Critical raw materials, conflict minerals and shortfall of elements used in electronic and electrical devices. An approach taking into account recycling and recovery of materials

Topic: Robots and society, ethics, and legal issues

Daniela Cristina NASTAC

Glossary

Critical raw materials (CRMs): raw materials of a high importance to the economy of the EU and whose supply is associated with a high risk.

- Economic Importance (EI) and Supply Risk (SR) are used to determine the criticality of the material for the EU. The list of CRMs is established on the basis of the raw materials which reach or exceed the thresholds for both parameters.

Conflict minerals: due to internal conflict situations in a few mining regions in the world, there is a risk of armed conflicts being financed by the proceeds from the sale of minerals.

- Columbite-tantalite (‘coltan‘; commodity for niobium and tantalum extraction), incl. as a component of condensers; used for the production of steel (Niobium)
- Cassiterite (black tin; commodity for tin extraction), incl. as a component of catalytic converters, semiconductors, alloys; used in soldering processes, as a stabiliser for PVC, in packagings (food cans)
- Wolframite (commodity for tungsten extraction), incl. as a component of alloys in the automotive industry; used in microelectrodes, ‘tungsten wire‘
- Gold, incl. in jewellery making, the electronics, optical and medical industries, as coins and ingots in payment transactions

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Glossary

Shortfall / endangered elements: Of the 118 elements that make up everything—from the compounds in a chemist's arsenal to consumer products on the shelf—44 will face supply limitations in the coming years. These critical elements include rare earth elements, precious metals, and phosphorus.

- There are 9 elements (He, Zn, Ga, Ge, As, Ag, In, Te, Hf) for which there is concern that there is a serious threat to their supply within the next 100 years
- There are 7 elements (Ru, Rh, Ta, Os, Ir, Pt, U) for which there is a rising threat due to increased use.

Critical Raw Materials

- **Economic Importance (EI):** looks in detail at the allocation of raw materials to end-uses based on industrial applications.
- **Supply risk (SR):** looks at the country-level concentration of global production of primary raw materials and sourcing to the EU, the governance of supplier countries, including environmental aspects, the contribution of recycling (i.e. secondary raw materials), substitution, EU import reliance and trade restrictions in third countries.
- The 2020 EU list of CRMs contains 30 materials
    - 14 materials in 2011
    - 20 materials in 2014
    - 27 materials in 2017

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Critical Raw Materials List

Antimony	Hafnium	Phosphorus
Baryte	Heavy Rare Earth Elements (HREE): Dy, Er, Eu, Gd, Ho, Lu, Tb, Tm, Yb, Y	Scandium
Beryllium	Light Rare Earth Elements (LREE): Ce, La, Nd, Pr, Sm	Silicon metal
Bismuth	Indium	Tantalum
Borate	Magnesium	Tungsten
Cobalt	Natural Graphite	Vanadium
Coking Coal	Natural Rubber	**Bauxite**
Fluorspar	Niobium	**Lithium**
Gallium	Platinum Group Metals (PGM): Ir, Pd, Pt, Rh, Ru	**Titanium**
Germanium	Phosphate rock	**Strontium**

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CRMs – selected uses

CRM	Stage	Main global producers	Main EU sourcing countries	Import reliance	Selected uses
Be	E	United States (88%) China (8%) Madagascar (2%)	n/a	n/a	- Electronic and Communications Equipment - Automotive, aero-space and defense components
Borate	E	Turkey (42%) United States (24%) Chile (11%)	Turkey (98%)	100%	- High performance glass - Fertilisers - Permanent magnets
Co	E	Congo (59%) China (7%) Canada (5%)	Congo (68%) Finland (14%) French Guiana (5%)	86%	- Batteries - Super alloys - Catalysts - Magnets

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CRMs – selected uses

CRM	Stage	Main global producers	Main EU sourcing countries	Import reliance	Selected uses
Ga	P	China (80%) Germany (8%) Ukraine (5%)	Germany (35%) UK (28%) China (27%) Hungary (2%)	31%	- Semiconductors - Photovoltaic cells
Ge	P	China (80%) Finland (10%) Russia (5%)	Finland (51%) China (17%) UK (11%)	31%	- Optical fibers and Infrared optics - Satellite solar cells - Polymerisation catalysts
In	P	China (48%) Korea, Rep. (21%) Japan (8%)	France (28%) Belgium (23%) UK (12%) Germany (10%) Italy (5%)	0%	- Flat panel displays - Photovoltaic cells and photonics - Solders

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CRMs – selected uses

CRM	Stage	Main global producers	Main EU sourcing countries	Import reliance	Selected uses
PGMs	P	South Africa (84%) - Ir, Pt, Rh, Ru Russia (40%) - Pd	n/a	100%	- Chemical and automotive catalysts - Fuel Cells - Electronic applications
HREEs	P	China (86%) Australia (6%) United States (2%)	China (98%) Other non-EU (1%) UK (1%)	100%	- Permanent magnets for electric motors and electricity generators - Lighting Phosphors - Catalysts - Batteries - Glass and ceramics
LREEs	P	China (86%) Australia (6%) United States (2%)	China (99%) UK (1%)	100%	

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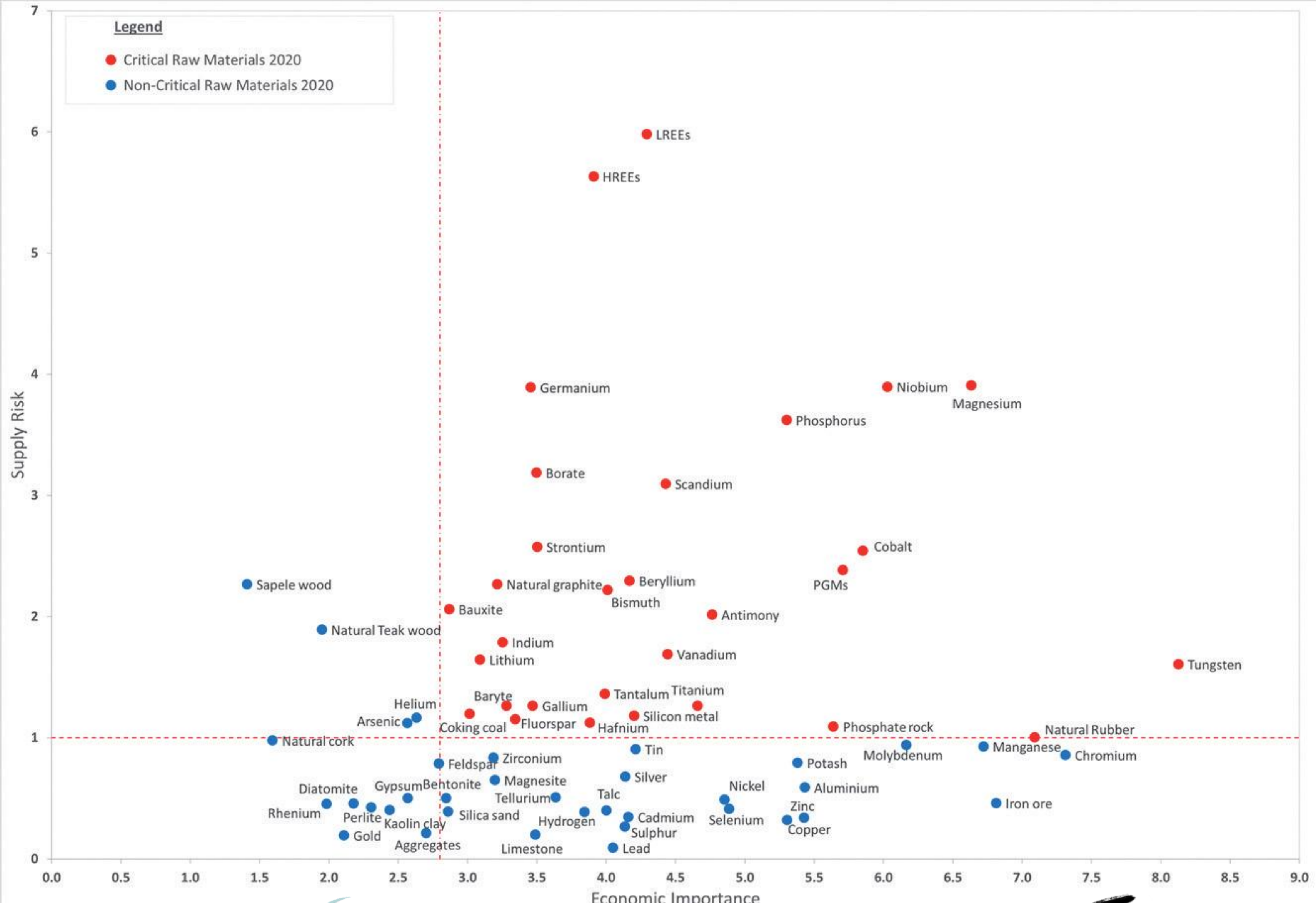
Critical Raw Materials



