

Eleonora Polo, CNR-ISOF

When will we run out of metals?

Scenarios and perspectives



Periodic Table of the Elements

Period	1 IA 1A	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1	1 H Hydrogen 1.008																	2 He Helium 4.003
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
5	37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29
6	55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
7	87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [271]	111 Rg Roentgenium [272]	112 Cn Copernicium [285]	113 Nh Nihonium [284]	114 Fl Flerovium [289]	115 Mc Moscovium [288]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

Atomic Number	Atomic Mass
Symbol	
Name	
Electron Shells	
Electron Configuration	

Element symbol represents state at room temperature.
Solid, **Liquid** or **Gas**

57 138.905 Lanthanum 2 8 18 18 2 [Xe] 5d ¹ 6s ²	58 140.116 Cerium 2 8 18 28 8 2 [Xe] 4f ¹ 6s ²	59 140.908 Praseodymium 2 8 18 21 9 2 [Xe] 4f ³ 6s ²	60 144.243 Neodymium 2 8 18 28 8 2 [Xe] 4f ⁴ 6s ²	61 144.913 Promethium 2 8 18 25 9 2 [Xe] 4f ⁵ 6s ²	62 150.36 Samarium 2 8 18 24 9 2 [Xe] 4f ⁶ 6s ²	63 151.964 Europium 2 8 18 25 9 2 [Xe] 4f ⁷ 6s ²	64 157.25 Gadolinium 2 8 18 25 9 2 [Xe] 4f ⁷ 5d ¹ 6s ²	65 158.925 Terbium 2 8 18 27 9 2 [Xe] 4f ⁹ 6s ²	66 162.500 Dysprosium 2 8 18 28 9 2 [Xe] 4f ¹⁰ 6s ²	67 164.930 Holmium 2 8 18 28 9 2 [Xe] 4f ¹¹ 6s ²	68 167.259 Erbium 2 8 18 30 9 2 [Xe] 4f ¹² 6s ²	69 168.934 Thulium 2 8 18 31 9 2 [Xe] 4f ¹³ 6s ²	70 173.055 Ytterbium 2 8 18 32 9 2 [Xe] 4f ¹⁴ 6s ²	71 174.967 Lutetium 2 8 18 32 9 2 [Xe] 4f ¹⁴ 5d ¹ 6s ²
89 227.028 Actinium 2 8 18 32 18 9 2 [Rn] 6d ¹ 7s ²	90 232.038 Thorium 2 8 18 32 18 9 2 [Rn] 6d ² 7s ²	91 231.036 Protactinium 2 8 18 32 18 9 2 [Rn] 5f ² 6d ¹ 7s ²	92 238.029 Uranium 2 8 18 32 21 9 2 [Rn] 5f ³ 6d ¹ 7s ²	93 237.048 Neptunium 2 8 18 32 21 9 2 [Rn] 5f ⁴ 6d ¹ 7s ²	94 244.064 Plutonium 2 8 18 32 24 9 2 [Rn] 5f ⁶ 6d ² 7s ²	95 243.061 Americium 2 8 18 32 25 9 2 [Rn] 5f ⁷ 6d ¹ 7s ²	96 247.070 Curium 2 8 18 32 25 9 2 [Rn] 5f ⁷ 6d ² 7s ²	97 247.070 Berkelium 2 8 18 32 27 9 2 [Rn] 5f ⁹ 6d ¹ 7s ²	98 251.080 Californium 2 8 18 32 28 9 2 [Rn] 5f ¹⁰ 6d ¹ 7s ²	99 [254] Einsteinium 2 8 18 32 28 9 2 [Rn] 5f ¹¹ 6d ¹ 7s ²	100 257.095 Fermium 2 8 18 32 30 9 2 [Rn] 5f ¹² 6d ¹ 7s ²	101 258.1 Mendelevium 2 8 18 32 31 9 2 [Rn] 5f ¹³ 6d ¹ 7s ²	102 259.101 Nobelium 2 8 18 32 32 9 2 [Rn] 5f ¹⁴ 6d ¹ 7s ²	103 [262] Lawrencium 2 8 18 32 32 9 2 [Rn] 5f ¹⁴ 6d ² 7s ²

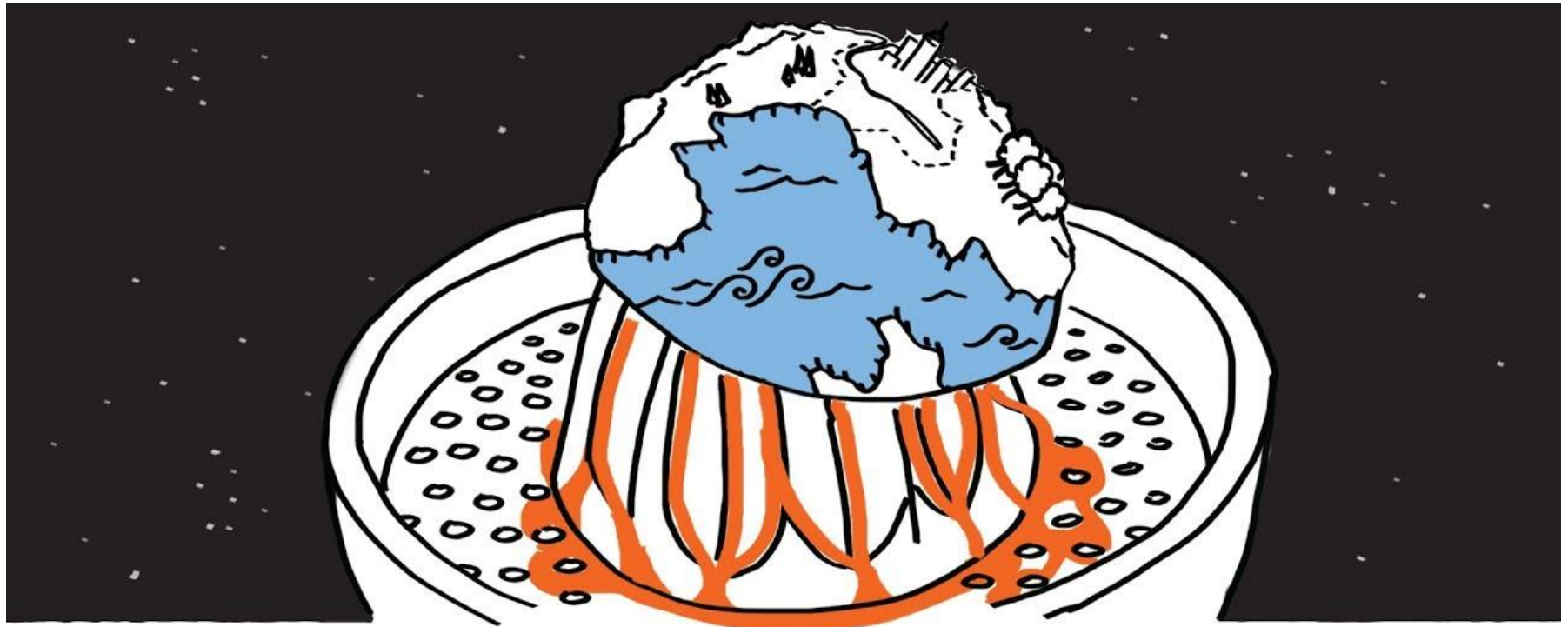
- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Metalloid
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide



THE UNITED NATIONS PROCLAIMS THE INTERNATIONAL YEAR OF THE PERIODIC TABLE OF CHEMICAL ELEMENTS

28 December 2017

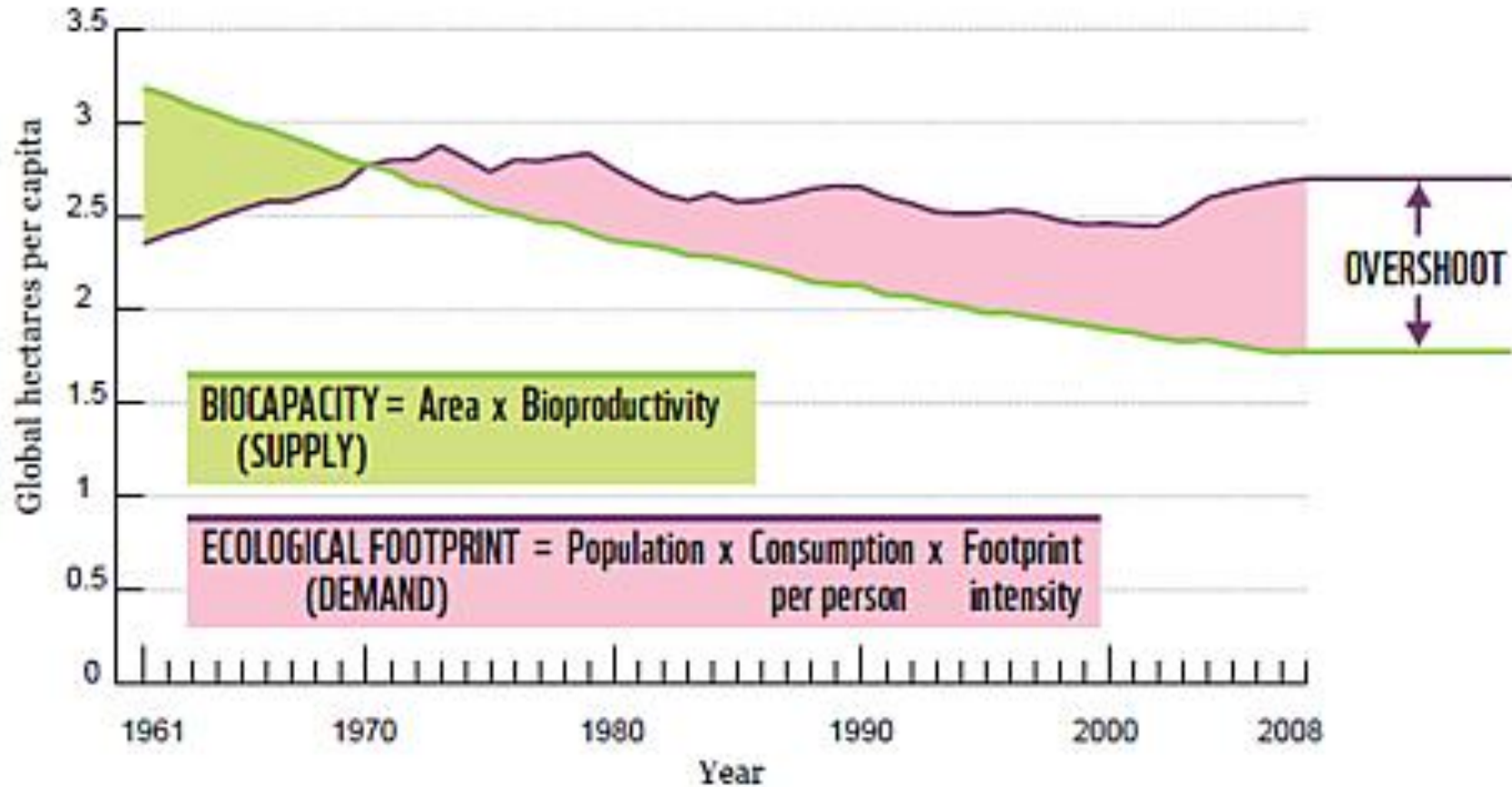


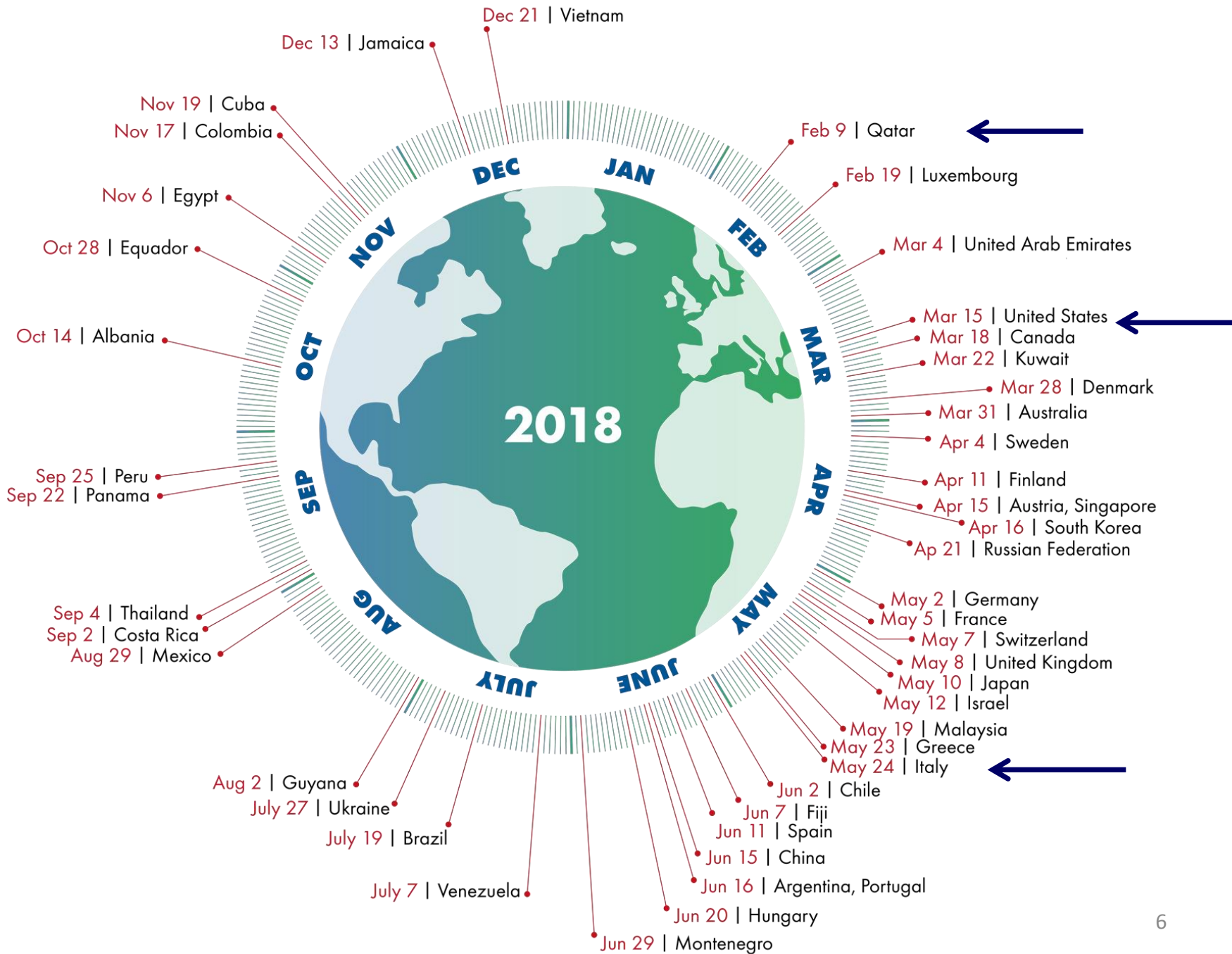


EARTH OVERSHOOT DAY:
AUG. 1, 2018



EARTH OVERSHOOT DAY



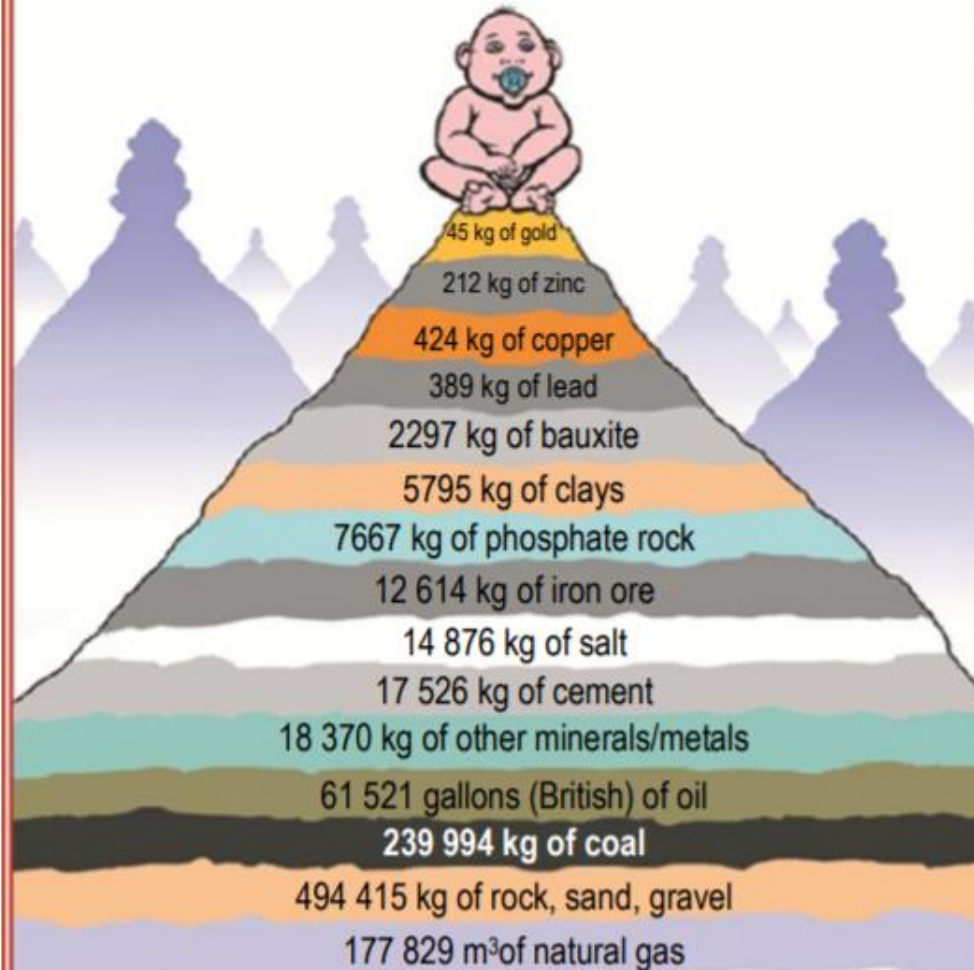


If we could postpone the Overshoot Day of 4,5 days a year, we could reach balance 0 within the year 2050.

