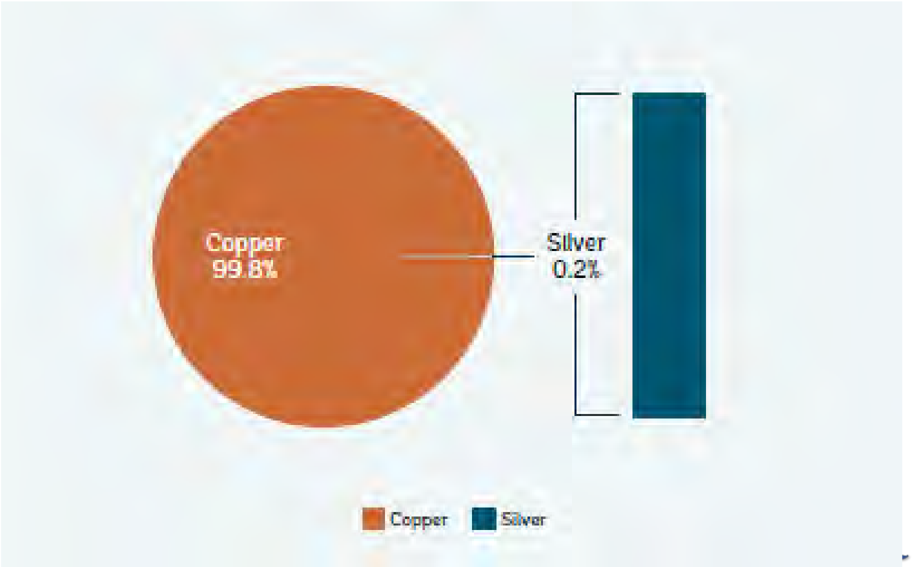
➢ *Copper is the second*



Moving Towards Renewables (Shifting Demands)

- *Minerals/Metals for Concentrated Solar Power (CSP)*

  - *Technology make use of mirrors to heat wáter and drive steam turbines*
  - *Main advantages for the technology is that it can be equipped with molten salts to store the heat, which can be used when the sun rises*
  - *It has higher cost in comparison to Solar PV and has geographic constraints*
  - *Herein Copper is dominant*



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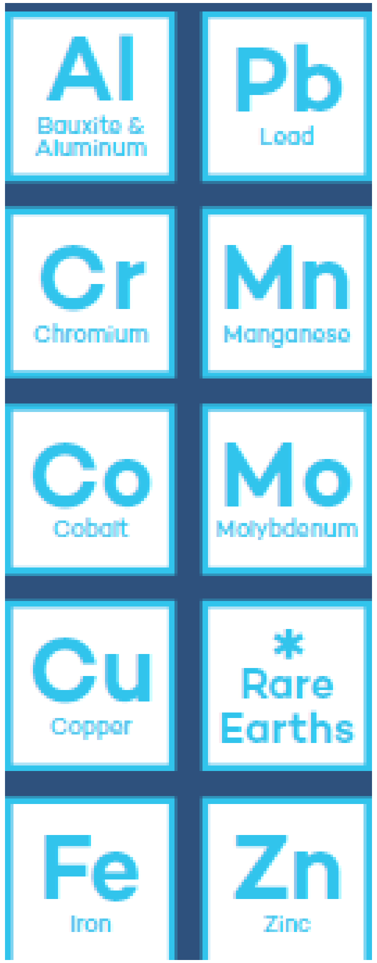
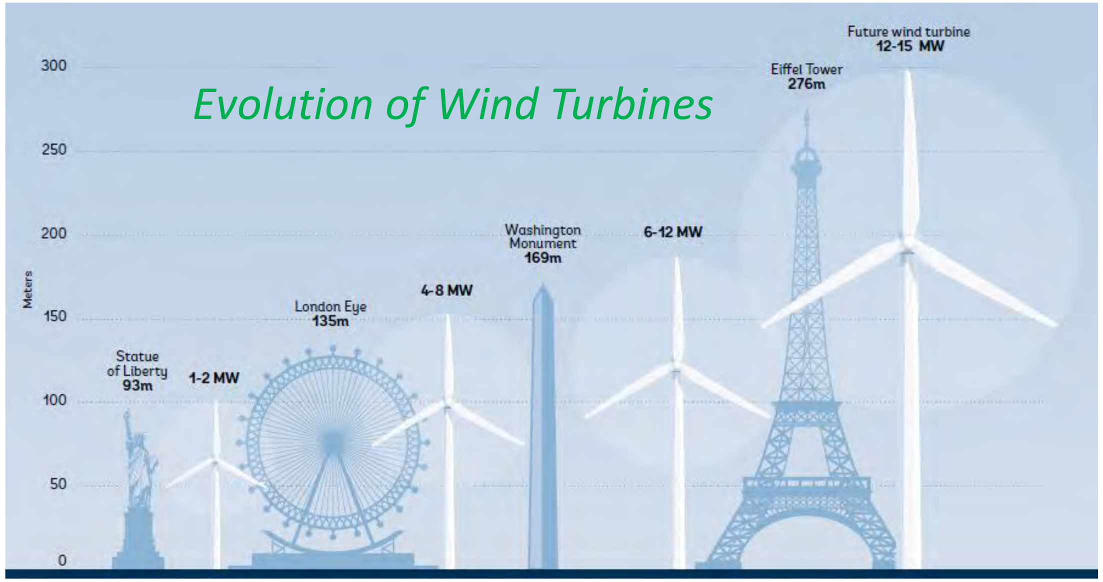
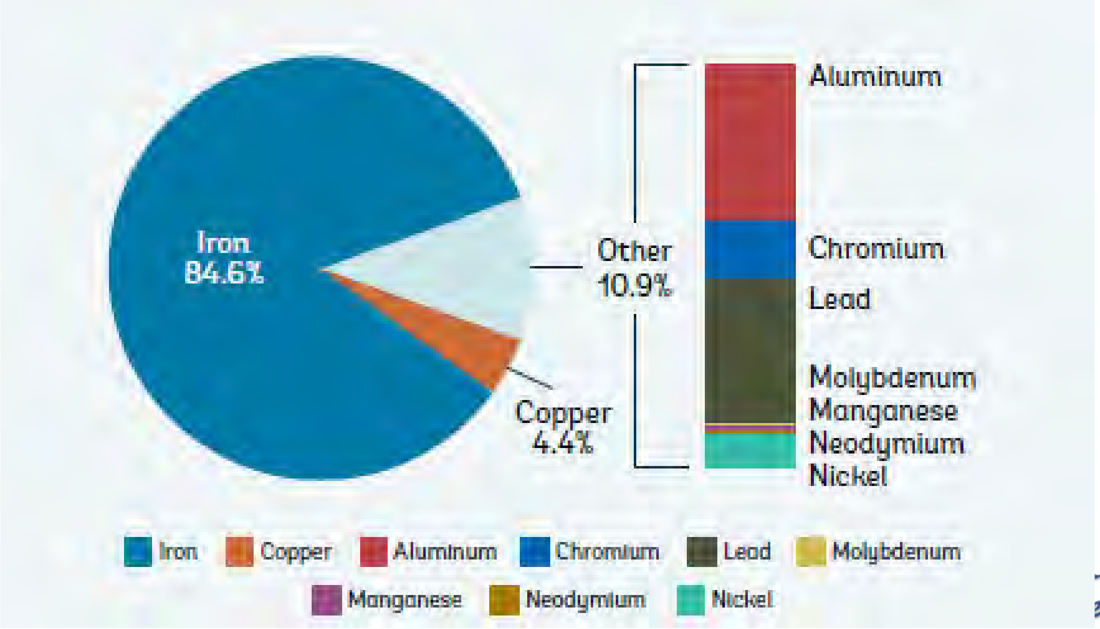
Moving Towards Renewables (Shifting Demands)

➢ *Minerals/Metals for Wind Technology*



- ➢ *Surprisingly, Iron is the major metal/mineral used for the technology*
- ➢ *Copper is the second*