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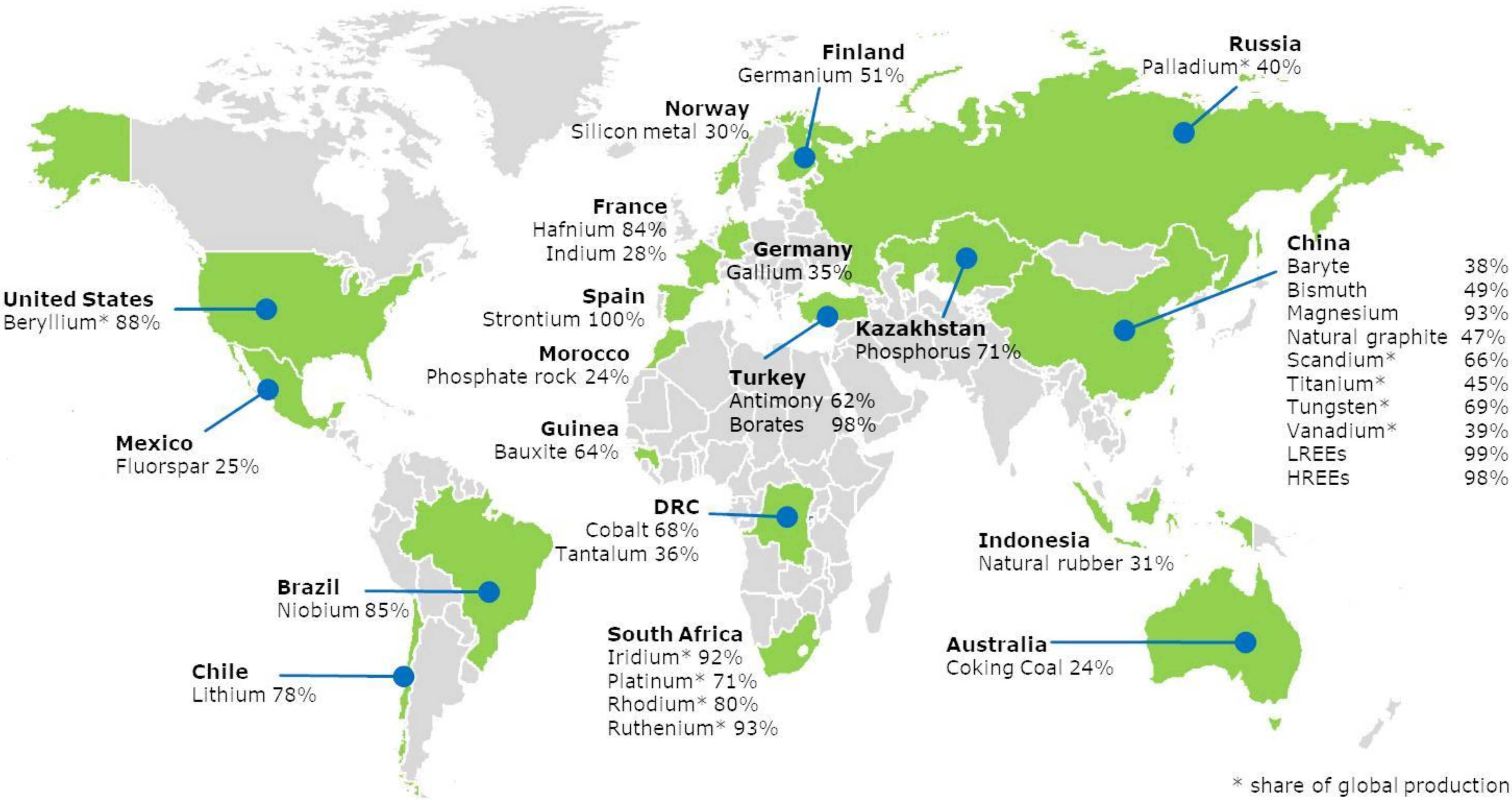
Biggest supplier countries for CRMs



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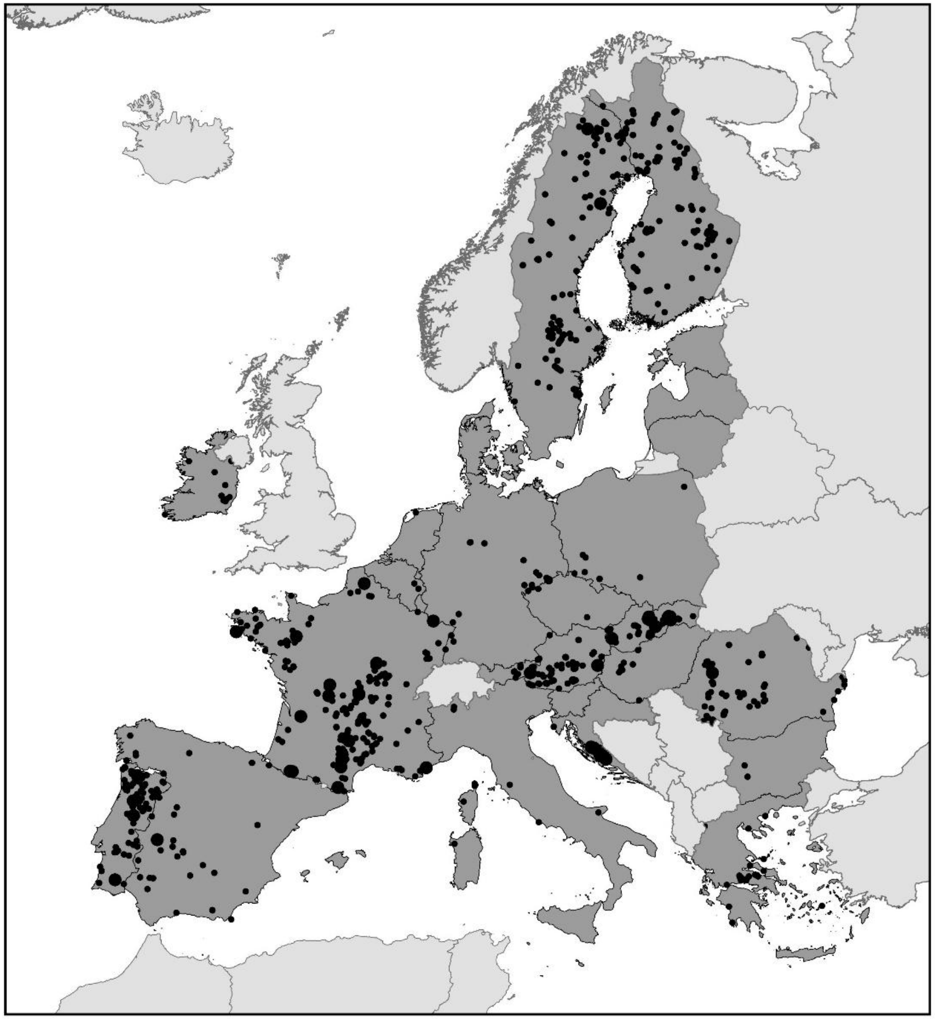
CRM EU-27 deposits

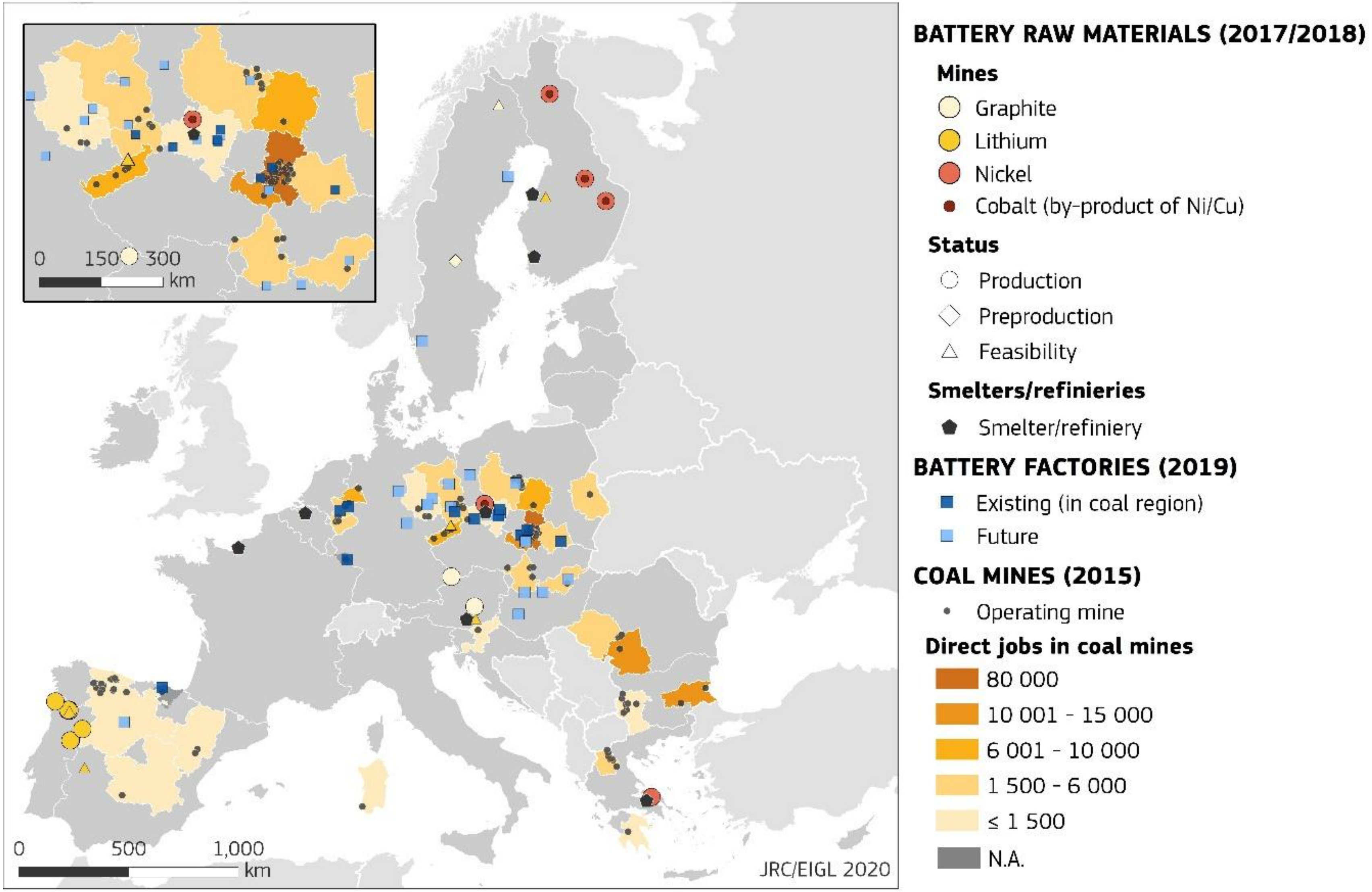
CRITICAL RAW MATERIALS RESOURCES POTENTIAL IN THE EU



Data provided by EuroGeoSurveys combined with other EU data sources

- Europe is well-endowed with aggregates and industrial minerals as well as certain base metals such as copper and zinc
- EU is less successful in developing projects to source critical raw materials, even though there is significant potential for these.
- The reasons are multi-faceted: lack of investment in exploration and mining, diverse and lengthy national permitting procedures or low levels of public acceptance.
- The development of battery raw materials such as Li, Ni, Co, graphite and Mn provides interesting opportunities.

Battery raw material mines, battery factories and coal mines



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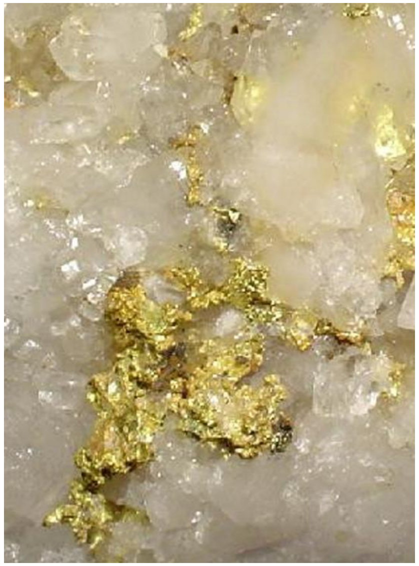
Conflict Minerals

- Conflict minerals are minerals mined in conditions of armed conflict and human rights abuses, and which are sold or traded by armed groups.


