Components and materials of WEEE and their recovery

Modul 1 – Science and Engineering

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From the model «Take-Make-Dispose» to «Circular Economy»

http://www.ncps-care.eu/?p=1638

https://www.dccae.gov.ie/en-ie/environment/topics/sustainable-development/circular-economy/Pages/default.aspx

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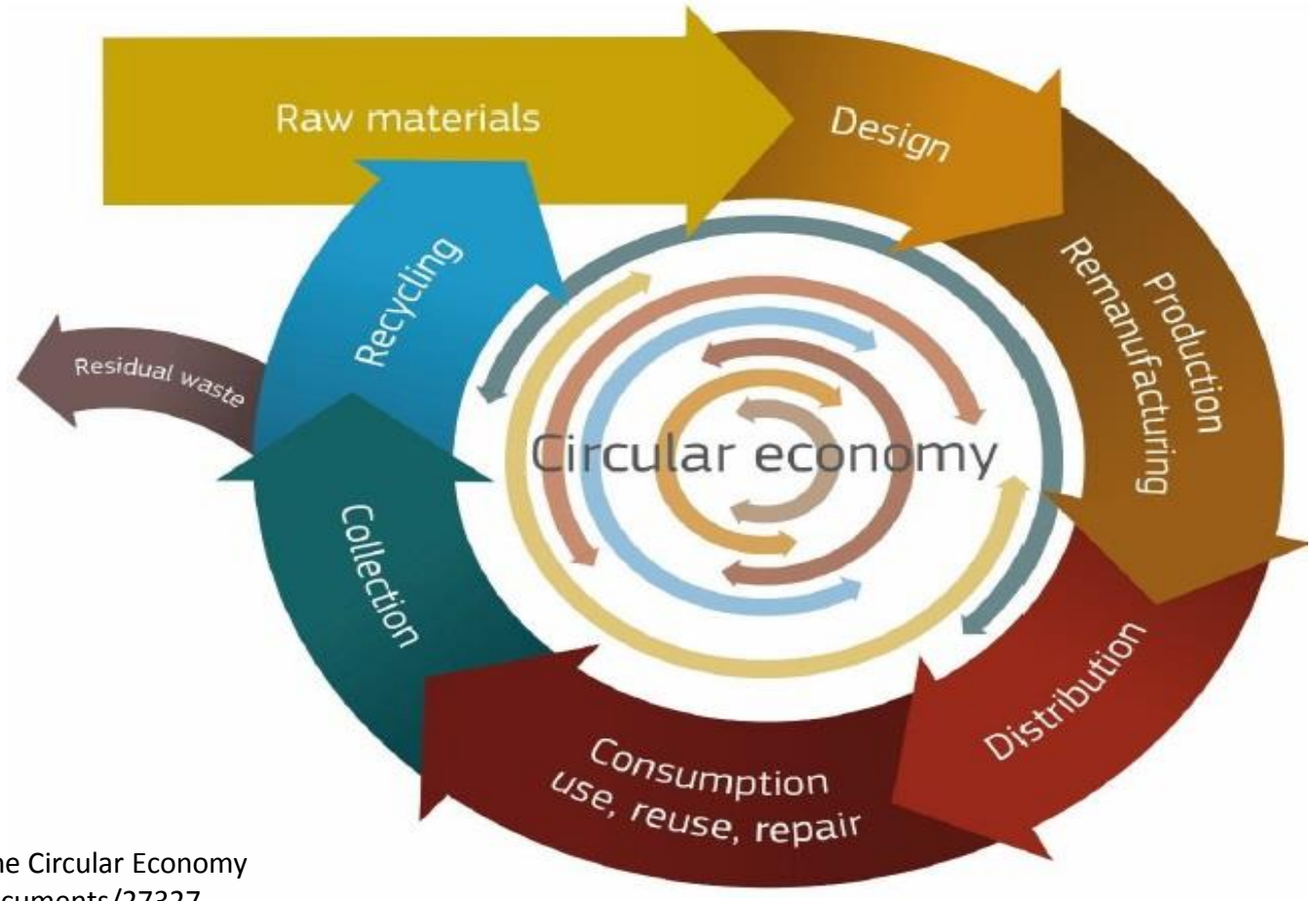
Circular Economy: conceptual diagramm

The raw material comes back to the production system



Report on Critical Raw Materials and the Circular Economy
https://ec.europa.eu/docsroom/documents/27327

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The 5 R of waste management: reduce, reuse, recycle, re-collection and recover

1	REDUCE	Waste reduction's at its origin: politics and choises of individual citizen
2	REUSE	Repair, reinvent and relocate products and goods that are still reusable
3	RECYCLE	Re-enter a secondary resource in the production cycle in the role of first resource
4	RE-COLLECTION	Separate collection, through the separation of the waste produced, by materials categories' and packaging.
5	RECOVER	Energy valorization (eletrical and thermal energy recovery)

https://www.econote.it/2014/08/28/le-5-r-dei-rifiuti/

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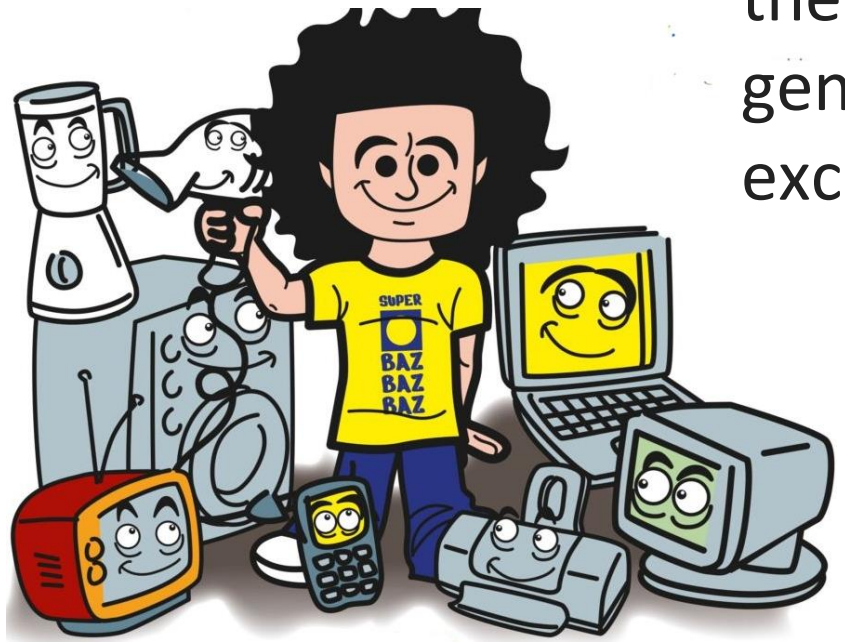
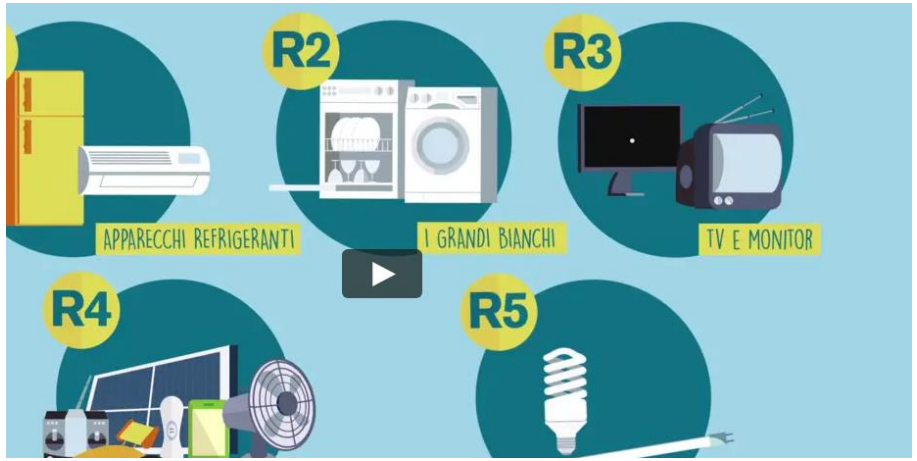
EEE: (electrical and electronical equipment)



The AEE are devices that depend on electricity for their correct operation, both as users and as generators, designed to operate at voltages not exceeding 1000 V



CENTRO DI COORDINAMENTO RAEE

https://www.cdcraee.it/GetPage.pub_do?id=2ca980954c2d51e3014c2d99793a0031

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WEEE: (wastes from electrical and electronical equipments)

WEEE are wastes from electrical and electronic equipments, ie all those EEE that the owner wants to dispose of due to obsolescence, breakdown, inactivity, etc.

End users, manufacturing companies, WEEE collection and recovery centers are the main actors in the correct disposal of this wastes.

European Regulation principle "**the polluter pays**".

The collection target to which European countries must aim by the end of 2019 is: 65% of the average weight of EEE placed on the market in the previous three years.

https://www.lentepubblica.it/wp-content/uploads/2015/02/RAEE.jpg

https://www.cdcraee.it/GetHome.pub_do

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Categories of WEEE

WEEE differ from each other for the raw materials they are made of and in the use they had before becoming waste.

R1	R2	R3	R4	R5
refrigerators, freezers and air-conditioners	washing and cooking appliances, extractor hoods and water-heaters	TVs and VDUs	small appliances and IT, consumer electronics and lighting devices	light sources
				
(dangerous)	(non dangerous)	(dangerous)	(dangerous and non dangerous)	(dangerous)

Source: ECW – European Catalog of Wastes

CENTRO DI COORDINAMENTO RAEE

RAPPORTO ANNUALE 2017
RITIRO E TRATTAMENTO DEI RIFIUTI DA APPARECCHIATURE ELETTRICHE ED ELETTRONICHE IN ITALIA

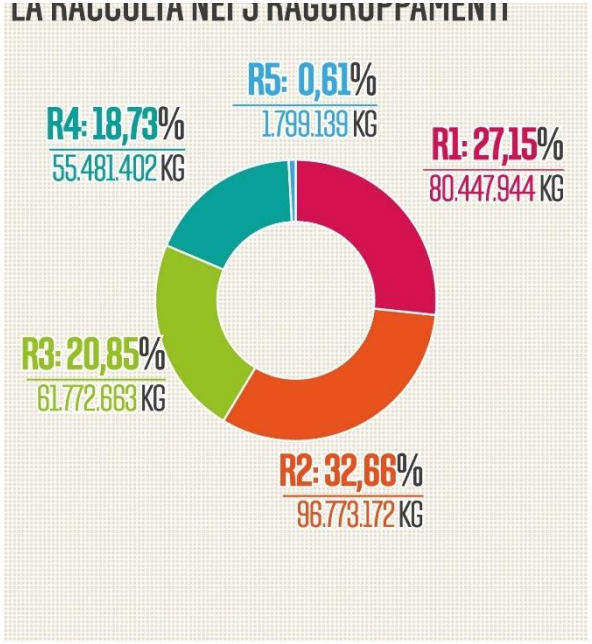
OVERALL COLLECTION

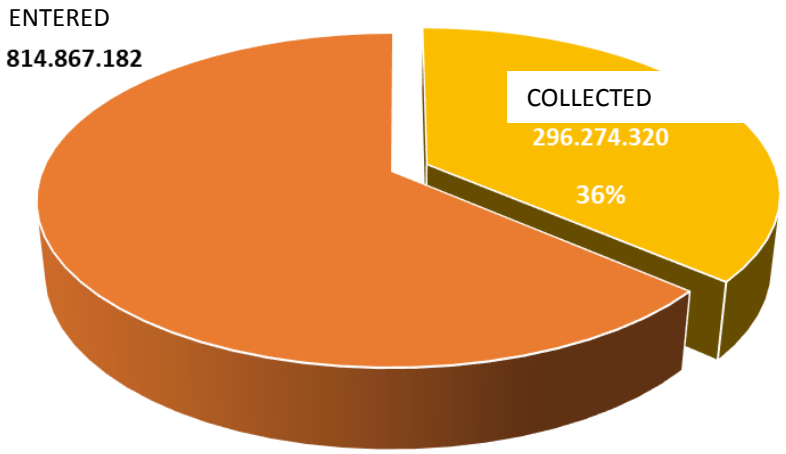
296.274.320 KG

+4,66 % INCREASE IN COLLECTION VS 2016

NATIONAL PER CAPITA COLLECTION **4,89 KG**

COLLECTION IN THE 5 CATEGORIES





COLLECTION % 2017 RESPECT TO THE ENTRY OF 2016

COLLECTION 2017 [kg]