What can we do?

- Rationalize the uptake of non-renewable resources: minerals and metal ores, fossil fuels (coal, petroleum, natural gas), and minimize wastes
- Repair and reuse as much as possible
- Properly recycle urban waste

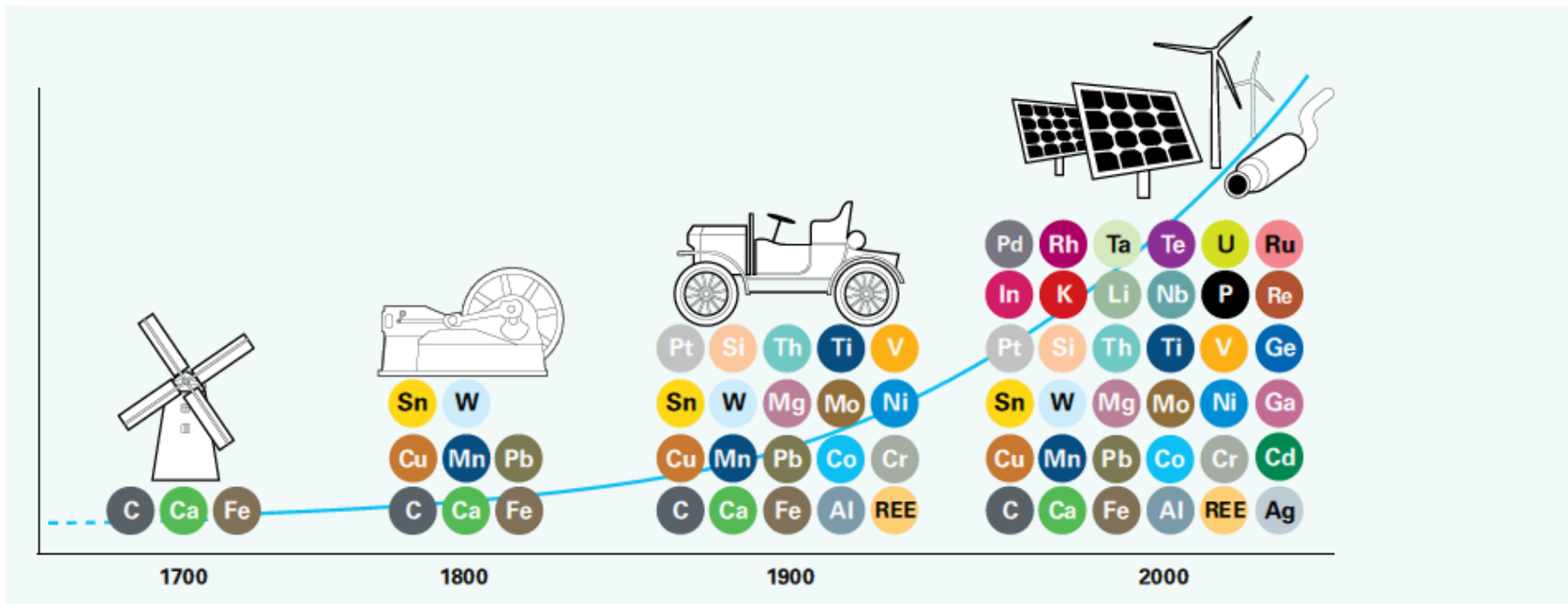
A child born today in the United States consumes on average:



...during the whole of his life. What gives the total of 1342 632 kg or 1 343 m³ of minerals, metals and fuels. It is more than 17 tons per 1 person/year

Source: Mineral Information Institute – www.mil.org





Elements widely used in energy pathways

N.B. Position on the time axis is indicative only

Who is «clearing» the periodic table?

1 H 1.00794	<p style="text-align: center;">Remaining years until depletion of known reserves (based on current rate of extraction)</p> <table border="1" style="margin: auto;"> <tr><td style="background-color: red;">5-50 years</td></tr> <tr><td style="background-color: orange;">50-100 years</td></tr> <tr><td style="background-color: yellow;">100-500 years</td></tr> </table>																5-50 years	50-100 years	100-500 years	2 He 4.002602
5-50 years																				
50-100 years																				
100-500 years																				
3 Li 6.941	4 Be 9.012182													5 B 10.811	6 C 12.0107	7 N 14.00674	8 O 15.9994	9 F 18.99840	10 Ne 20.1797	
11 Na 22.98977	12 Mg 24.3050													13 Al 26.98153	14 Si 28.0855	15 P 30.97376	16 S 32.066	17 Cl 35.4527	18 Ar 39.948	
19 K 39.0983	20 Ca 40.078	21 Sc 44.95591	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.93804	26 Fe 55.845	27 Co 58.93320	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.904	36 Kr 83.80			
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9085	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.8682	48 Cd 112.411	49 In 114.818	50 Sn 118.760	51 Sb 121.760	52 Te 127.60	53 I 126.9044	54 Xe 131.29			
55 Cs 132.9054	56 Ba 137.327	57 La * 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.9665	80 Hg 200.59	81 Tl 204.3833	82 Pb 270.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)			
87 Fr (223)	88 Ra 226.025	89 Ac ‡ (227)	104 Rf (257)	105 Db (260)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (271)	111 Rq (272)	112 Uub (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Lv (292)	117 Uus	118 Uuo			

Lanthanides *	58 Ce 140.9077	59 Pr 144.24	60 Nd (145)	61 Pm 150.36	62 Sm 151.964	63 Eu 157.25	64 Gd 158.9253	65 Tb 158.9253	66 Dy 162.50	67 Ho 164.9303	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967
	Actinides ‡	90 Th 232.0381	91 Pa 231.0289	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

What will we finish first?

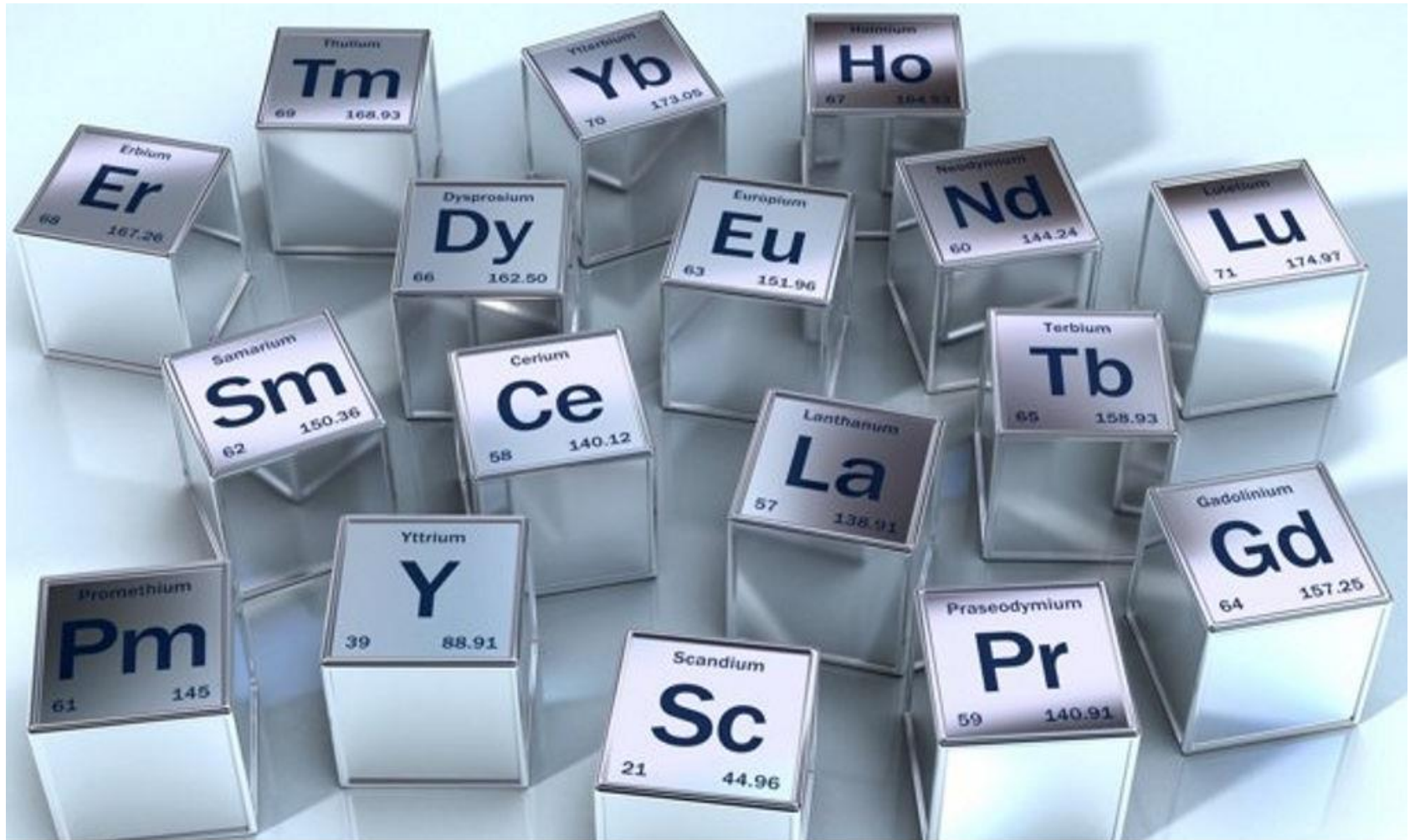


UE Critical Raw Materials Third review

Critical Raw Materials			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

European Commission, Report on Critical Raw Materials and the Circular Economy, 16/01/2018

REE (Rare Earths Elements)



REE (Rare Earths Elements)


atomic number										Symbol								standard atomic weight							
1 H 1.007 - 1.009																	2 He 4.003								
3 Li 6.938 - 6.967	4 Be 9.012																	5 B 10.81 - 10.83	6 C 12.00 - 12.02	7 N 14.00 - 14.01	8 O 15.99 - 16.00	9 F 19.00	10 Ne 20.18		
11 Na 22.99	12 Mg 24.31																	13 Al 26.98	14 Si 28.08 - 28.09	15 P 30.97	16 S 32.05 - 32.06	17 Cl 35.44 - 35.45	18 Ar 39.95		
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38(2)	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96(3)	35 Br 79.90	36 Kr 83.80								
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94(2)	43 Tc 101.1	44 Ru 101.07	45 Rh 106.4	46 Pd 107.87	47 Ag 107.87	48 Cd 112.4	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.6	53 I 126.91	54 Xe 131.3								
55 Cs 132.9	56 Ba 137.3	57 - 71	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [209]	85 At [210]	86 Rn [222]								
87 Fr [223]																	88 Ra [226]								

Light (LREE)
Heavy (HREE)

Sc } } Y

Lanthanoids	57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm [145]	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
Actinoids	89 Ac [227]	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [260]

Sc 21
Scandium




Bicycles

La 57
Lanthanum



Telescope Lenses

Ce 58
Cerium




Lighter Flint

Pr 59
Praseodymium





Torchworkers' Eyeglasses

Nd 60
Neodymium



Electric Motor Magnets

Pm  61
Promethium




Luminous Dials

Sm 62
Samarium




Electric Motor Magnets

Eu 63
Europium



Color Televisions

Gd 64
Gadolinium



MRI Diagnosis


Light
(LREE)

Y 39
Yttrium



Lasers

Tb 65
Terbium




Fluorescent Lamps

Dy 66
Dysprosium



Smart Material Actuators

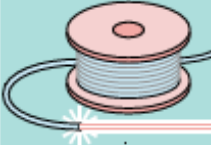
Ho 67
Holmium



Laser Surgery


Heavy
(HREE)

Er 68
Erbium




Optical Fiber Communications

Tm 69
Thulium



Laser Surgery

Yb 70
Ytterbium



Scientific Fiber Lasers

Lu 71
Lutetium






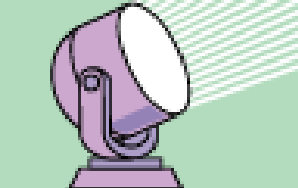














Photodynamic Medicine

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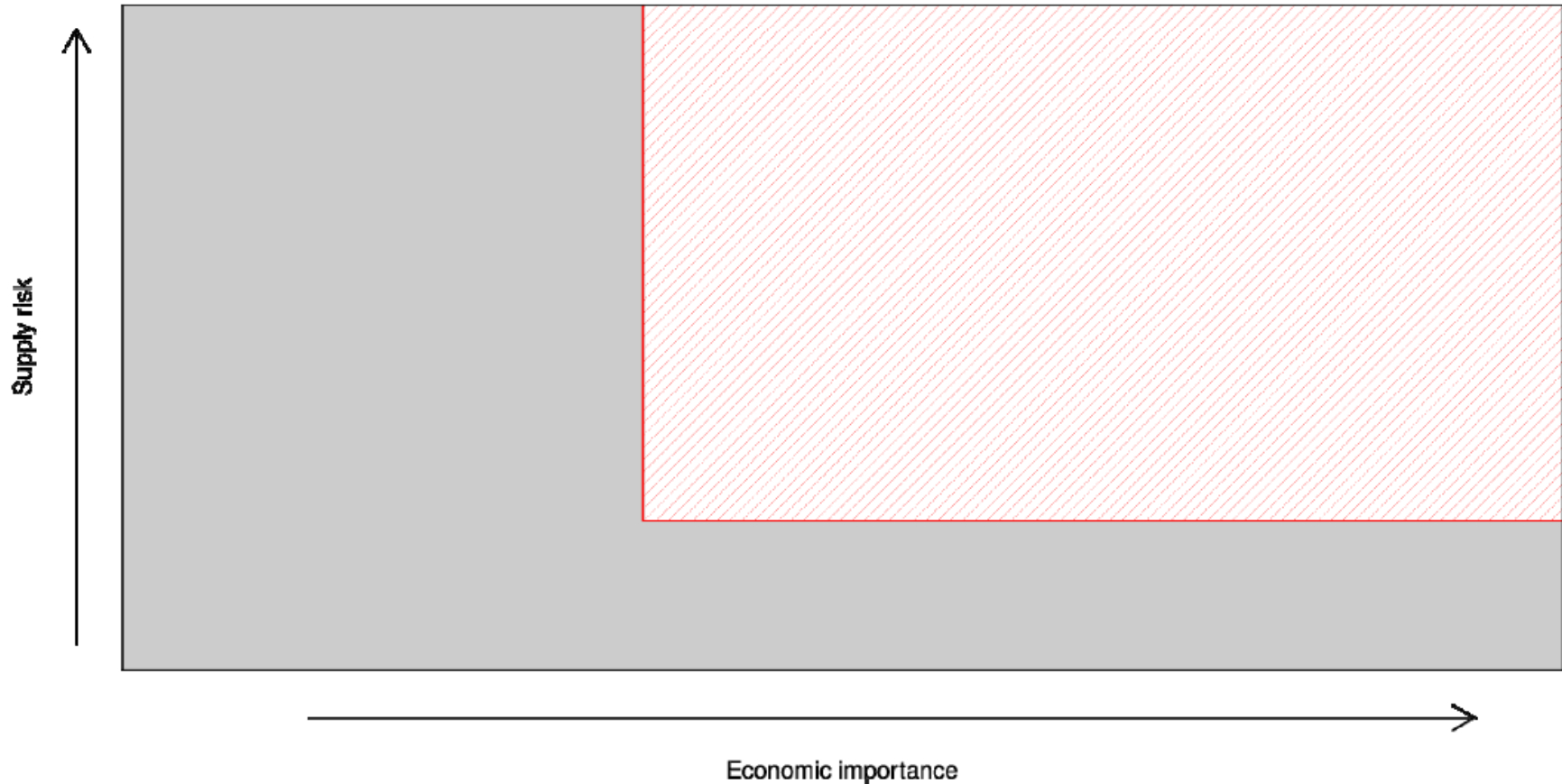
PGMs, Platinum Group Metals

26	27	28	29
Fe	Co	Ni	Cu
44	45	46	47
Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag
76	77	78	79
Os Osmium	Ir Iridium	Pt Platinum	Au