Coltan


Cassiterite


Wolframite


Gold

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Conflict Minerals

Mineral	Description	Major uses
Cassiterite	Tin (Sn) is extracted	Plating and solders for joining pipes and electronic circuits
Columbite-tantalite	Tantalum (Ta) is extracted	Electrical components (including those used in mobile phones, computers, videogame consoles), aircraft and surgical components
Wolframite	Tungsten (W) is extracted	Metal wires, electrodes and contacts in lighting, electronic, electrical, heating and welding applications
Gold	Rare metal found in a native (pure) form and obtained as a by-product of other mining operations	Jewellery, electronic, communications and aerospace equipment

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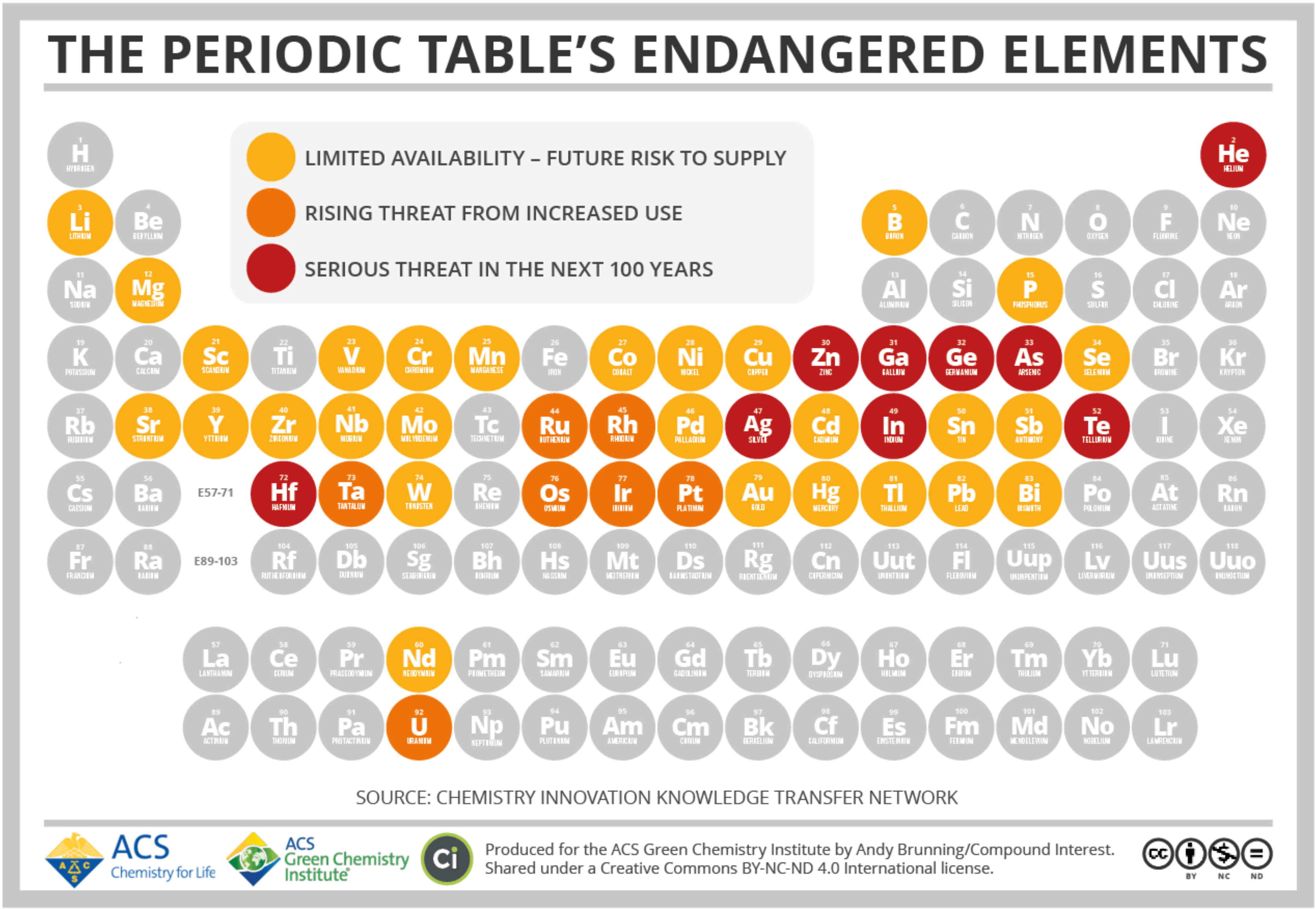

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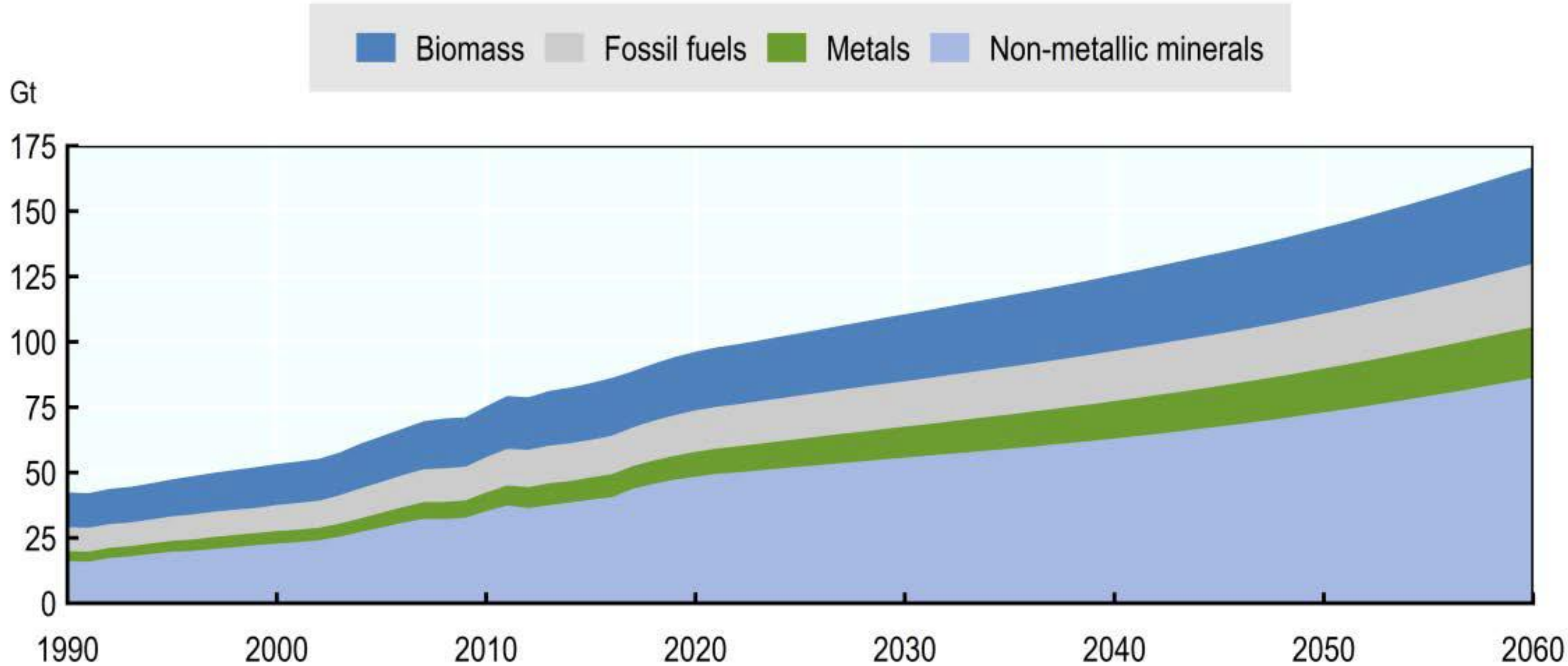
Materials extraction projection by 2060



Global materials extraction is projected to increase across all material types

- Biomass and fossil fuel resources can be directly linked to the coal power and iron and steel production activities; for metals and non-metallic minerals, the projections of materials use are linked to the input of extractive commodities into a processing sector.
- Global materials use is projected to reach 111 Gt in 2030 and 167 Gt in 2060, from 89 Gt in 2017. Thus, total materials extraction is projected to increase by 88% (i.e. almost double) over 43 years.