https://www.cdcraee.it/GetPage.pub_do?id=2ca980954c369c25014ce55c67350385

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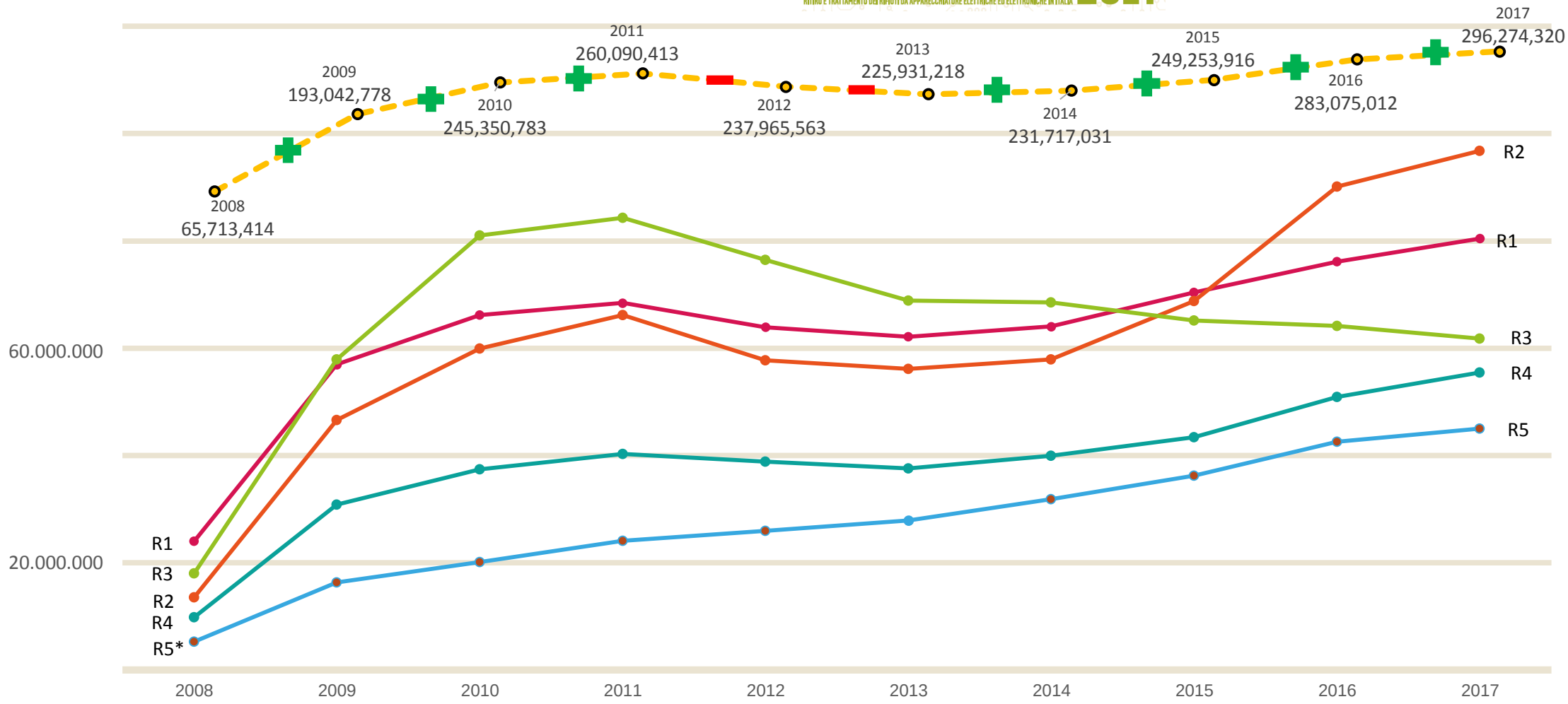
Collection trend in the last 10 years [kg]

https://www.cdcraee.it/GetPage.pub_do?id=2ca980954c369c25014ce55c67350385

RAPPORTO ANNUALE 2017
RITIRO E TRATTAMENTO DEI RIFIUTI DA APPARECCHIATURE ELETTRICHE ED ELETTRONICHE IN ITALIA



*valore moltiplicato per 5

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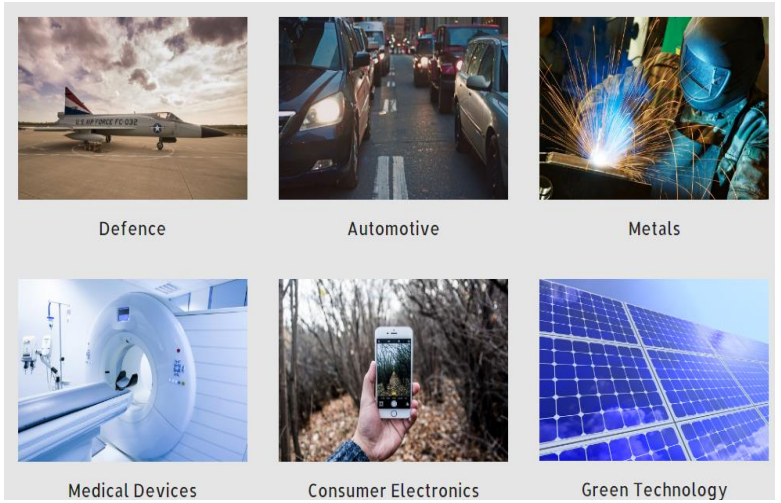
Why the WEEE recovery's is important

- Materials componing WEEE are not biodegradable
- Risk of enviromental pollution
- Exhaustible natural resources
- Critical raw materials



http://www.sudpress.it/rifiuti-crocetta-potremo-requisire-bellolampo-orlando-emergenza-frutto-di-un-governo-inadeguato/

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What is a landfill?
Why shouldn't WEEE be abandoned?

Realization phase

Operational phase

Closing phase

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Realization phase

http://www.pisatoday.it/cronaca/visita-enrico-rossi-discarica-peccioli-25-luglio-2019.html

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http://www.legambientepuglia.it/area-stampa/comunicati-stampa/197-sequestro-discarica-di-conversano

Operative phase

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https://canavesenews.it/news/comital-volpiano-annullato-tavolo-regione-domani-lincontro-decisivo-al-ministero-del-lavoro-roma/

Closing phase

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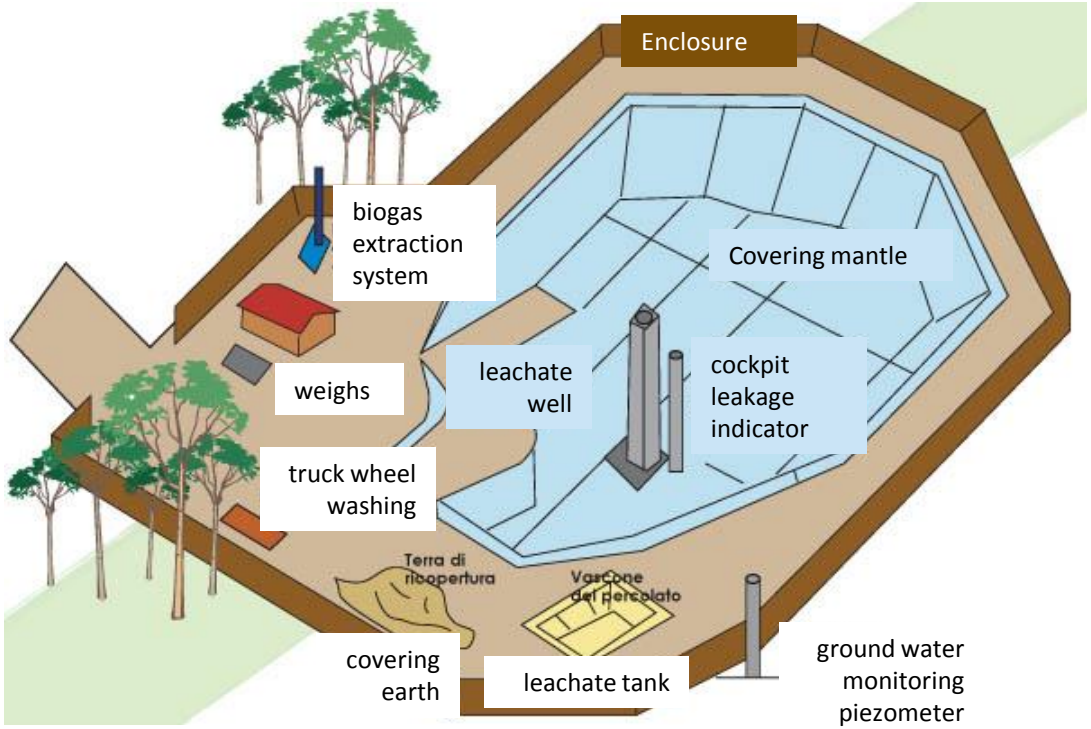
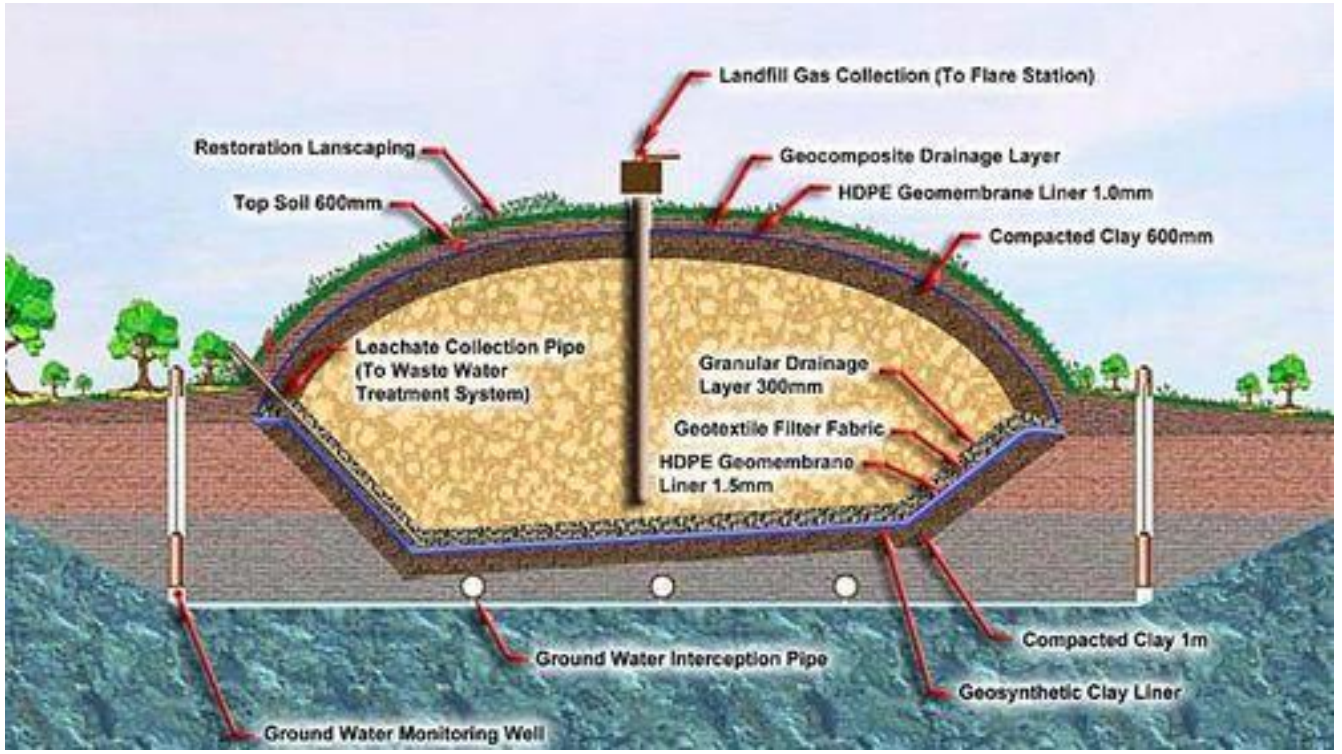
How a landfill works: what the dangers are!



http://www.crati.it/por_calabria/Sito/Pannello10/Discariche.html



http://www.geotecnologie.unisi.it/corsinew.php?act=det&wat=0&id=1901

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The WEEE and their recovery

https://www.youtube.com/watch?v=hB2DzYB4Tt0

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What is my old pc made of?

What materials

Personal Computer

Material properties

How to recover materials

What are the most important materials and why

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What is my old pc made of?
Materials and their properties

Personal Computer

Material	Content %	Material	Content %	Material	Content %
Plastic materials	22,9	Tantalum	$16x\ 10^{-3}$	Silver	19×10^{-3}
Lead	6,4	Indium	2×10^{-3}	Antimony	9×10^{-3}
Aluminum	14,2	Vanadium	2×10^{-4}	Chrome	$6,3 \times 10^{-3}$
Germanium	2×10^{-3}	Beryllium	$15,7 \times 10^{-3}$	Cadmium	$9,4 \times 10^{-3}$
Gallium	1×10^{-3}	Gold	$1,6 \times 10^{-3}$	Selenium	$1,6 \times 10^{-3}$
Iron	20,5	Europium	2×10^{-3}	Radium	1×10^{-3}
Tin	1	Titanium	$15,7 \times 10^{-3}$	Platinum	$0,1 \times 10^{-3}$
Copper	6,9	Ruthenium	$1,6 \times 10^{-3}$	Mercury	$2,2 \times 10^{-3}$
Barium	$3,2 \times 10^{-2}$	Cobalt	$15,7 \times 10^{-3}$	Silicon (glass)	24,9
Nickel	0,9	Palladium	3×10^{-4}		
Zinc	2,2	Manganese	$31,5 \times 10^{-3}$		

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Materials present in WEEE

METALS

WEEE

PLASTIC MATERIALS (polymers)