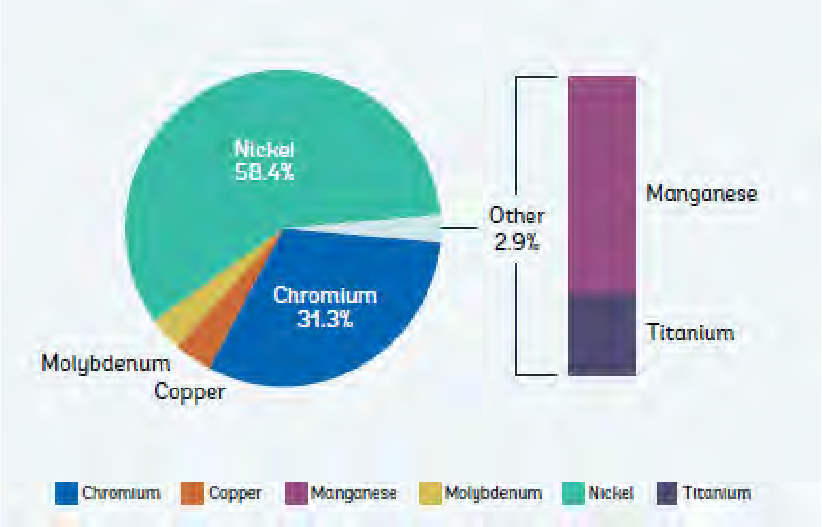
Moving Towards Renewables (Shifting Demands)

- *Minerals/Metals for GeoThermal Technology*

  - *Generation of energy from thermal energy located below the Earth's Surface, in liquid, trapped stream, or rocks*

  - *Needs for high level resistance alloys, the use of steel per MW capacity is 6-10 times as much as wind technology*

  - *Ni is the main metal used followed with Cr, Cu and Mo*



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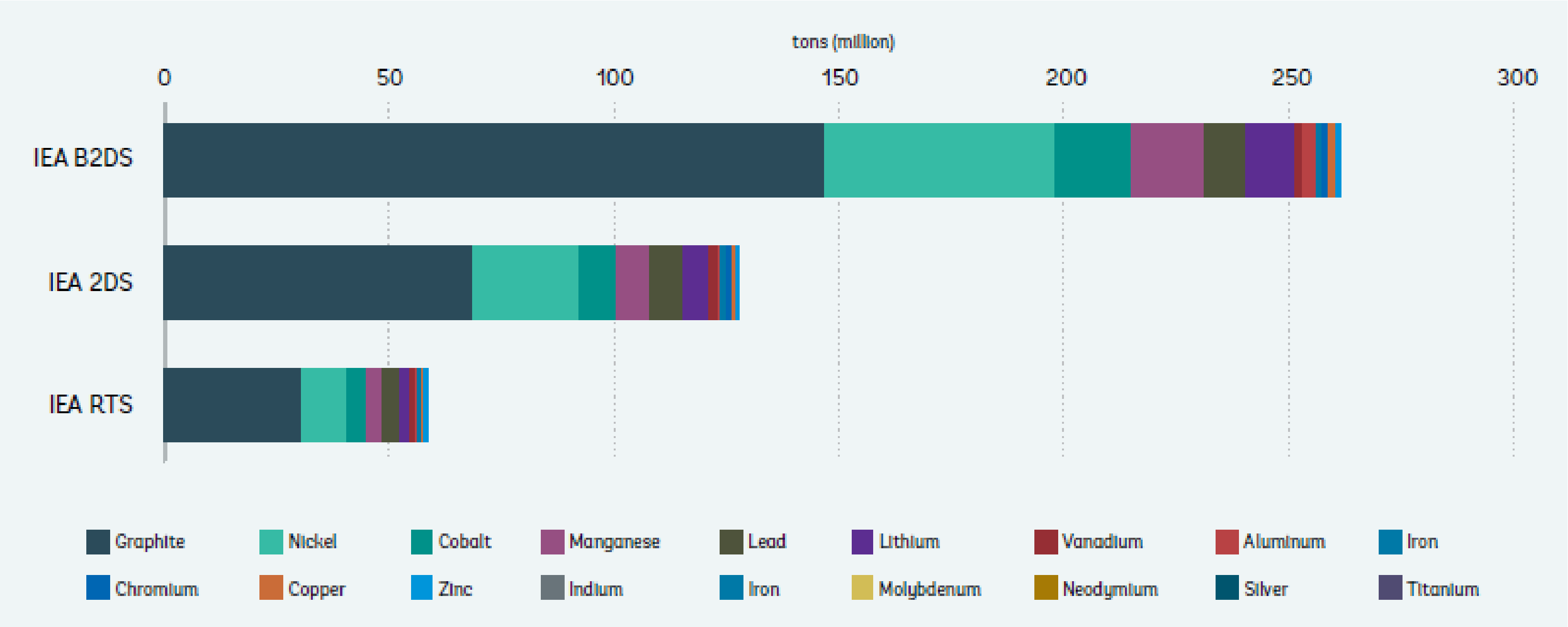
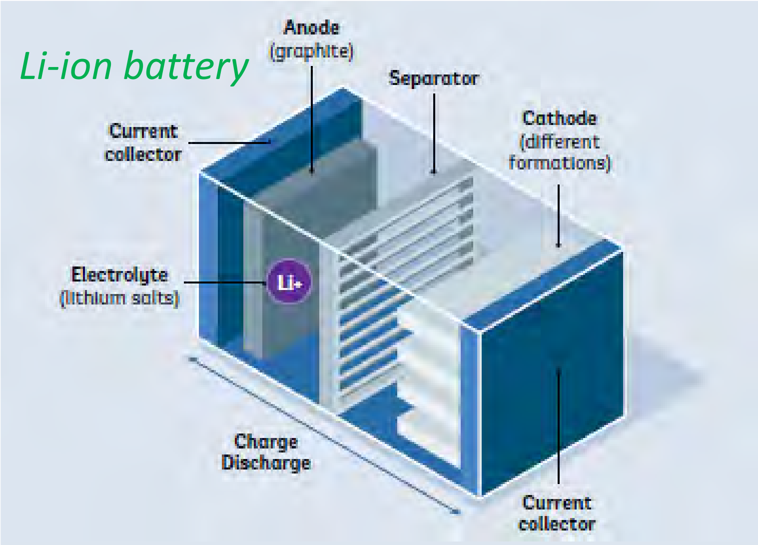
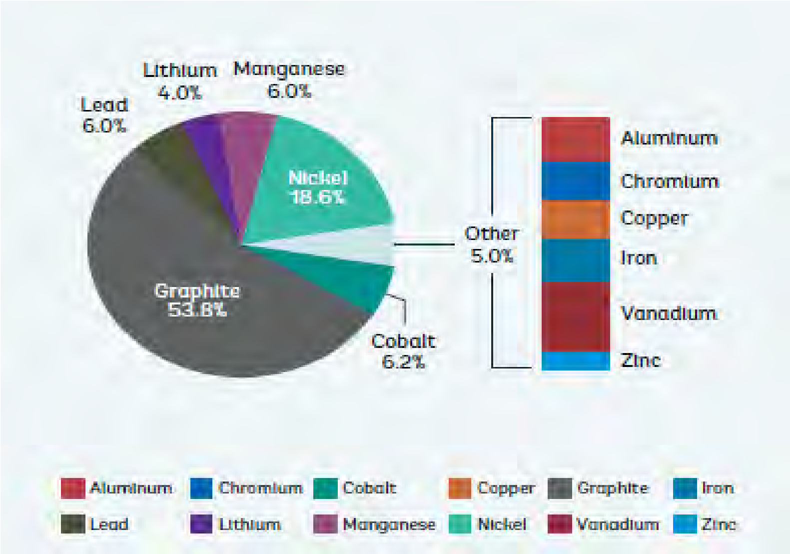
Moving Towards Renewables (Shifting Demands)

- *Minerals/Metals for Energy Storage Technologies*
  - *Graphite, Ni, Co, Pb, Mn, and Li are the main Metals/Minerals*