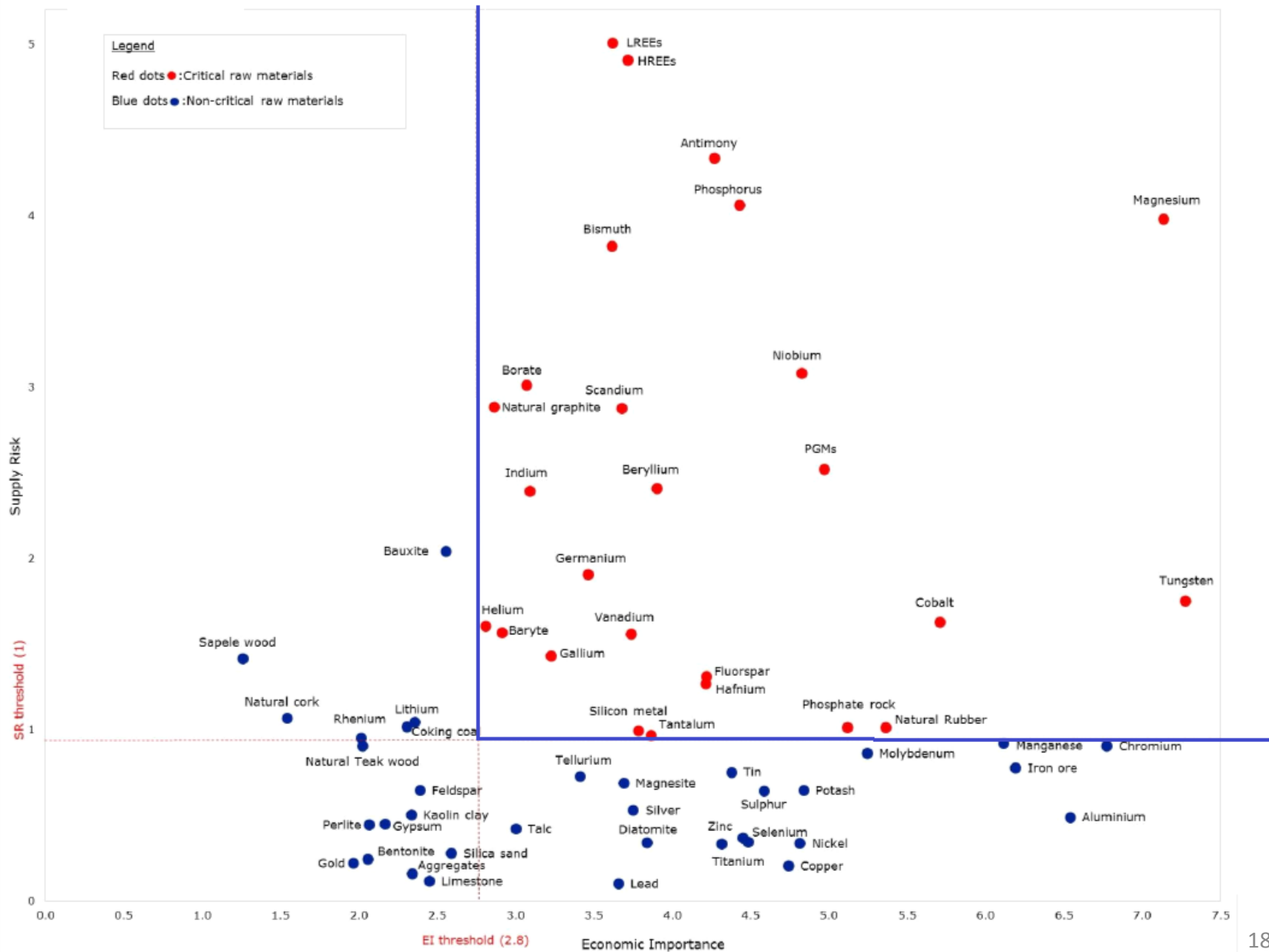
<p>Ru   44 Ruthenium</p>  <p>Electric Switches</p>	<p>Rh   45 Rhodium</p>  <p>Searchlight Reflectors</p>	<p>Pd   46 Palladium</p>  <p>Pollution Control</p>
<p>Os   76 Osmium</p>  <p>Pen Points</p>	<p>Ir   77 Iridium</p>  <p>Spark Plugs</p>	<p>Pt   78 Platinum</p>  <p>Labware</p>

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The EC criticality methodology



Economic importance and supply risk results of 2017 criticality assessment



Why a material becomes critical?



1. Low abundance on Earth's crust

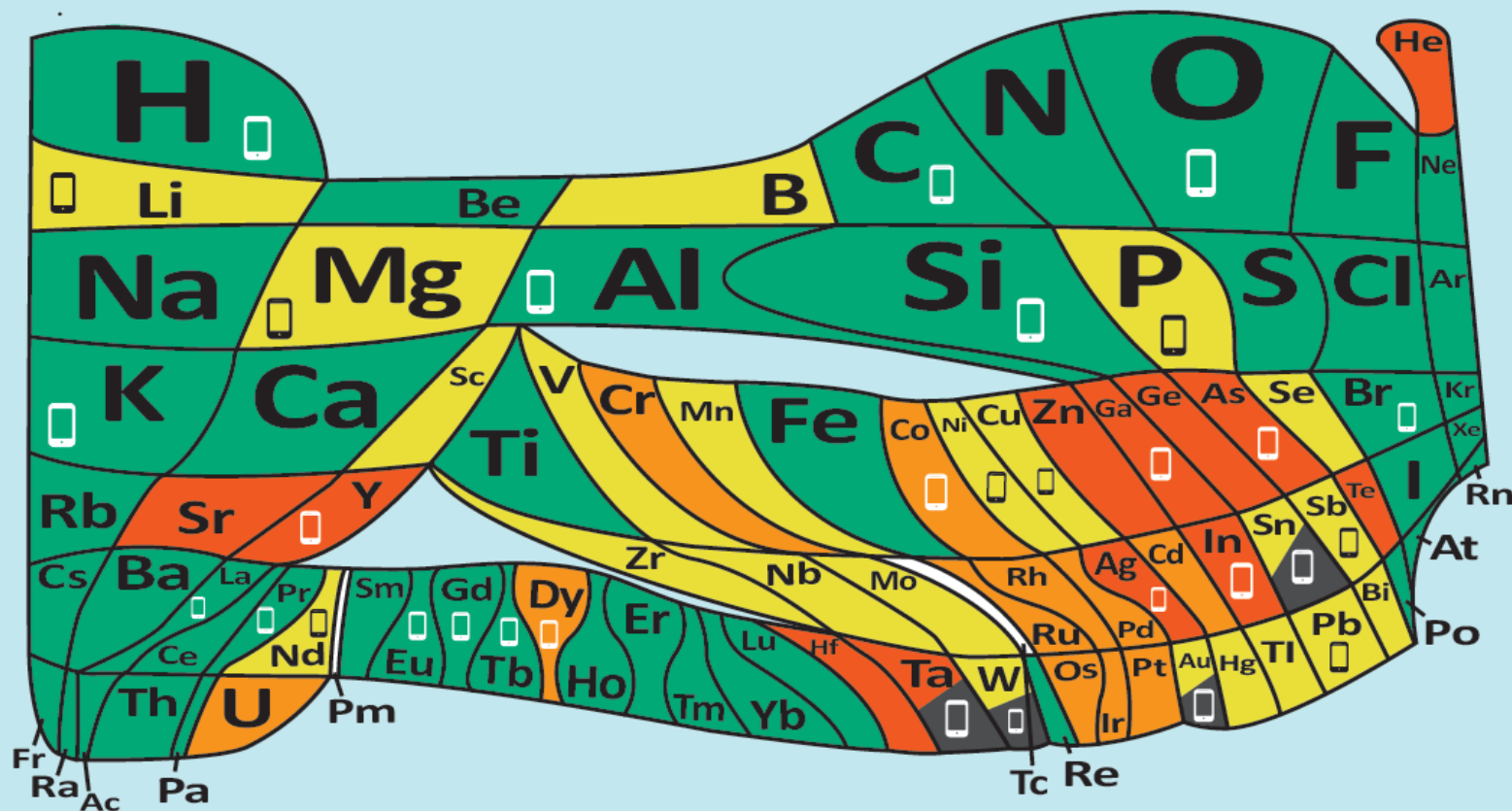


United Nations
Educational, Scientific and
Cultural Organization



International Year
of the Periodic Table
of Chemical Elements

The 90 natural elements that make up everything
How much is there? Is that enough?



- Serious threat in the next 100 years
- Rising threat from increased use
- Limited availability, future risk to supply
- Plentiful Supply
- Synthetic
- From conflict minerals
- Elements used in a smart phone

Read more and play the video game <http://bit.ly/euchems-pt>



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Abundance of some chemical elements on the Earth's crust (ppm)

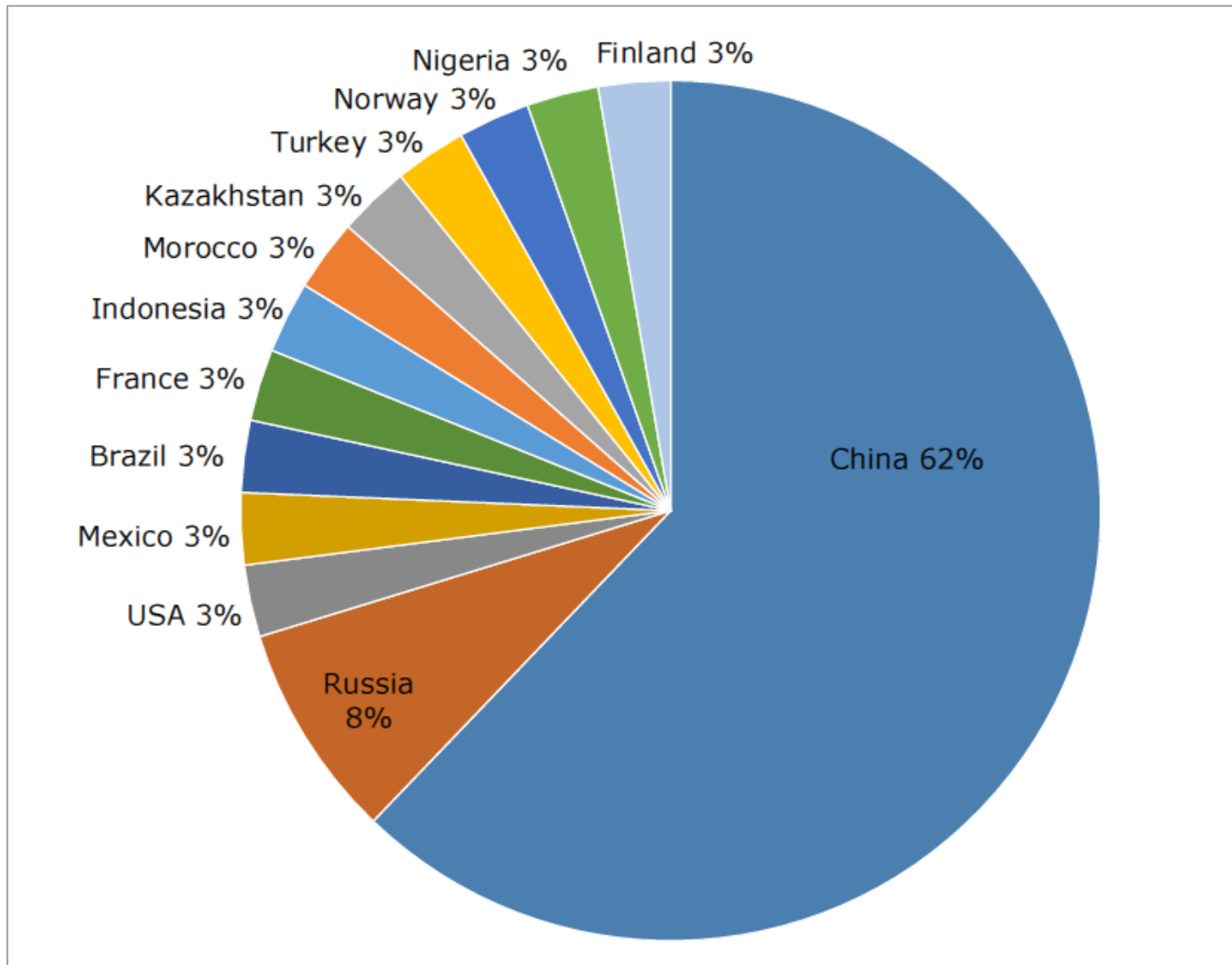
Alluminio	84.149	Niobio	8
Ferro	52.157	Torio	5,6
Magnesio	28.104	Arsenico	2,5
Sodio	22.774	Stagno	1,7
Titanio	4.136	Uranio	1,3
Manganese	774	Tungsteno	1
Fosforo	567	Iodio	0,71
Bario	456	Tantalo	0,7
Zolfo	404	Lutezio	0,3
Stronzio	320	Antimonio	0,2
Cromo	135	Cadmio	0,08
Zinco	72	Argento	0,055
Rame	27	Mercurio	0,03
Cobalto	26,6	Palladio	0,0015
Nickel	26,6	Platino	0,0015
Lantanio	20	Oro	0,0013
Litio	16	Rutenio	0,00057
Piombo	11	Iridio	0,000037

Fonte: rielaborazione dati
British Geological Survey

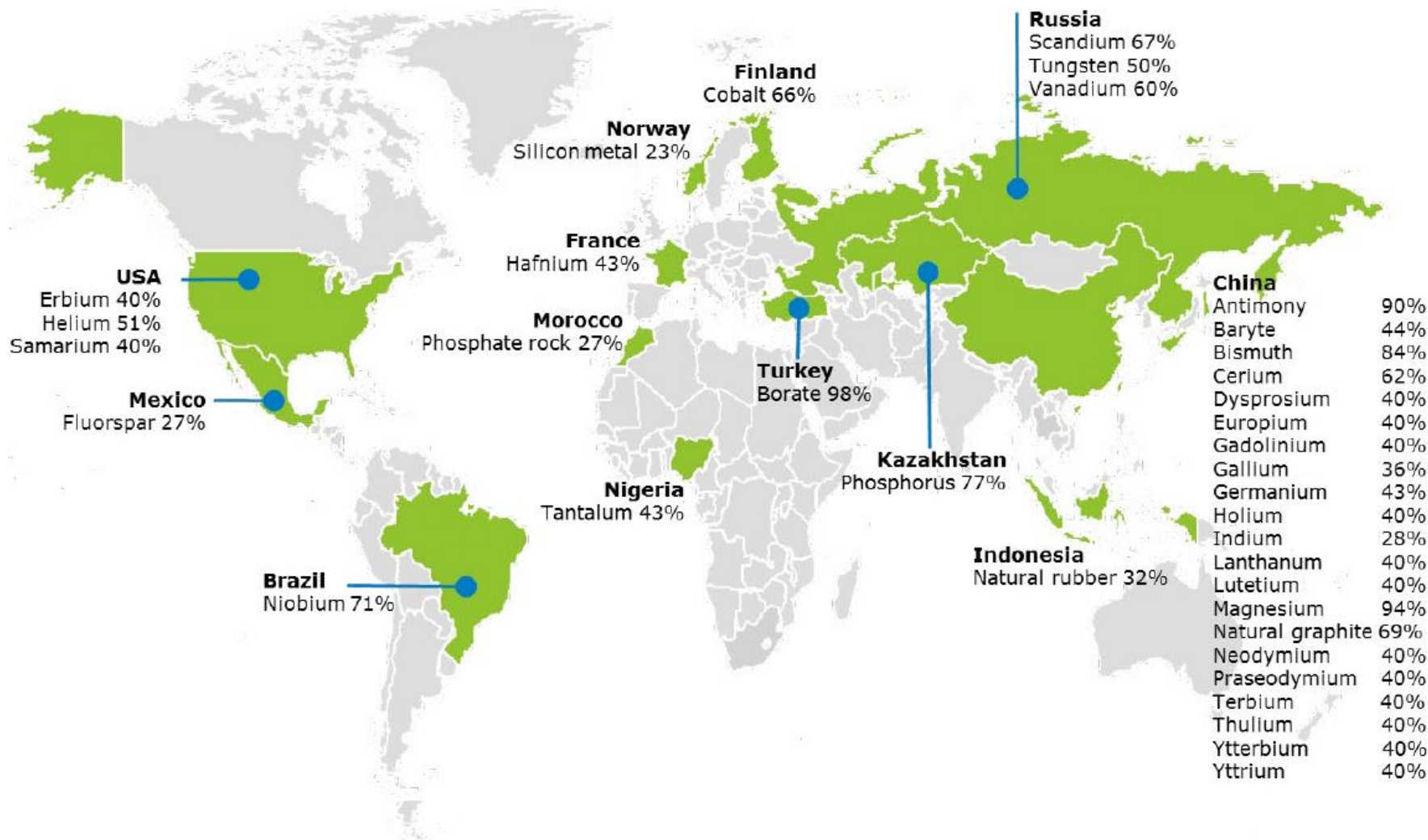
2. Deposits are localized in one or very few countries