CRMs

GLASSES

CHEMICAL COMPOUNDS

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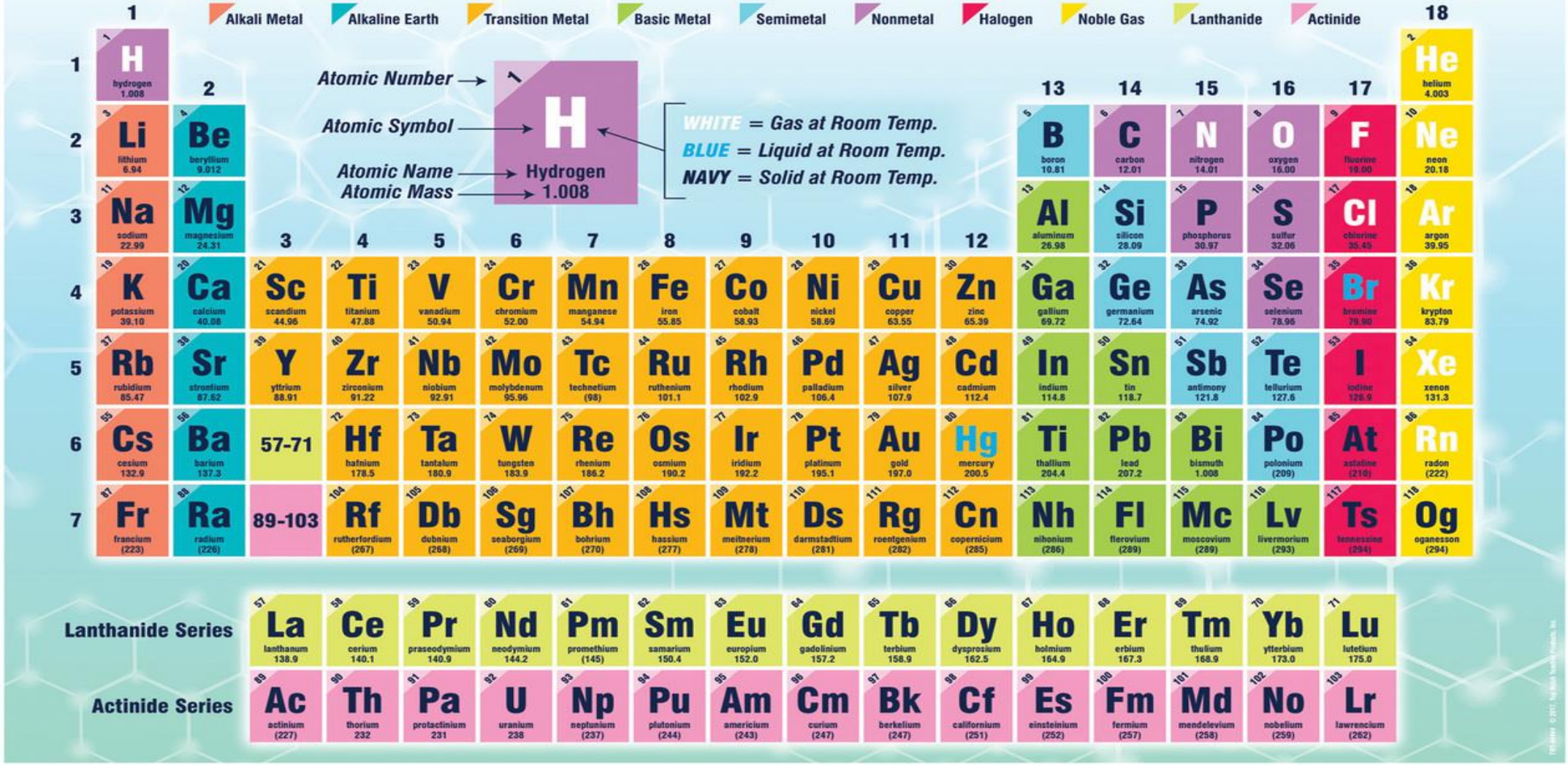
Periodic Table of the Elements



http://topnotchteacher.com/periodic-table-of-the-elements-chart-magnetic/

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The Metals

- Definition of metallic material, what are its properties?
- Differences between common metal and noble metal
- What is the passivation of a metal or alloy?
- In what form are they commonly found in nature? What are the sources?

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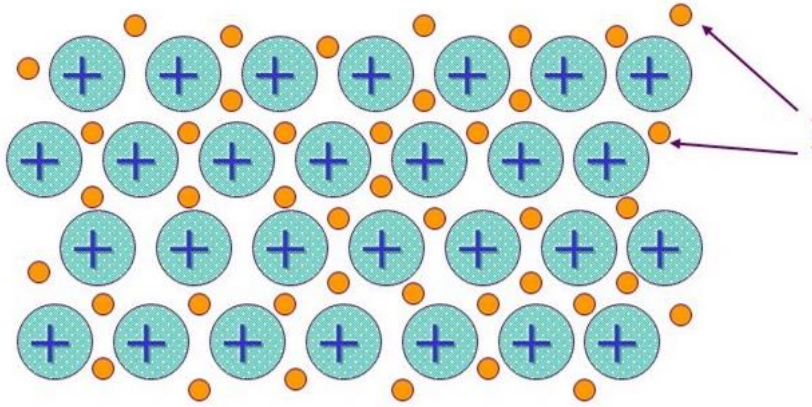
Metallic materials

Metallic materials

1. Mechanical resistance
2. Electrical and themal conductivity
3. Ductility

Simplifier model of the metal bond

Lattice of cations immersed in a «sea» of mobile electron



The bonds are delocalized in the whole crystal and the valence electrons are not tied to a particular atom but can move freely from one atom to another

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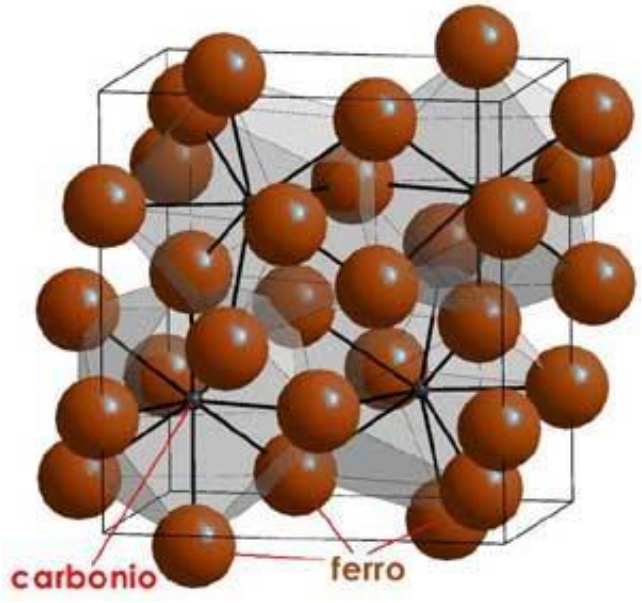
Metallic materials and alloys

An alloy is a combination, in solution or in mixture, of two or more elements, of which at least one is a metal and the resulting material has metallic properties different from those of the relative components.



Steel: Alloy Fe-C

Mild Steel: C < 2%

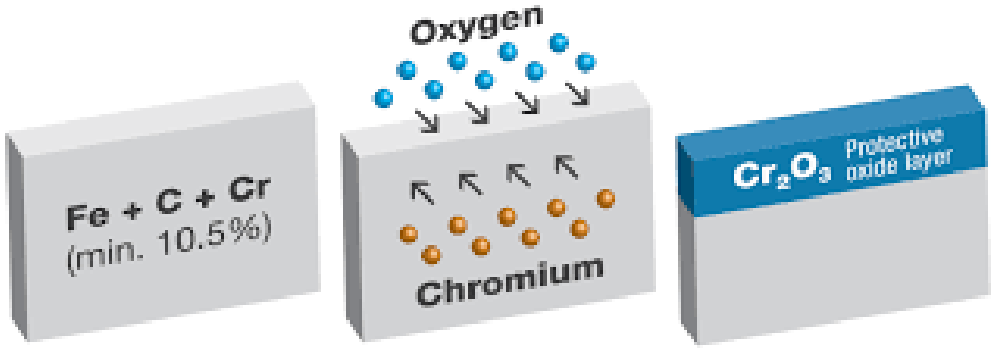
Cast Iron: C> 2%

Steel: INOX

AISI (*American Iron and Steel Institute*),

AISI 304 - Cr (18%) Ni (10%) C (0,05%);

AISI 316 - Cr (16%) Ni (11.3/13 %) Mo (2/3 %)



http://www.brunoacciai.it/tecniche_materiali/acciaio_caratteristiche.php

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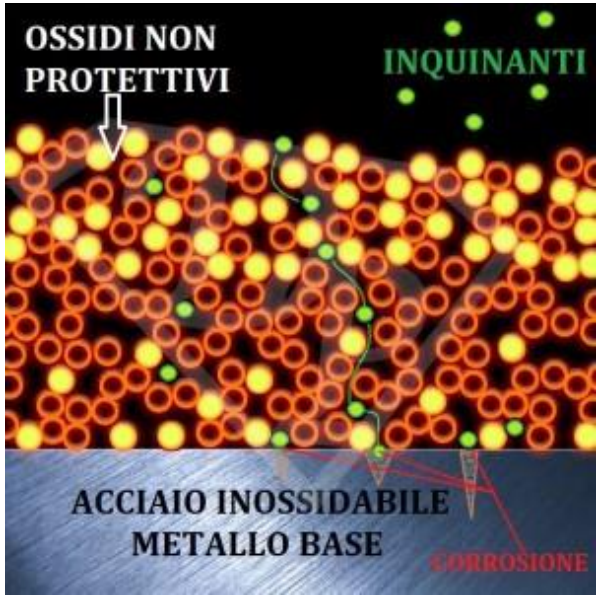
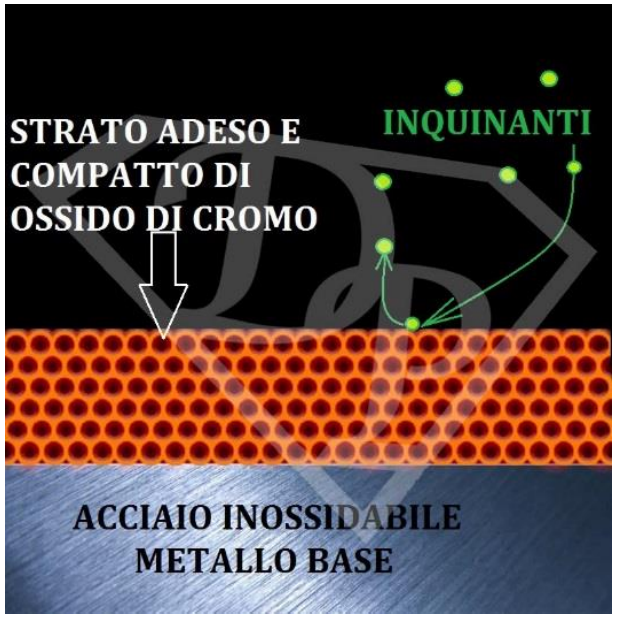
Corrosion and passivation of metals

<u>Corrosion</u>: uncontrolled oxidation with the formation of a porous and non-adhered oxide layer.

<u>Passivation</u>: controlled oxidation of metal with the formation of a thin layer of adherent and non-porous metal oxide.



Non- passivated metal



Passivated metal

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Corrosion of metals

What happens to my phone when it falls into the water?

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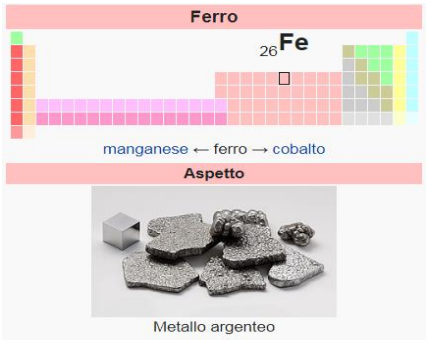
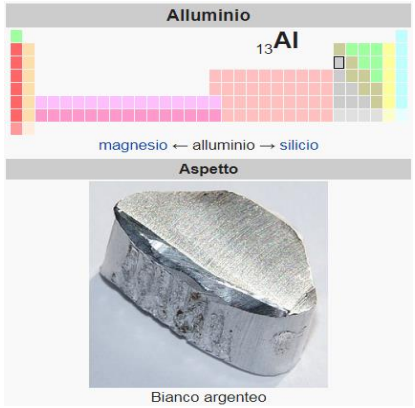
Classification of metals: common metals

Iron (Fe)