Li-ion battery





Mineral Demand for Energy Storage 2050

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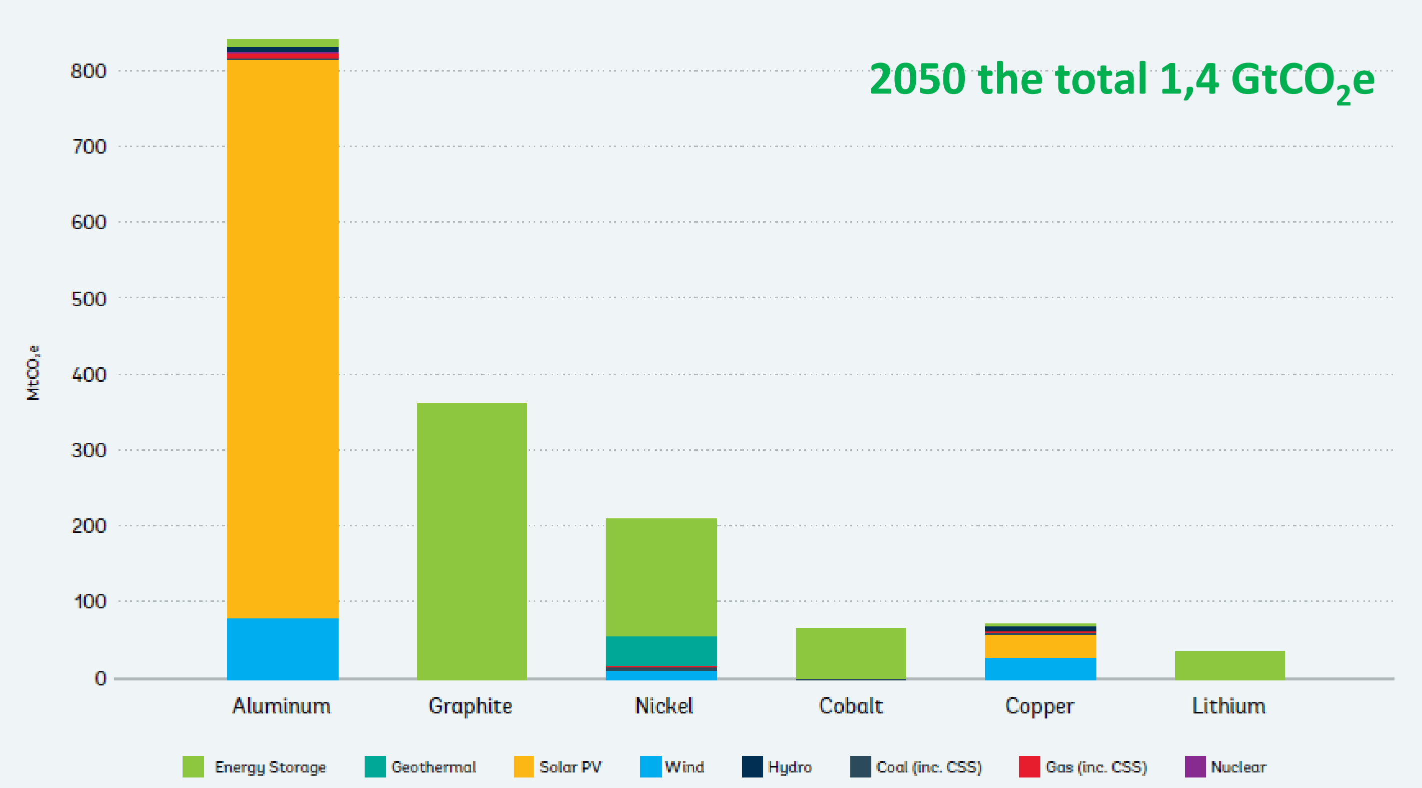
Mining Industry Strategies to Reduce CO2

- *The most effective way of decarbonization is to move towards renewables, howevere, under Paris Agreement there is a need to address the "Mineral Intensity" of clean technologies:*
  - *Emission from new technologies is just 6% of coal gas generation under 2DS: (it will be 16 Gt CO_2e by 2050, which is equal to USA and China emission by 2018)*



Prediction of 2050 "Global Warming" potential emission by extracting and processing of minerals under 2 degee standard 2DS (not including operations)

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Moving Towards Renewables (Shifting Demands)

- *There are other technologies to be developed further for implementation*
  - *Carbon Capture and Storage (CSS) – an expensive option, depends on “Carbon Tax”*
  - *Next Generation of Batteries*
    - *Solid-State Batteries (Replacing liquid electrolyte with solid alternative like polymer or ceramic – replacing graphite anode with lithium mineral anode to increase storage potential), creating greater storage, faster charging, improved safety, reducing fire risk*
    - *Zinc-Air Batteries (high specific energy density, safe, environmentally friendly, simple and cheap)*
    - *Lithium-Air Batteries (higher energy density)*
  - *Floating Offshore Wind*
    - *Using similar minerals as wind turbines, however, the biggest difference is the length of transmisión cabling and Steel needs for structuring*
  - *Fuel Cells and Hydrogen*
    - *Proton Exchange memberancefuel cells*
    - *Solid oxides fuel cells*

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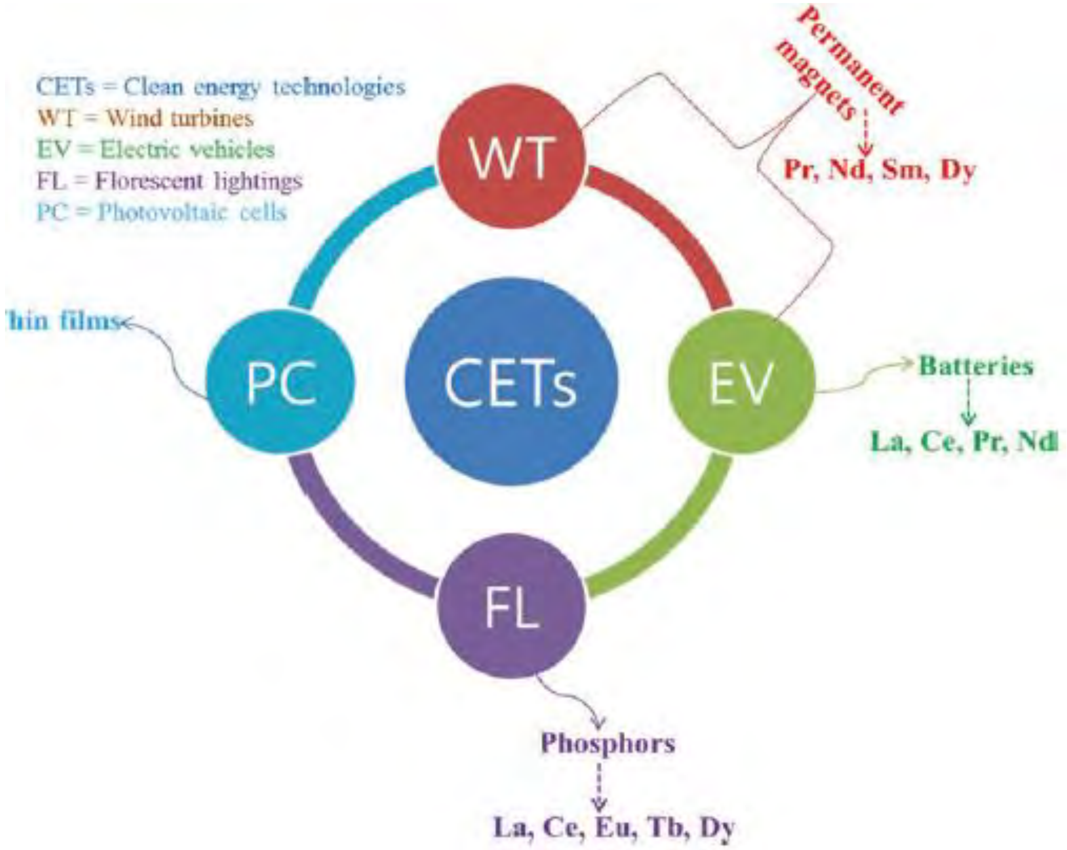
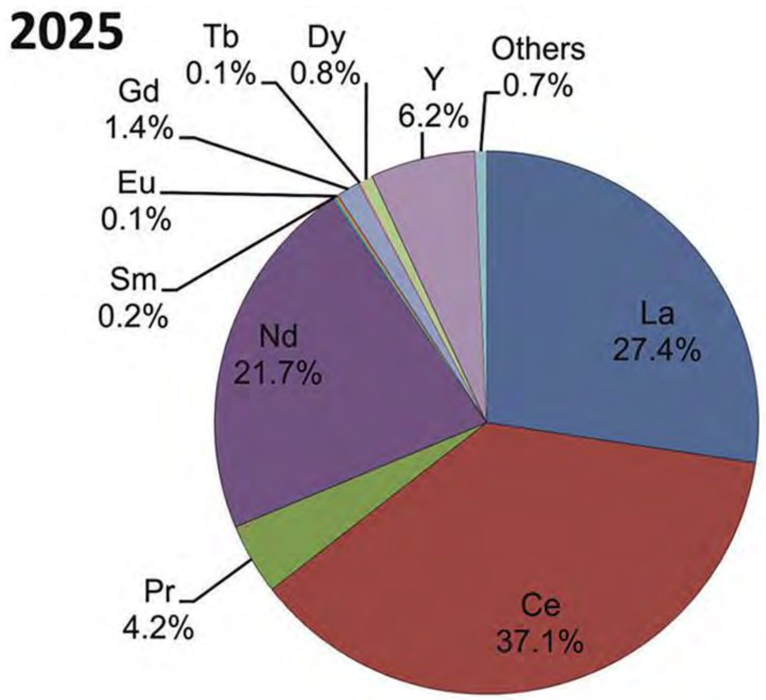
Mining Industry and Sustainability – Changing Paradigm

