



Alberto Zanelli



This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

The challenge of raw materials





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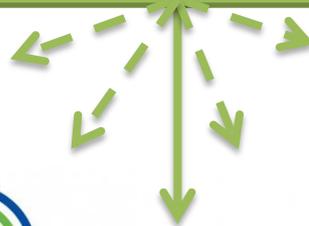
Pure research



Pure research projects submitted by single researchers.



Applied research



A community of research institutions and companies



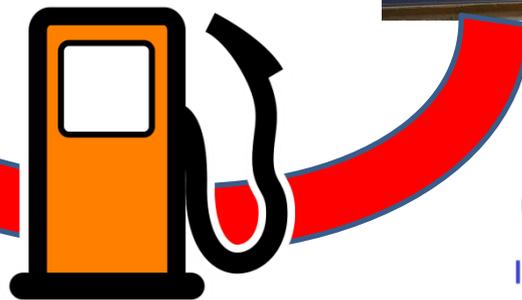
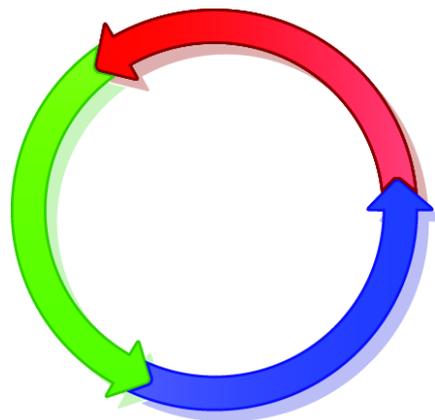
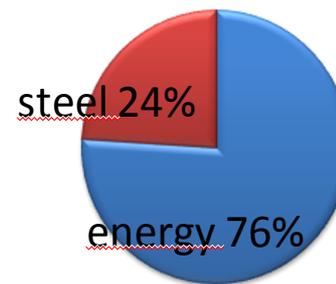
The Italian National Research Council is a public institution devoted to research. Its institutes are present on the whole territory of Italy and are dealing with all kinds of scientific issues.



Everything that is not food or energy is a raw material



7 billions of tonnes of coal per year



- Elements are the simplest raw materials.
- Elements are “the smallest bricks” of the Universe.
- At the present we do not know a convenient way to convert an element to another.

(Dimitrij M. Mendeleev, 1869)

PERIODIC TABLE OF THE ELEMENTS

Legend:

- Nonmetals:** Other nonmetals (yellow), Halogens (orange), Noble gases (purple)
- Metals:** Alkali metals (light blue), Alkaline earth metal (medium blue), Lanthanoids (pink), Actinoids (light green), Transition metals (green)
- Metalloids:** Grey
- Post-transition metals:** Cyan

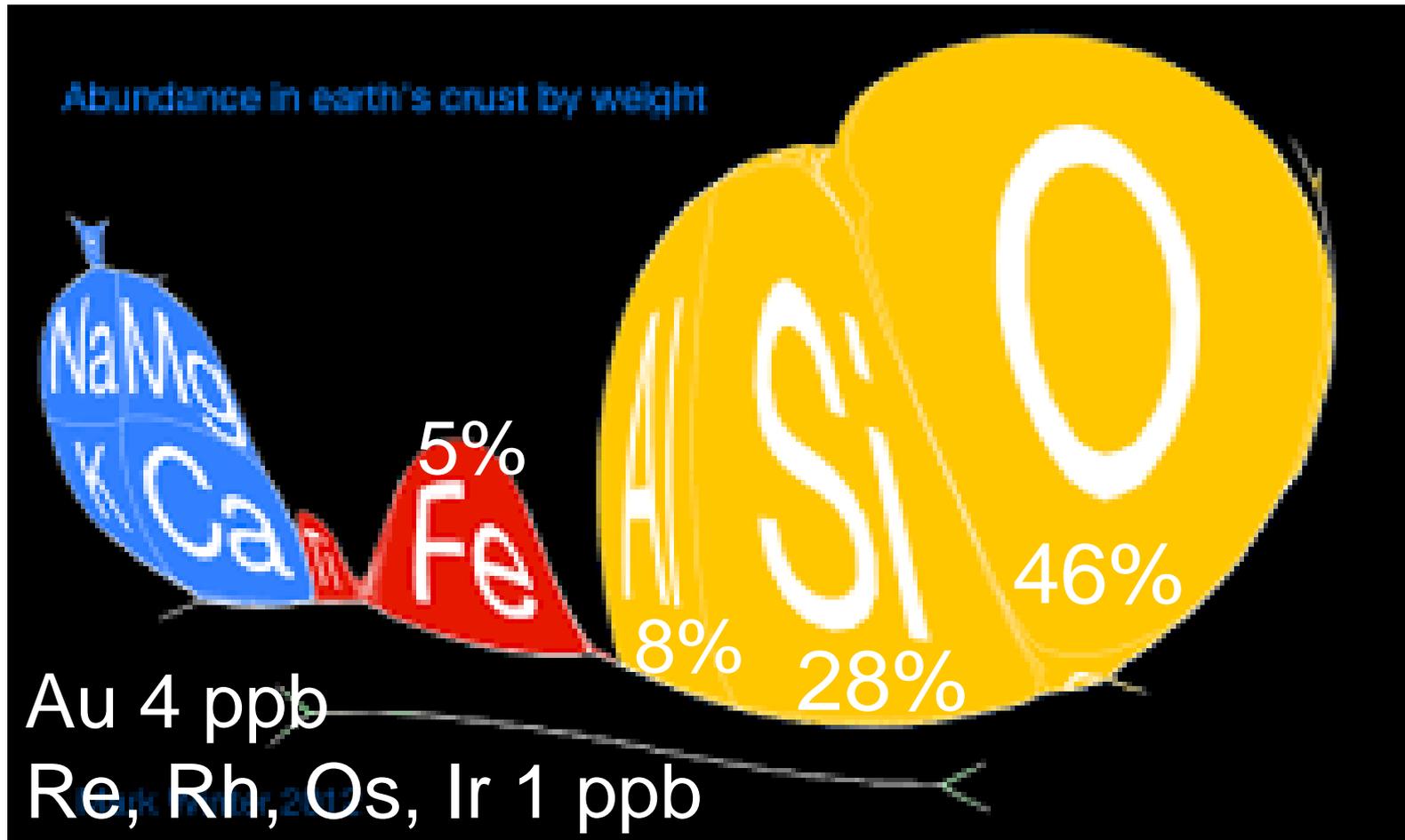
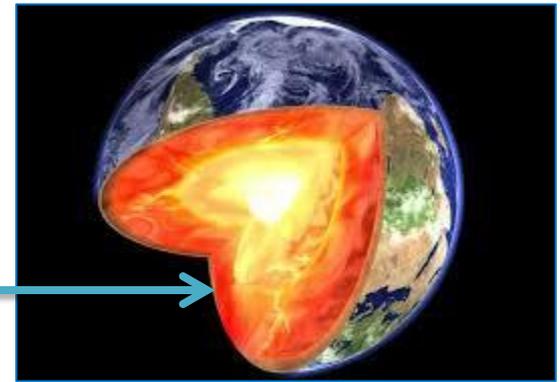
Callout for Potassium (K):

- Group: IUPAC 1, CAS IA
- Atomic number: 19
- Symbol: K
- Relative atomic mass: 39.098
- Element name: Potassium