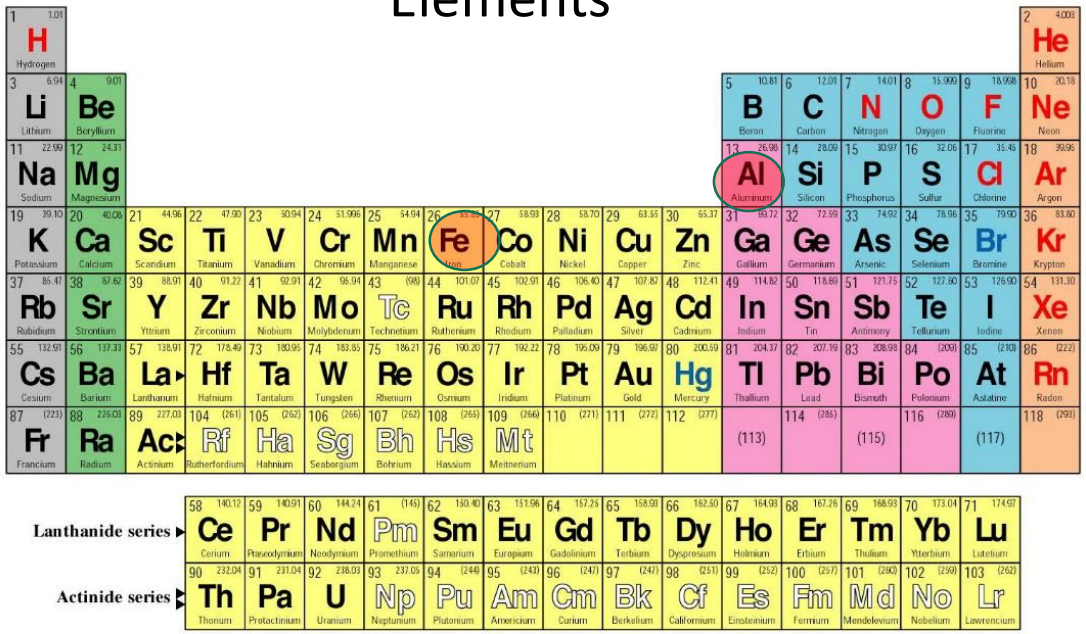
pf 1538 °C,
E_{redox}= -0.41 V
40 €/t

Aluminum (Al)



pf 660 °C,
E_{redox}= -1.66 V
1.7 €/kg

- Periodic table of the Elements



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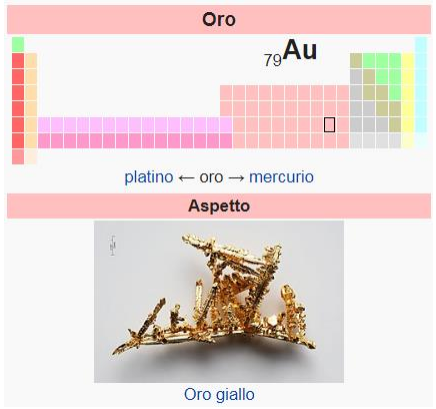
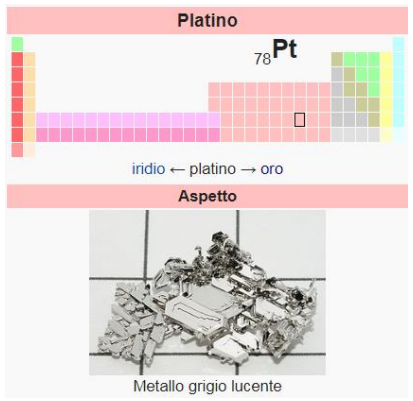
Noble Metals

Gold (Au)



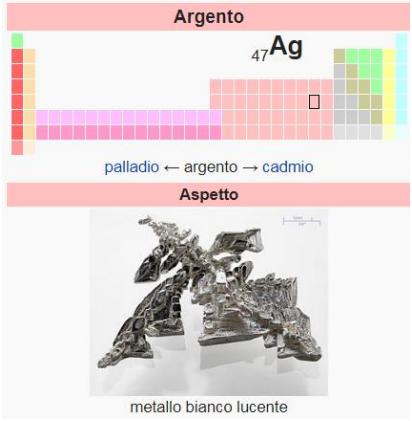
pf 1069 °C,
E_{redox}= 1.69 V
34.8 €/g

Platinum (Pt)



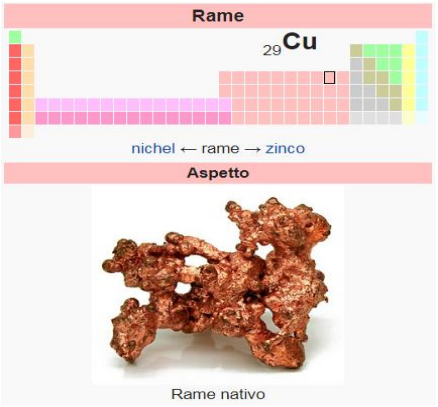
pf 1768 °C,
E_{redox}= 1.19 V
24.8 €/g

Silver (Ag)



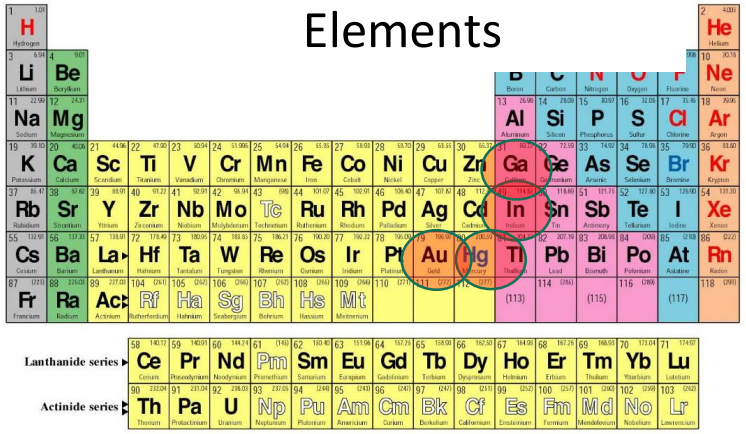
pf 981 °C,
E_{redox}= 0.80 V
0.4 €/g

Copper (Cu)



pf 1084 °C,
E_{redox}= 0.34 V
5.4 €/kg

Periodic table of the Elements



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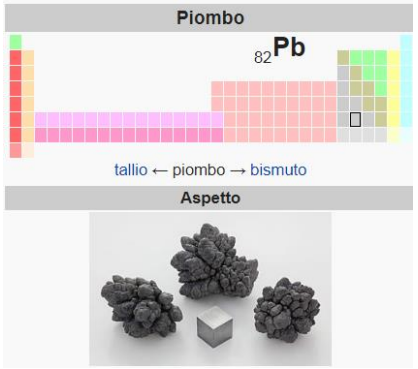
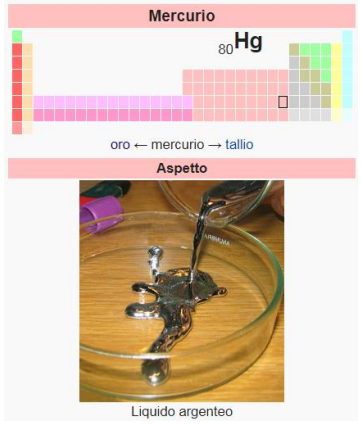
Other metals

Lead (Pb)



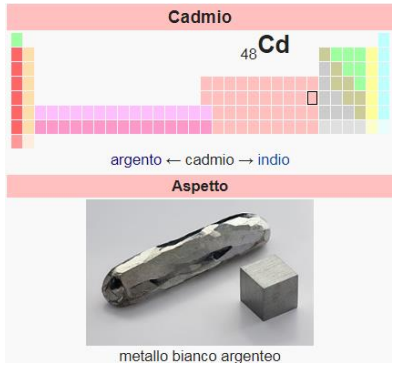
pf 327 °C,

Mercury (Hg)



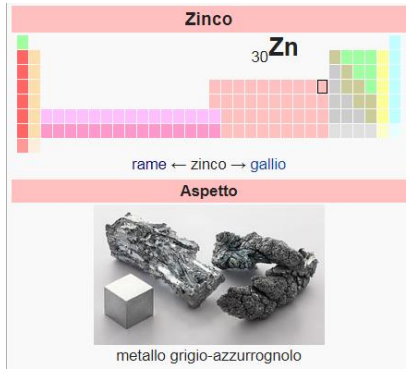
pf – 38 °C,

Cadmium (Cd)



pf 594 °C,

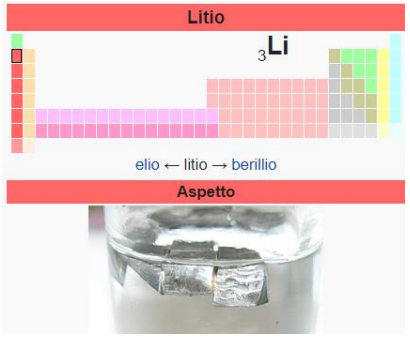
Zinc (Zn)



pf 693 °C,

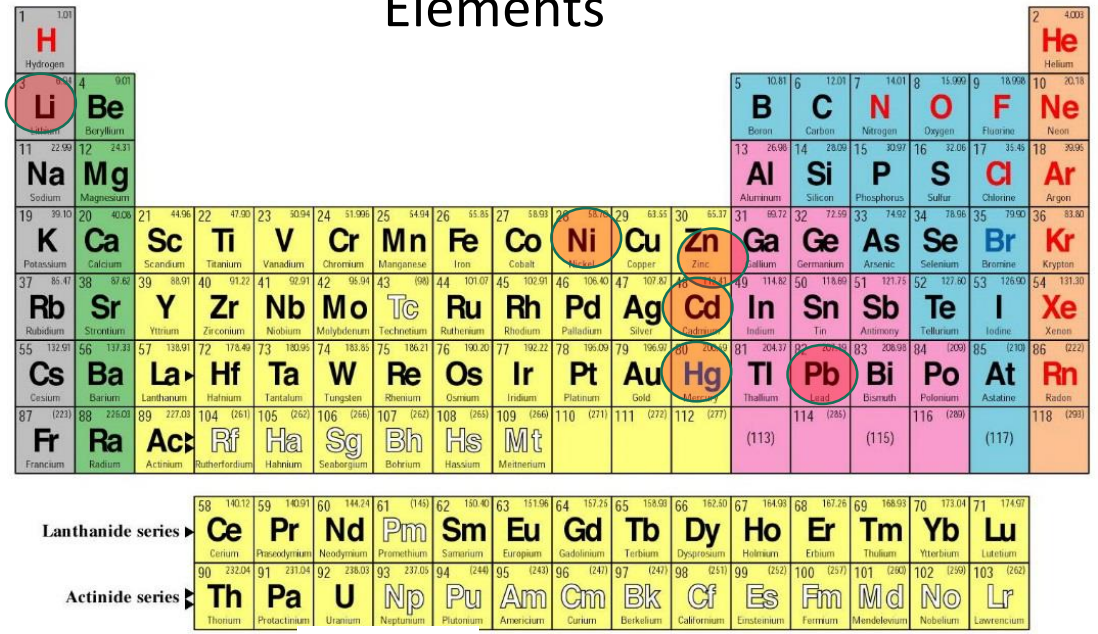
E_{redox}= -0.77 V

Lithium (Li)

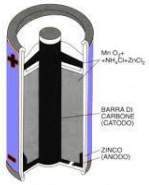


pf 454 °C,

Periodic table of the Elements



Zn



Ni/ Cd

Li

Pb

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Metals: mineral sources

Magnetite (Fe_3O_4)

Bauxite (ricco in $Al(OH)_3$)

Chalcopyrite ($CuFeS_2$)

https://www.minieredicalamita.it/capoliveri-miniere/cuore-terra.html

https://itimoni.it/america/viaggio-in-cile-e-isola-di-pasqua/

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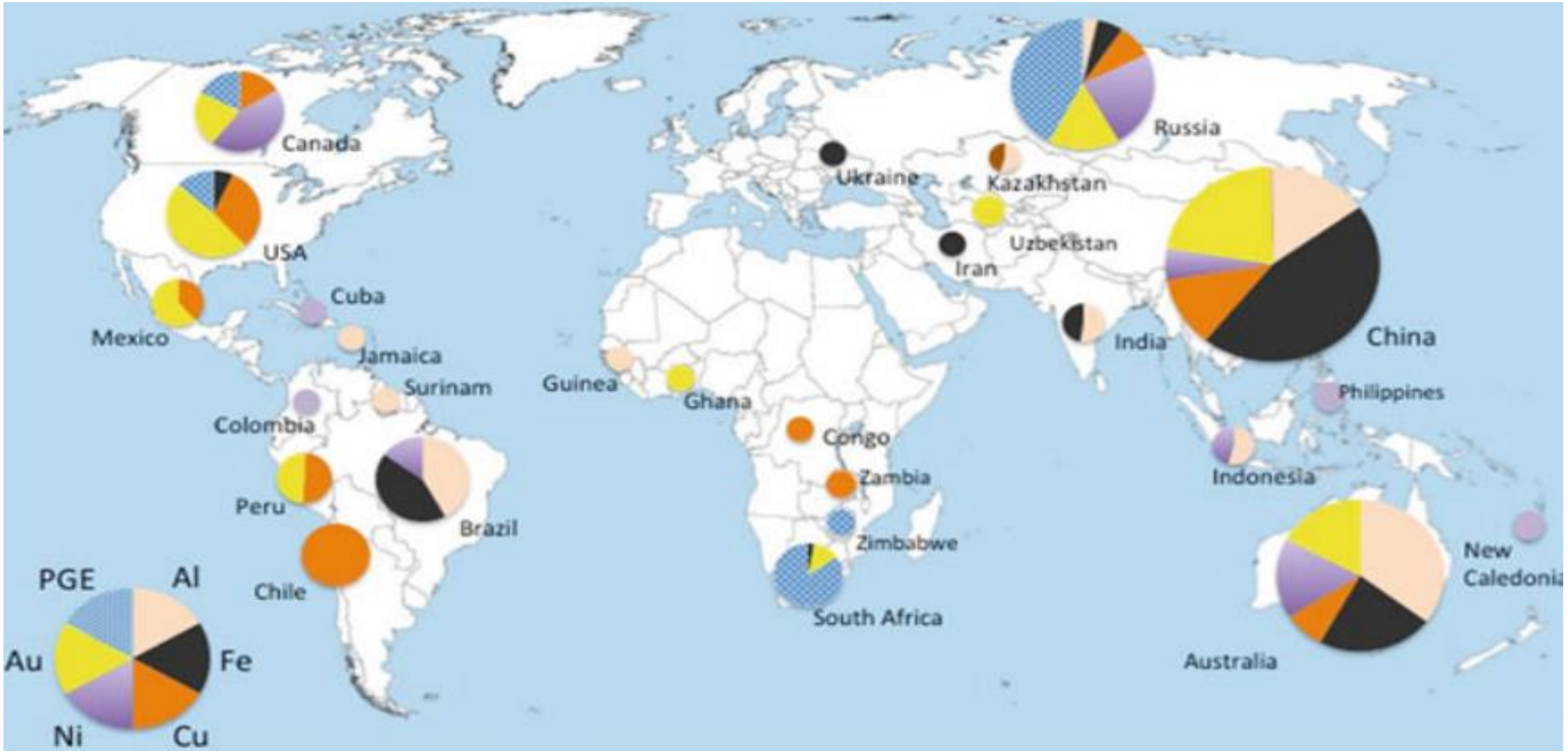
Global distribution of metals