- *REEs for Green Energy Techologies*
  - ✓ *Neodymium and Dysporsium are vital:*
    - *Wind Turbines: Permanent magnets (200 kg/ MW - 31% Nd, 2-4% Dy)*
    - *Electric Vehicles: Permanente magnets (1 Kg magnet/ Vehicle 31% Nd, 4.5-6% Dy)*





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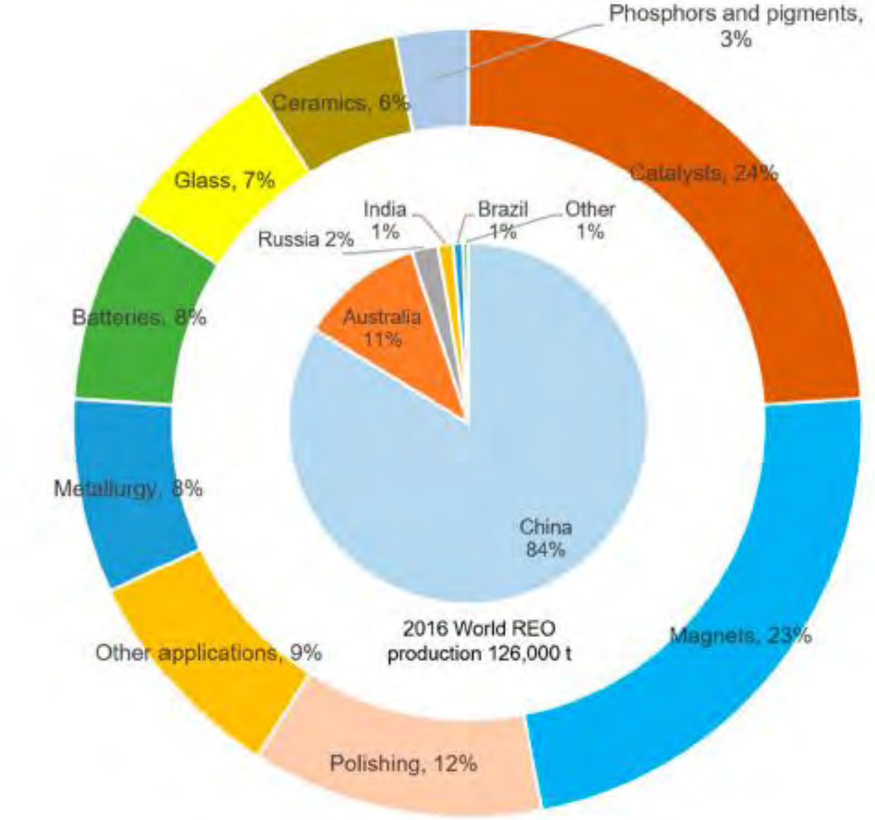
Mining Industry and Sustainability – Changing Paradigm

➢ *REEs for Green Energy Techologies*

- ✓ *Total World production of REOs: (~ 160000 t - about 25-30% for Clean Technologies)*
- ✓ *Poosible potential growth rate of 3-5%*
- ✓ *World's Resources REO: (~ 480 Mt)*



Application	La (kg)	Ce (kg)	Nd (kg)	Eu (kg)	Tb (kg)	Dy (kg)	Y (kg)
Wind turbines (/WM)			120			12	
Electric vehicles (/motor)			0.45			0.075	
Electric bicycles (/motor)			0.038			0.031	
NiMH battery (/battery)	0.61	0.86	0.255				
CFL (/bulb)	0.0000765	0.00018		0.0000405	0.000045		0.000558
LFL (/bulb)	0.000462	0.000137		0.0000945	0.000105		0.0013
LED (/bulb)				0.0000004			0.000005
Catalytic converter (/auto)		0.02					

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Mining Industry and Sustainability – Changing Paradigm

Demand for Green Metals/Minerals for Decarbonization Strategy

Element	World's Reserve (t)	Production (t)	Rating	Associated Technology
REE: Dy, Pr, Nd, Eu, Tb, Y	*		High	Vehicles, Wind + Lightning
Gallium		260	High	Lightning, Solar
Tellurium		470	High	Solar
Graphite	77000000	925000	Medium-High	Vehicle
Rhenium	2500	49	Medium-High	Fossil fuel
Hafnium		64	Medium-High	nuclear
Germanium		120	Medium-High	lightning
Platinum	63000	192	Medium-High	Fuel cells
Indium		640	Medium-High	Solar, Lightning, Nuclear
REE: La, Ce, Sm, Gd			Medium	Vehicle + Lightning
Selenium		2670	Low-Medium	Electrolytic Mn
Cobalt	7500000	98000	Medium	Vehicles, Fossil fuels
Tantalum	120000	790	Medium	Geothermal, Fossil fuels
Niobium	3000000	63000	Medium	Carbon Capture
Vanadium	14000000	60000	Medium	Carbon Capture
Tin	4800000	270000	Medium	Solar
Chromium	480000000	24000000	Medium	Desalination
Cadmium	640000	21500	low	Batteries
Lithium	13000000	34000	Low-Medium	Batteries
Molybdenum	10000000	250000	Low-Medium	Power generator
Nickel	80000000	1800000	Low	Batteries
Silver	530000	23800	Low-Medium	Solar