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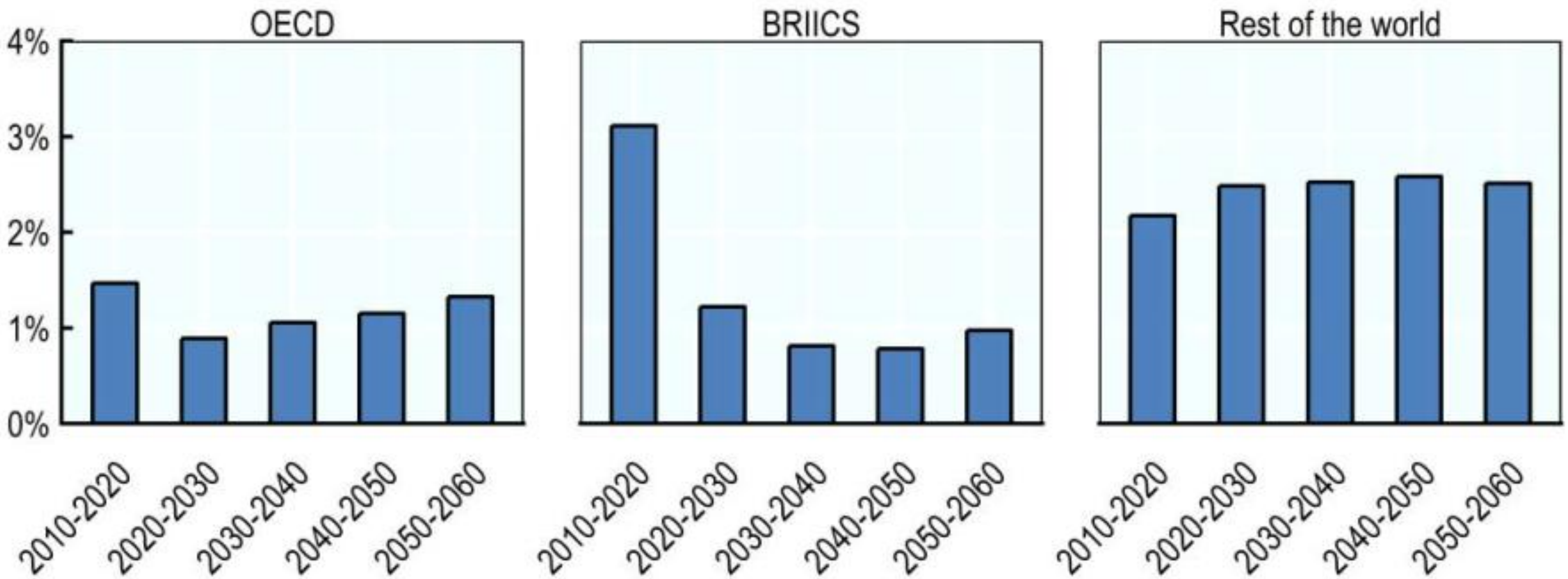
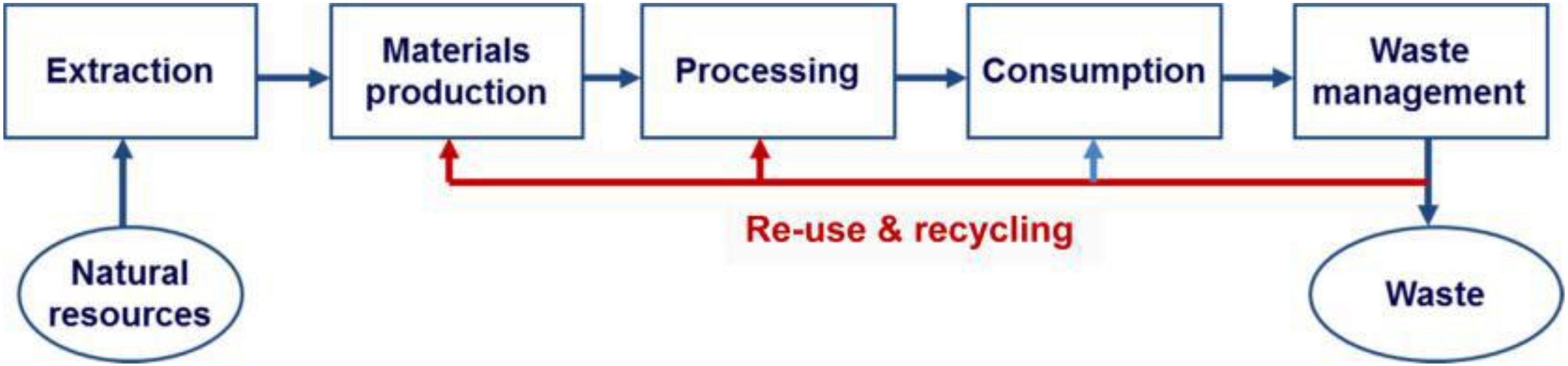
Materials extraction projection by 2060



Average growth rates of materials use by decade for groups of countries

- Growth rates of materials use at the macro-regional level are strongly affected by the economic dynamics in these regions. They are projected to be fairly stable in OECD countries. In the BRIICS countries, growth rates of materials use are projected to be high in the short run, following the growth boom, and then to fall gradually back to levels similar to those of the OECD. The developing countries are projected to continue to catch up and sustain growth rates above those of the OECD throughout the projection horizon.

Recycling: A Key Factor for Resource Efficiency



Closing the loops. Shifting from a linear economy to a circular economy requires the closing of loops to ensure that products and materials are reused or recycled

- Historically, industry has operated as an open system, transforming resources to products that are eventually discarded to the environment. This, has led to growing impacts on the environment.
- Waste is becoming a large problem, as we are running out of land for landfilling, and end-of-life waste treatment has negative environmental and health impacts. This is especially a problem for emerging economies, where material use (and hence discarding of it) is growing very rapidly, while limited waste management infrastructure exists.

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Recycling: A Key Factor for Resource Efficiency

- To maintain our level of welfare, services by resources should be provided more efficiently using less (environmental) resources per unit of activity; i.e. we must improve the resource efficiency of our society. There are several ways that we can improve the resource efficiency of society:
  - Use resources more efficiently in the provision of an activity or product (including lifetime lengthening).
  - Use less resource-related services.
  - Reuse product and services.
  - Recycle the resources and materials in products.
- Waste is only waste if it cannot be used again or if its economic value, including dumping costs, is not sufficient to make its exploitation economically feasible. Economic recycling enables waste to become a resource; however, various aspects hinder it becoming totally reusable. Recycling is the reprocessing of recovered materials at the end of product life, returning them into the supply chain.

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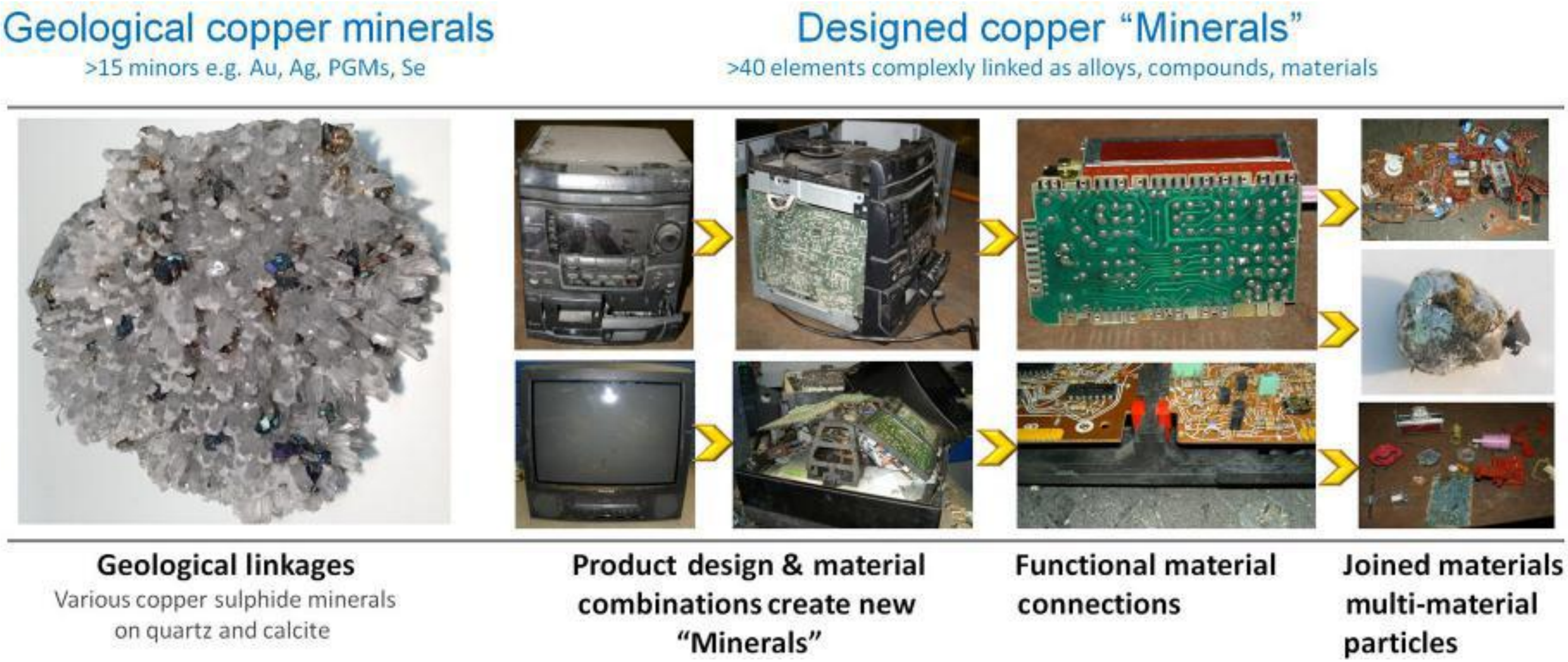
Recycling: A Key Factor for Resource Efficiency



- Conventional extraction processes can recovery various elements from geological ores economically, while much work has to be done to recover all metals from complex designer copper "minerals".
- Less than 1% of the REEs in waste are currently being recycled as these go lost owing to the complexity. The fraction of a material that can reenter the life cycle will depend both on the material itself and on the mineralogy of the product from which it is being recovered.

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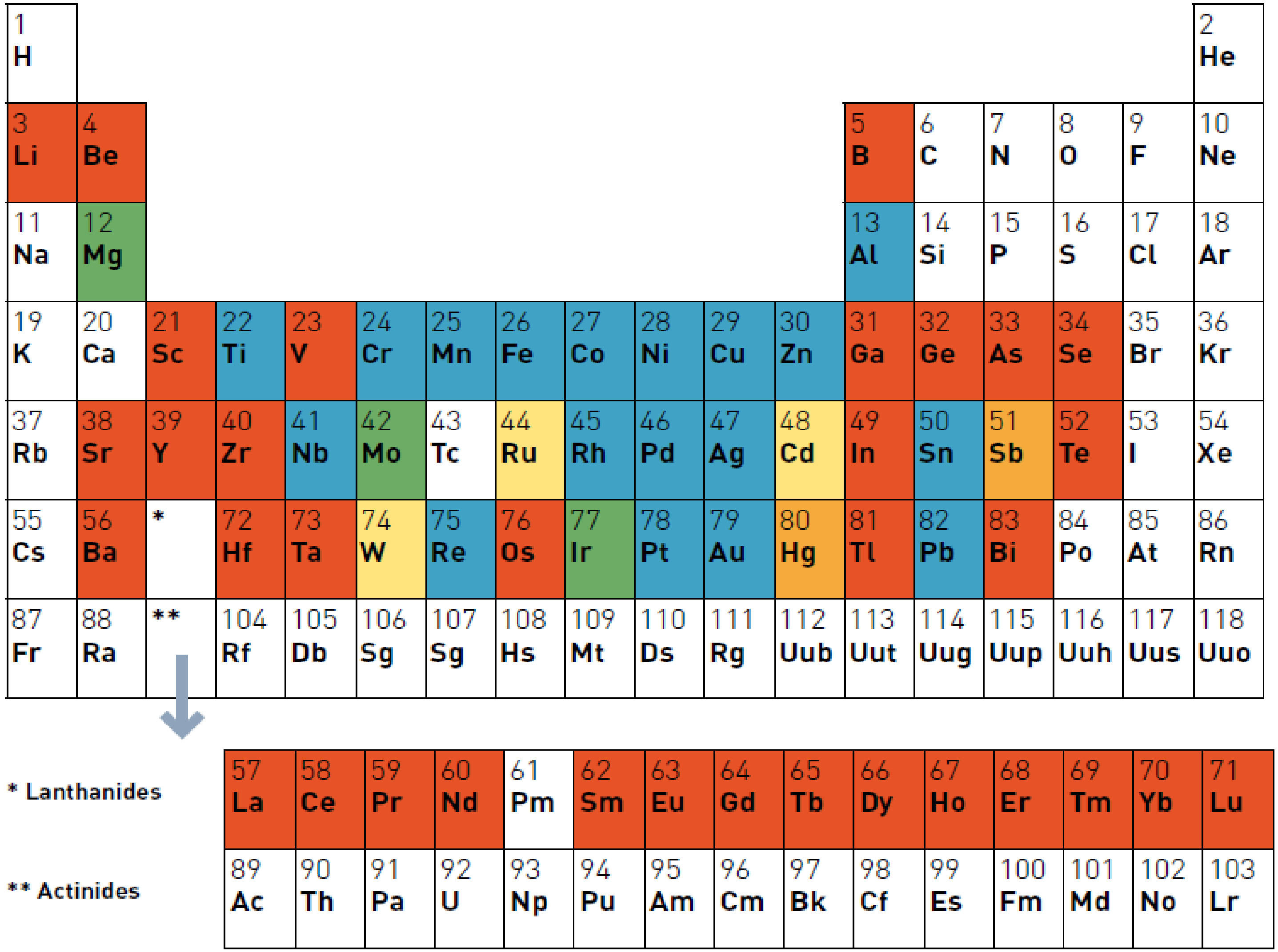
Functional recycling of metals: ferrous and nonferrous