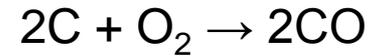
| | | | | | | | | | | | | | | | | | |
|----------------------------------|---------------------------------|------------------------------------|-----------------------------------|--------------------------------|---------------------------------|---------------------------------|----------------------------------|--------------------------------|---------------------------------|--------------------------------|-------------------------------|---------------------------------|----------------------------------|----------------------------------|---------------------------------|----------------------------------|---------------------------------|
| 1 H 1.0079 Hydrogen | | | | | | | | | | | | | | | | | 2 He 4.0026 Helium |
| 3 Li 6.941 Lithium | 4 Be 9.0122 Beryllium | | | | | | | | | | | 5 B 10.81 Boron | 6 C 12.011 Carbon | 7 N 14.007 Nitrogen | 8 O 15.999 Oxygen | 9 F 18.998 Fluorine | 10 Ne 20.180 Neon |
| 11 Na 22.990 Sodium | 12 Mg 24.305 Magnesium | | | | | | | | | | | 13 Al 26.982 Aluminum | 14 Si 28.086 Silicon | 15 P 30.974 Phosphorus | 16 S 32.065 Sulfur | 17 Cl 35.453 Chlorine | 18 Ar 39.948 Argon |
| 19 K 39.098 Potassium | 20 Ca 40.078 Calcium | 21 Sc 44.956 Scandium | 22 Ti 47.867 Titanium | 23 V 50.942 Vanadium | 24 Cr 51.996 Chromium | 25 Mn 54.938 Manganese | 26 Fe 55.845 Iron | 27 Co 58.933 Cobalt | 28 Ni 58.693 Nickel | 29 Cu 63.546 Copper | 30 Zn 65.39 Zinc | 31 Ga 69.723 Gallium | 32 Ge 72.63 Germanium | 33 As 74.922 Arsenic | 34 Se 78.96 Selenium | 35 Br 79.904 Bromine | 36 Kr 83.80 Krypton |
| 37 Rb 85.468 Rubidium | 38 Sr 87.62 Strontium | 39 Y 88.906 Yttrium | 40 Zr 91.224 Zirconium | 41 Nb 92.906 Niobium | 42 Mo 95.94 Molybdenum | 43 Tc 98 Technetium | 44 Ru 101.07 Ruthenium | 45 Rh 102.91 Rhodium | 46 Pd 106.42 Palladium | 47 Ag 107.87 Silver | 48 Cd 112.41 Cadmium | 49 In 114.82 Indium | 50 Sn 118.71 Tin | 51 Sb 121.76 Antimony | 52 Te 127.60 Tellurium | 53 I 126.90 Iodine | 54 Xe 131.29 Xenon |
| 55 Cs 132.91 Cesium | 56 Ba 137.33 Barium | 57-71 La-Lu Lanthanide | 72 Hf 178.49 Hafnium | 73 Ta 180.95 Tantalum | 74 W 183.84 Tungsten | 75 Re 186.21 Rhenium | 76 Os 196.23 Osmium | 77 Ir 192.22 Iridium | 78 Pt 195.08 Platinum | 79 Au 196.97 Gold | 80 Hg 200.59 Mercury | 81 Tl 204.38 Thallium | 82 Pb 207.2 Lead | 83 Bi 208.98 Bismuth | 84 Po 209 Polonium | 85 At 210 Astatine | 86 Rn 222 Radon |
| 87 Fr 223 Francium | 88 Ra 226 Radium | 89-103 Ac-Lr Actinide | 104 Rf 261 Rutherfordium | 105 Db 262 Dubnium | 106 Sg 266 Seaborgium | 107 Bh 264 Bohrium | 108 Hs 269 Hassium | 109 Mt 268 Meitnerium | 110 Uun 271 Ununnilium | 111 Uuu 272 Unununium | 112 Uub 277 Unbibium | 113 Uut 284 Ununtrium | 114 Uuq 289 Ununquadium | 115 Uup 288 Ununpentium | 116 Uuh 285 Ununhexium | 117 Uus 289 Ununseptium | 118 Uuo 286 Ununoctium |
| 57 La 138.91 Lanthanide | 58 Ce 140.12 Cerium | 59 Pr 140.91 Praseodymium | 60 Nd 144.24 Neodymium | 61 Pm 145 Promethium | 62 Sm 150.36 Samarium | 63 Eu 151.96 Europium | 64 Gd 157.25 Gadolinium | 65 Tb 158.93 Terbium | 66 Dy 162.5 Dysprosium | 67 Ho 164.93 Holmium | 68 Er 167.26 Erbium | 69 Tm 168.93 Thulium | 70 Yb 173.04 Ytterbium | 71 Lu 174.96 Lutetium | | | |
| 89 Ac 227 Actinide | 90 Th 232.04 Thorium | 91 Pa 231.04 Protactinium | 92 U 238.03 Uranium | 93 Np 237 Neptunium | 94 Pu 244 Plutonium | 95 Am 243 Americium | 96 Cm 247 Curium | 97 Bk 247 Berkelium | 98 Cf 251 Californium | 99 Es 252 Einsteinium | 100 Fm 257 Fermium | 101 Md 258 Mendelevium | 102 No 259 Nobelium | 103 Lr 260 Lawrencium | | | |



The periodic table of elements in agreement with the relative abundance on the Earth crust



Iron technology



Es. red siderite

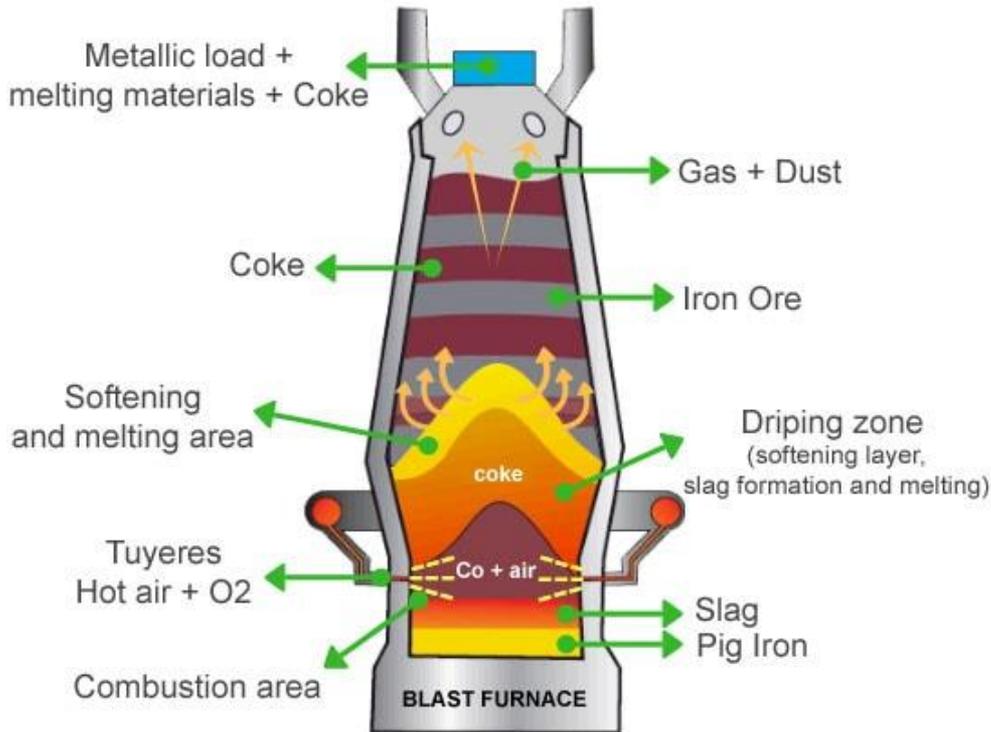
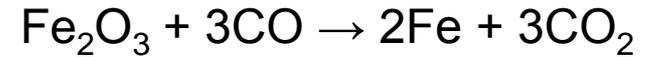
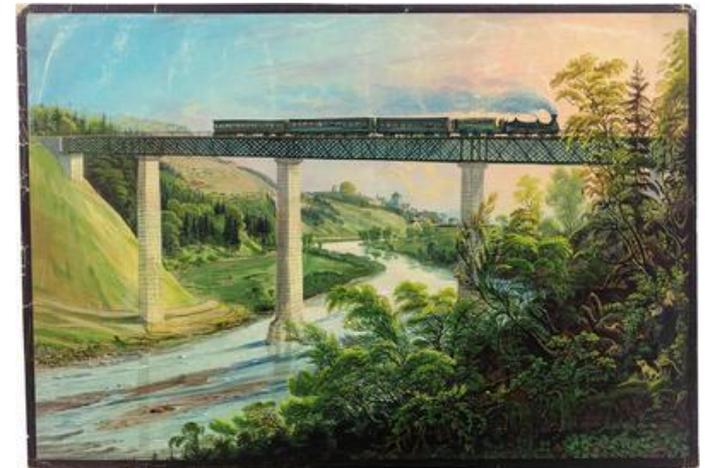
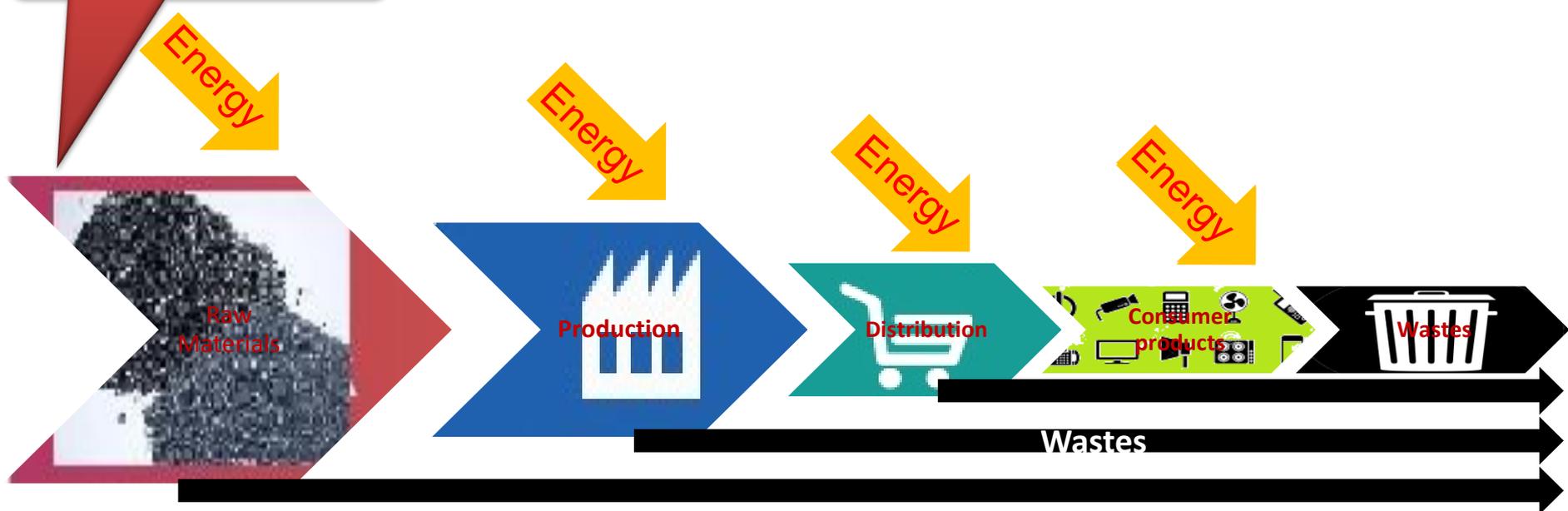