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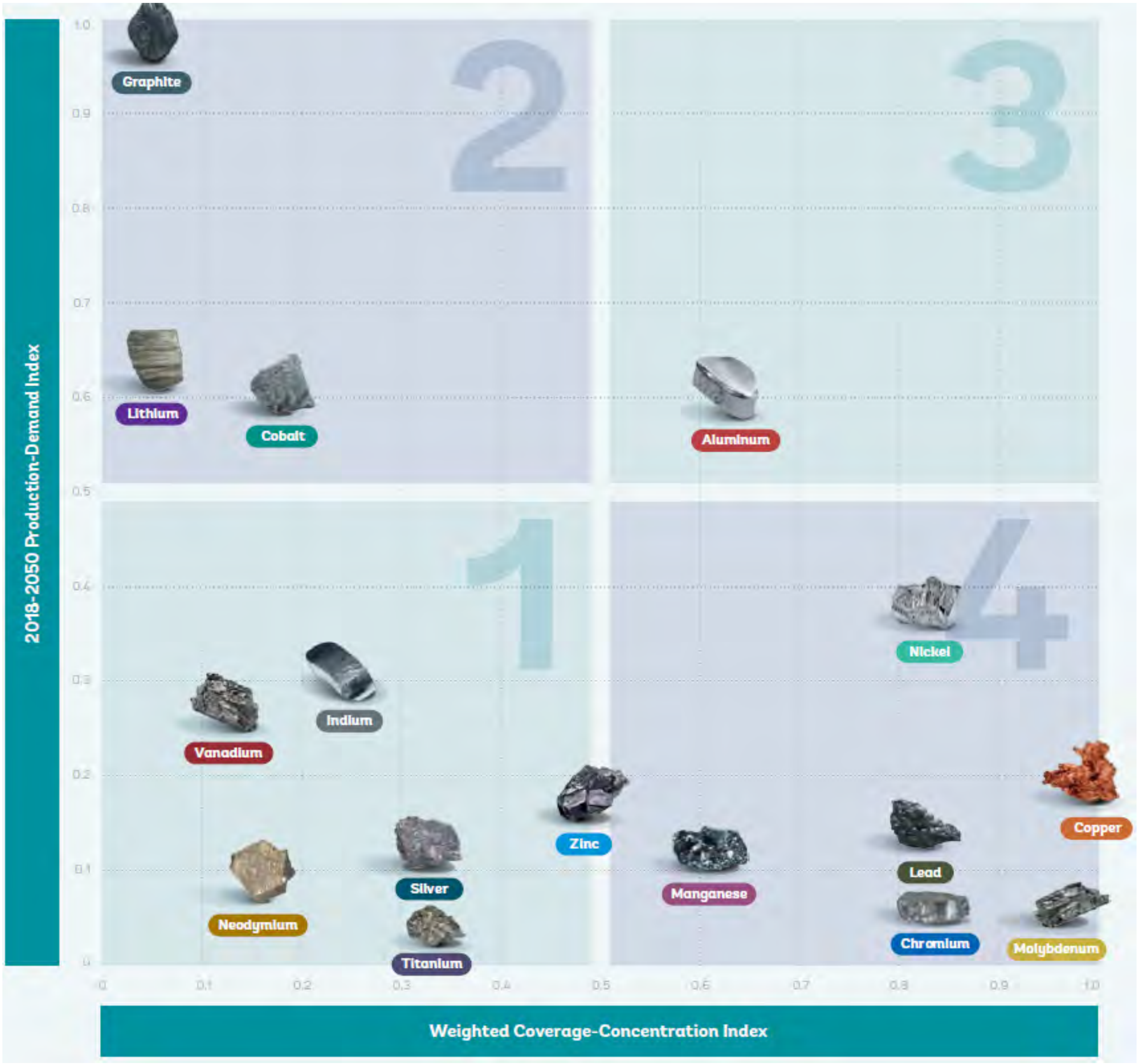
Mining Industry and Sustainability – Changing Paradigm

Impact of Minerals with Respect to the Technolgies



1- Medium Impact Minerals: featuring only small range of energy technologies and anticipated increases in demands are a small precentage of current demands

2- High Impact Minerals: featuring in small number of technogies but their level of future demands is much grater than current situation, changing technologies have big implications for overall levels of demand

3- High-Impact , Cross-Cutting Minerals: theses are critical in demand, however, their use is widspread across a varity of technologies

4- Cross-Cutting Minerals: Those have overall demand across different technolgies, however, the demand is not as dramatic as the minerals within groups 2 and 3,

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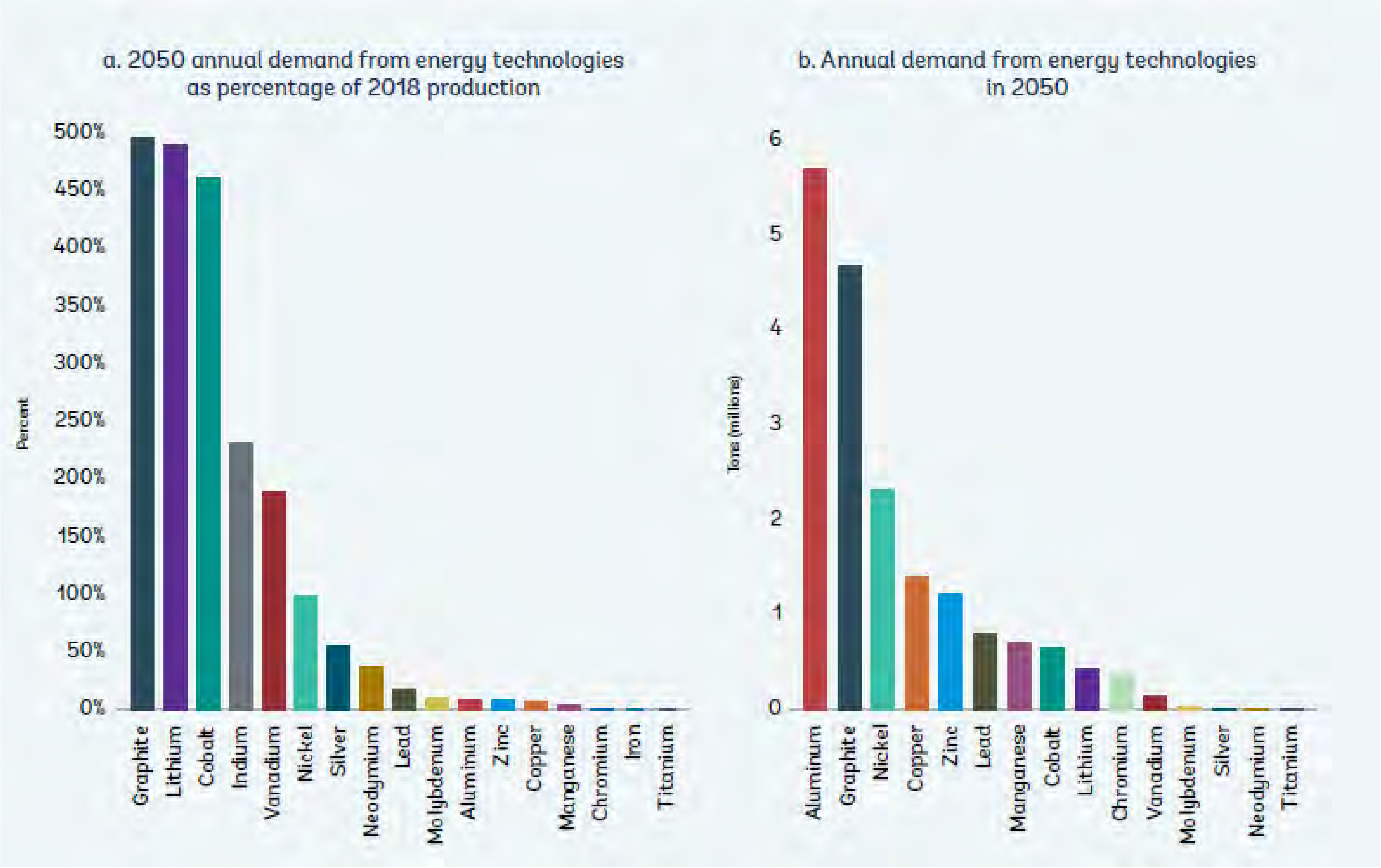
Mining Industry and Sustainability – Changing Paradigm

Needs for Metas/Minerals in 2050 (two different scenarios)