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Metals: the sources of copper

$CuFeS_2$

Cu_5FeS_4

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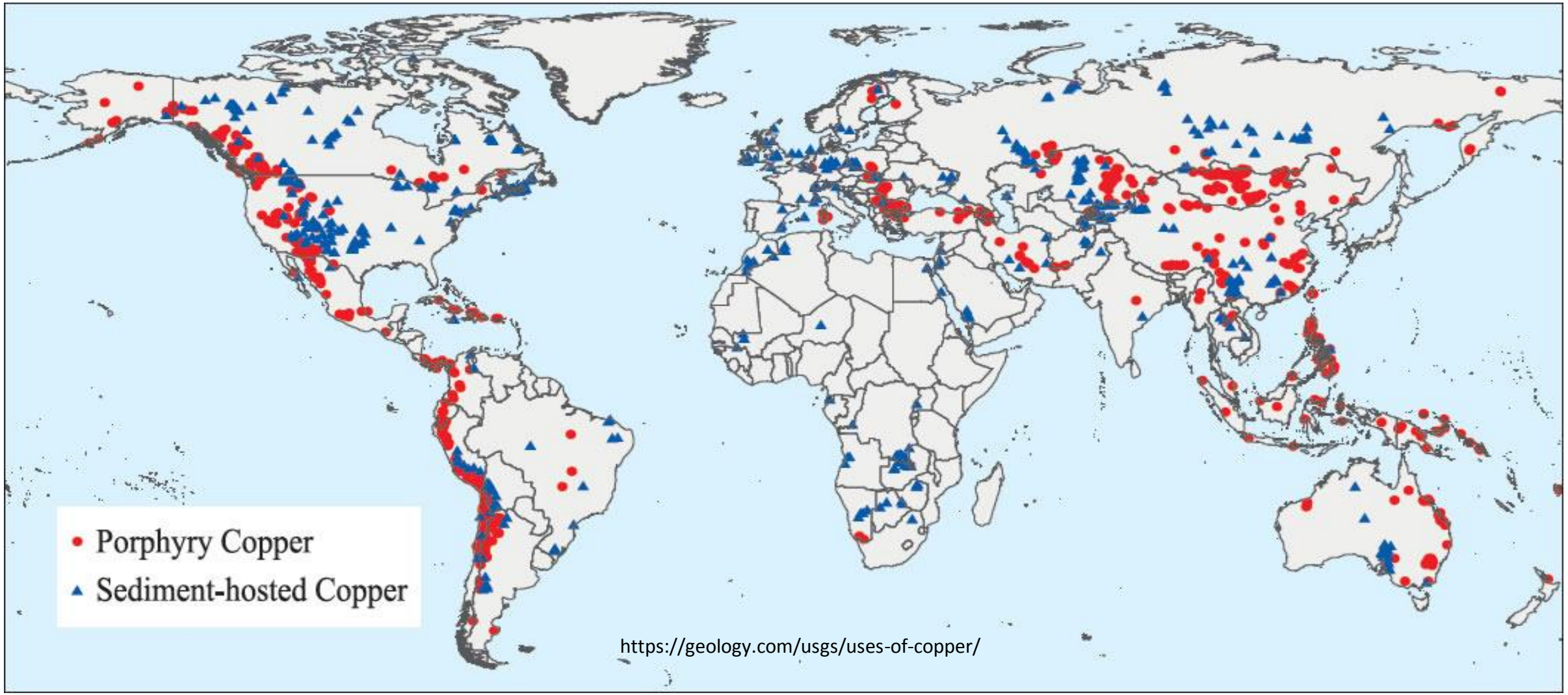
Global distribution of copper



https://geology.com/usgs/uses-of-copper/

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Copper mines

https://www.youtube.com/watch?v=Z-kfODjpB7M

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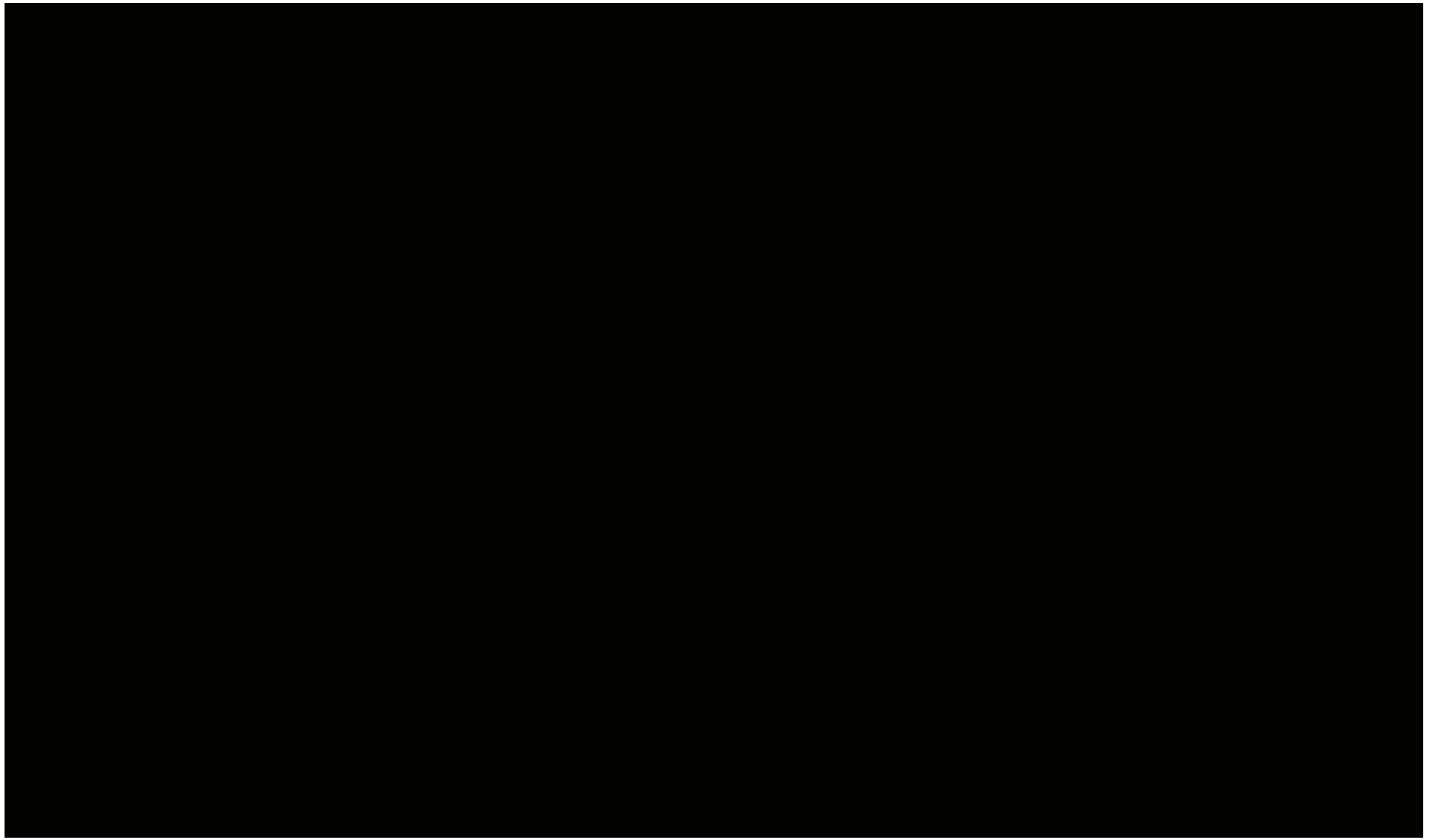
Copper mines

https://www.youtube.com/watch?v=Z-kfODjpB7M



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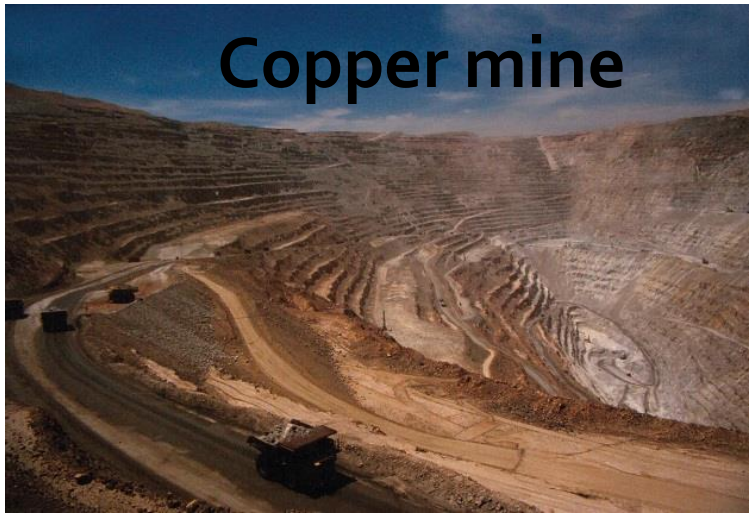
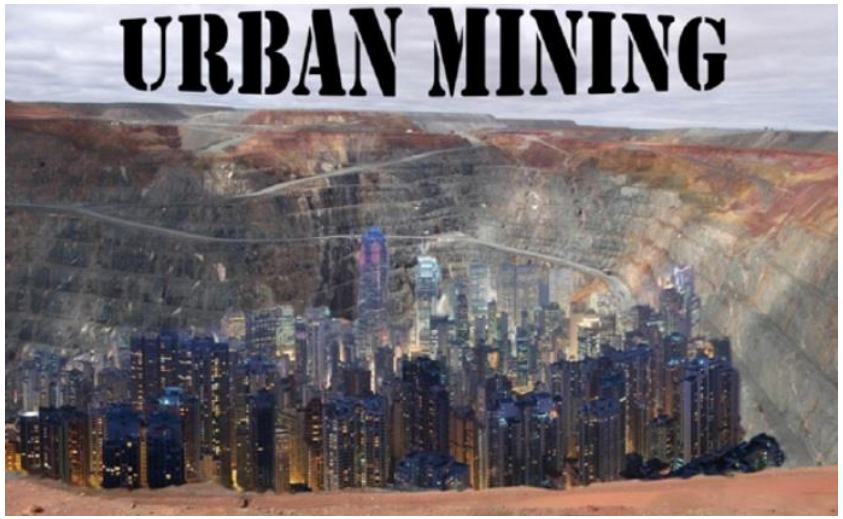
From traditional mine to urban mine



To Mine or not To Mine?



- Extraction of copper
- Crusching and grinding
- Floatation
- Concentration
- Roasting
- Casting and conversion
- Thermal refining
- Electrolytic refining

- Collection of WEEE
- Copper recovery from WEEE
- Casting
- Thermal refining
- Electrolytic refining

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Polymeric materials

WEEE

https://www.eco-mind.it/portfolio-articoli/rifiuti-raee/

Grinding of plastics

https://www.ecoambientesud.it/raee.html

Polymeric materials (Plastics)

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Polymers

- What is a polymeric material?
- Natural and synthetic polymers, sources and examples
- What is it mean for Thermoplastic, Thermosetting and Rubber?
- Amorphous and crystalline polymer?
- Definition of composite materials
- Recovery and valorization of polymeric materials

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Polymers - definitions

A polymer is a macromolecular or a molecule substance with a high molecular weight, consisting of the repetition of a large number of identical or different (co-polymer) repetitive units, linked together by covalent bonds.

1 **Linear polymer Homo-polymer (one type of repeat unit)**

2 **Linear polymer Co-polymer (at least two repeat units)**

3 **Linear polymer Co-polymer (random)**

4 **Linear polymer Co-polymer (blocks)**

5 **Linear polymer Co-polymer (graft)**

https://it.wikipedia.org/wiki/Polimero

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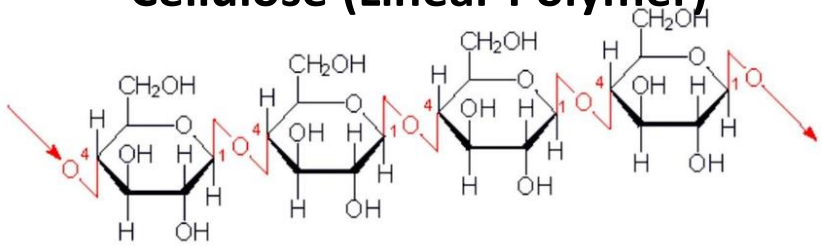
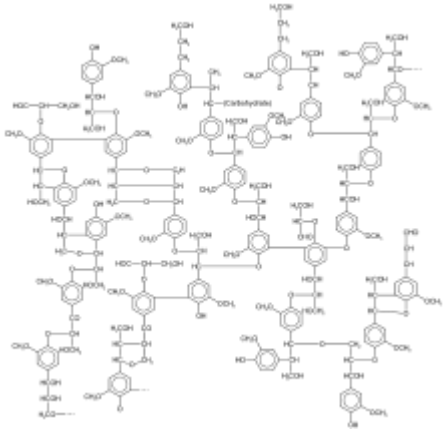
Natural and synthetic polymers

Natural Polymers

Cellulose (Linear Polymer)

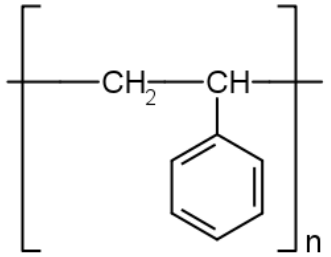


Lignin (Cross-linked polymer)

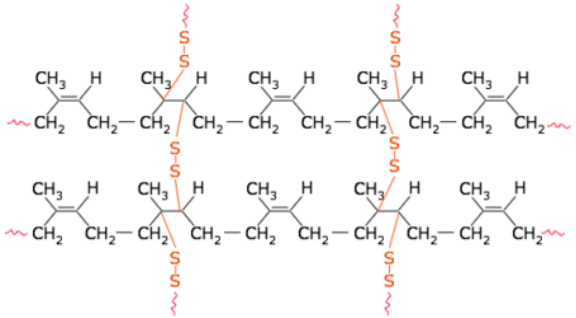


Synthetic Polymers

polystyrene (Linear Polymer)



Polybutadiene (Cross-linked polymer)



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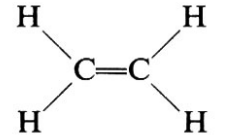
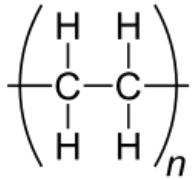
Polymers: the sources

The thermoplastic polymers such as polyethylene and polypropylene are synthesized by addition of the respective monomers: ethylene and propylene which derive from mineral and oil.