Figure 1 - Blast Furnace Operation



Raw materials

LINEAR ECONOMY





EuChemS



European Chemical Society



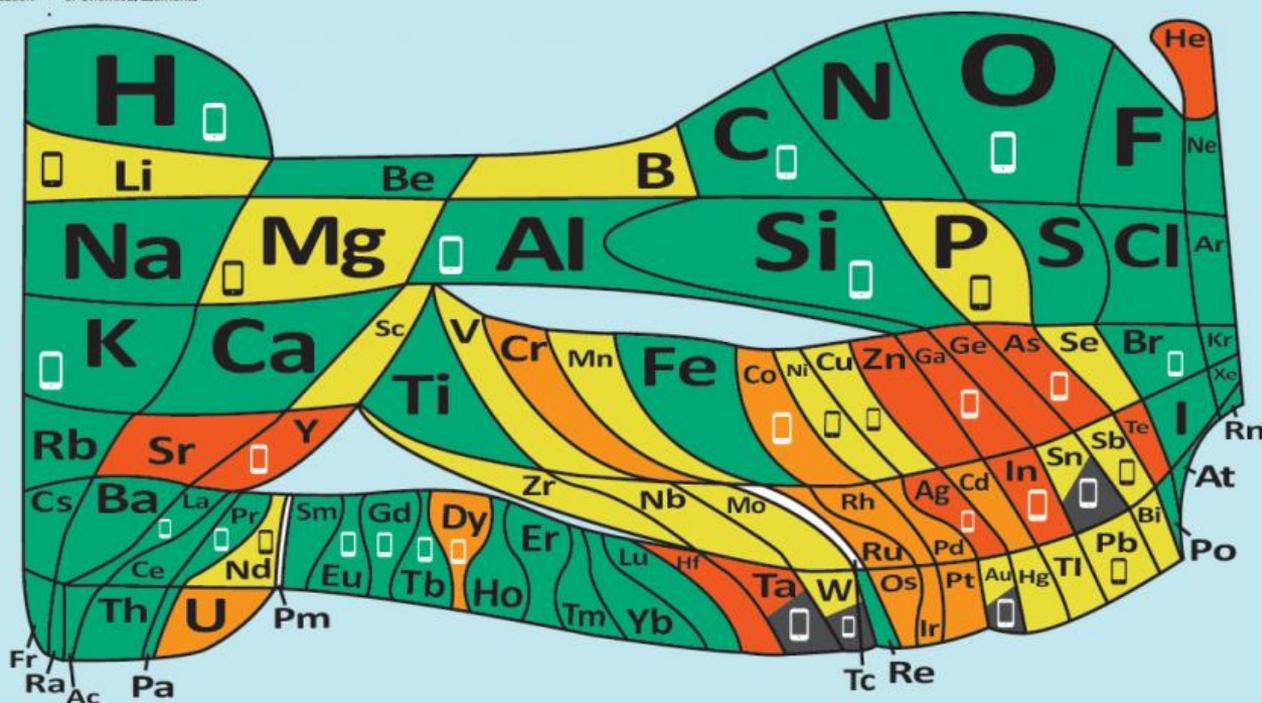
United Nations
Educational, Scientific and
Cultural Organization



2019
IYPT
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

Inspired by WF Sheehan's 'A Periodic Table with Emphasis', published in Chemistry, 1976, 49, 17-18'

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



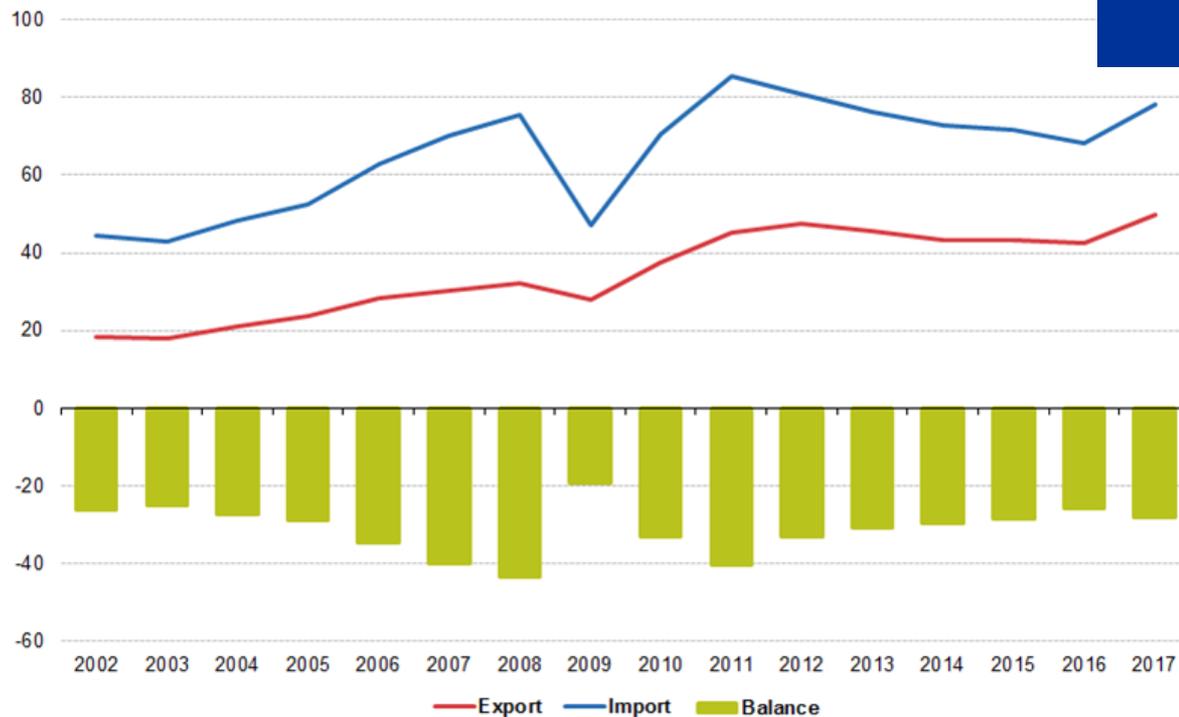
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<https://www.euchems.eu/>