Mn: present at 0.3-1.0% in nearly all steels
Cr: chief additional constituent of stainless steel
Co: superalloys, catalysts and batteries
Mo: high performance stainless steels
Nb: high strength-low alloy steels and superalloys
Zn: coating steel (galvanizing)
Cu: conducting electricity and heat
Ni: constituent of stainless steel and superalloys



> 50 %
> 25–50 %
> 10–25 %
1–10 %
< 1 %

Functional recycling: recycling in which the physical and chemical properties that made material desirable in the first place are retained for subsequent use

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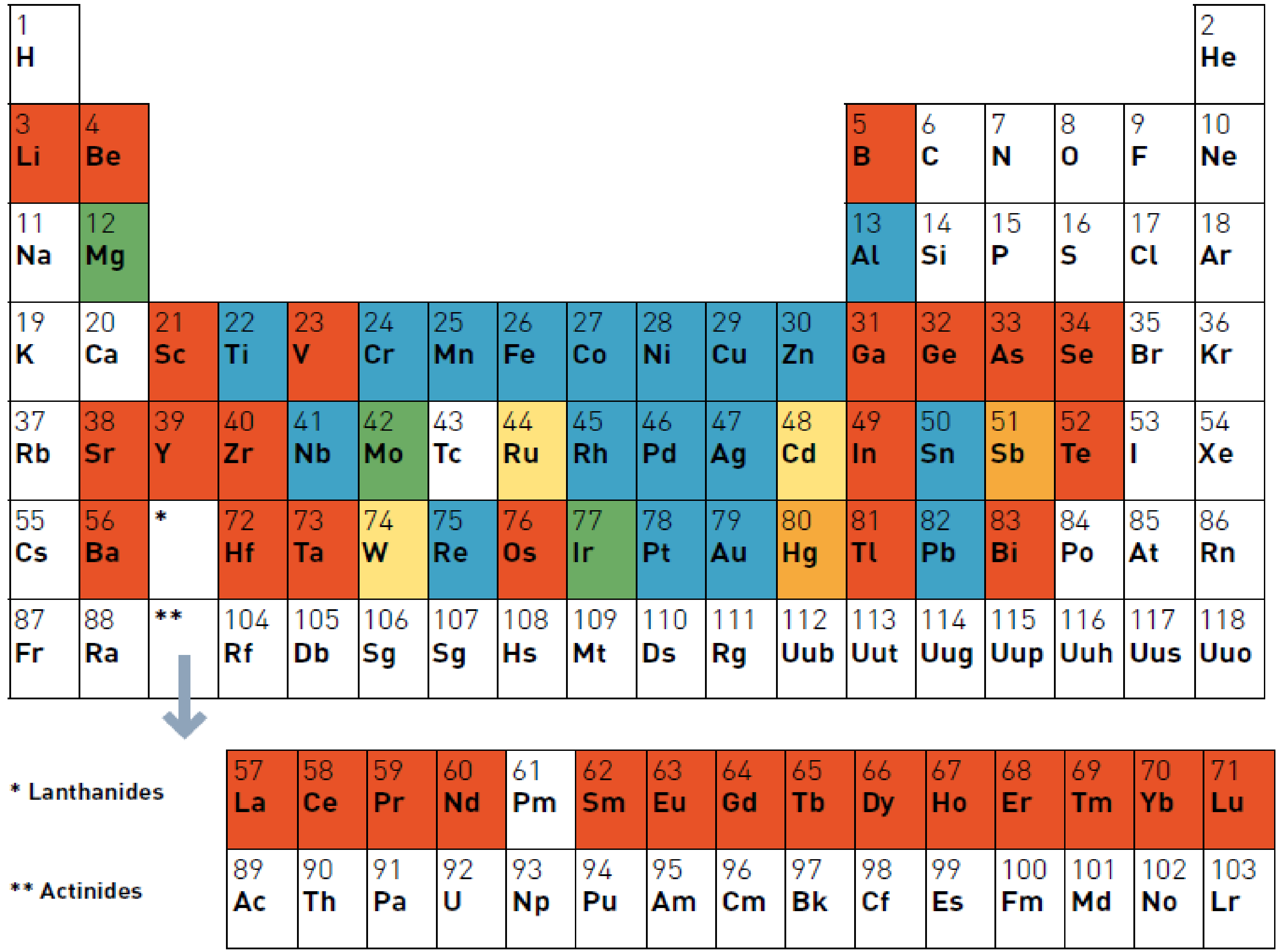
Functional recycling of metals: precious metals

Ru: electronics (hard disk drives) and process catalysts / electrochemistry
Rh, Pd: auto catalysts
Ag: electronics, catalysts, batteries, glass mirrors
Ir: electrochemistry, crucibles for monocrystal growing
Os: catalysts, has little industrial importance
Pt: catalysts
Au: electronics



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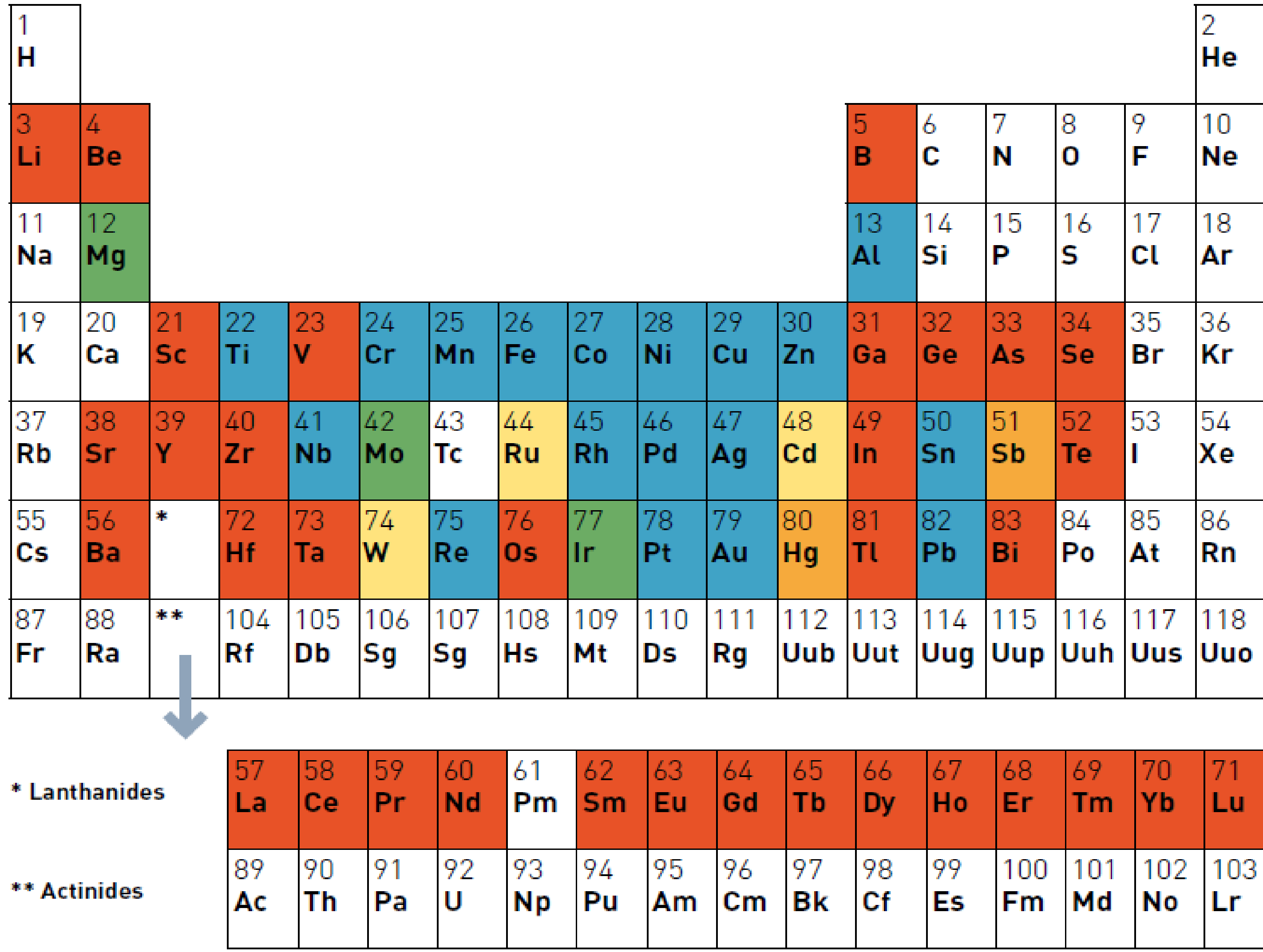
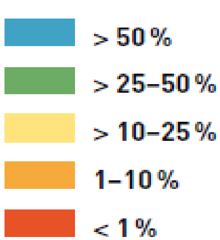
Functional recycling of metals: specialty metals