Ethylene

PE
polyethylene



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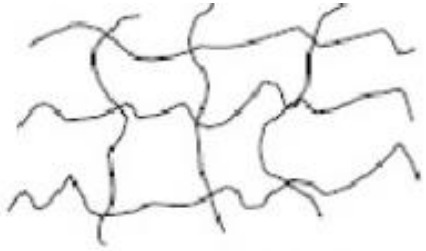
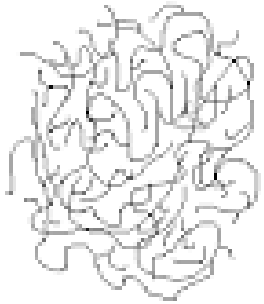
Amorphous and crystalline polymers

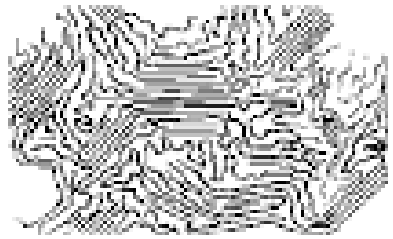
Linear polymer



Cross-linked polymer



Amorphous structure (random)



Semi – crystalline structure

Branched polymer

Structure with thermosetting cross-links

High Density Polyethylene HDPE

Low density Polyethylene LDPE

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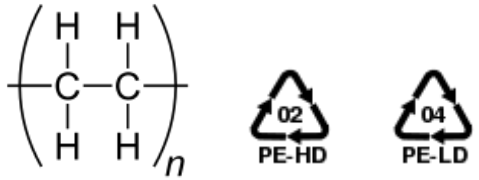
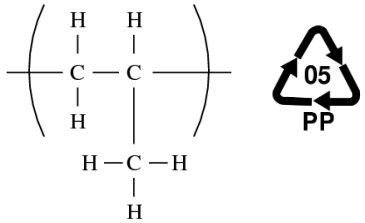
Thermoplastic polymers

Thermoplastic polymers are fuses and therefore can be melted and reshaped

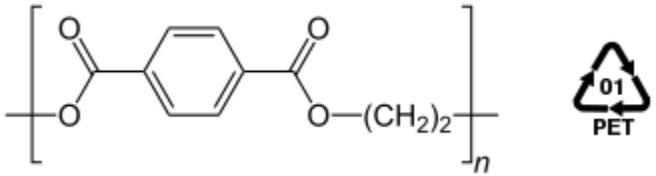
PE polyethylene



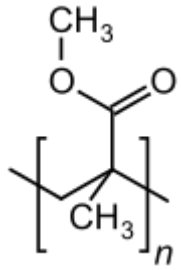
PP polypropylene

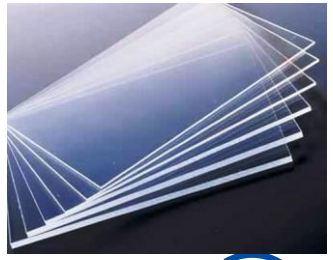


PET polyethylentereftalato



PMMA polymethylmetacrylato (plexiglass)





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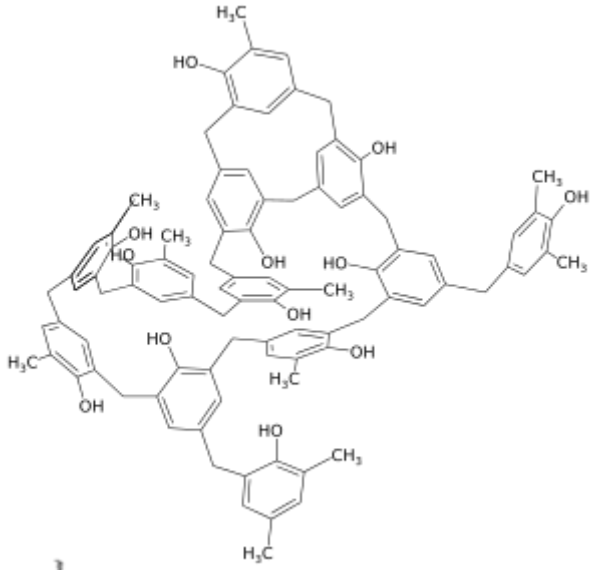
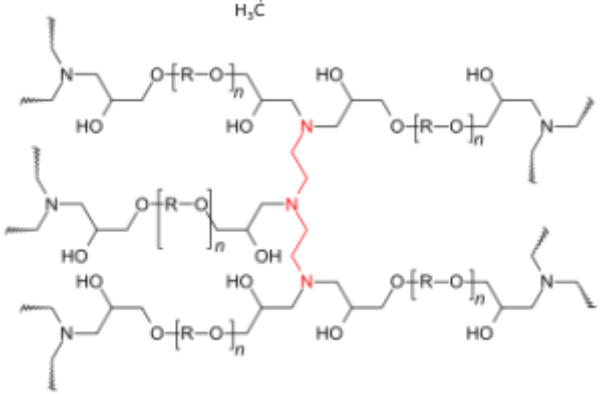
Thermosetting polymers

Thermosetting polymers are non-fusible crosslinked compounds with high mechanical, thermal and chemical properties. However they undergo decomposition at high temperatures.

Bakelite (fenolic resin)



Epoxyn Resin



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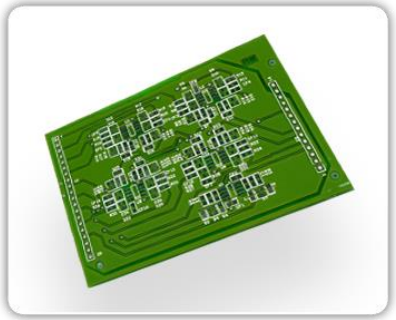
Composite materials

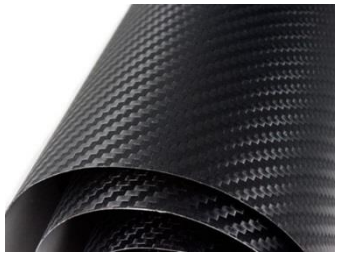
Composite materials consist of more materials that together give an object with high mechanical and chemical characteristics. An example is the fiberglass carbon fiber composite material carbon fibers and epoxy resin

Fiberglass fabric

Phthalic resin



PCB Plate



Fiberglass carbon fiber

Phthalic Resin

Advanced electronic components

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Polymers: collection, recycling and valorization

WEEE Collection and separation of plastics

Object in recycled plastic

Thermovalorization

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WEEE – glasses and chemical compounds
(Critical Raw Materials)

WEEE- Monitor

https://www.regionieambiente.it/ritiro-e-trattamento-dei-raee/

Chatode ray tube

https://www.qsl.net/ik1hgi/472khz/impedenza.htm

GLASSES

Rare Hearth

Phosphorous

The rare earths, the phosphorus and other materials such as europium and red phosphorus, but also other rare earth chemical compounds, are used in cathode ray tubes and liquid crystal displays.
These elements are among those indicated as critical raw materials

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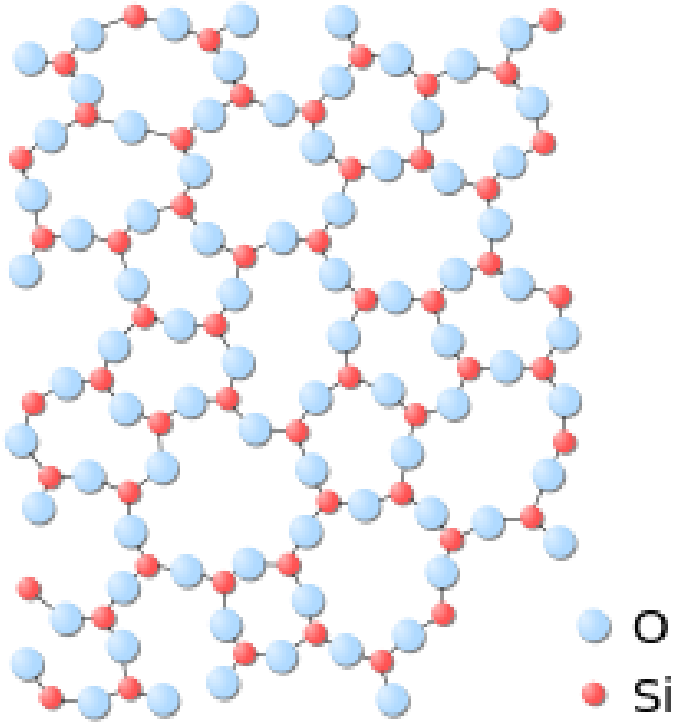
The Glass

The glass is a subcooled liquid that appears as an amorphous solid or a substance in which atoms have not arranged in a crystal lattice.



Special glass PYREX

Boron is added in the form of borax ($Na_2B_4O_7$) or boric acid (H_3BO_3) to improve thermal and electrical characteristics (PYREX).

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The Glass - recycle

Glass can be recycled an unlimited number of times without any alteration. In the recycling process, to obtain high quality glass, the different types of glass must be separated to avoid the presence of unwanted additives.

https://www.ecofocus.it/2016/01/da-vetro-rinasce-vetro/

http://www.elysglass.com/glassIdeas.asp

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European Commission Publishes New Critical Raw Materials List – 27 CRMs Confirmed

On 13 September 2017, the European Commission published a Communication on its long-awaited 2017 list of Critical Raw Materials (CRMs), which features 27 raw materials and updates the 2014 list. The primary purpose of the list is to identify the raw materials with a high supply-risk and a high economic importance to which reliable and unhindered access is a concern for European industry and value chains.
Following an objective methodology the list provides a factual tool for trade, innovation and industrial policy measures to strengthen the competitiveness of European industry in line with the renewed industrial strategy for Europe, for instance by:

- **identifying investment needs which can help alleviate Europe's reliance on imports of raw materials;**
- **guiding support to innovation on raw materials supply under the EU's Horizon 2020 research and innovation programme;**
- **drawing attention to the importance of critical raw materials for the transition to a low-carbon, resource-efficient and more circular economy**

It is hoped that the list will help incentivize the European production of critical raw materials through enhancing recycling activities and when necessary to facilitate the launching of new mining activities.