Raw materials trade balance (millions of euros)



EU-28 exports, imports and trade balance in raw materials, 2002-2017
(EUR billion)



Source: Eurostat (online data code: DS-018995)

eurostat

(EUROSTAT http://ec.europa.eu/eurostat/statistics-explained/index.php/International_trade_in_raw_materials)

CRITICAL RAW MATERIALS

Raw materials becomes critical when the value in European economy is combined with high supply risk



Study on the review of the list of
Critical Raw Materials
Critical Raw Materials Factsheets

Written by
Deloitte Sustainability
British Geological Survey
Bureau de Recherches Géologiques et Minières
Netherlands Organisation for Applied Scientific Research
June 2017

Deloitte.



brgm

TNO innovation
for life



Critical raw material list

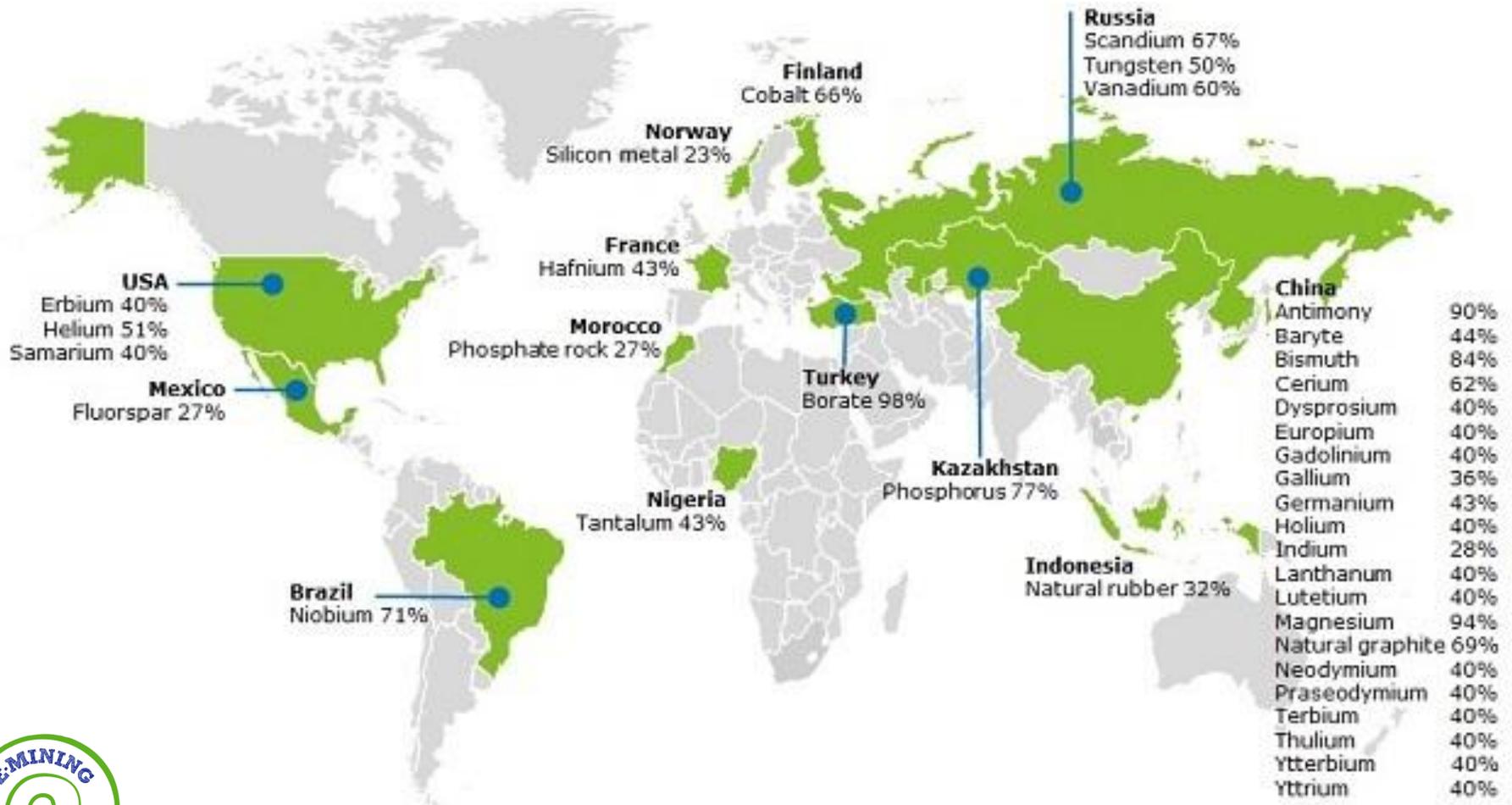
The image shows a periodic table with several elements highlighted in yellow and callouts pointing to them. The callouts are:

- Natural rubber, natural graphite and carbon coke. (points to C)
- Phosphor and phosphates (points to P)
- fluorites (points to F)
- borates (points to B)
- Platinum group metals (points to Ru, Rh, Pd, Os, Ir, Pt)
- barite (points to Ba)
- Light rare earths (points to La, Ce, Pr, Nd, Pm, Sm)
- heavy rare earths (points to Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu)

| | | | | | | | | | | | | | | | | | |
|---------------------------------|-------------------------------|----------------------------------------|------------------------------------|---------------------------------------|-------------------------------------|--------------------------------------|---------------------------------------|---------------------------------------|----------------------------------------|---------------------------------------|-----------------------------------------|-----------------------------------------|--------------------------------------|------------------------------------------|---------------------------------------|-----------------------------------------|----------------------------|
| 1 IA H idrogeno | 2 IIA He elio | | | | | | | | | | | | | | | | |
| 3 Li litio | 4 Be berillio | | | | | | | | | | | 5 B boro | 6 C carbonio | 7 N azoto | 8 VIA O ossigeno | 9 VIIA F fluoro | 10 Ne neon |
| 11 Na sodio | 12 Mg magnesio | 13 IIIB Al alluminio | 14 IVA Si silicio | 15 VA P fosforo | 16 VIA S zolfo | 17 VIIA Cl cloro | 18 Ar argon | | | | | | | | | | |
| 19 K potassio | 20 Ca calcio | 21 IIIB Sc scandio | 22 IVB Ti titanio | 23 VB V vanadio | 24 VIB Cr cromo | 25 VIIB Mn manganese | 26 VIII B Fe ferro | 27 Co cobalto | 28 Ni nicchel | 29 IB Cu rame | 30 IIB Zn zinc | 31 Ga gallo | 32 Ge germanio | 33 As arsenico | 34 Se selenio | 35 Br bromo | 36 Kr kripton |
| 37 Rb rubidio | 38 Sr stronzio | 39 IIIB Y ittrio | 40 IVB Zr zirconio | 41 VB Nb niobio | 42 VIB Mo molibdeno | 43 VIIB Tc tecnecio | 44 VIII B Ru rutenio | 45 Rh rodio | 46 Pd palladio | 47 IB Ag argento | 48 IIB Cd cadmio | 49 In indio | 50 Sn stagno | 51 Sb antimonio | 52 Te tellurio | 53 I iodio | 54 Xe xeno |
| 55 Cs cesio | 56 Ba bario | 57 IIIB La lantanio | 58 IVB Ce cerio | 59 VB Pr praseodimio | 60 VIB Nd neodimio | 61 VIIB Pm promezio | 62 VIII B Sm samario | 63 VIII B Eu europio | 64 VIII B Gd gadolinio | 65 VIII B Tb terbio | 66 VIII B Dy disprosio | 67 VIII B Ho olmio | 68 VIII B Er erbio | 69 VIII B Tm tulio | 70 VIII B Yb itterbio | 71 VIII B Lu lutezio | |
| 87 Fr francio | 88 Ra radio | 89-103 IIIB Ac attinio | 90 IVB Th torio | 91 VB Pa protoattinio | 92 VIB U uranio | 93 VIIB Np nettunio | 94 VIII B Pu plutonio | 95 VIII B Am americio | 96 VIII B Cm curio | 97 VIII B Bk berkelio | 98 VIII B Cf californio | 99 VIII B Es einsteinio | 100 VIII B Fm fermio | 101 VIII B Md mendelevio | 102 VIII B No nobelio | 103 VIII B Lr laurenzio | |