Zr, Hf: nuclear reactors
In: coating in flat panel displays
Cd: batteries (85%)
Ga: electronics – LED, diodes, solar cells
Ge: nigth vision (IR) lenses, PET catalysts, fiber optics, solar cells concentrators
Sr: pyrotechnics, ferrite ceramic magnets for electronics
Se: glass manufacture, LEDs, photovoltaics, IR optics
As: semiconductors (electronics, PVs), alloying element





Specialty metals: present in small amounts for their specific physical and chemical properties

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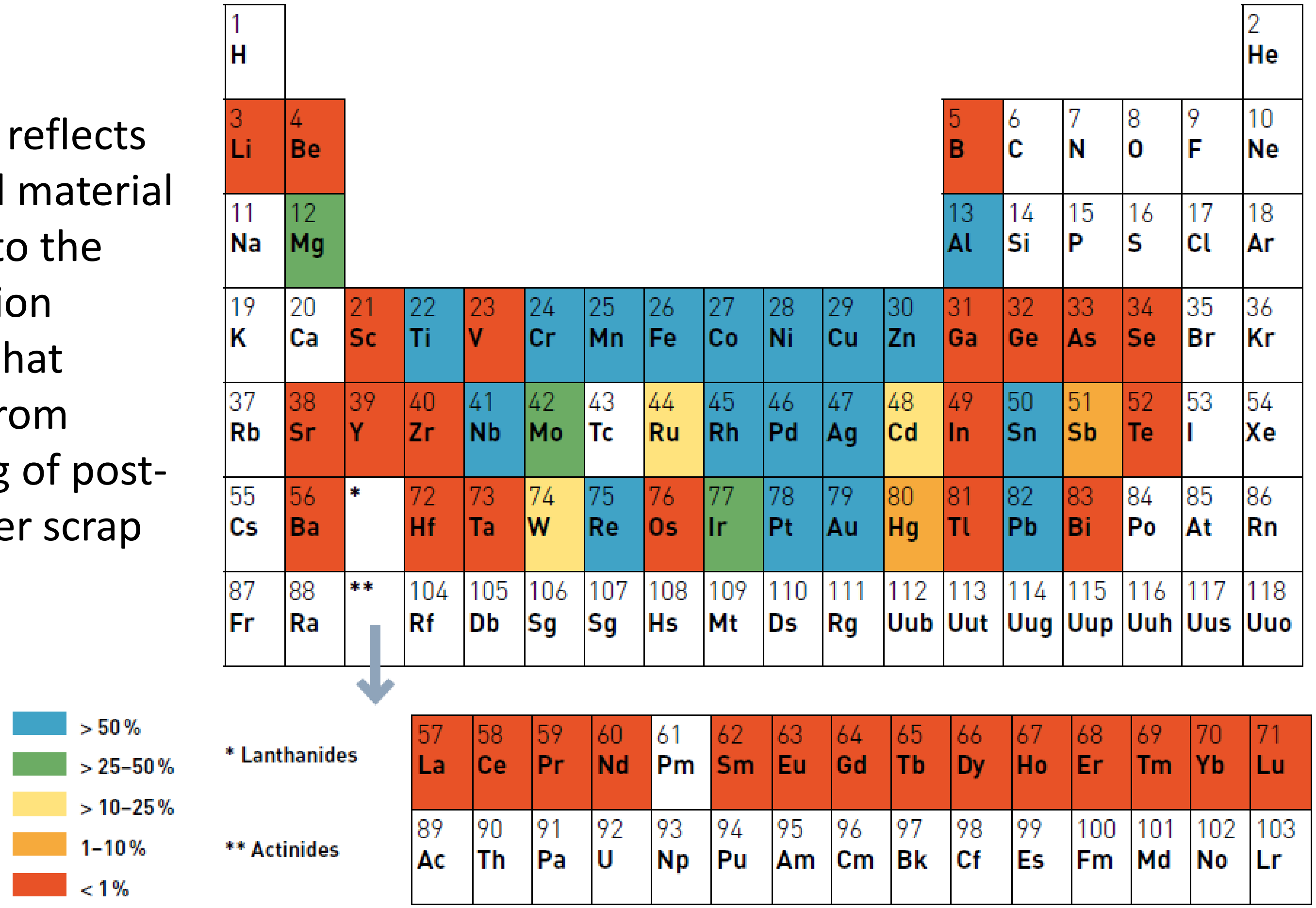
End of Life-recycling rate for metals

EOL-RR: reflects the total material input into the production system that comes from recycling of post-consumer scrap



- It is noteworthy that for only 18 of the 60 metals are the EOL-RR values above 50%. Another three metals are in the 25-50% group, and three more in the 10-25% group. For a very large number, little or no EOL recycling is occurring, either because is not economic, or no suitable technology exists

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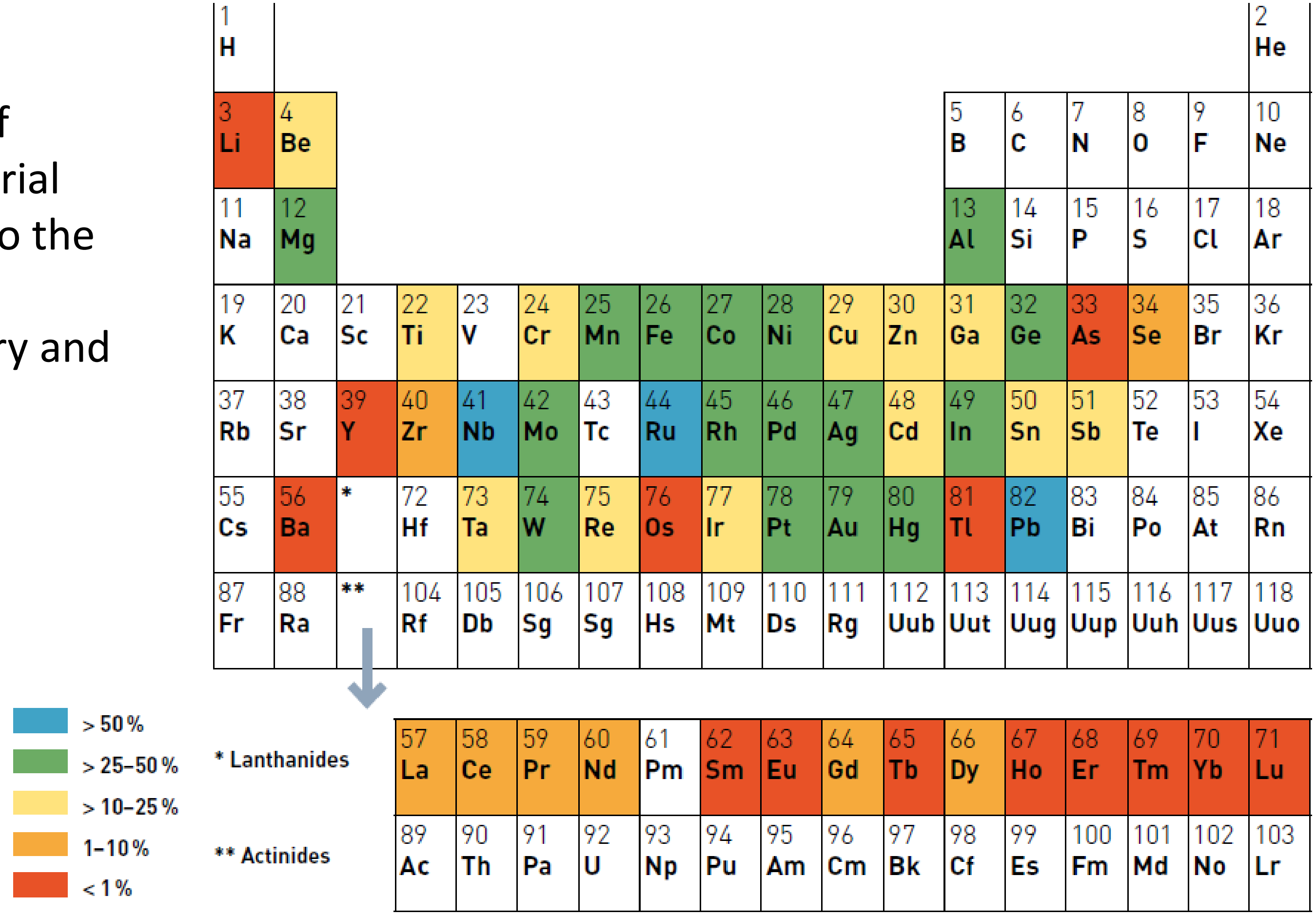
Recycling input ratio for metals

RIR: the input of secondary material from old scrap to the total input of material (primary and secondary)



- Pb, Ru and Nb are the only metals for which RIR >50%, but 16 metals have RIR in the >25-50% range. This reflects a combination in several cases of efficient employment of new scrap as well as better than average EOL recycling.