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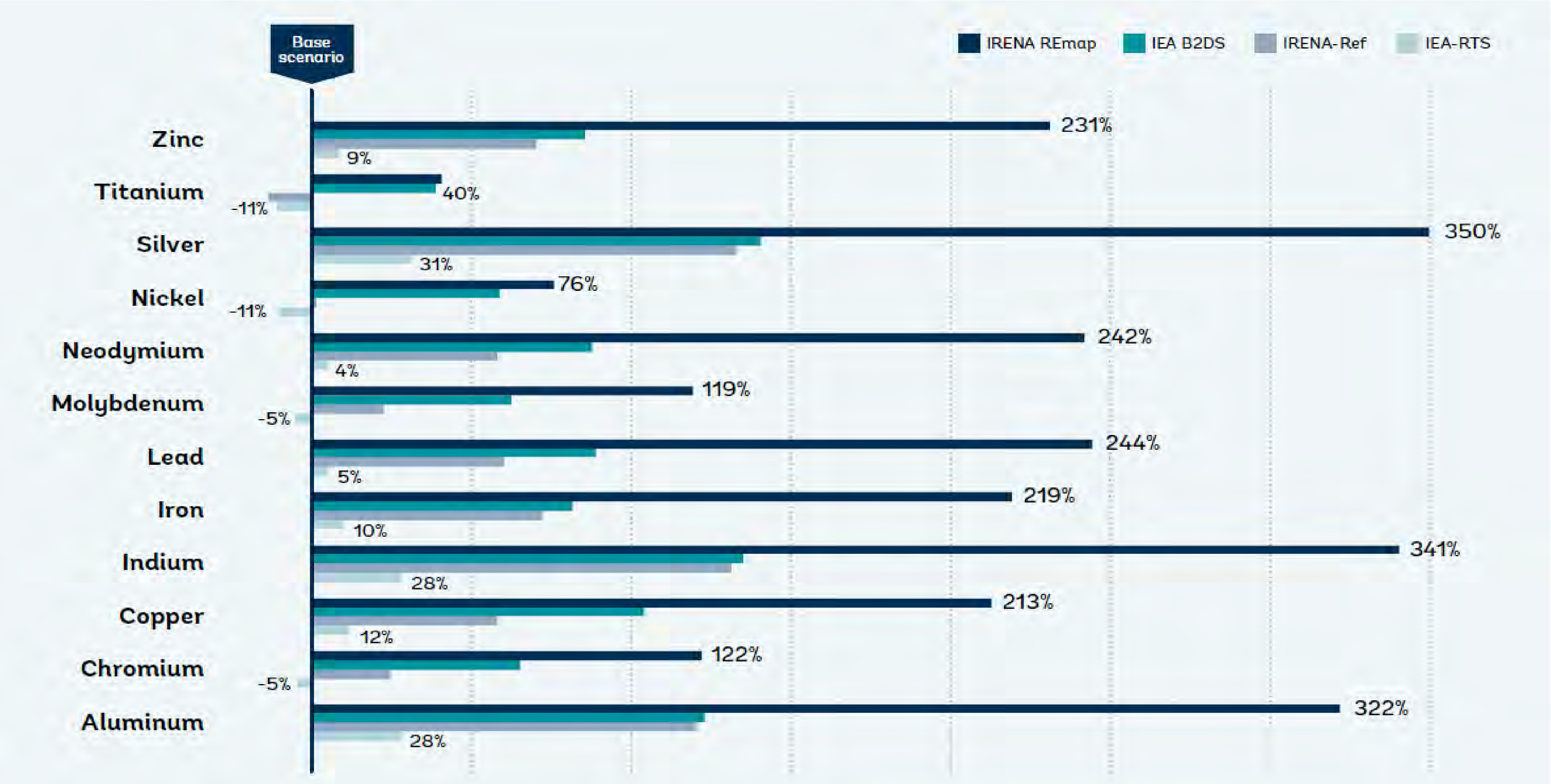
Mining Industry and Sustainability – Changing Paradigm

International renewable energy agency – renewable map (IRENA REmap)	Internatioal energy agency 2 degree base (IEA B2DS)	Internatioal renewable energy agency– Reference renewables (IRENA Red)	Internatioal energy agency – Reference technology (IEA-RTS)



Changing in needs for energy minerals for different scenarios by 2050

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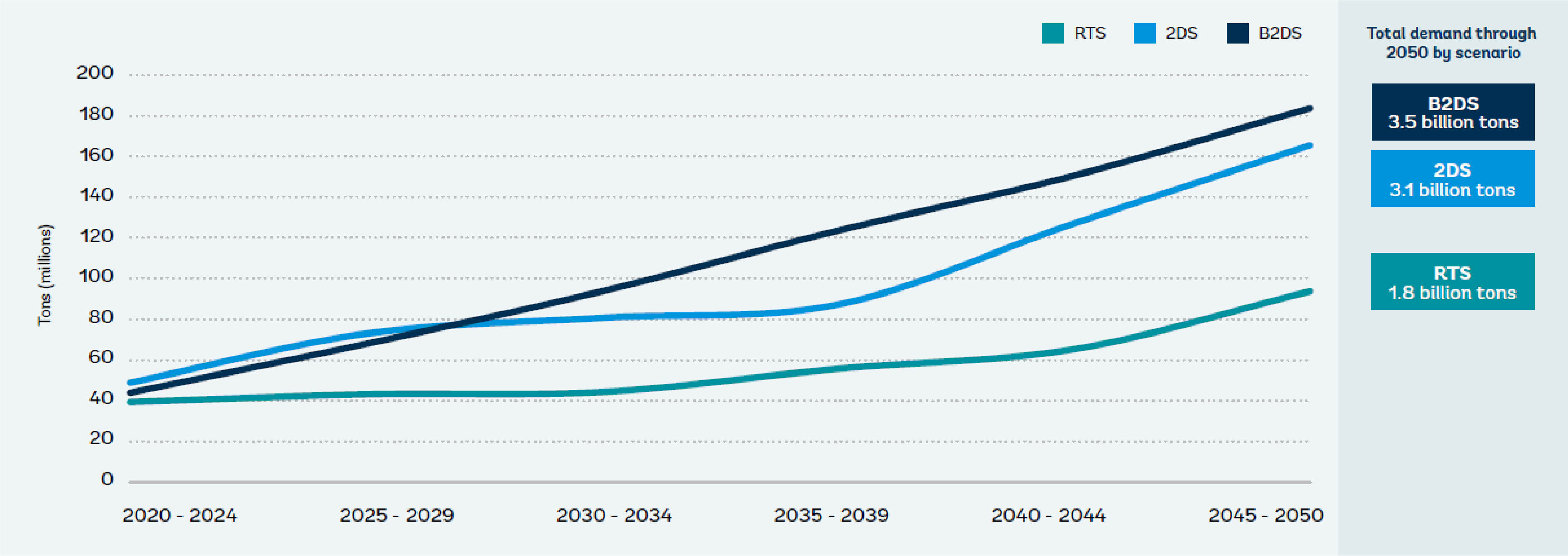
Mining Industry – Changing Paradigm

- ***Shifting Towards Demand for Key Energy Minerals:*** *Production to support renewable energy strategies will change the mining paradigm towards* ***Green Metals/Minerals*** *production*
  - ✓ *e.g., about 3,000 solar panels are needed for provide 1MW electricity by solar PV (a 200 MW solar PV project could be as big as 550 American football fields).*

Reference Technology Senario (RTS)	*2 Degree Senario(2DS)*	*Beyond 2 degree Senarion (B2DS)*



Future demand for minerals through different climate scenarios (Hund et al., 2020)