Communication of the European Commission COM(2017)490.

Geography of the critical raw material suppliers



Coke



Produced by thermal treatment of coal at 1100-1200°C. It is used in metallurgy. EU imports 63%, it is prudentially considered critical.

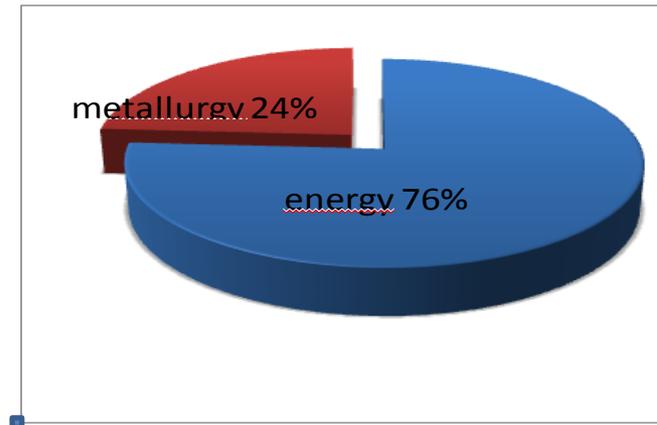
World production per year:

7,5 billions of tonnes

Price ~100 €/tonn

China 54%, Australia 15%, USA

7%, Russia 7%, **EU 5%**



Phosphate rocks and white Phosphor



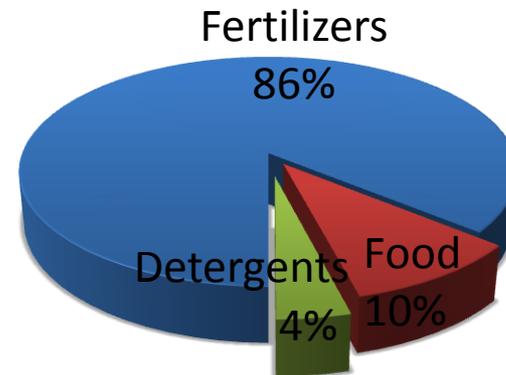
Rocks with general composition $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$. EU import 88%. White Phosphor is produced by an energy intensive process. P is used in chemistry (90%), electronics (5%) and metallurgy (5%).

World production per year:
218 million of tonnes,

Price ~100 €/ton;

China 44%, Morocco 13%, USA
13%, **EU 0,4%.**

White Phosphor 915000 tonnes



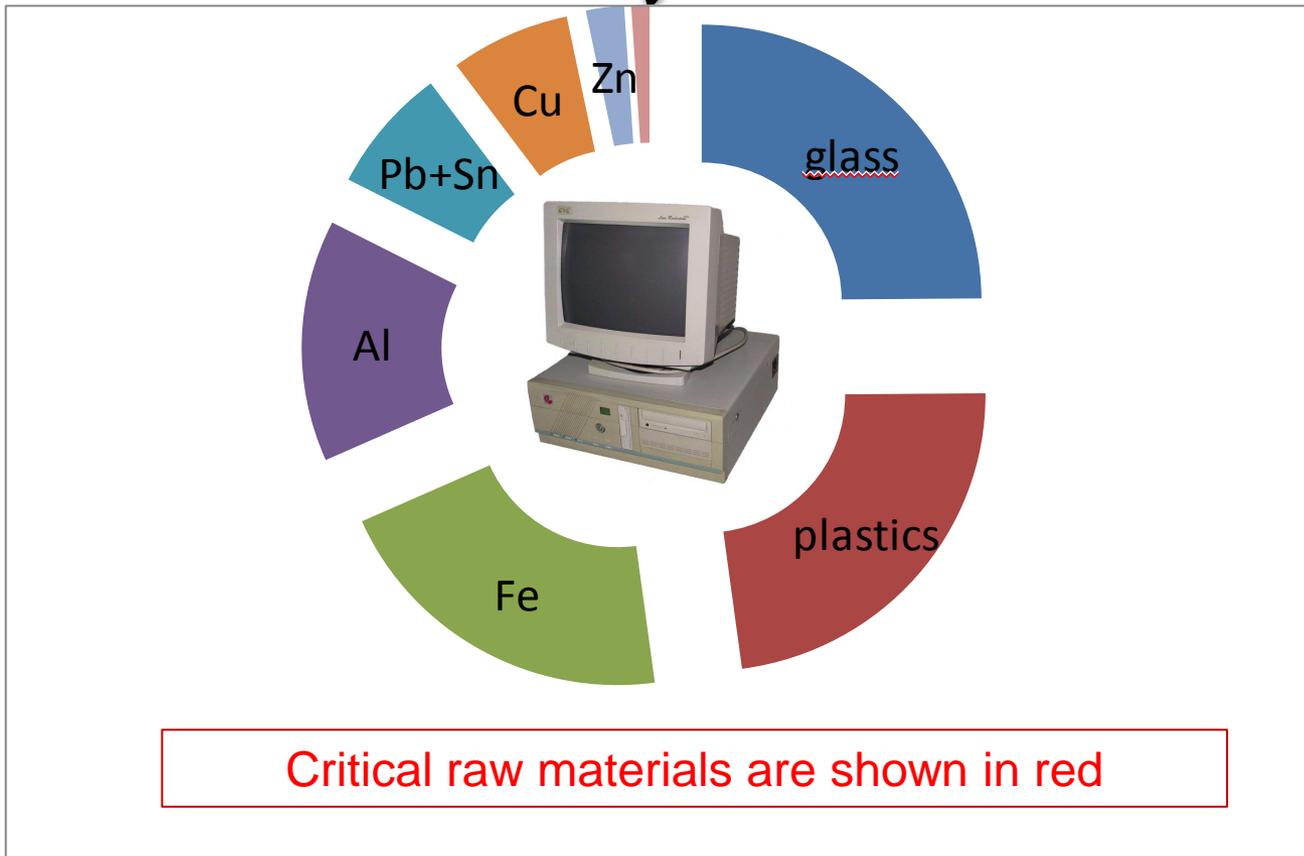
Rare, expensive, usefull and extra-EU

Gold 24 carats from 9600 to 66600 \$/kg in between 2001 and 2018

| Element | World T/year | Abb. Ppm | Price \$/kg | Use |
|-----------------------------------------------|--------------|----------|-------------|------------------------------------|
| Iridium | 7,1 | 0,001 | 35000-45000 | Electrics, electrochemistry |
| Scandium (as Sc ₂ O ₃) | 15 | 22 | 4400-15000 | Magnetism |
| Rodium | 21,5 | 0,001 | 7000-35000 | Catalysts for cars ... |
| Ruthenium | 27,7 | 0,001 | 2000-14000 | Electrochemistry |
| Hafnium | 72 | 3 | 1200 | Special alloys |
| Berillium | 320 | 2,3 | 7480 | Electronics,telecommunicatio ns |
| Gallium | 340 | 19 | 525 (2010) | Electronics, photovoltaics |
| Terbium | 407 | 1,2 | 420-720 | Lighting, magnetism |
| Europium | 470 | 2 | 150-370 | Lighting, banknotes |
| Indium | 689 | 0,001 | 180-1000 | <i>Display</i> , photovoltaics |
| Germanium | 740 | 1,2 | 940-1700 | Optical fibres, photovoltaics |
| Holmium,Lutetium,Ytterbium,Thulium | 1764 | 3,2-1,3 | 2400-70000 | Optics |