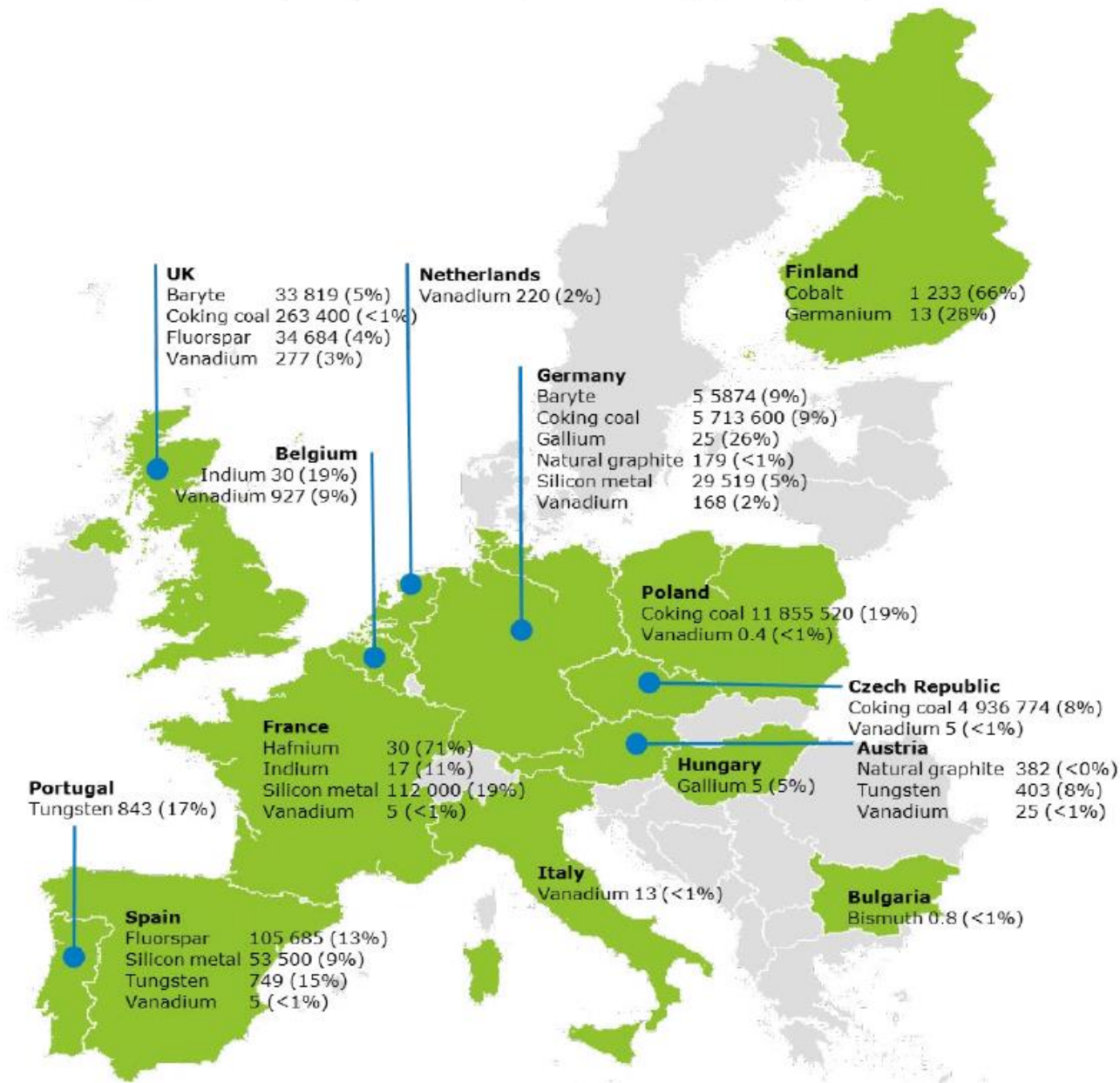
Figure D: Main EU suppliers of CRMs (based on number of CRMs supplied out of 37), average from 2010-2014



Contribution of primary global suppliers of critical raw materials, average from 2010-2014

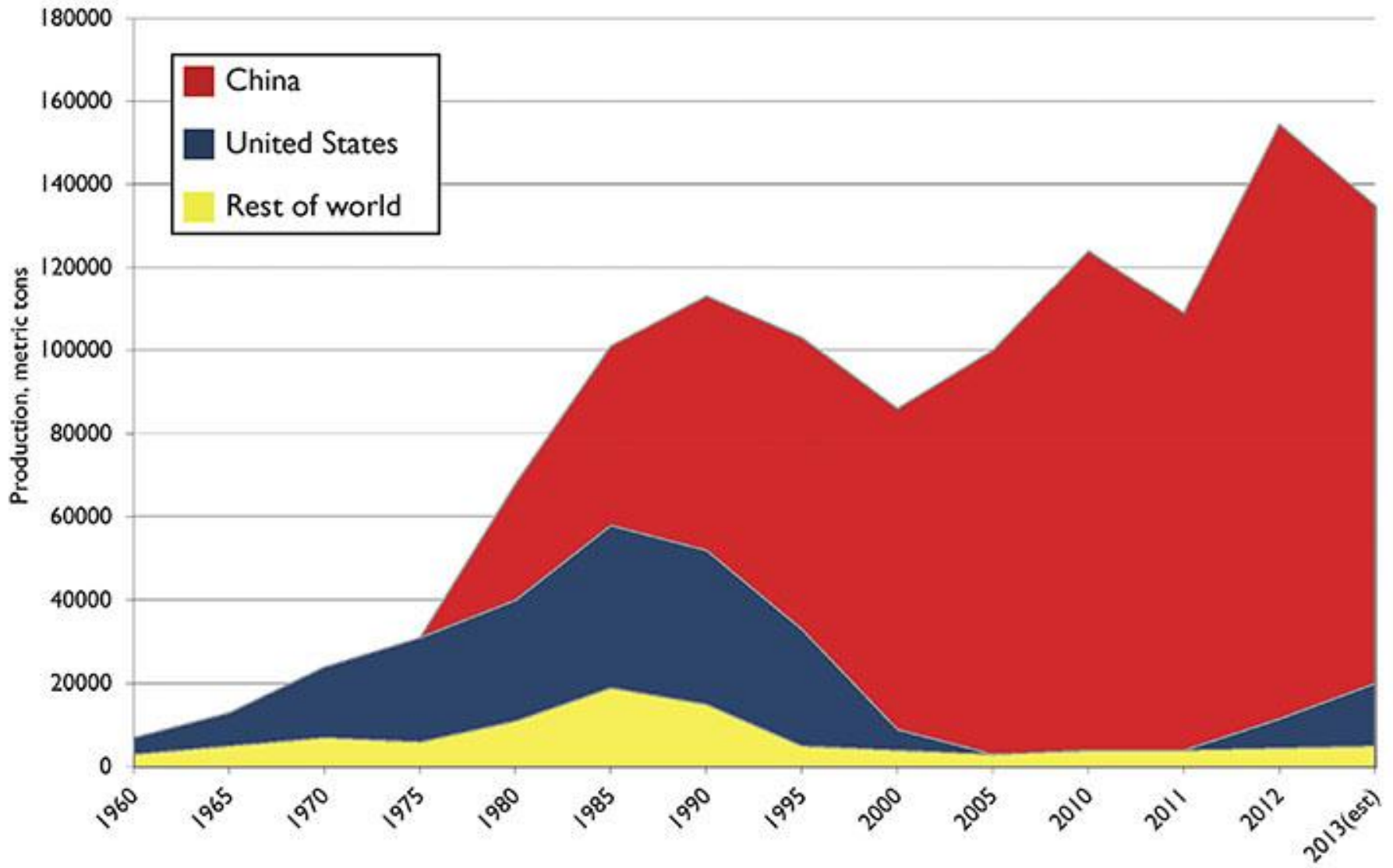


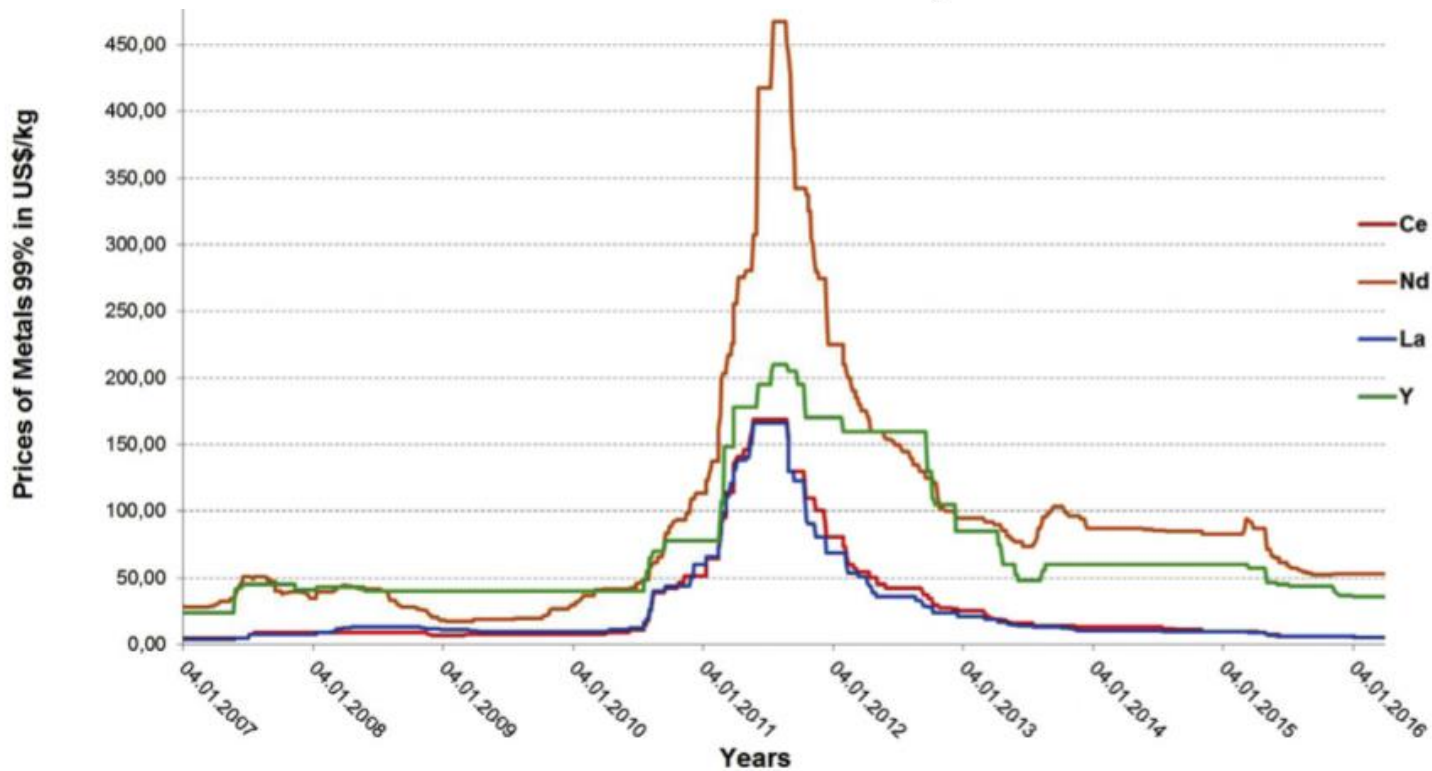
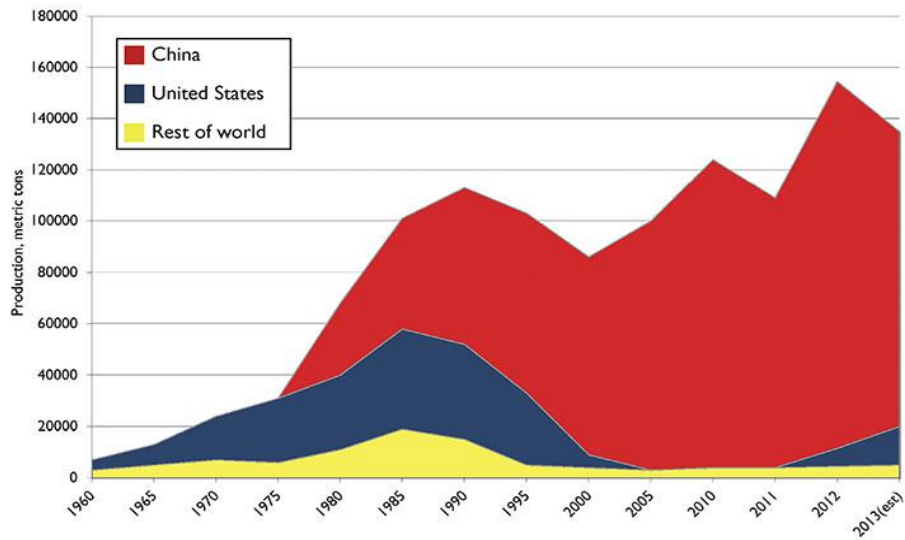
EU production of primary CRMs in tonnes (and share of supply to EU), average from 2010-2014



The rare earth crisis







Metal prices development during the last 10 years for selected REE (Metal-pages, 2016).

As Rare Earth Fell, So Did Molycorp

Mining company fate tied to neodymium prices

■ China Neodymium Metal Market Price Shanghai (R1) ■ Molycorp Inc (L1)



3. The extraction method is dangerous and/or produces pollution



Argentina, cyanide spill caused the pollution of five rivers



acids from a copper mine



fishes killed by a cyanide spill



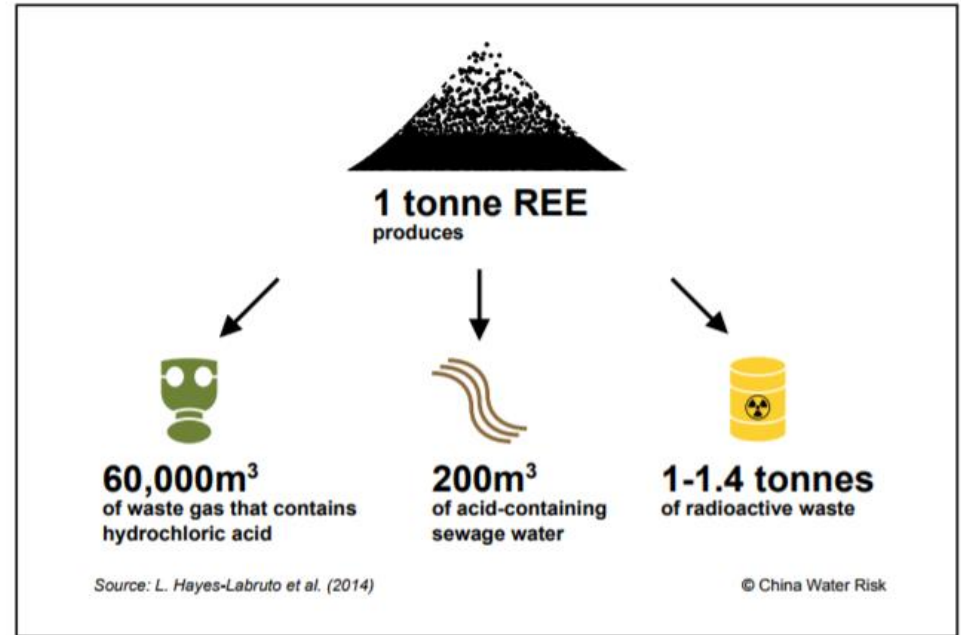
Mining town of Norilsk (Russia)



**Production of 35% Pd, 25% Pt,
20% Ni, 10% Co of the world**



Mountain Pass mine (USA)

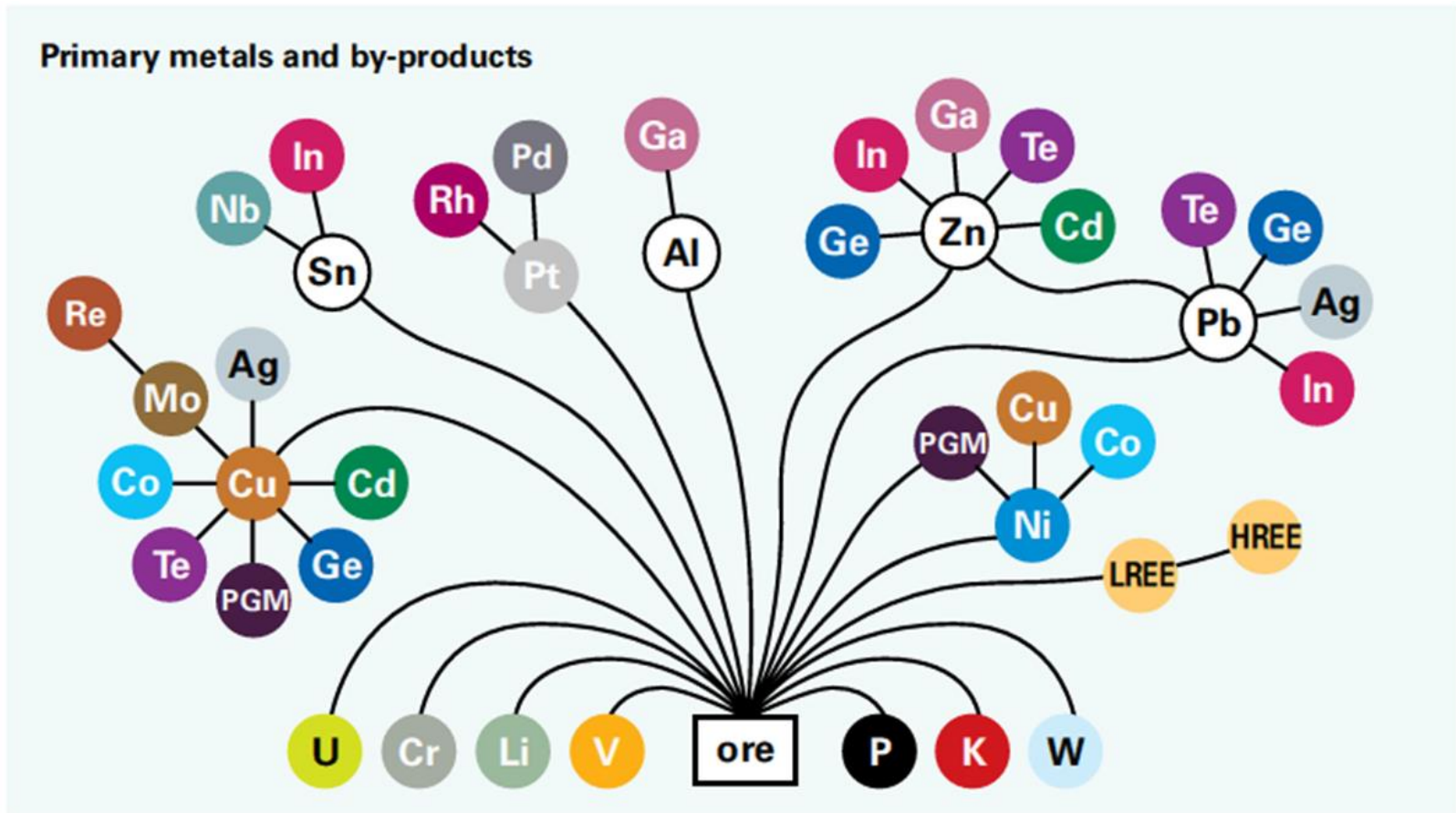


Documentary by Guillaume Pitron, Serge Turquier (2012)
<https://www.youtube.com/watch?v=C9SDUmEZZxk>





The hitch-hikers

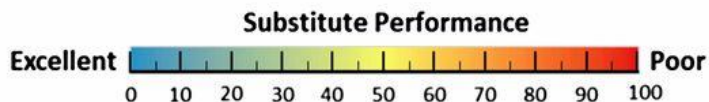


Schematic representation of the routes from ore to elements described in this handbook, indicating primary versus those produced as co- or by-products (adapted from Hagelüken & Meskers, 2010).