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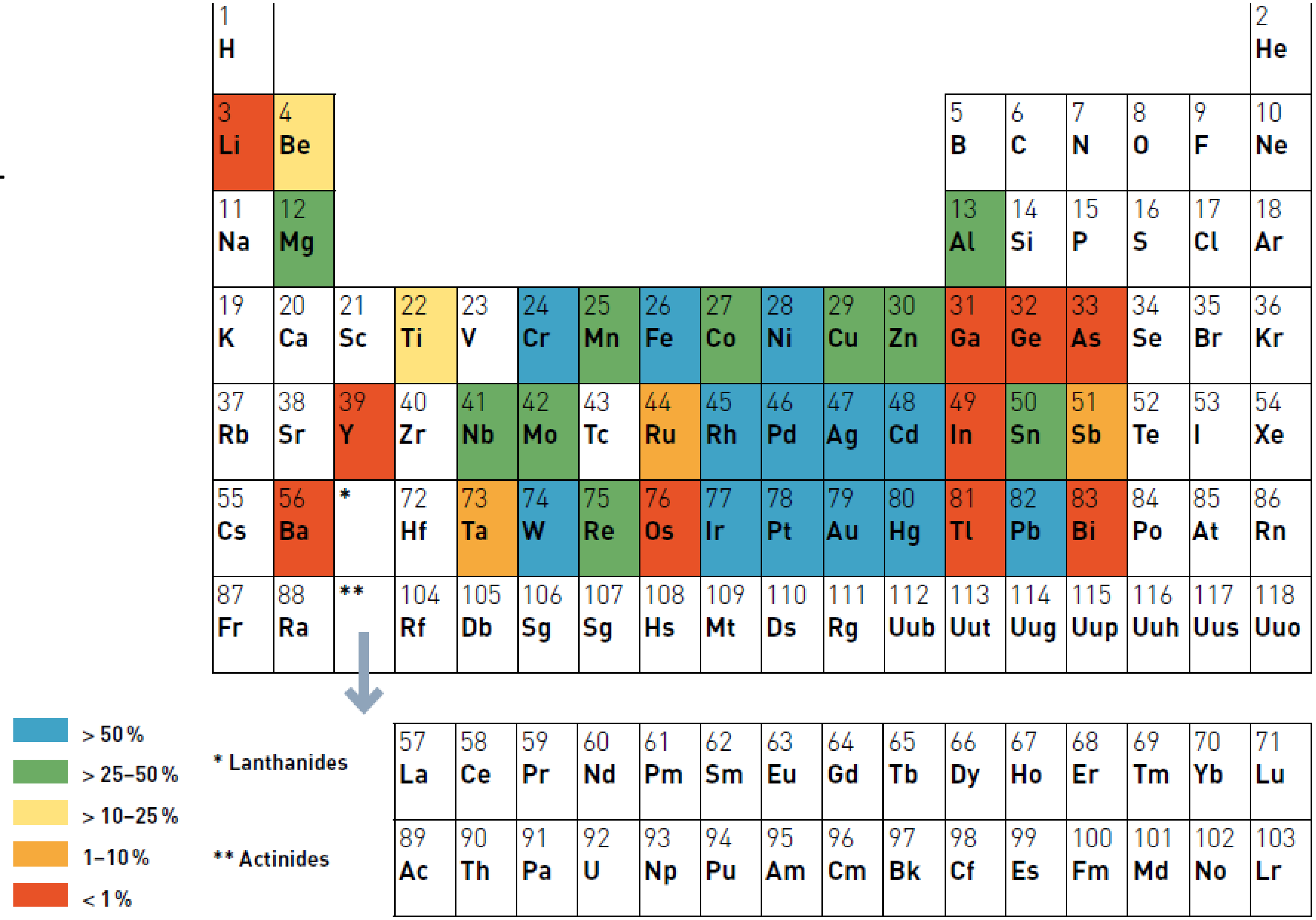
Old scrap ratio for metals

OSR: quantify the share of old (or end-of-life, EoL) scrap in the overall recycling flow



- OSR results tend to be high for valuable materials, because they are utilized with minimal losses in manufacturing processes and collected at EOL with relatively high efficiency.
- Collection and recycling at EOL are high for the hazardous metals Cd, Hg, Pb. Overall, 13 metals have OSR >50%, and another 10 have OSR >25-50%.

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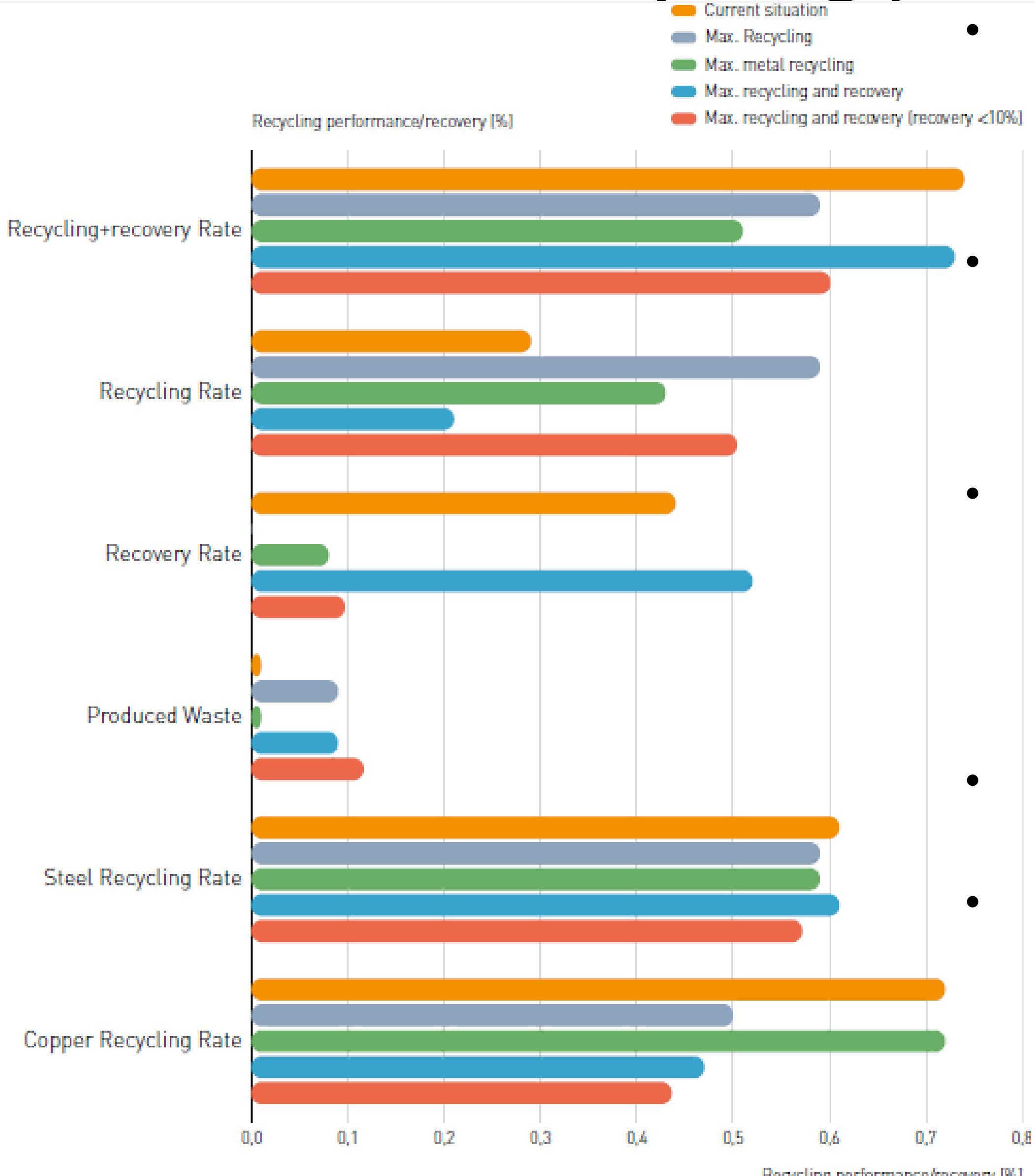
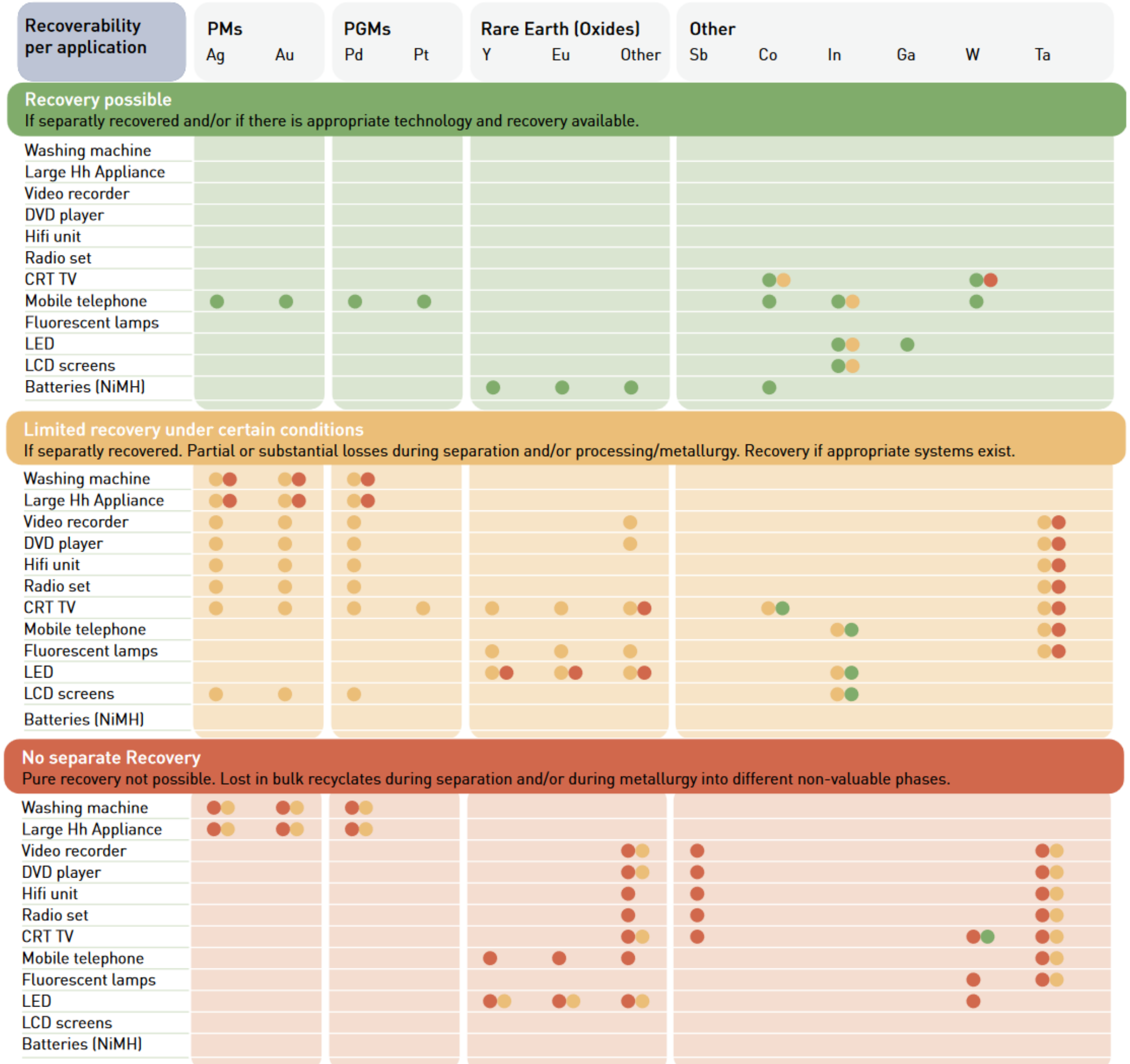
Recycling performance



- EoL recycling rates can be vastly different, depending on the economic actuators used, and whether they focus on material or energy recovery.
- Economics rather than simple legislation-imposed rates should drive recycling, as legislation cannot capture fully the complexity of a recycling system.
- There is more than one recycling rate for metals in a product. Depending on whether economics, processing technology, etc., are the main motivation for recycling, the recycling rates will be different.
- These rates reflect a statistical-distribution range.
- One-dimensional linear recycling-rate definitions are limiting cases, as they cannot consider the complex non-linear interactions found in most recycling systems.