Elements in a 27 kg computer (1996)

Si+Ga+Ge+Ba+Ni+Ta+Ir+V+Tb+Be+Au+Eu+Ti+Ru+Co+
Pd+Mn+Ag+Sb+Bi+Cr+Cd+Se+Nb+Y+Rh+Pt+Hg+As



Computer disposal at the Research Area in Bologna (2010)



RAW MATERIAL SUBSTITUTION



30 ÷ 10 kg



5 ÷ 2 kg



1 ÷ 0,5 kg



0,18 ÷ 0,10 kg



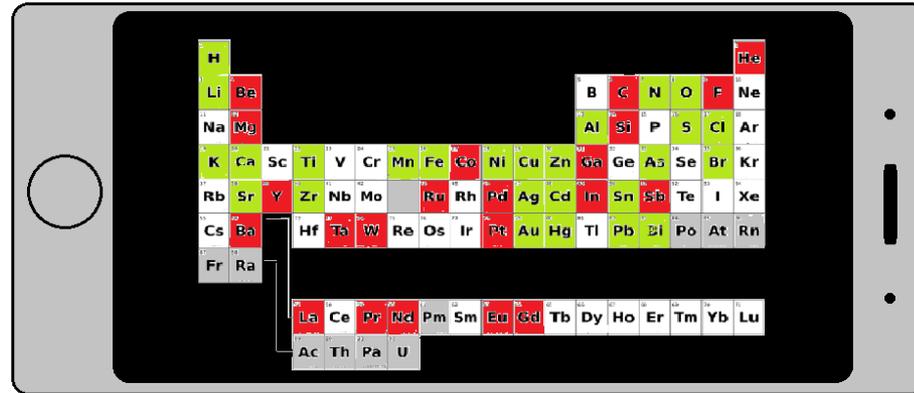
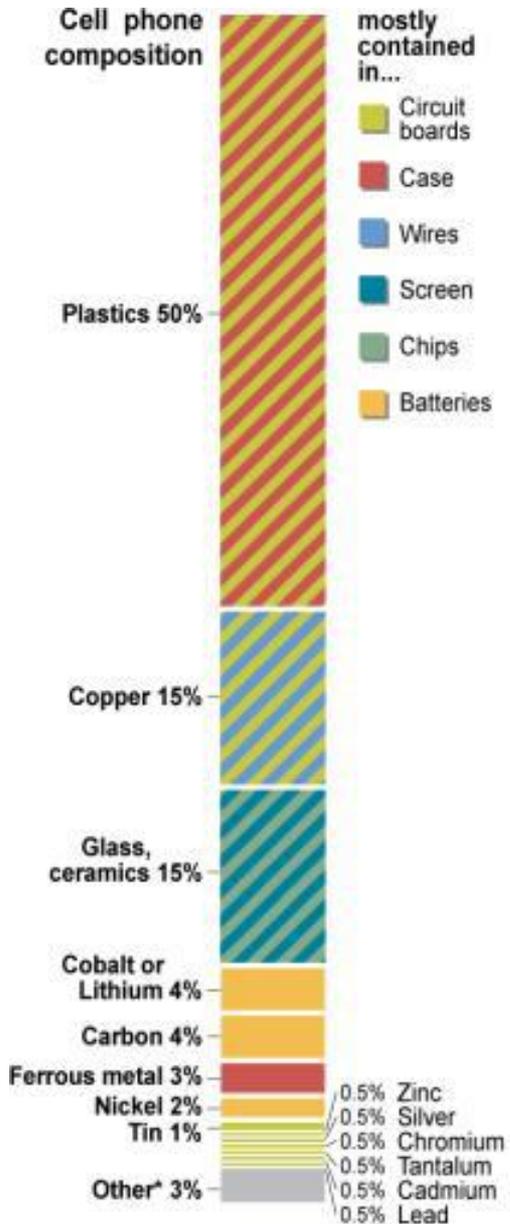
RawMaterials

RM@Schools



Consiglio Nazionale delle Ricerche
Istituto per la Sintesi Organica e la Fotoreattività

Elements in a smartphone



Smartphone weight: ~100 g

Content:

Cu: 13.7 g

Ag: 0.189 g

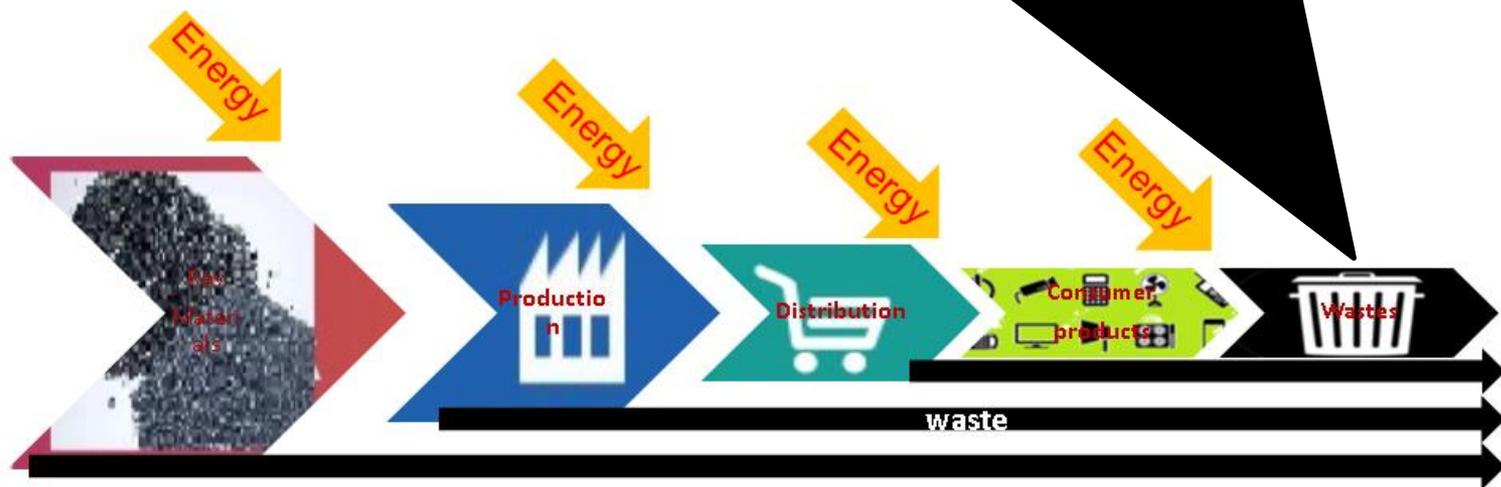
Au: 0.028 g

Pd: 0.014 g

Ta: 0.5 g

In EU 120.000.000 smartphones per year are sold

The black side of the linear economy: THE WASTE



EU waste production in 2014: 2.5 billions of tonnes



6.8 millions of tonnes per day



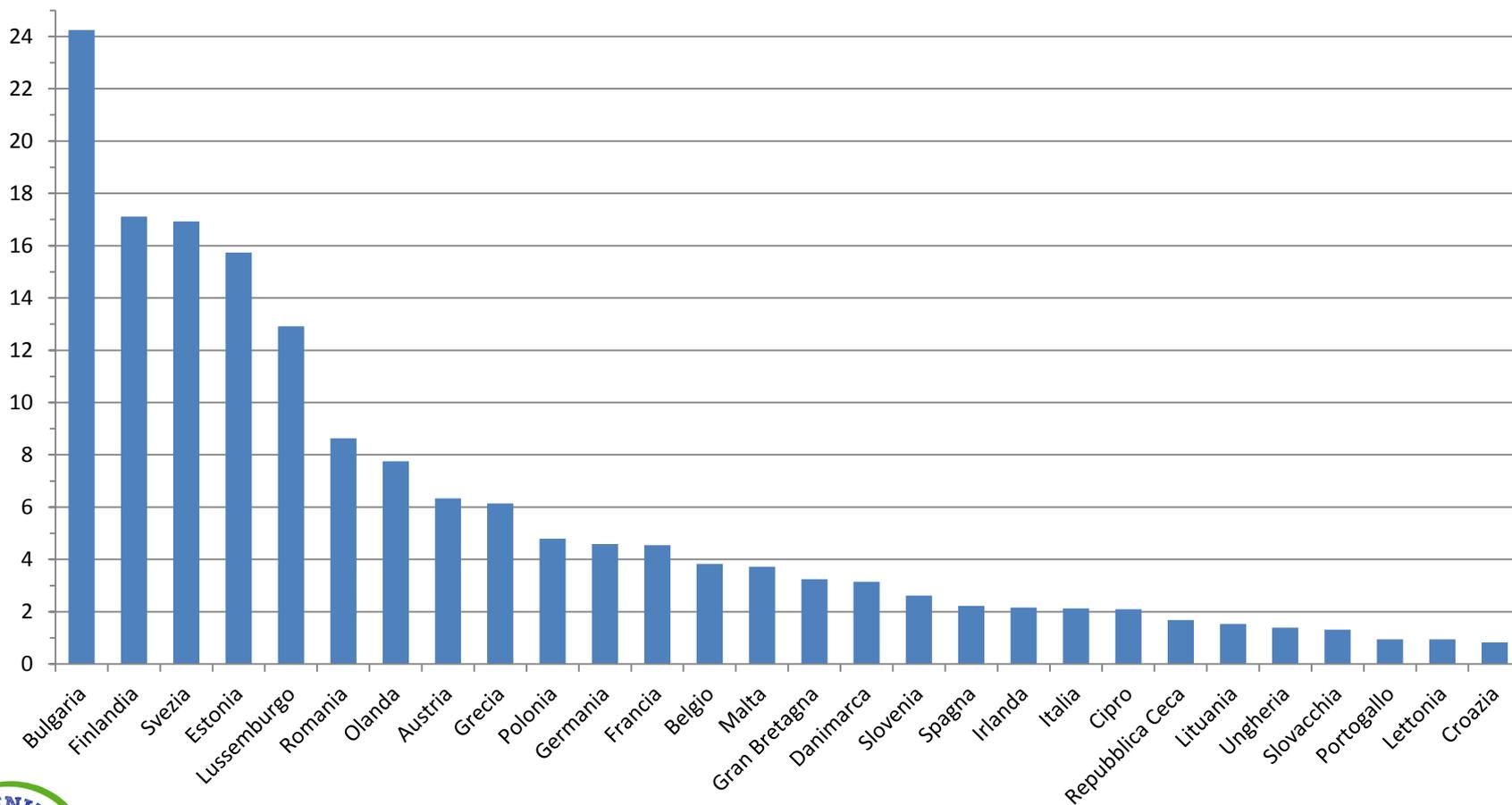
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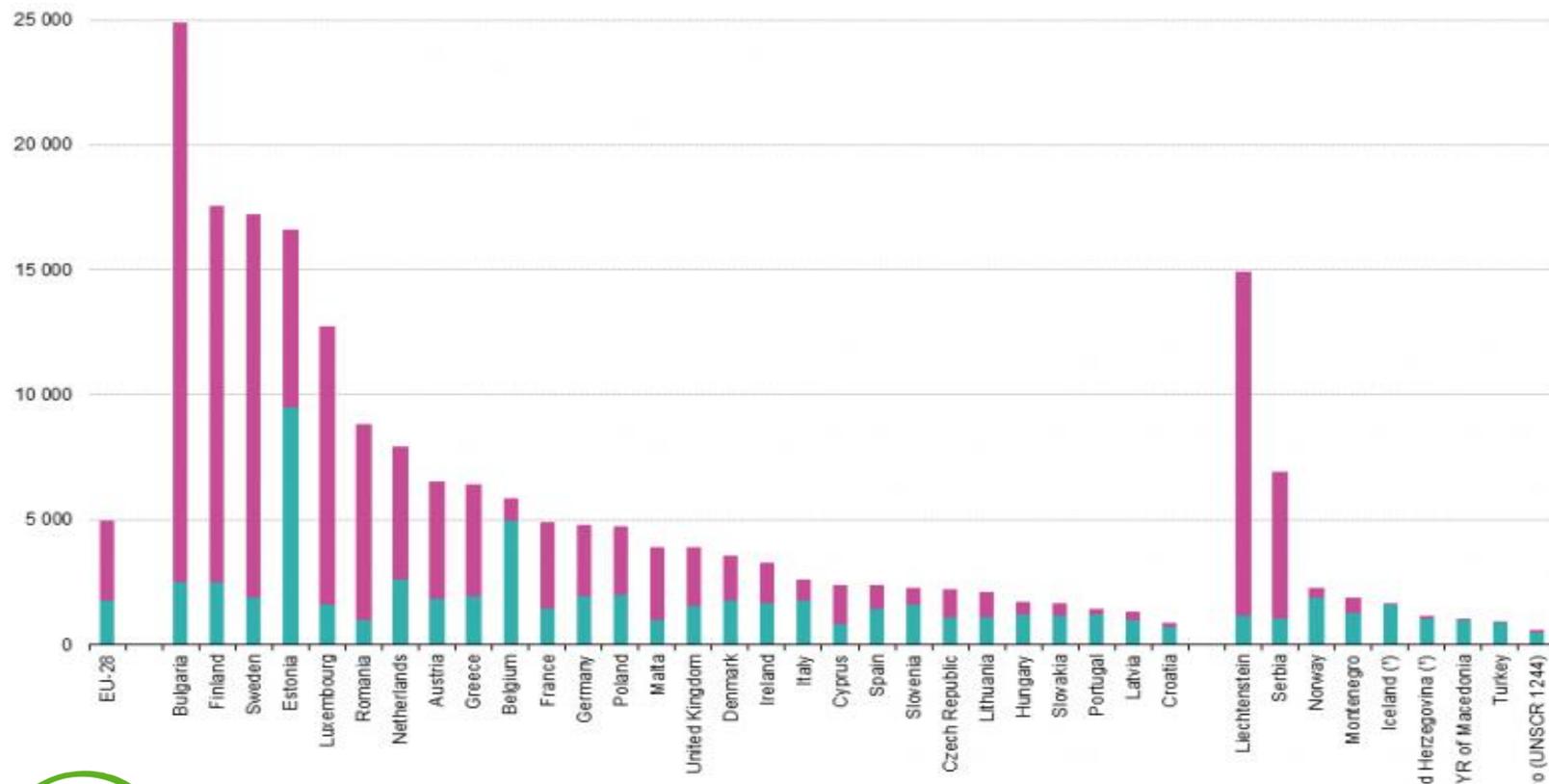
14 Times the weigh
of the highest
building of the World

480 kg of waste per year per EU
citizen.