The new list features 27 raw materials: Antimony, Beryllium, Borates, Cobalt, *Coking Coal, Fluorspar, Gallium, Germanium, Indium, Magnesium, Natural Graphite, Niobium, Phosphate Rock, Silicon Metal, Tungsten, Platinum Group Metals, Light Rare Earths and Heavy Rare Earths, Baryte, Bismuth, Hafnium, Helium, Natural Rubber, Phosphorus, Scandium, Tantalum, and Vanadium.
*it is important to note that Coking Coal is considered a borderline case. Although it narrowly misses the economic importance threshold, for the sake of caution, coking coal is kept on the list of critical raw materials for the EU and thus included in the table. However, it will be phased out from the next list should it fail to meet the criteria in full.

https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF

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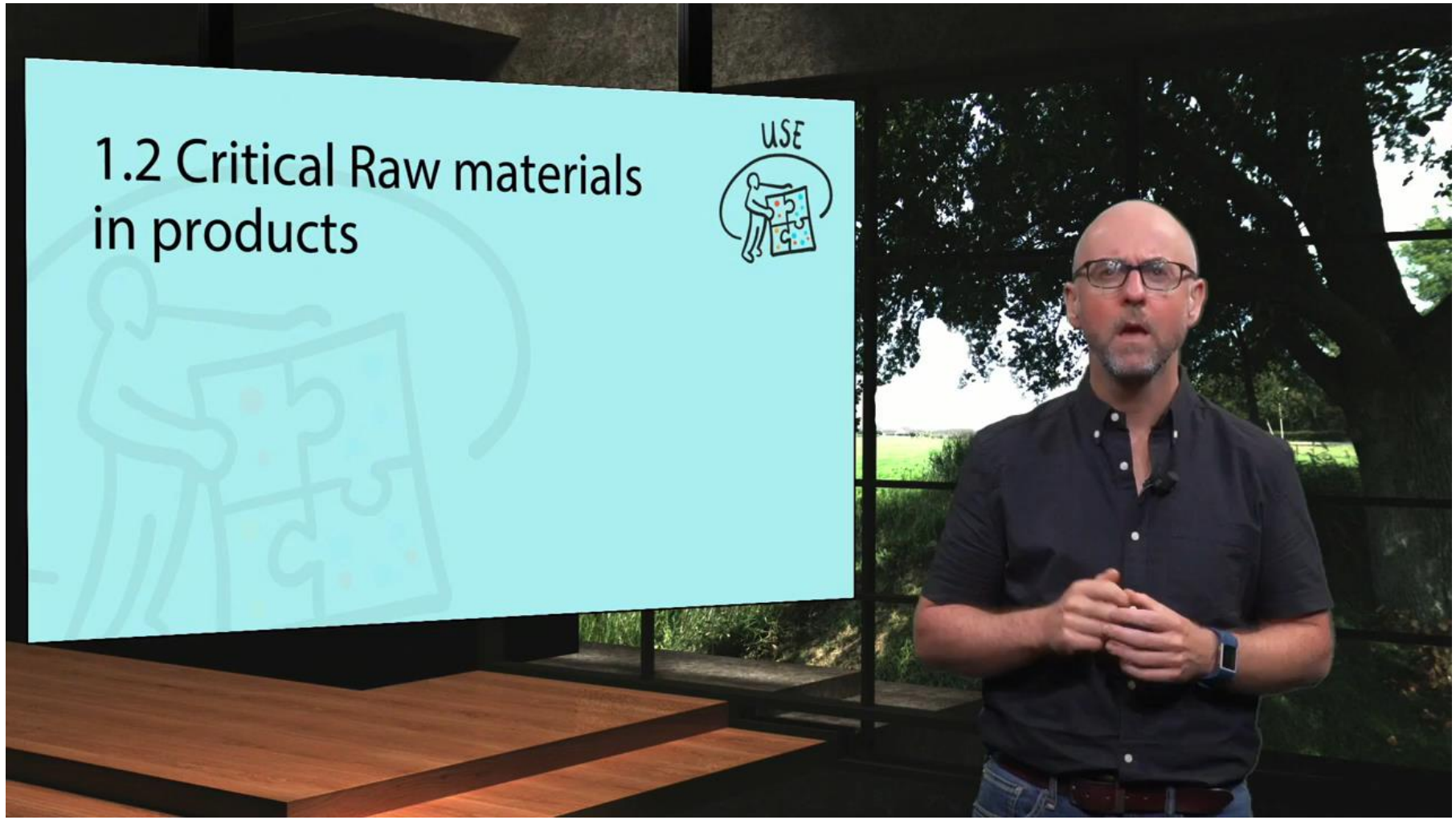
Critical Raw Materials «CRMs» in WEEE

https://youtu.be/03E1-GIhLQs



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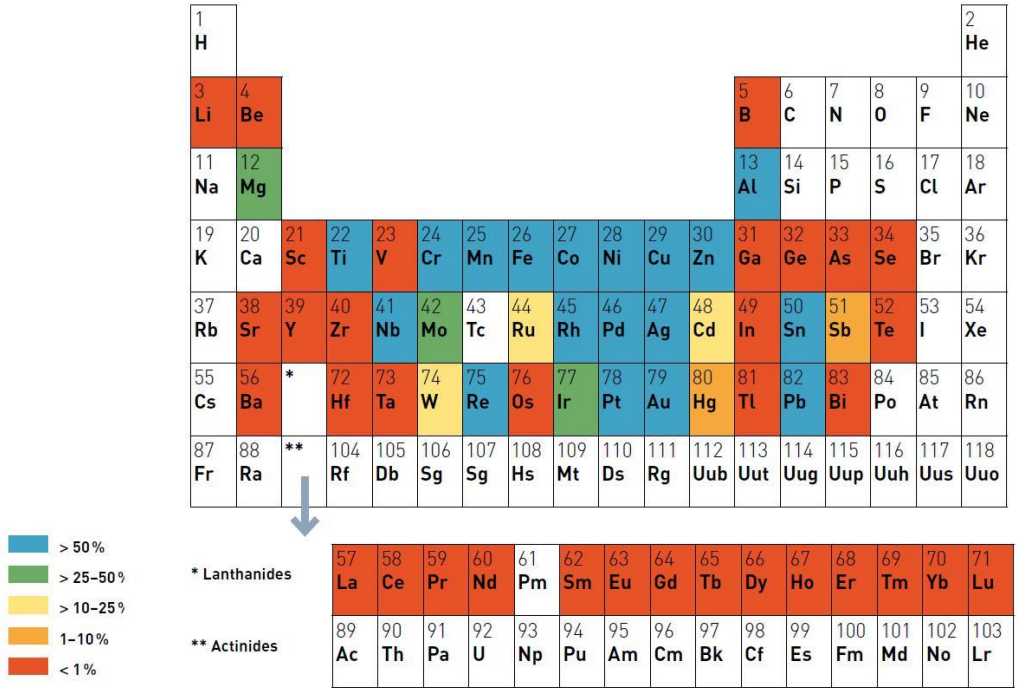
Critical Raw Materials «CRMs»

In a specific document, the European Commission identifies the critical materials as materials that have a high strategic importance for their use in high-tech sectors, materials that are not replaceable and that present supply problems due to their reduced quantity and geopolitical problems which limit the possibility of retrieval.



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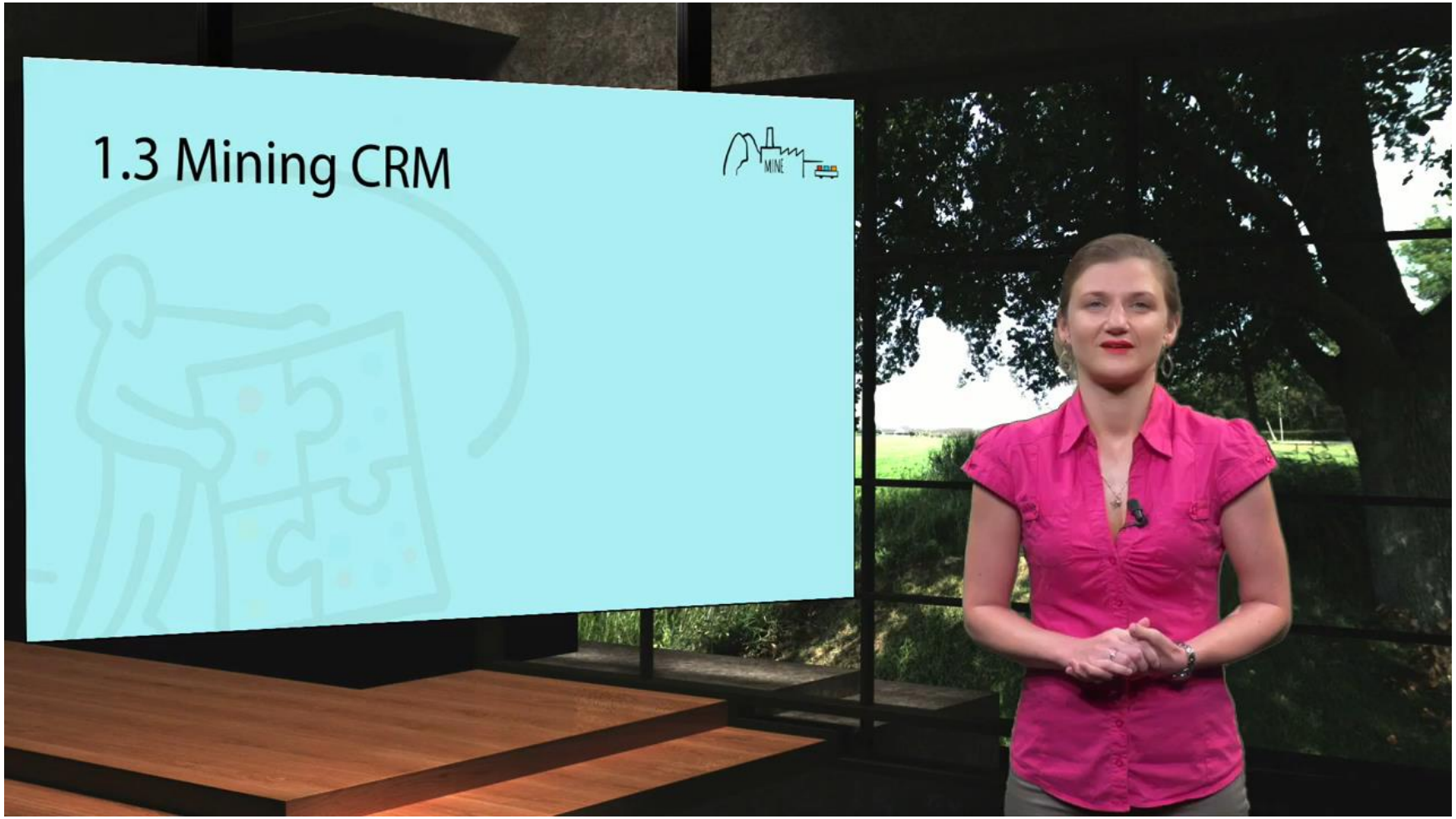
Critical Raw Materials: supply problems

https://youtu.be/tknkjWyJ5S4



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Critical Raw Materials- The key factors

It is important to note that these raw materials are NOT classified as critical exclusively for the scares reserve but rather because:

1. High economic importance for key factors of the European economy, such as electronics, environmental technologies, automotive sector, aerospace, defense, health and steel production

2. High supply risk due to high dependency and high concentrations of categories of these materials in specific countries

3. Lack of (possible) substitutes, due to the unique properties of these materials for existing and future applications.

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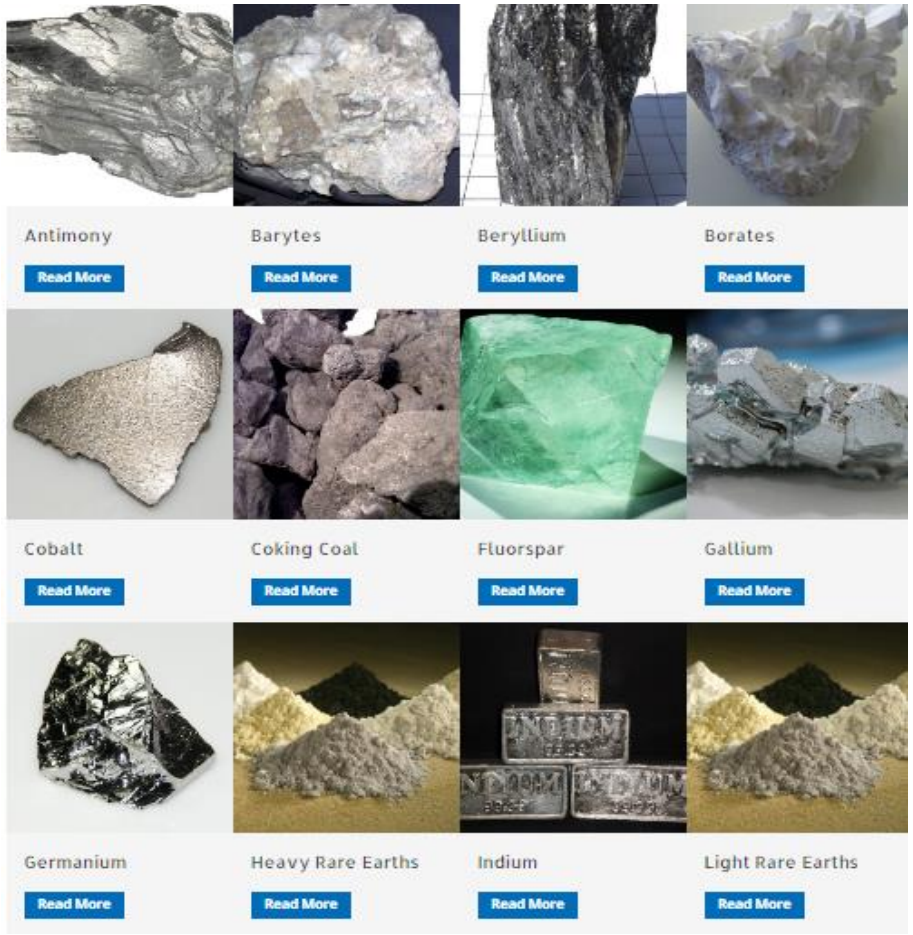
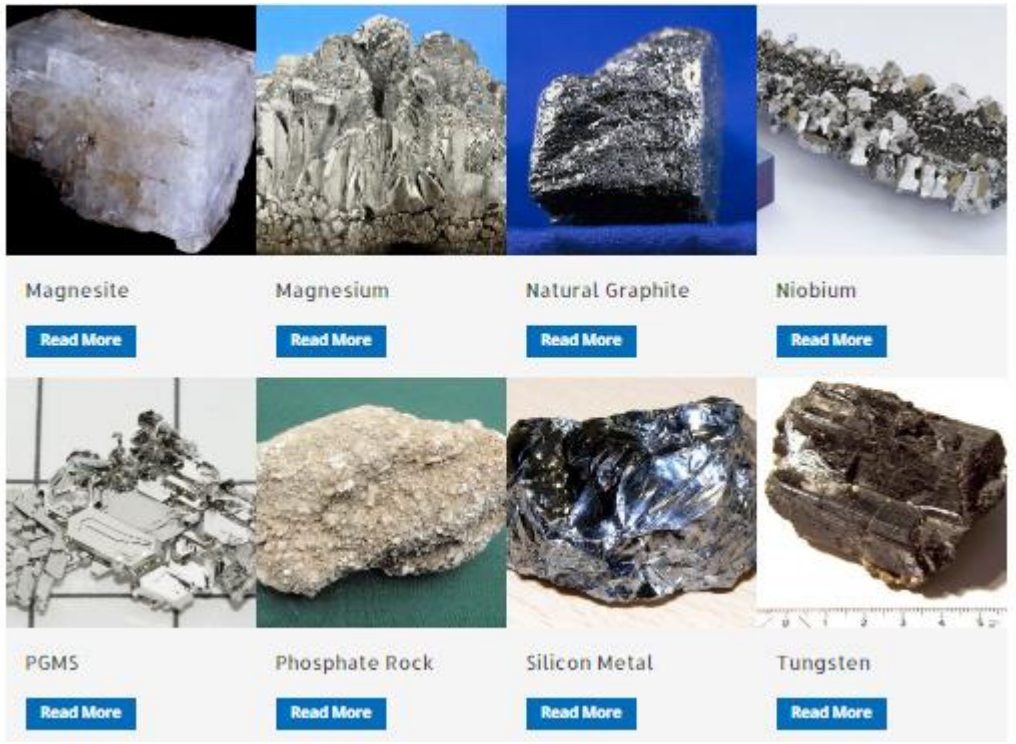
27 Critical Raw Materials