4. Cannot be substituted in one or more technological application

H																	He
Li 41	Be 63											B 41	C	N	O	F	Ne
Na	Mg 94											Al 44	Si	P	S	Cl	Ar
K	Ca	Sc 65	Ti 63	V 63	Cr 76	Mn 96	Fe 57	Co 54	Ni 62	Cu 70	Zn 38	Ga 38	Ge 44	As 38	Se 47	Br	Kr
Rb	Sr 78	Y 95	Zr 66	Nb 42	Mo 70	Tc	Ru 63	Rh 96	Pd 39	Ag 44	Cd 38	In 60	Sn 36	Sb 57	Te 38	I	Xe
Cs	Ba 63	.	Hf 38	Ta 41	W 53	Re 90	Os 38	Ir 69	Pt 66	Au 40	Hg 45	Tl 100	Pb 100	Bi 46	Po	At	Rn
Fr	Ra	..	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

* Lanthanides	La 75	Ce 60	Pr 41	Nd 41	Pm	Sm 38	Eu 100	Gd 63	Tb 63	Dy 100	Ho 63	Er 63	Tm 88	Yb 88	Lu 63
** Actinides	Ac	Th 35	Pa	U 63	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



Demand Surge

Global metals and materials demand from EV lithium-ion batteries

■ Graphite ■ Nickel ■ Aluminum ■ Copper ■ Lithium ■ Cobalt ■ Manganese



Source: Bloomberg New Energy Finance

Bloomberg

ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ● ALKALI METAL ● ALKALINE EARTH METAL ● TRANSITION METAL ● GROUP 13 ● GROUP 14 ● GROUP 15 ● GROUP 16 ● HALOGEN ● LANTHANIDE

SCREEN

49 In Indium	8 O Oxygen	
50 Sn Tin		
13 Al Aluminium	14 Si Silicon	
8 O Oxygen	19 K Potassium	
39 Y Yttrium	57 La Lanthanum	65 Tb Terbium
59 Pr Praseodymium	63 Eu Europium	66 Dy Dysprosium
64 Gd Gadolinium		

Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al₂O₃) and silica (SiO₂). This glass also contains potassium ions, which help to strengthen it.

A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

ELECTRONICS

29 Cu Copper	47 Ag Silver	
79 Au Gold	73 Ta Tantalum	
28 Ni Nickel	66 Dy Dysprosium	59 Pr Praseodymium
65 Tb Terbium	60 Nd Neodymium	64 Gd Gadolinium
14 Si Silicon	8 O Oxygen	51 Sb Antimony
33 As Arsenic	15 P Phosphorus	31 Ga Gallium
50 Sn Tin	82 Pb Lead	

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.

Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.

Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.

Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

BATTERY

3 Li Lithium	27 Co Cobalt	8 O Oxygen
6 C Carbon	13 Al Aluminium	

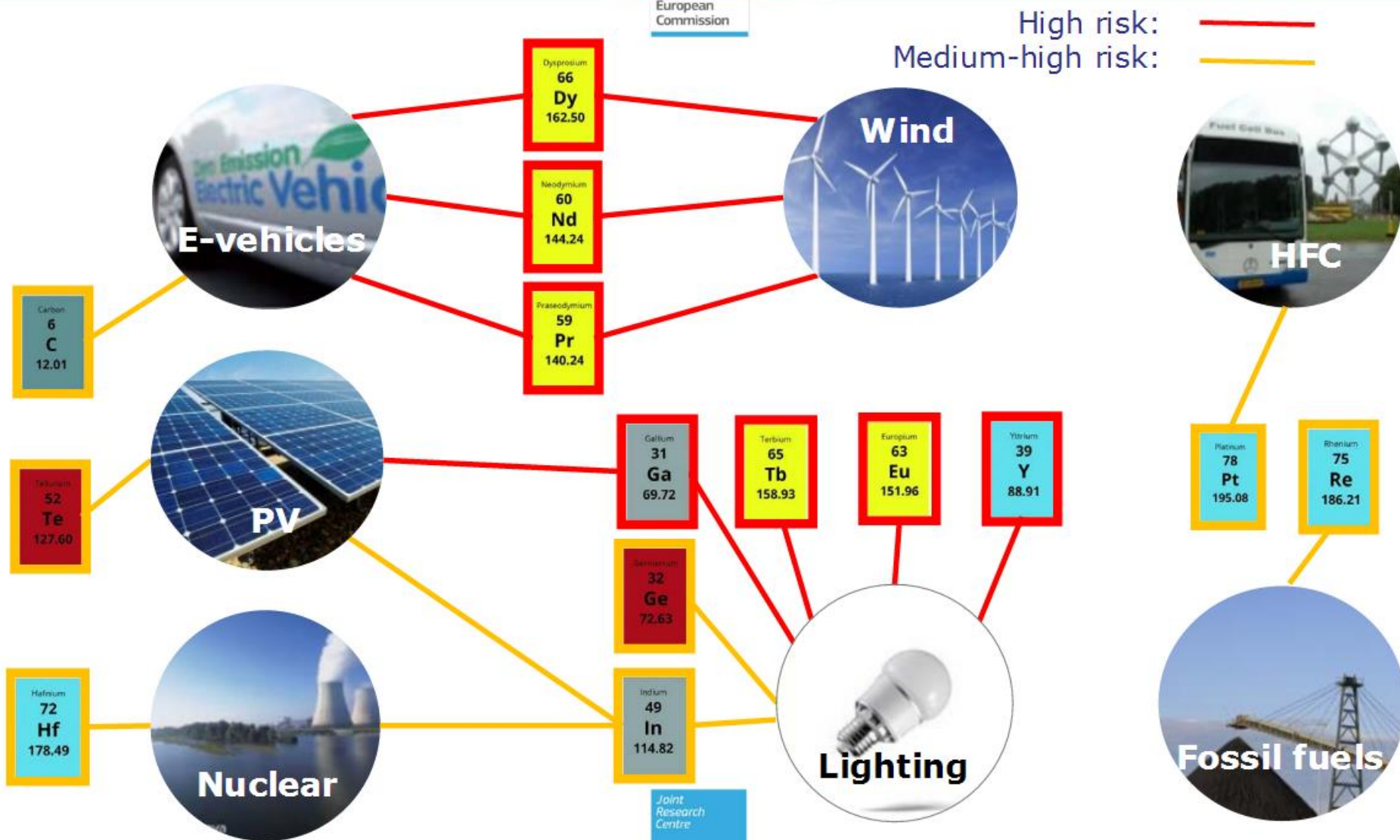
The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

CASING

6 C Carbon	12 Mg Magnesium
35 Br Bromine	28 Ni Nickel

Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

Energy technologies at risk

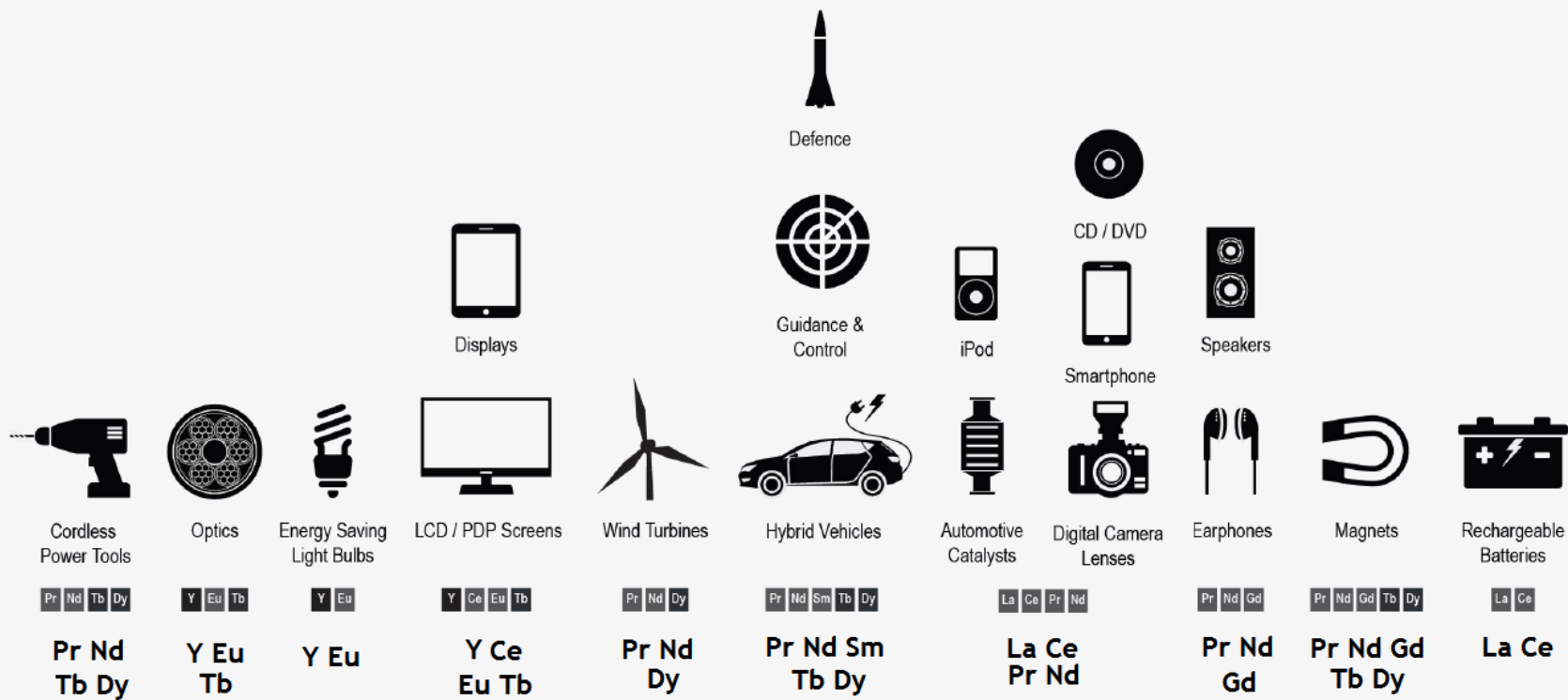




One 3-MW turbine contains

- 335 tons of steel
- 4.7 tons of copper
- 1,200 tons of concrete (cement and aggregates)
- 3 tons of aluminum.
- 2 tons of rare earth elements
- zinc
- molybdenum

Source: (NW Mining Association)



21 Sc Scandium	39 Y Yttrium	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
Light Rare Earth Elements (LREE)									Heavy Rare Earth Elements (HREE)							



5. Recyclig is absent, insufficient or difficult

End-of-life recycling input rates (EOL-RIR) in the EU-28 (CRMs and non-CRMs)

End-of-life recycling input rate (EOL-RIR) [%]

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-Lu ¹	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
Fr	Ra	Ac-Lr ²	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo				



¹ Group of Lanthanide	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
² Group of Actinide	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Aggregates	Bentonite	Coaking Coal	Diatomite	Feldspar	Gypsum	Kaolin Clay	Limestone	Magnesite	Natural Cork	Natural Graphite	Natural Rubber	Natural Teak Wood	Perlite	Sapele wood	Silica Sand	Talc
7%	50%	0%	0%	10%	1%	0%	58%	2%	8%	3%	1%	0%	42%	15%	0%	5%

* F = Fluorspar; P = Phosphate rock; K = Potash, Si = Silicon metal, B = Borates.

THE RECYCLING RATES OF SMARTPHONE METALS

COLOR KEY: ● < 1% RECYCLE RATE ● 1-10% RECYCLE RATE ● 10-25% RECYCLE RATE ● 25-50% RECYCLE RATE ● > 50% RECYCLE RATE ● NON-METAL (OR RECYCLE RATE UNKNOWN)

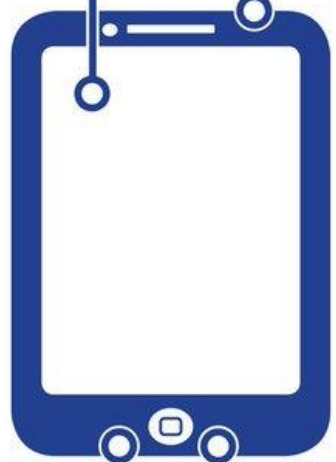
SCREEN



TOUCH: INDIUM TIN OXIDE
 Mainly used in a transparent film over the phone's screen that conducts electricity. This allows the screen to function as a touch screen.

GLASS: ALUMINA & SILICA
 On most phones the glass is aluminosilicate glass, a mix of aluminium oxide & silicon dioxide. It also contains potassium ions, which help strengthen it.

COLORS: RARE EARTH METALS
 A variety of rare earth metal-containing compounds are used to help to produce the colors in a smartphone's screen. Some of these compounds are also used to help reduce light penetration into the phone. Many of the 'rare earths' occur commonly in the Earth's crust, but often at levels too low to be economically extracted.



ELECTRONICS

WIRING AND MICROELECTRONICS
 Copper is used for wiring, and for microelectrical components along with gold and silver. Tantalum is the major component in microcapacitors.

MICROPHONES AND VIBRATIONS
 Nickel is used in the microphone and for electrical connections. Rare earth element alloys are used in magnets in the speaker and microphone, and the vibration unit.

THE SILICON CHIP
 Pure silicon is used to manufacture the chip, which is then oxidized to produce nonconducting regions. Other elements are added to allow the chip to conduct electricity.

CONNECTING ELECTRONICS
 Tin and lead were used in older solders; newer, lead-free solders use a mix of tin, copper and silver.



BATTERY



Most phones use lithium ion batteries, composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Sometimes other metals, such as manganese, are used in place of cobalt. The battery casing is often made of aluminium.

CASING

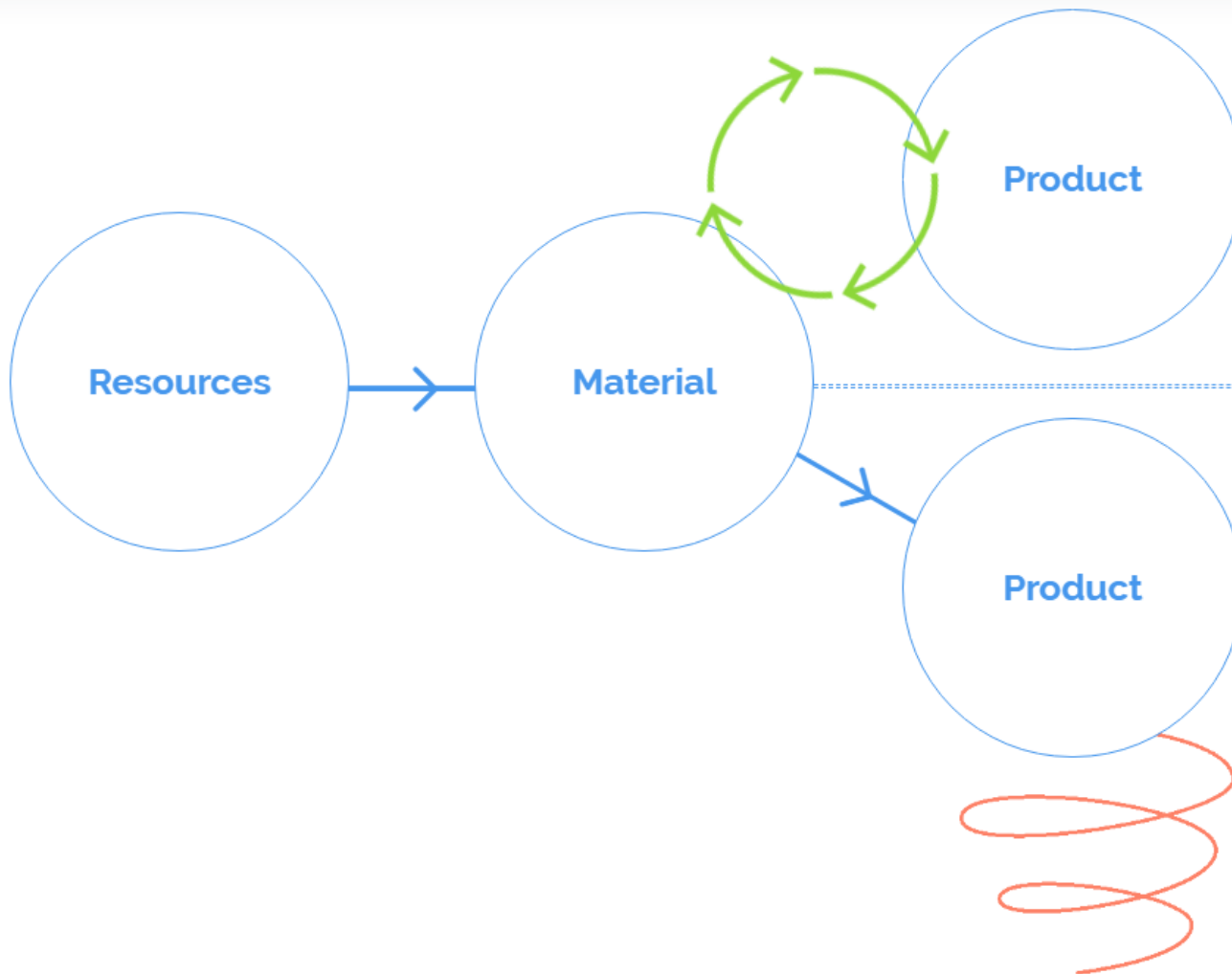


Magnesium alloy is used to make some phone cases, while many others are made of plastics, which are carbon-based. Plastics will also include flame retardant compounds, some of which contain bromine, and nickel can be included to reduce electromagnetic interference.