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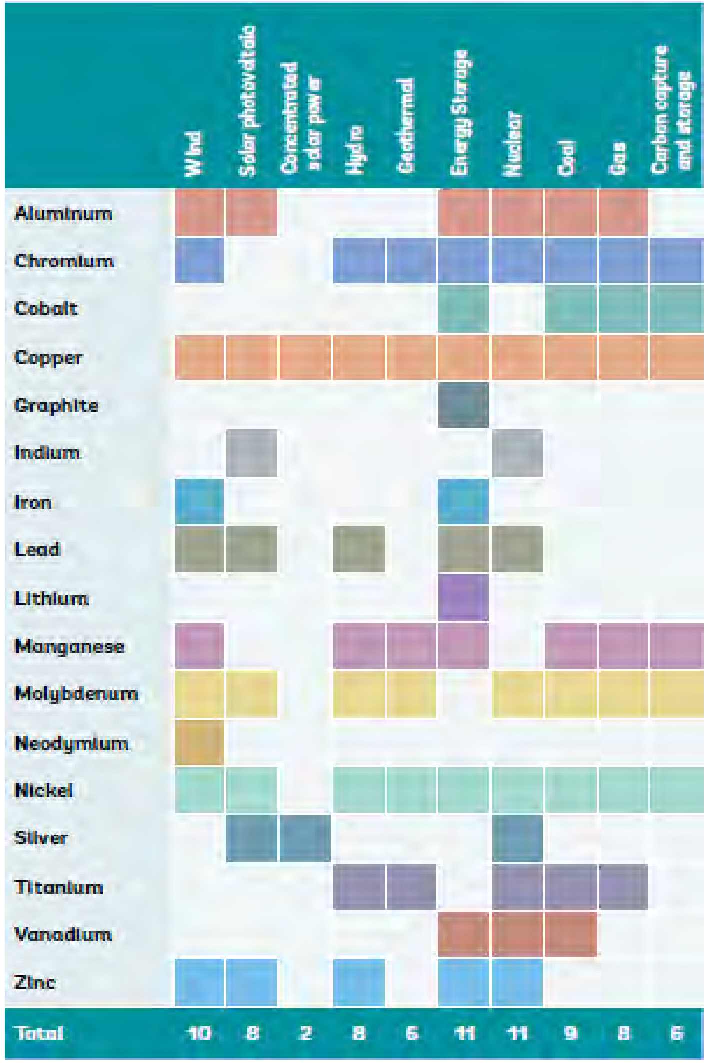
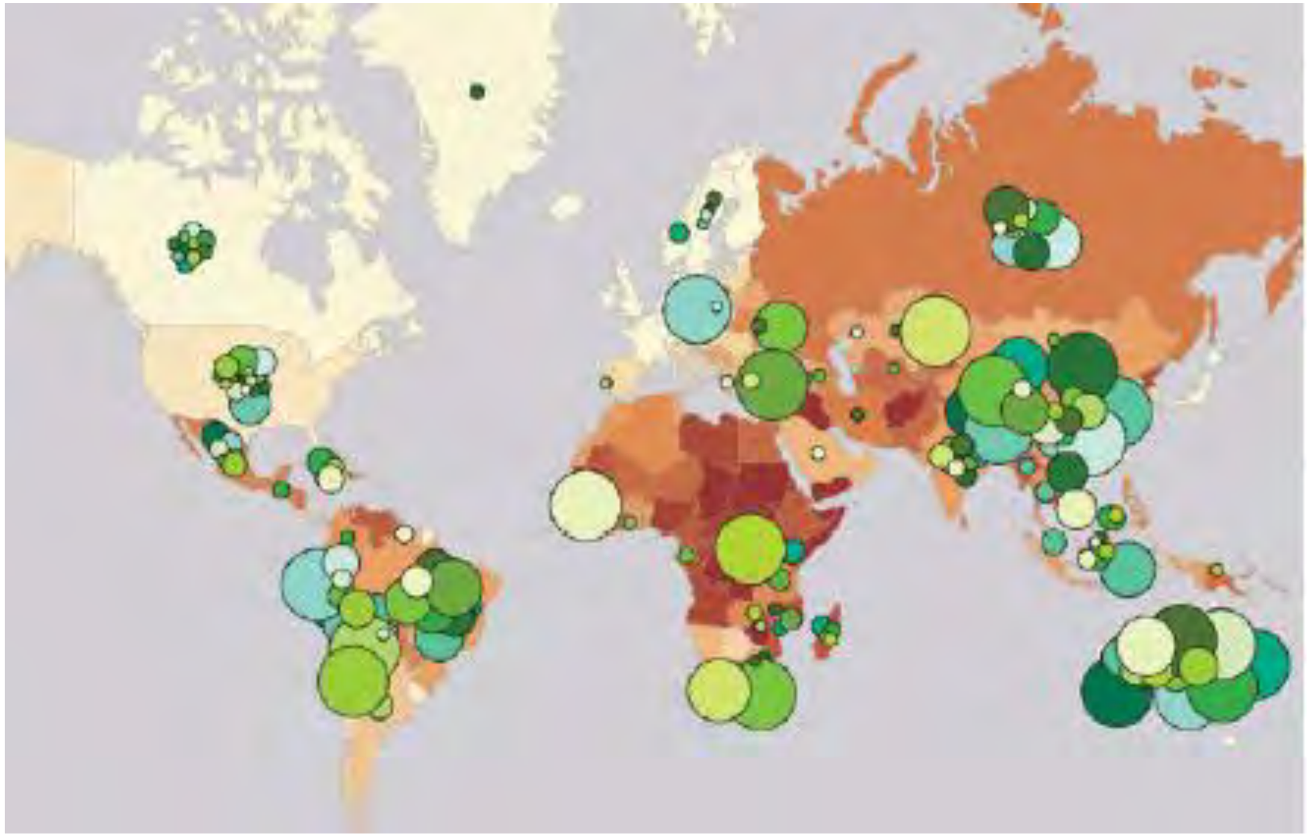
Mining Industry and Sustainability – GHG Removal

➢ ***Where the Metals/Minerals for the Green Technologies Coming From?***





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Mining Industry and Sustainability – GHG Removal

Mineral	Fragility		Corruption	
	Global Reserves Located in Very Fragile States[a]	Global Reserves Located in Fragile or Very Fragile States[b]	Global Reserves Located in States Perceived as Very Corrupt[c]	Global Reserves Located in States Perceived as Corrupt or Very Corrupt[d]
Bauxite & Alumina	28%	44%	0%	**68%**
Cadmium	*Data not available*			
Chromium	0%	**55%**	0%	**100%**
Cobalt	**56%**	**70%**	**56%**	**70%**
Copper	4%	41%	4%	41%
Gallium	*Data not available*			
Germanium	*Data not available*			
Graphite	1%	**73%**	7%	**100%**
Indium	*Data not available*			
Iron	0%	42%	0%	**60%**
Lead	0%	49%	0%	49%
Lithium	0%	21%	0%	34%
Manganese	0%	**66%**	0%	**86%**
Molybdenum	0%	**70%**	0%	**72%**
Nickel	2%	42%	2%	**59%**
Rare Earths	0%	**58%**	0%	**94%**
Selenium	0%	**76%**	0%	**76%**
Silicon	*Data not available*			
Silver	0%	**52%**	0%	**52%**
Tellurium	0%	**67%**	0%	**67%**
Tin	6%	**69%**	3%	**84%**
Titanium	12%	**57%**	6%	**62%**
Zinc	0%	**52%**	0%	**59%**

- ***Critical Green Minerals/Metals are mostly coming from the states with high fragility and corruption:***
  - ✓ *Co and Ni in Congo,*
  - ✓ *Cr in South Africa and Zimbabwe,*
  - ✓ *Ni and Li in Guatemala,*
  - ✓ *Al in Guinea*
  - ✓ *Li in Zimbabwe*
  - ✓ *Li in Chile, Argentina, Bolivia (Li – triangle)*
  - ✓ *REEs in China and North Korea (governmental control)*