Per capita waste production EU in 2014 (Eurostat)



Per capita mining waste production and other waste (2014 Eurostat)



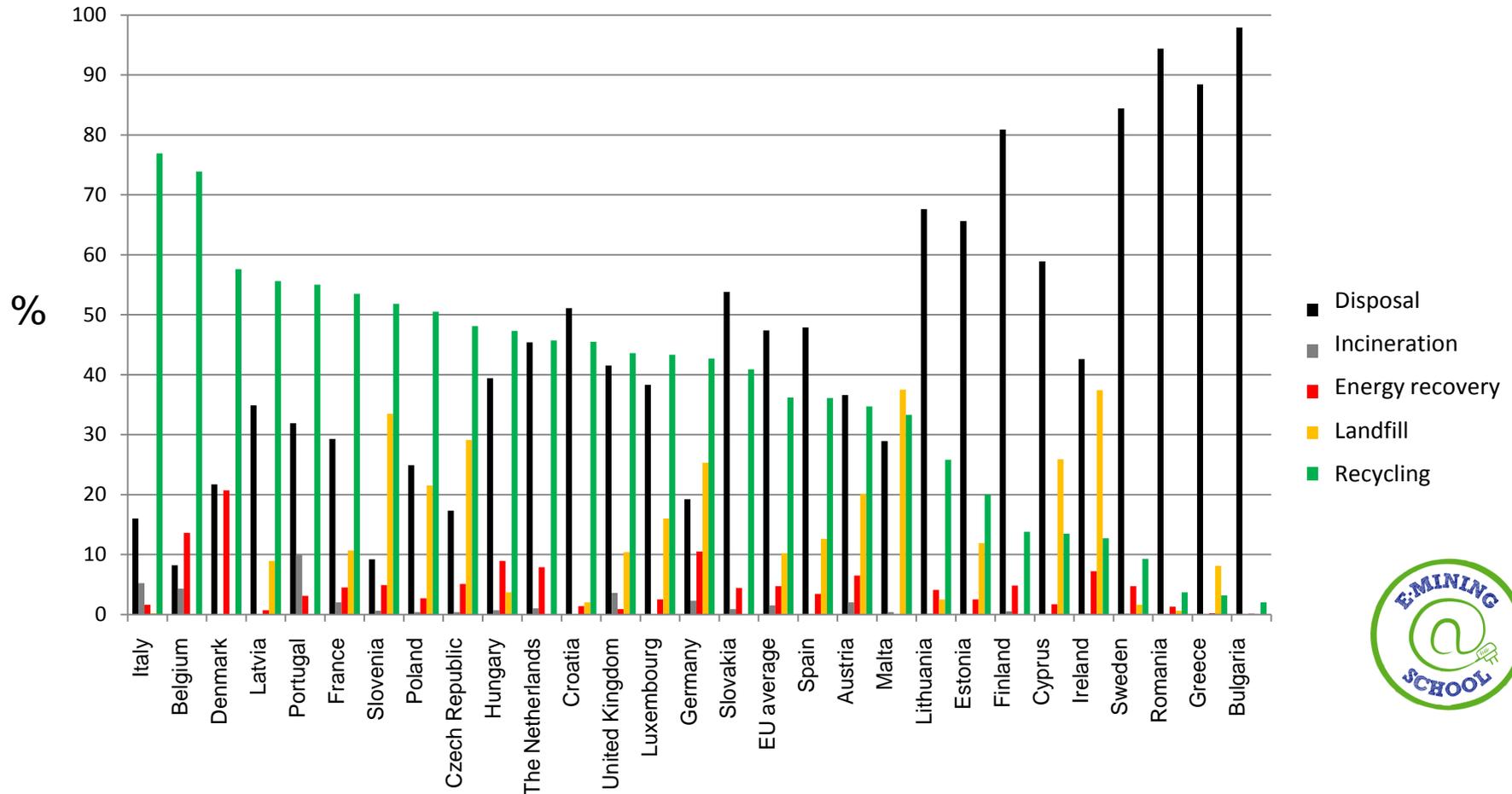
■ Major mineral waste
■ Waste excluding major mineral waste



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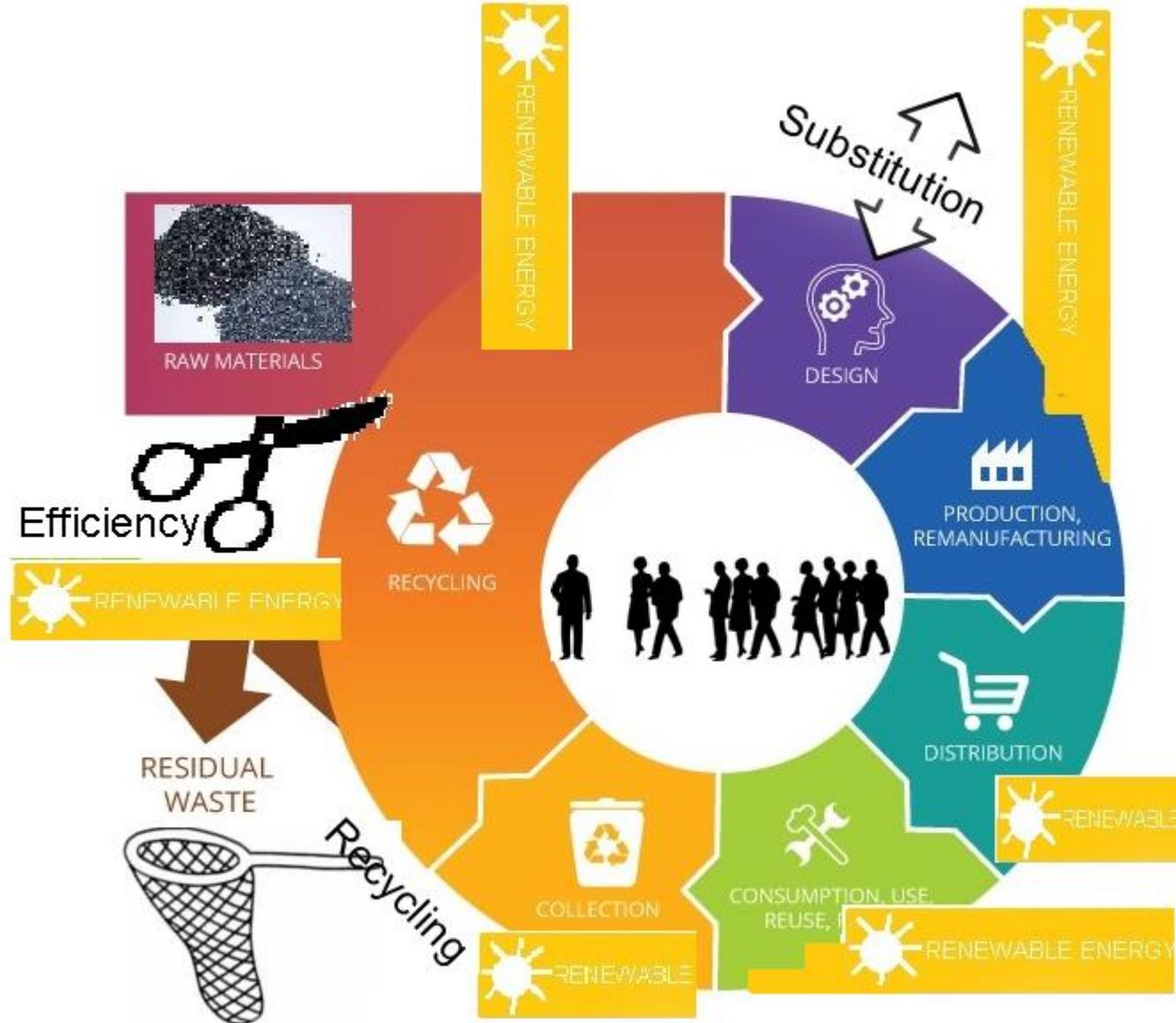
(*) 2012.
Source: Eurostat (online data code: env_wasgen)

Waste treatment in Europe (2014)





CIRCULAR ECONOMY



CIRCULAR ECONOMY

Circular economy is a system that ensures the highest use value on the time of products, their components and their materials to create technological cycles that do not modify natural ones.

Today only 9% of the raw materials are recycled.
There are a lot of job opportunities.
Creative and motivated persons are needed!

Actions to the circular economy

- Efficiency: use all the raw materials, byproducts included, and enhance product lifetime.
- Substitution: substitute critical raw materials with renewable raw materials (i.e. Graphene instead of indium tin oxide).
- Recycling: reuse and refurbish old devices, repair broken devices, recycle components and materials, recover energy from waste and use the residues for landfilling.
- Change products with services.



Thanks for your kind attention

Further info:

<https://rmschools.isof.cnr.it>

Alberto Zanelli

Tel: +39 0516399763

E-mail: alberto.zanelli@isof.cnr.it



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