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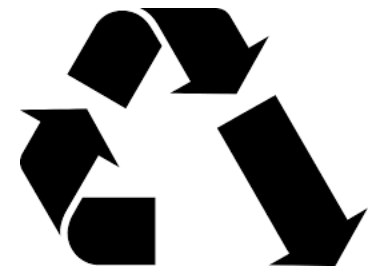


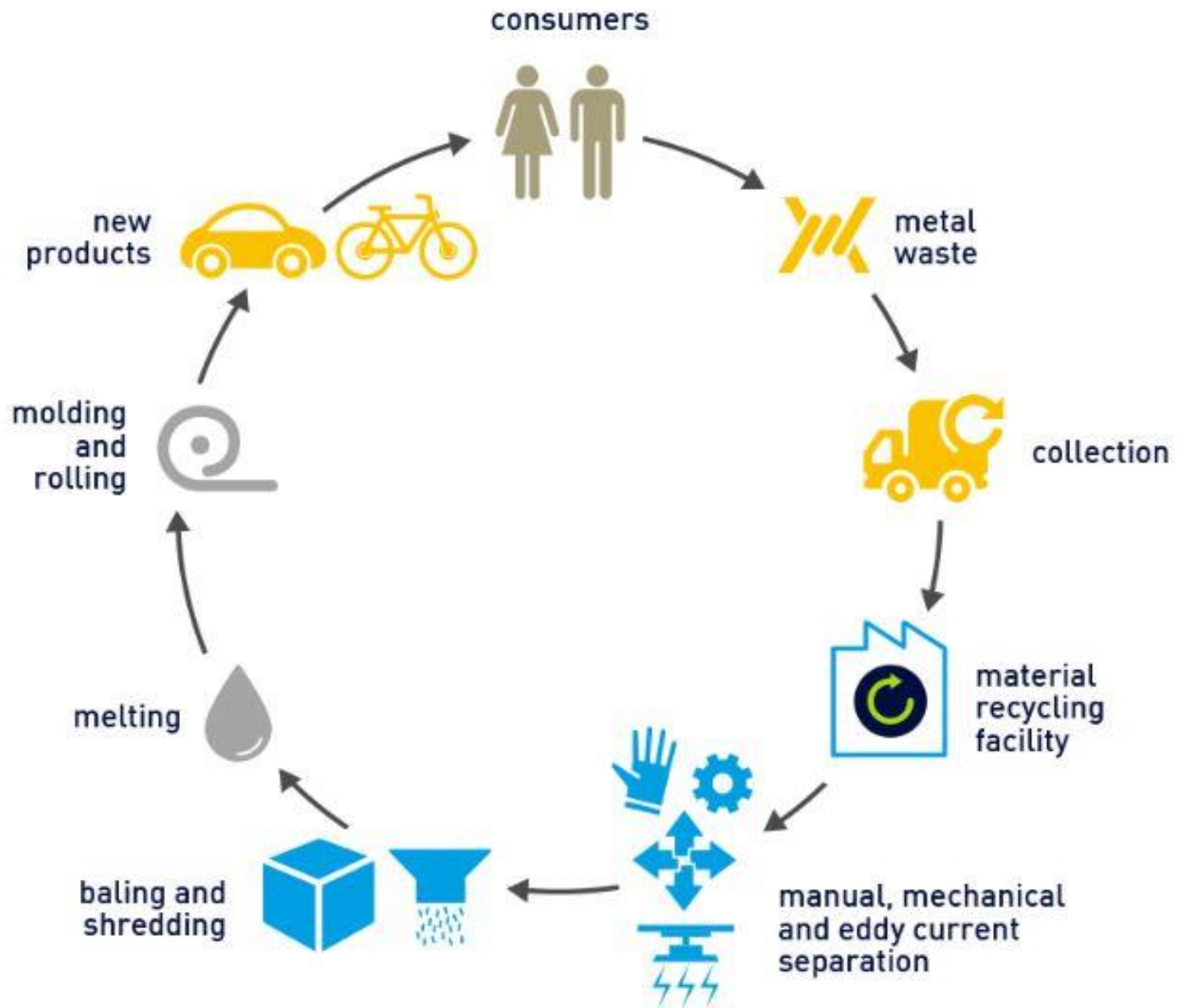


METAL

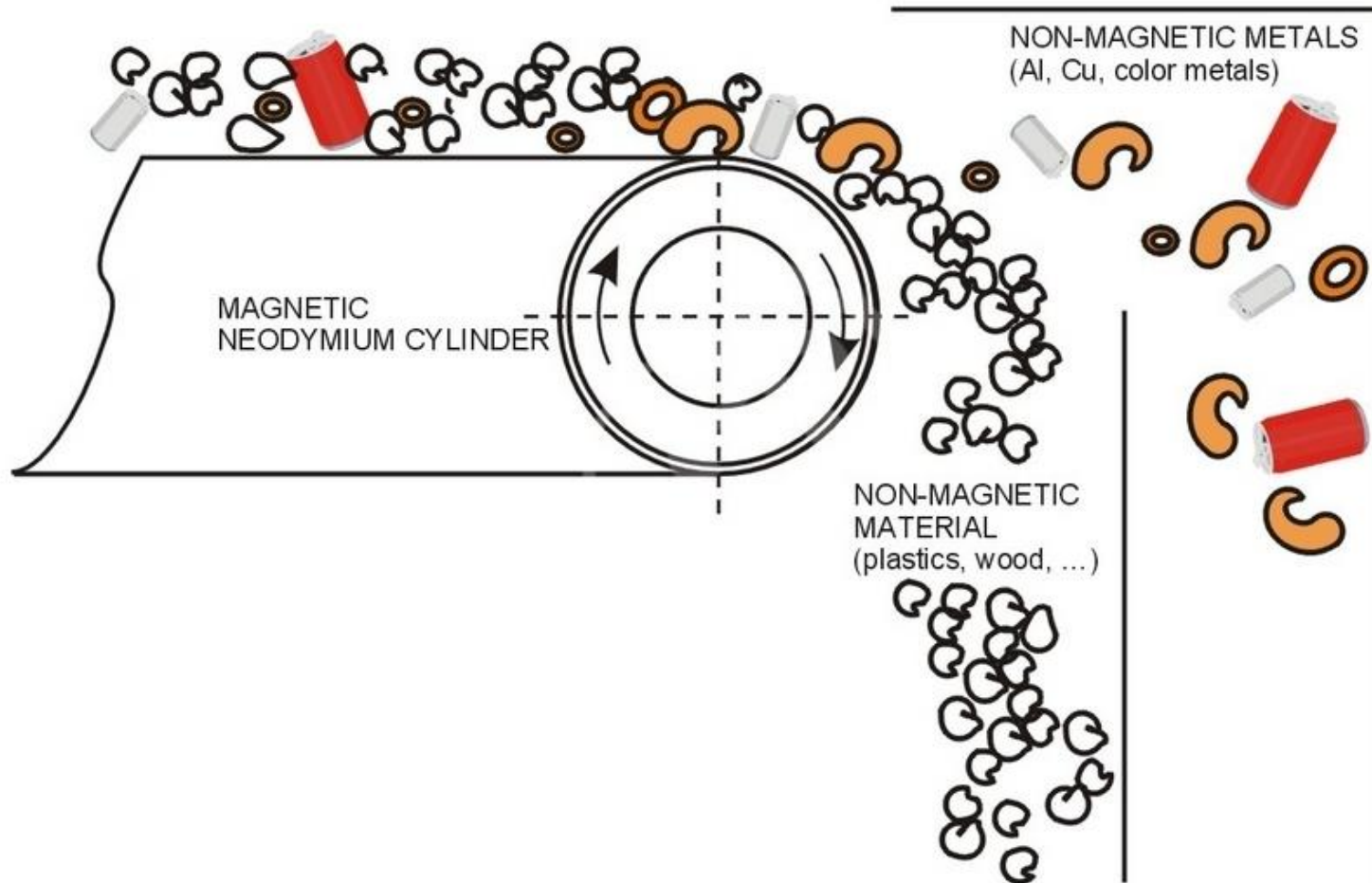
**recycles
 forever**
 Permanent
 material loop

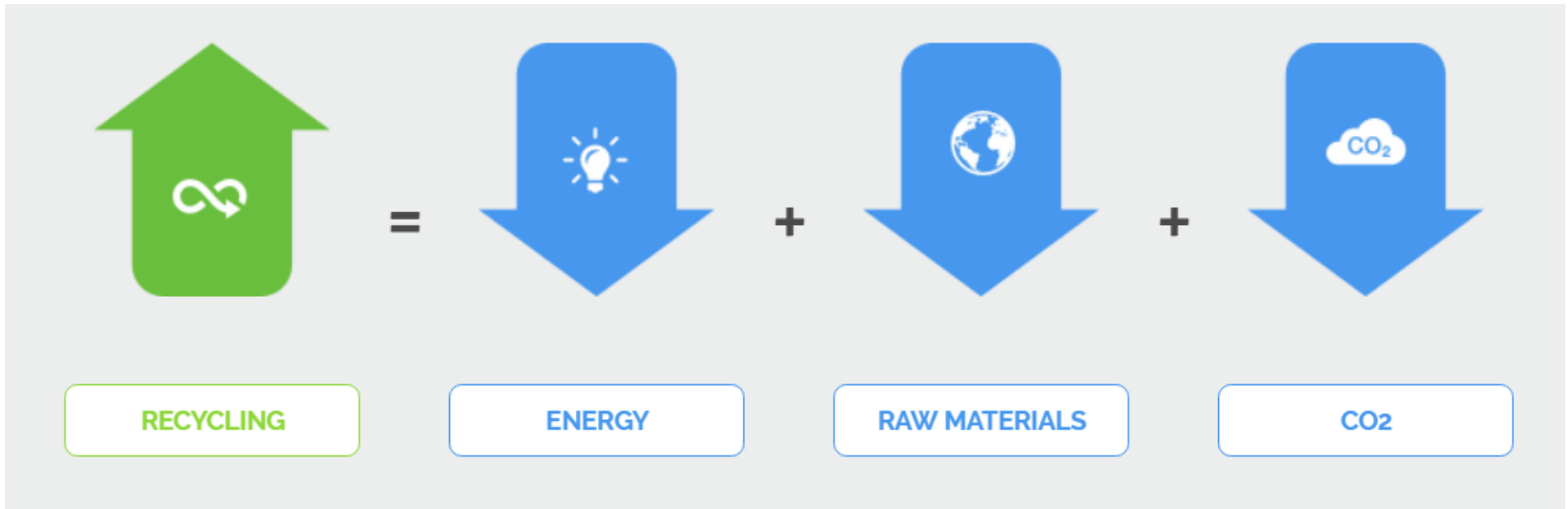
Non-permanent
 material spiral to
 end of life

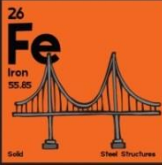
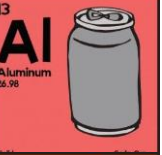


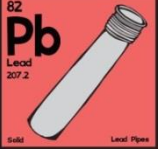
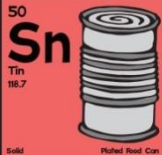
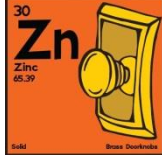




Metal waste separation





	Metal	Recycle (%)	Energy saved (%)	CO ₂ saved (%)
 <p>26 Fe Iron 55.85 Solid Steel Structures</p>	Steel	42	60	58
 <p>13 Al Aluminum 26.98</p>	Aluminum	40	95	92
 <p>28 Ni Nickel 58.69 Solid Coins</p>	Nickel	60	90	90
 <p>29 Cu Copper 63.55 Solid Electric Wires</p>	Copper	35	80	65
 <p>82 Pb Lead 207.2 Solid Lead Pipes</p>	Lead	74	98	99
 <p>50 Sn Tin 118.7 Solid Tinned Food Cans</p>	Tin	75	98	99
 <p>30 Zn Zinc 65.39 Solid Brass Doorknobs</p>	Zinc	20	60	76

Losses in the recovery chain

- ❖ WEEE are not collected, everything ends in a landfill
- ❖ WEEE are collected, but:
 - Are stolen in municipal collecting points or during the following recycling stages
 - Are legally exported in developing countries where recycling is not active
 - Are collected for sham recycling



E-waste in India





E-waste in India



“Low-tech” gold recycling in Bangalore/India (photo by courtesy of EMPA, Switzerland)



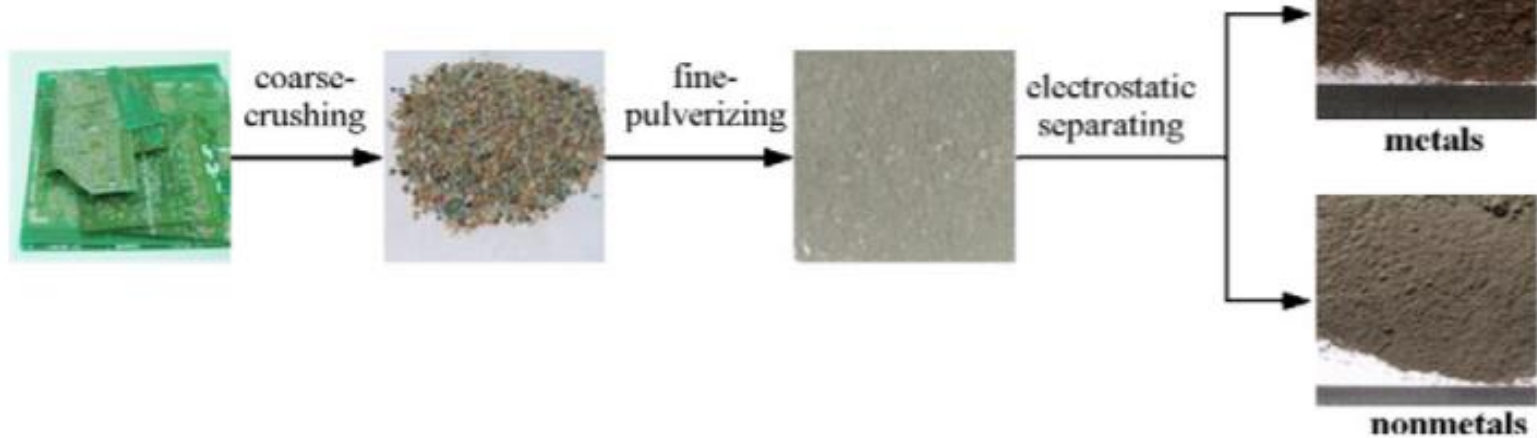




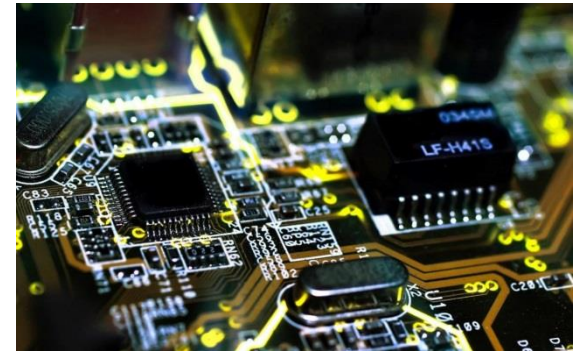
❖ When WEEE collection is active, there are losses in recycling due to:

- Wrong separate collection

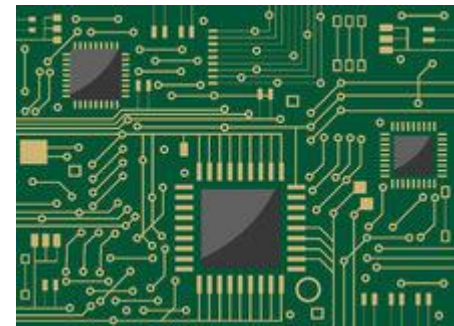
- Losses in the mechanical treatment



- Technical limits for the recovery of metals from several alloys



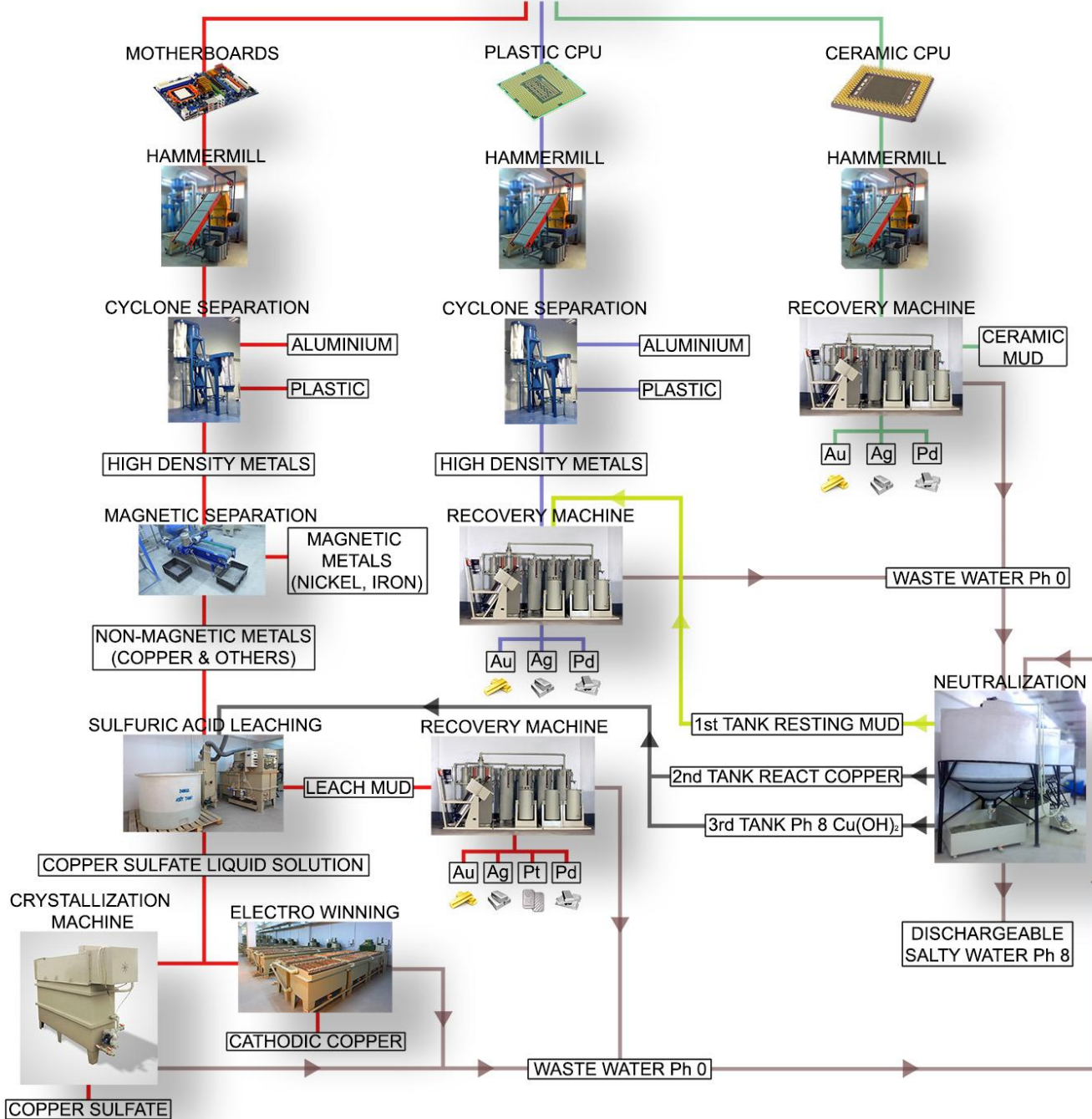
- Miniaturization and use of strong glues in circuits



- Many plants recover only metals with have an established and profitable market



E-WASTE



Materials recovered

**plastic
ceramic**

**gold
silver
platinum
palladium
copper
aluminum
nickel
iron**

Metals in waste

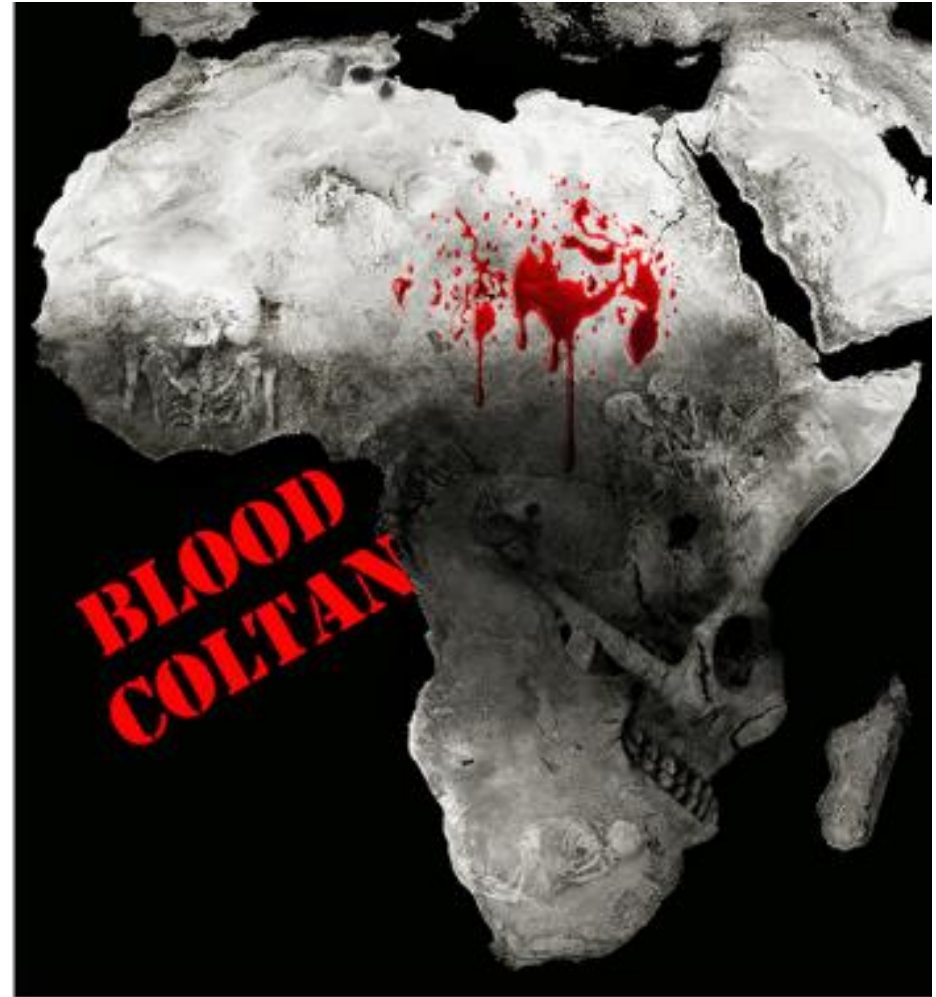
Industrial waste, car demolition, building, big equipments (mainly aluminum, iron, steel)

Urban waste (cans, metal containers, WEEE): a bit of everything, but are recovered mainly aluminum, iron, steel, copper, nickel, zinc, lead, and precious metals.

WEEE categories in Italy



THE DARK SIDE OF THE SMARTPHONES



11 MILLION DEATHS

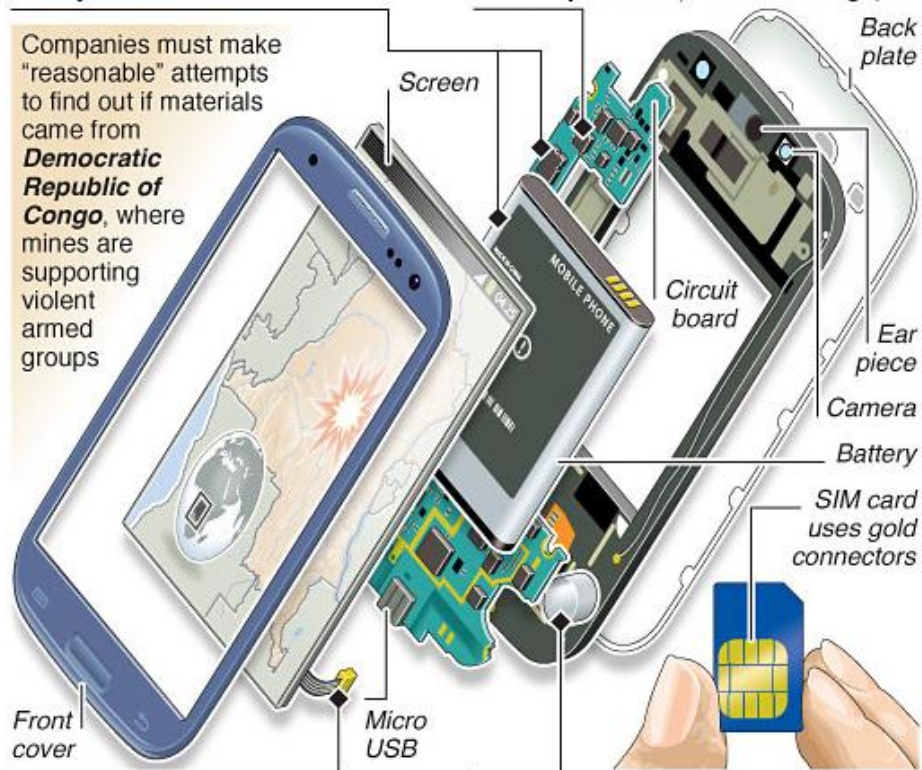
Conflict minerals clampdown

The *Securities and Exchange Commission* has ruled that U.S.-listed manufacturers such as Apple and Boeing must scrutinise the sources of four metals to make sure they don't help fund human rights abuses

ANATOMY OF A SMART PHONE

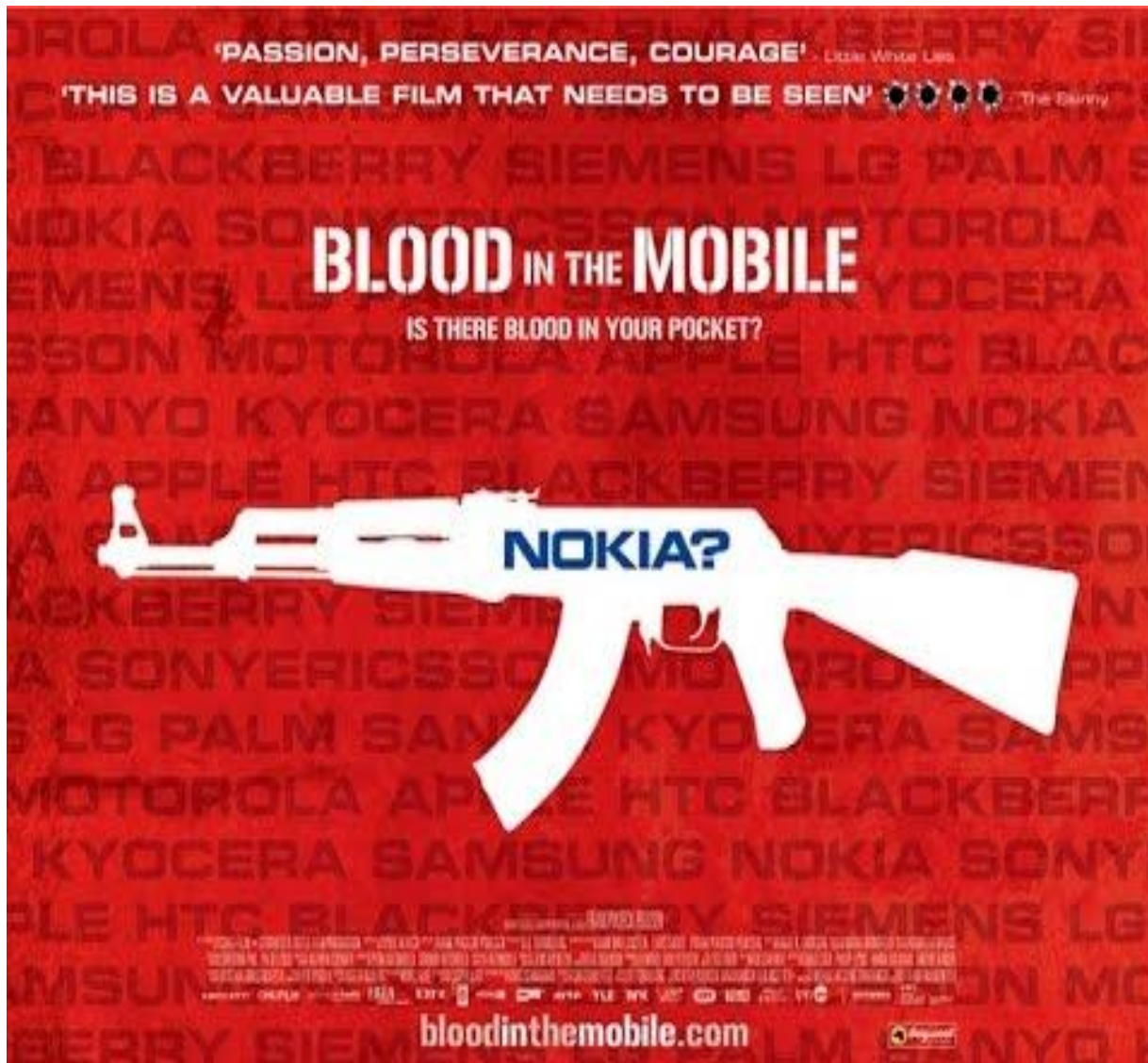
50
Sn
Tin
Tin aka *stannum* (Latin)
Silvery, malleable metal that does not easily oxidize in air
Source: Cassiterite
Use: Circuit board **solder** and battery **anodes**

73
Ta
Tantalum
Tantalum from *Tantalus* (Greek mythological figure)
Rare, hard, lustrous metal. Highly corrosion resistant
Source: Columbite-tantalite (Coltan)
Use: **Capacitors** (electrical storage)



79
Au
Gold
Gold aka *aurum* (Latin)
Dense, soft, malleable metal
Source: Nuggets or grains in rock and alluvial deposits
Use: **Connectors** – does not corrode in air like silver and copper
Source: Wire agencies

74
W
Tungsten
Tungsten from *tung sten* (Swedish) meaning "heavy stone"; aka **wolfram** (German). Hard, rare metal
Source: Wolframite
Use: **Vibration motor**



Blood in the Mobile (2010) a documentary by Frank Piasecki Poulsen,
<https://www.youtube.com/watch?v=Tv-hE4Yx0LU>





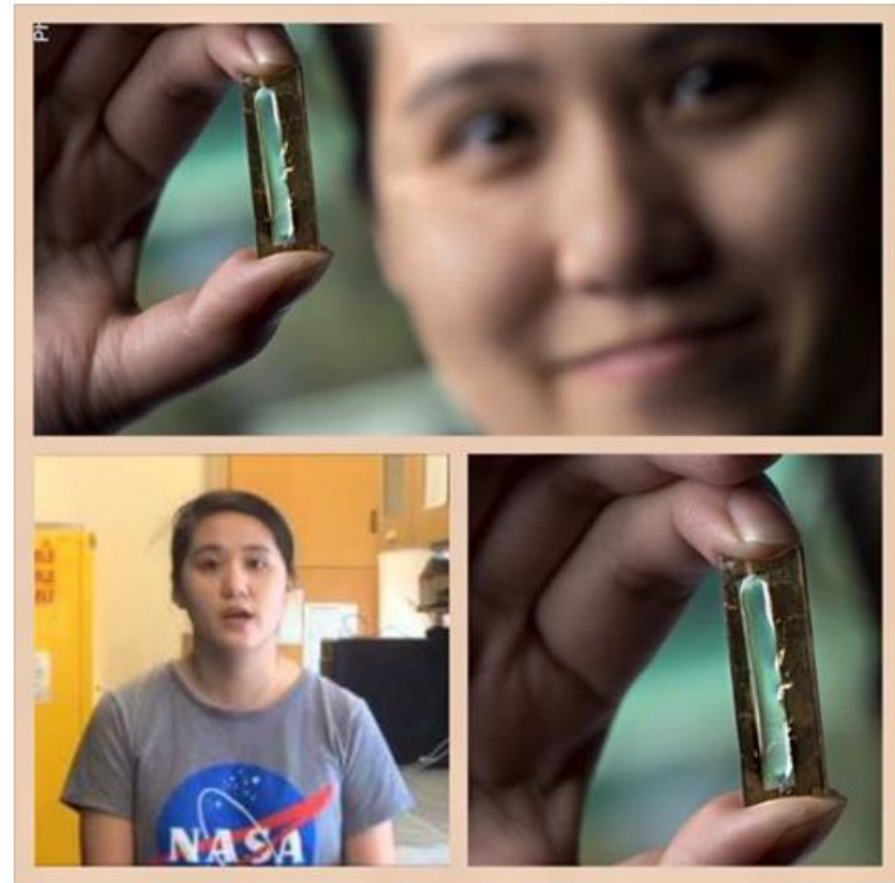
“Kids in Congo are being sent down into mines to die so that kids in Europe and America can kill imaginary aliens in their living rooms or text each other” (Oona King)

Solutions?



a) Research of substitutes more easily available or of innovative technological solutions

The person behind the important revolutionary discovery in this battery industry is Mya Le Thai, a Vietnamese-born graduate student who is preparing to earn her Ph.D. at UCI.



b1) Search of new mines, recover mineral wastes of old ones, sift the oceans, ...