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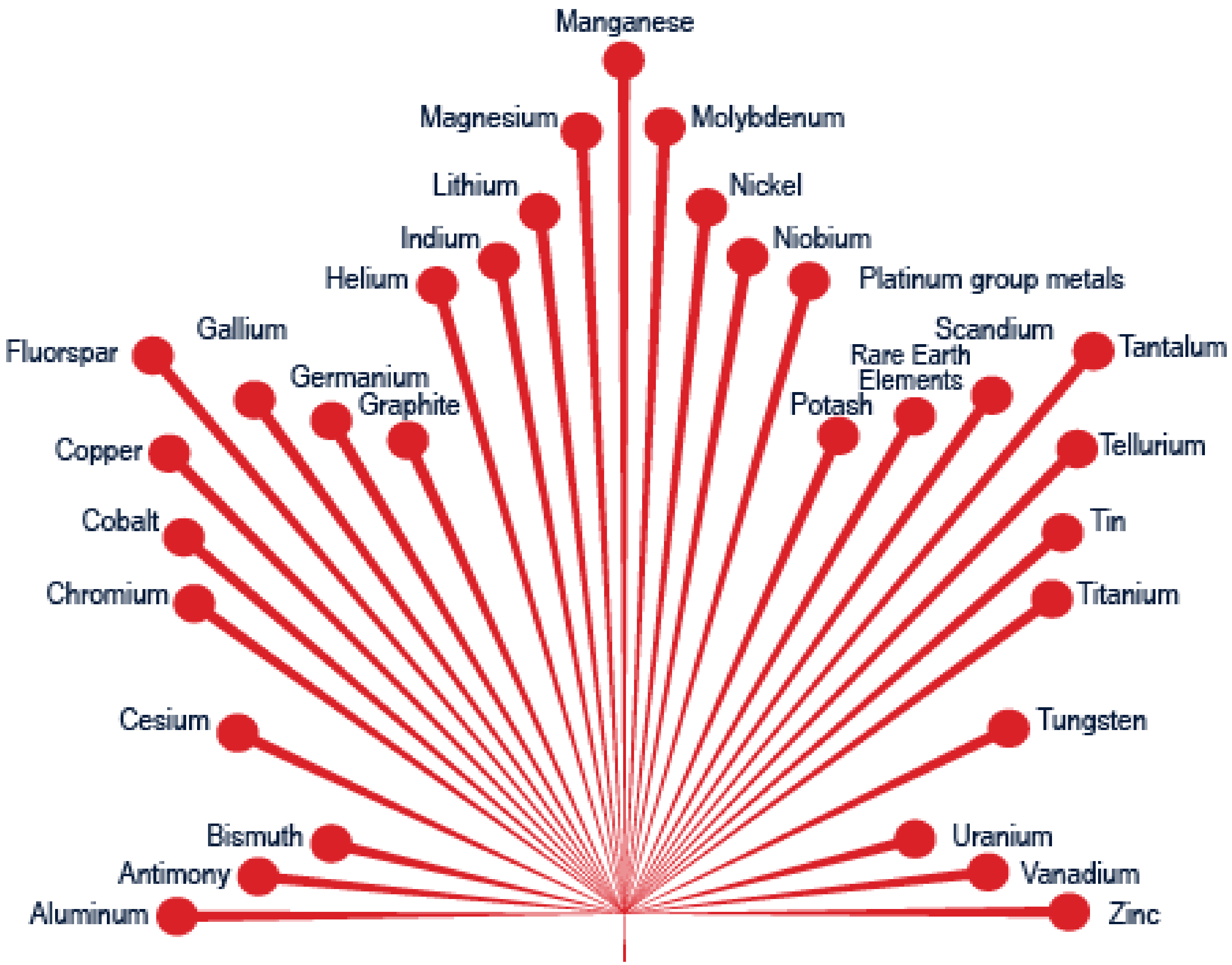
Mining Industry and Sustainability – GHG Removal

- ***Moving towards clean technologies by using Green Metals/Minerals requires***
  - ✓ *Developed Countries (USA, UK, European Union, Canada and Australia) need resources*
  - ✓ *There are needs to look at potential resources such as "Sub-Sea Mining" for sustainability – Ni, Co, Mn, Cu, Zn, Pb, Ag, etc., can be provided*
  - ✓ *There are needs for invest in potential thrid world countries, however for sustainable outcomes, except capital, there are needs for technology transfer, educational program, health and safety providing, and shaering benefits*
  - ✓ *Further development in extraction technolgies to increase recovery and productivity*
  - ✓ *Flowsheet development to recover by-products*
  - ✓ *Considering and developing recycling potential*

Mining Industry and Sustainability – GHG Removal

➢ *Canadian Critical Minerals List (2021):*



- ➢ *Critical Minerals/Metals: essential materials to the economic and national security from a supply chain perspective (having high economic value + high risks in supply)*

- ➢ *Strategic Minerals/Metals: essential to the security, defense, energy policy, etc., (strategic minerals/metals are always critical)*

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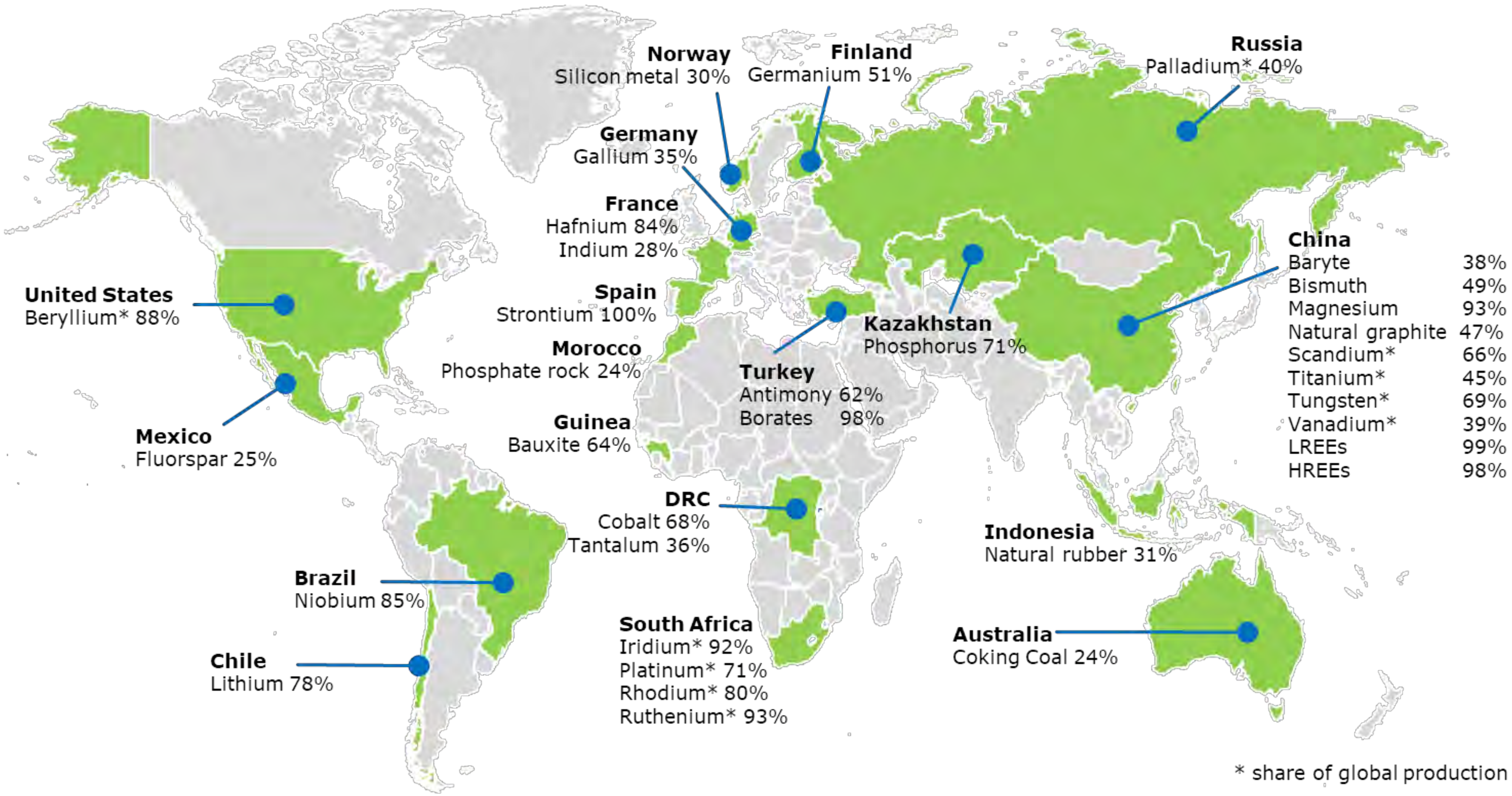
Mining Industry and Sustainability – GHG Removal

➢ ***Countries accounting for largest share of EU supply of Critical Raw Materials***



* share of global production

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Some References for Study

- ✓ Negative Emissions Technologies and Reliable Sequestration; 2019
- ✓ Global potential of rare earth resources and rare earth demand from clean technologies, 2017, Minerals 7 (203).
- ✓ Green Conflict Minerals, 2018, International Institute for Sustainable Development
- ✓ WHERE SHOULD METALS FOR THE GREEN TRANSITION COME FROM, 2020,
- ✓ Green Metal Nanoparticles, Wiley, 2018
- ✓ Rare Earth Metal Recovery for Green Technologies, Methods and Applications, Springer, 2020
- ✓ Minerals for Climate Action, 2020, World Bank Report
- ✓ Report on Critical Raw Materials and the Circular Economy, EU Commission, 2018
- ✓ Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector, EU Commission, 2013

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Thank You for Your Attention

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