The European Commission in the last update of the list of Critical Raw Materials includes 27 materials including those listed below:





http://criticalrawmaterials.org/

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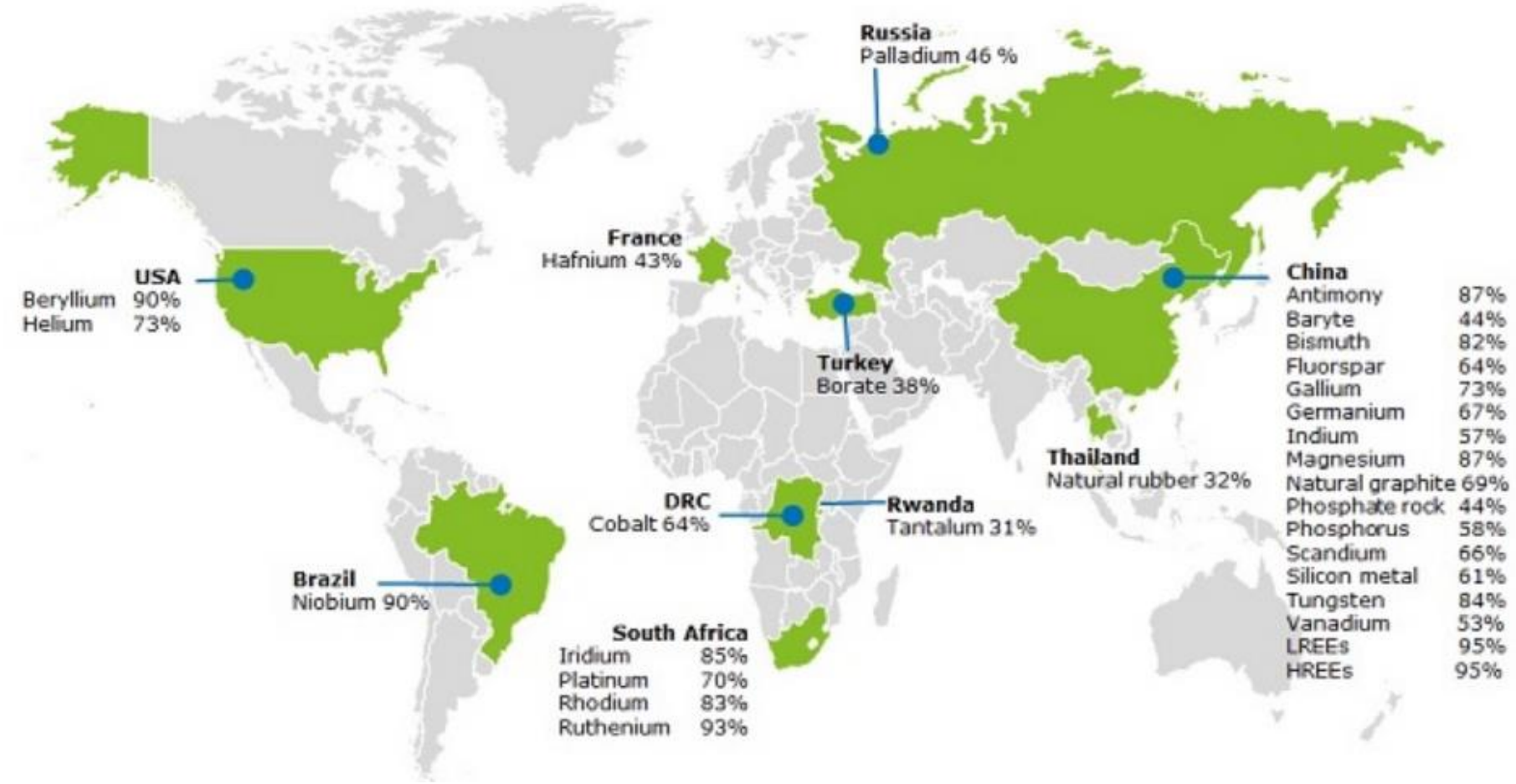
Global Share of Critical Raw Materials

Countries accounting for largest share of global supply of CRMs



http://criticalrawmaterials.org/

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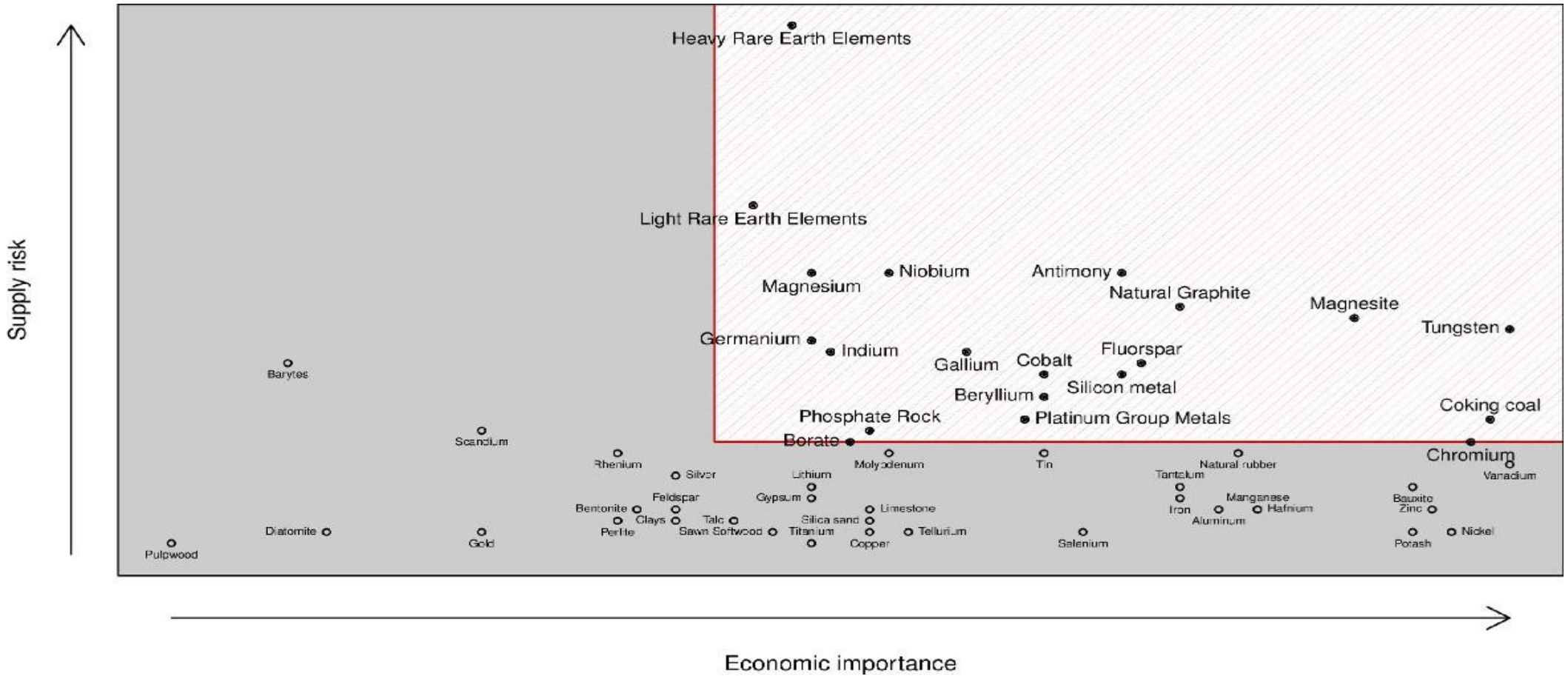
Critical Raw Materials

Magnesium, Antimony, Phosphorus, Rare Earths (light and heavy etc. are among the most highly regarded raw materials)



http://criticalrawmaterials.org/

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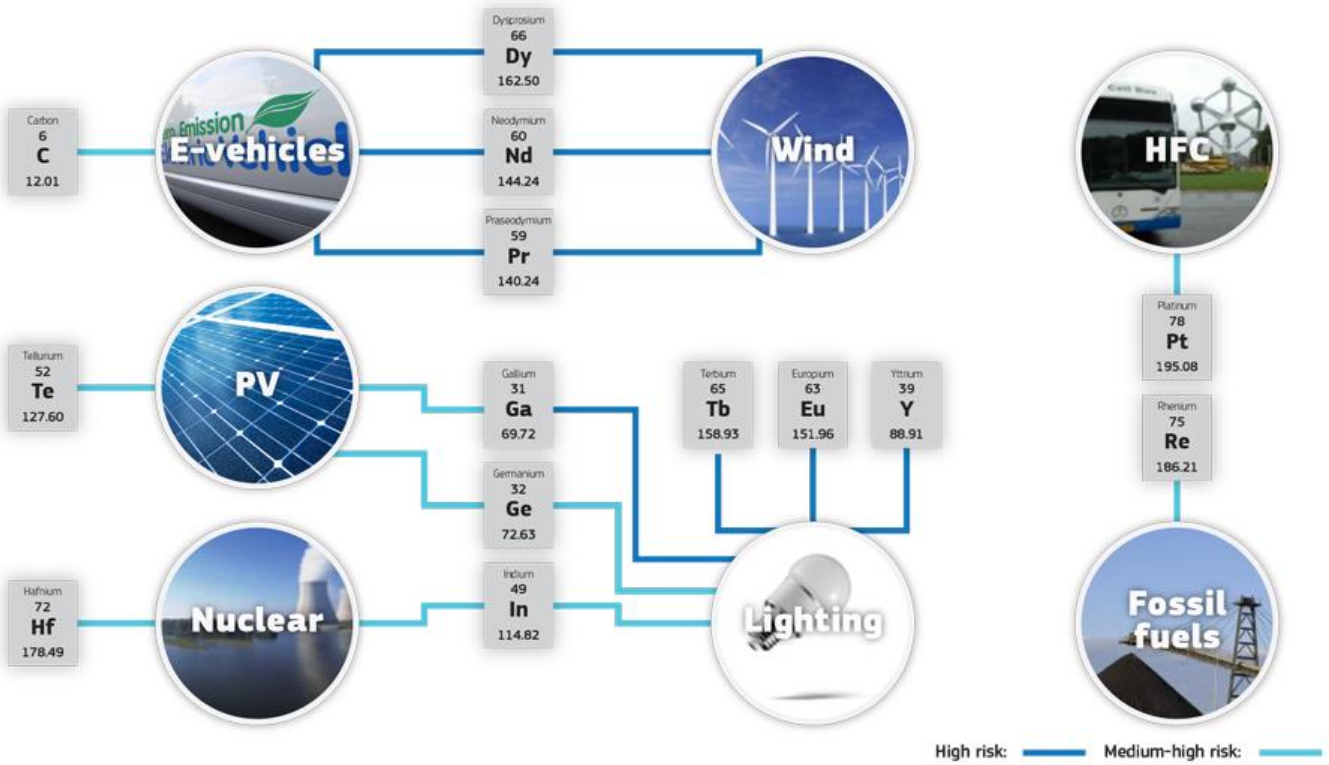
Critical Raw Materials – Risk Rating and Technology Applications

Raw Material	Risk Rating	Associated Technology
Rare Earths: Dy, Pr, Nd	High	e-vehicles, wind
Rare Earths: Eu, Tb, Y	High	lighting
Gallium	High	lighting, solar
Tellerium	High	solar
Grapghite	Medium-High	e-vehicles
Rhenium	Medium-High	fissil fuels
Halfnium	Medium-High	nuclear
Germanium	Medium-High	lighting
Platinum	Medium-High	fueal cells
Indium	Medium-High	solar, lighting, nuclear



http://criticalrawmaterials.org/

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The importance of the correct disposal of WEEE in SUMMARY

- **Recovery and saving of exhaustible raw materials and energy**

- **No emission of toxic substances in the environment**

- **The recovery and recycle of CRMs is of strategic importance for the European Union**

https://www.habitante.it/habitare/living-e-tendenze/imparare-il-risparmio-energetico-e-ledilizia-sostenibile-un-nuovo-lavoro/

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