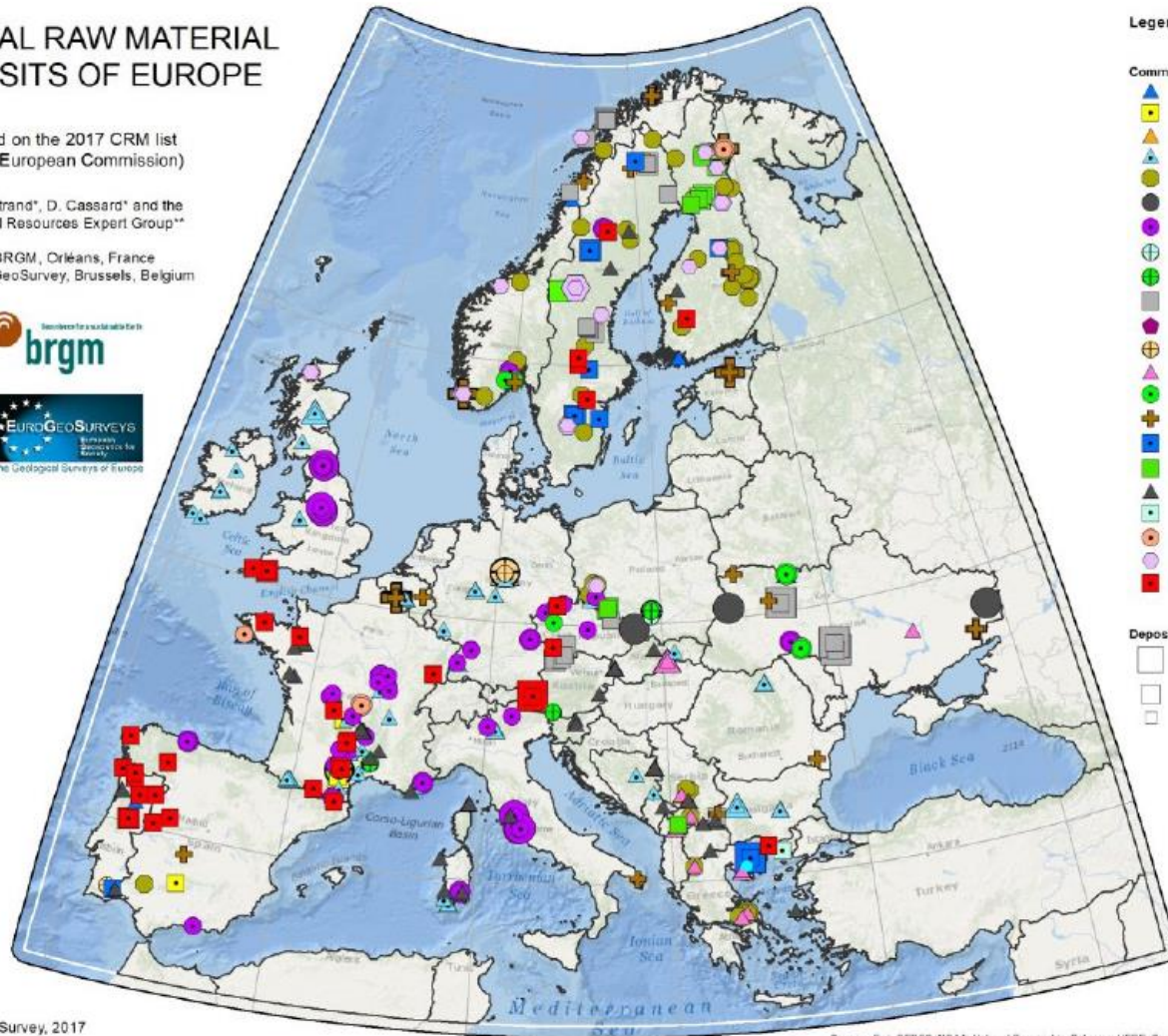
Map of CRM ore deposits in Europe

CRITICAL RAW MATERIAL DEPOSITS OF EUROPE

(based on the 2017 CRM list of the European Commission)

G. Bertrand*, D. Cassard* and the Mineral Resources Expert Group**

* BRGM, Orléans, France
 ** EuroGeoSurvey, Brussels, Belgium



Legend

Commodity

- Beryllium (BeO)
- Boron (metal)
- Boron (B₂O₃)
- Boric (BaSO₄)
- Cobalt (metal)
- Coking coal
- Fluorite (CaF₂)
- Gallium (metal)
- Germanium (metal)
- Graphite
- Iodine (metal)
- Iridium (metal)
- Magnesium, magnesium (Mg/CO₂)
- Niobium - columbium (Nb₂O₅)
- Phosphate (P₂O₅)
- Rare earth elements (RE₂O₃)
- Platinum, platinum group metals
- Antimony (metal)
- Scandium (metal)
- Tantalum (Ta₂O₅)
- Vanadium (metal)
- Wolfram (WCO)

Deposit size

- Class A (super large)
- Class B (large)
- Class C (medium)

b2) ... the Moon

WHY MINE THE MOON?

• ✨ Water ✨ •



There may be water on the moon brought there by asteroids during collisions. And we are in need of fresh water. NASA scientists found that in 37 aquifers of fresh water on the earth, **21 are past the sustainability point.** [4]



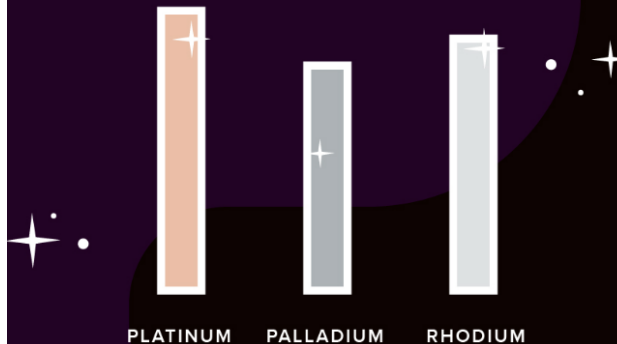
Rare earth metals (REMs)



The fifteen lanthanides, as well as scandium and yttrium – used in **modern electronics** and mostly produced in China

• ✨ Precious metals ✨ •

Many precious metals are used in everything from jewelry to smartphones to cancer treatments. Iron, nickel and cobalt may also be found on the moon.



• ✨ Helium-3 ✨ •

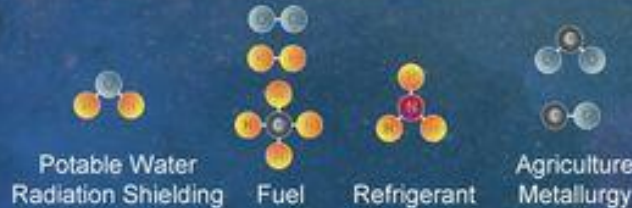
This element is rare on Earth, much more common on the moon and ideal for work in nuclear fusion. In recent years due to demand, the price of helium-3 can be as much as \$2,000 per liter.



b3) ... the asteroids

High Value Asteroid Materials

ASTEROID ELEMENTAL ABUNDANCE RELATIVE TO EARTH'S CRUST



VOLATILES AND H₂O
to fuel the growth of
humanity into new frontiers



INDUSTRIAL METALS
to construct and
sustainably service space
platforms



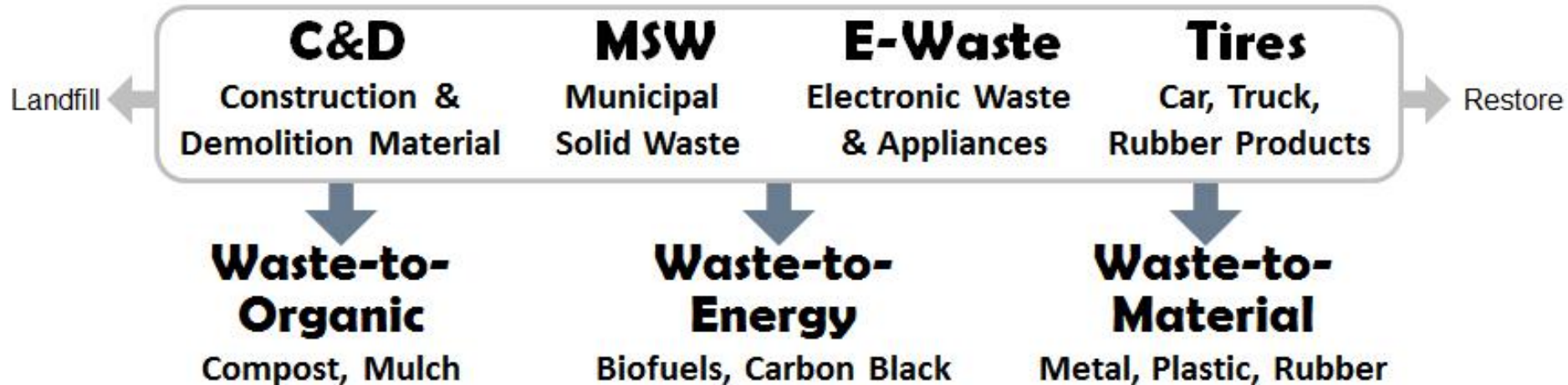
PLATINUM GROUP METALS
to support demand growth on
Earth



Despite desire to reduce dependency,
one-in-four manufactured goods require PGMs.

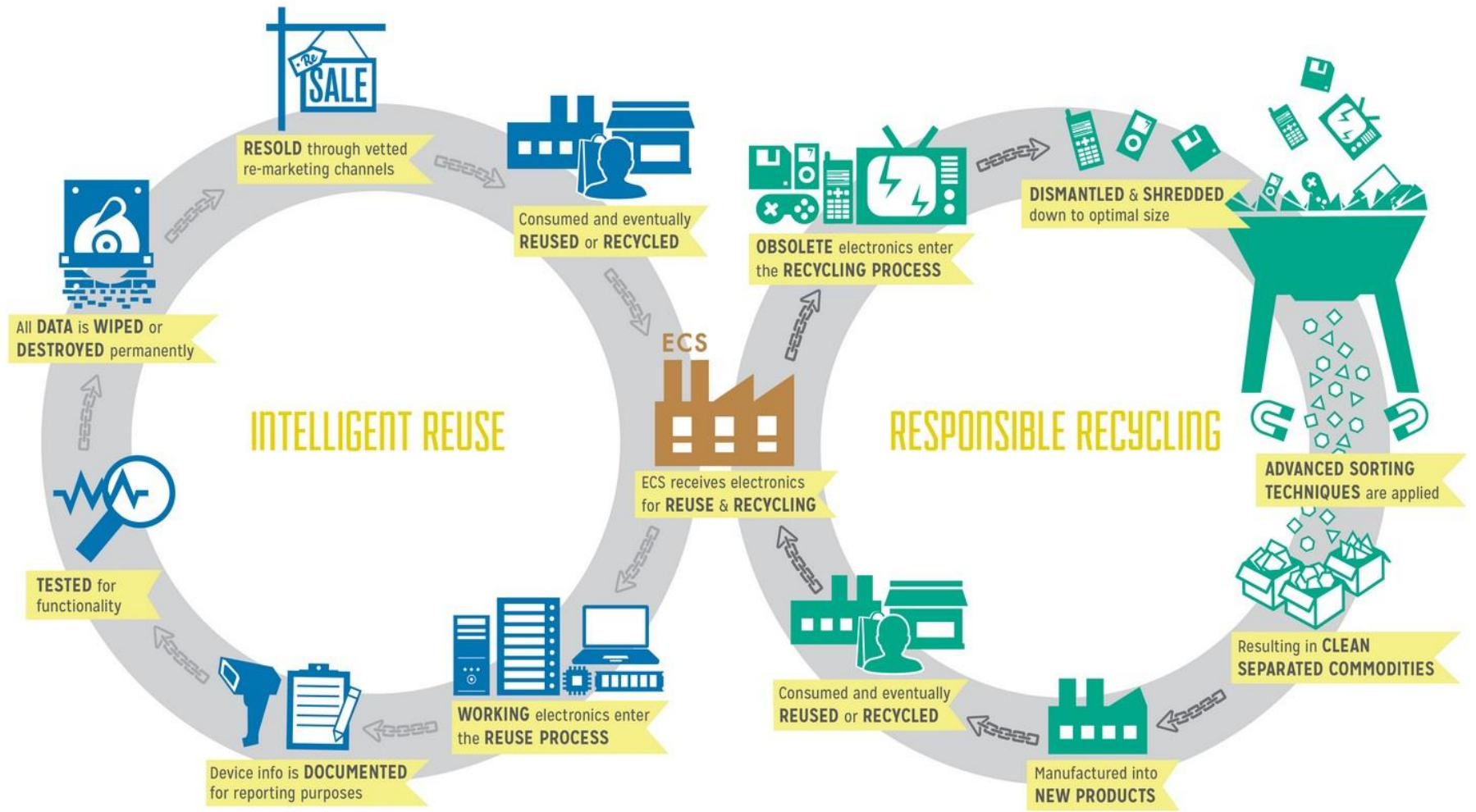
b4) ...urban minig

Urban Mining Process: Reclamation of valuable raw materials and metals from urban waste streams.



Urban Mining Goal: Monetize urban waste streams in order to produce revenue, businesses and jobs.

c) Improve E-waste recovery and reuse



d) Get informed before buying.

Prefer factories with more efficient design and ethical chain of supply



Design di lunga durata >



Materiali "fair" >



Buone condizioni di lavoro >

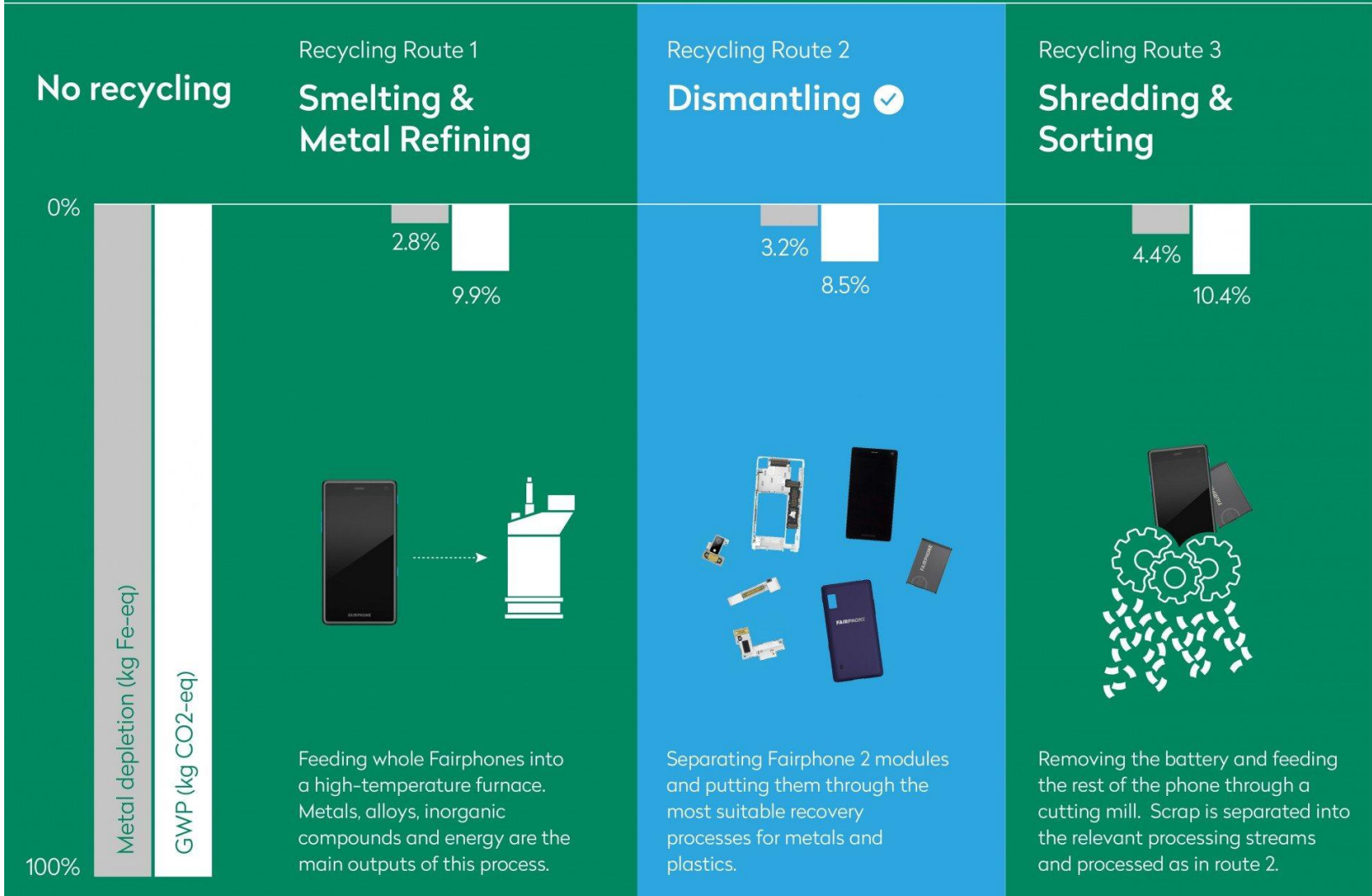


Riuso e riciclo >





Improvement relative to no recycling



The least metal depletion, but also the second-highest rate of global warming potential (GWP, measured by CO₂ equivalent).

A bit higher metal depletion than route 1, but with the lowest GWP

The least desirable results, both in terms of metal depletion and GWP

PuzzlePhone is the long-lasting smartphone with three easy-to-change modules. Repair and customize your device easily - make it last and make it your own. PuzzlePhone is reliable, upgradeable, and repairable!

Need more power? Did you break your screen? Need a special module with extra sensors? All are easily replaced - by the user!



1 Brain

The Brain contains critical electronics: the CPU, GPU, RAM, memory, and cameras.

2 Spine

The Spine is the structure: the high-res display. Core spine elements will be available in a variety of sizes and materials.

3 Heart

The Heart contains the battery: it will be the enabler of secondary electronics and features chosen by the user.

Phonebloks: a phone that can be built like Lego

Phonebloks is a smartphone made up of separate parts that can be swapped and replaced like Lego so it lasts for ever and can be customised



A screenshot of Phoneblok's design featured in the video Photo: DAVE MOVIES

Long queues outside London Apple store as new iPhone X goes on sale

With prices starting at £999, it is the most expensive iPhone ever.



People queue outside the Apple Store on Regent Street, London, as the iPhone X goes on sale (Martyn Landi/PA)