Compatibility matrix as a function of metallurgical recovery



- Depending on the process route followed, high recovery rates as well as high losses are possible.
- A careful attention to design, infrastructure, legislation etc. is necessary.
- This is especially possible for metals closely linked where one metal can be recovered while the other due to this selection of recovery then goes lost. This is driven by thermodynamics, technology, design etc.

Compatibility matrix as a function of metallurgical recovery

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Who gets the trash?

- WEEE constitutes about 8 % of municipal waste
- WEEE represents the fastest-growing waste stream in the EU, generating about 8.7 million tonnes in 2005. By 2020, this amount is estimated to reach 12.3 million tonnes, corresponding to an annual growth of about 2.6 %
- The e-waste stream also contains substantial amounts of metals, such as rare earths, lithium (batteries), ruthenium, antimony and tin. Most of the production of indium is used in electronic appliances.
- In many cases, sometimes despite legislation, small WEEE articles are not collected separately for recycling, but disposed of with mixed Municipal Solid Waste

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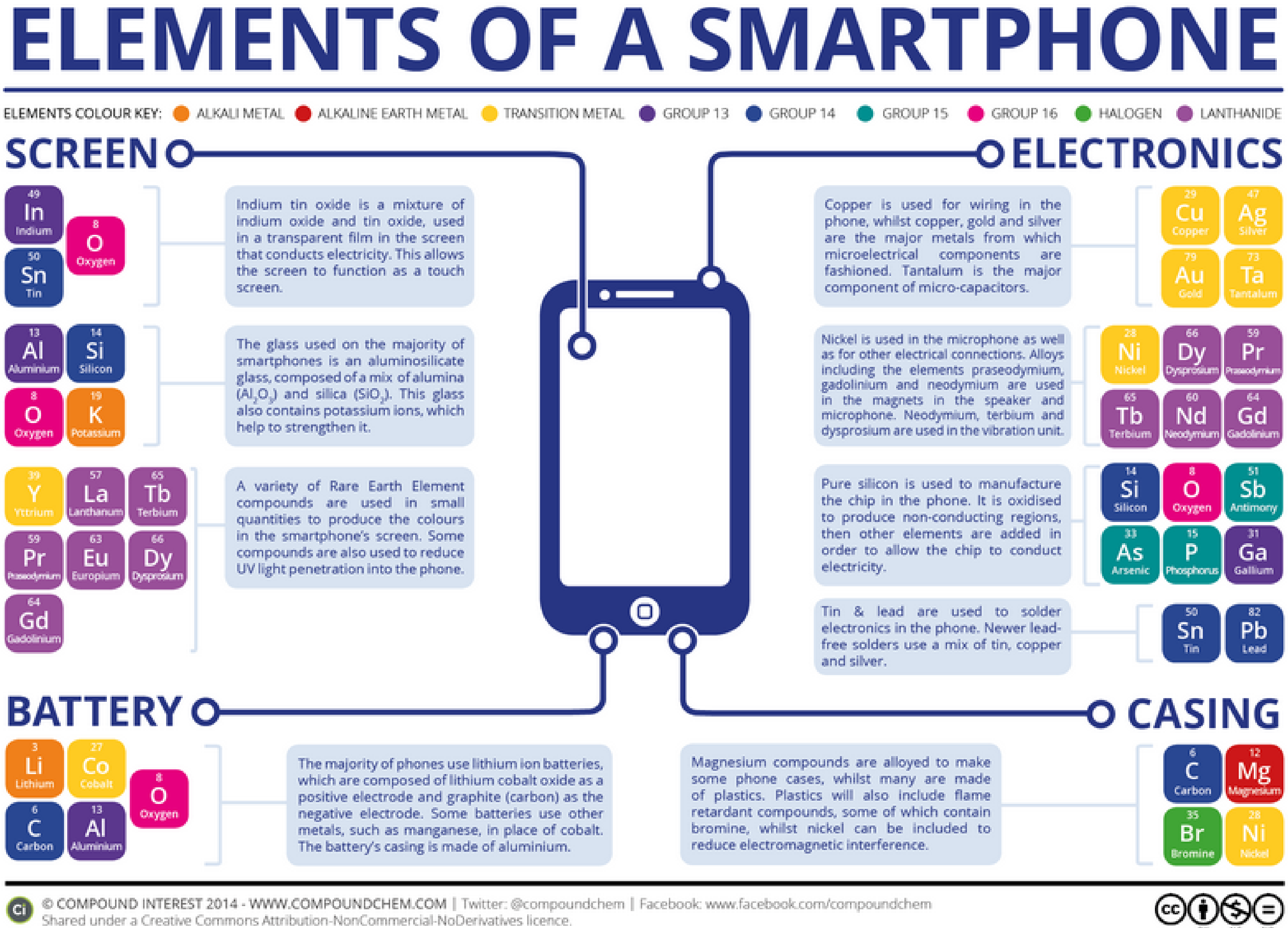

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Mobile phone - recycle

- Recycling electronic devices requires a combination of steps, including dismantling, size reduction (shredding), physical sorting and further metallurgical and other final treatment processing
- Materials are inevitably lost at every phase of the process, and the overall recycling efficiency also depends on the design of the products, the properties of the materials they are made of, how well the waste is collected and sorted
- Recycling consumes energy, meaning recovered materials still come at a cost to the environment
- For better recycling, one has to keep the complexity of intermediate materials to its lowest possible value. Creating complex mixtures of scrap and recyclate products negatively affects final recovery

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Mobile phone recycle - smelting

- Phone is introduced into a high temperature metallurgical reactor and materials are recovered mainly as metals, alloys and inorganic compounds
- This route enables the recovery of all metals that have a high affinity for copper (e.g. gold, silver, palladium and copper itself) while less noble metals such as magnesium, aluminum, lithium and tungsten and its alloy elements end in slag. All plastic reports to offgas as CO_2, H_2O, NO_x etc.
- The advantage of this approach is that the energy from the burning of the plastics saves the use of primary fuels.

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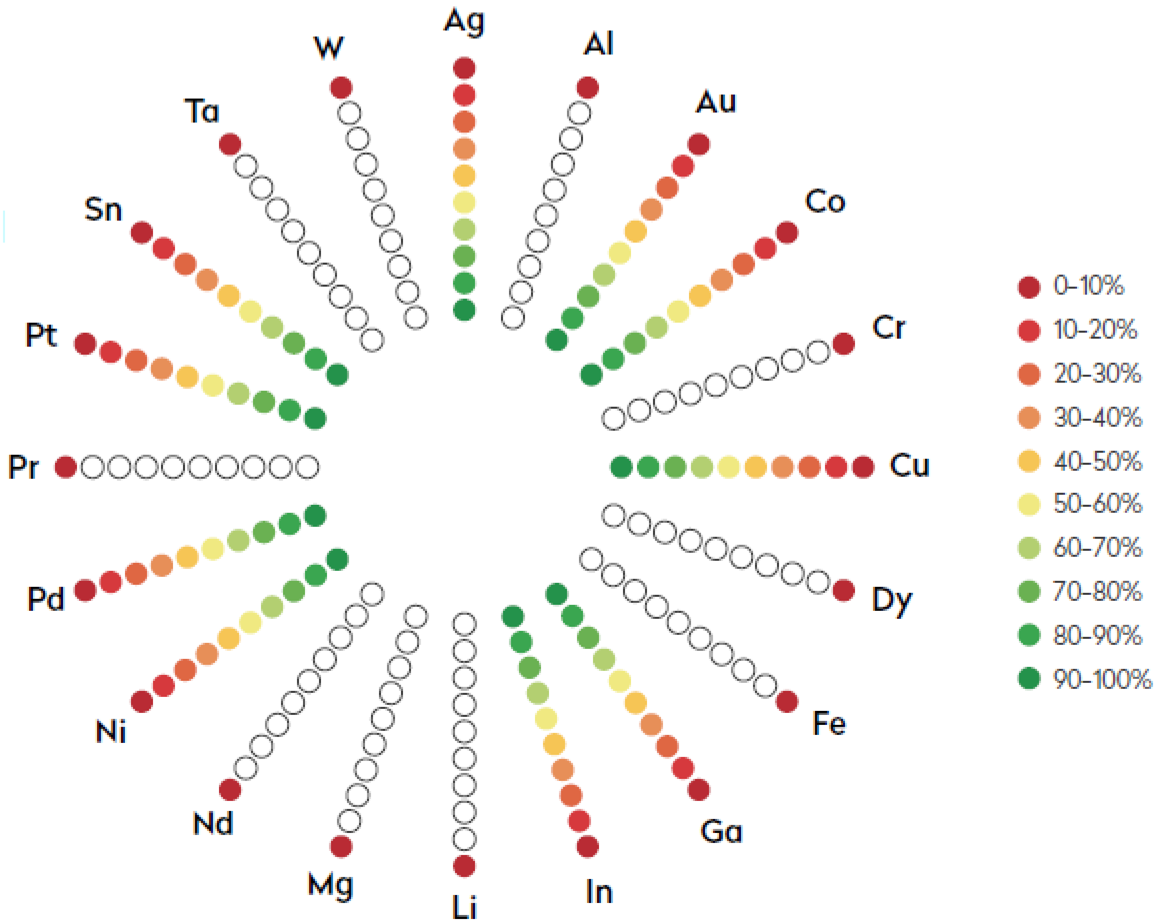
Mobile phone recycle - smelting



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Mobile phone recycle – dismantling and selective smelting

- The second route looked at selective smelting, which includes separating the phone modules and putting them through the most suitable metallurgical and plastic recovery processes
  - Camera, core, top and bottom modules go to top submerged lance (TSL) furnace
  - Display module goes to light metal remelt/refine, for optimal recovery of materials such as magnesium
  - Battery goes to an electric furnace, for optimal recovery of materials like lithium and cobalt
  - Back cover goes to the plastic extruder, for optimal recycling of the polycarbonate (plastic)
- This route tests the effect of modularity

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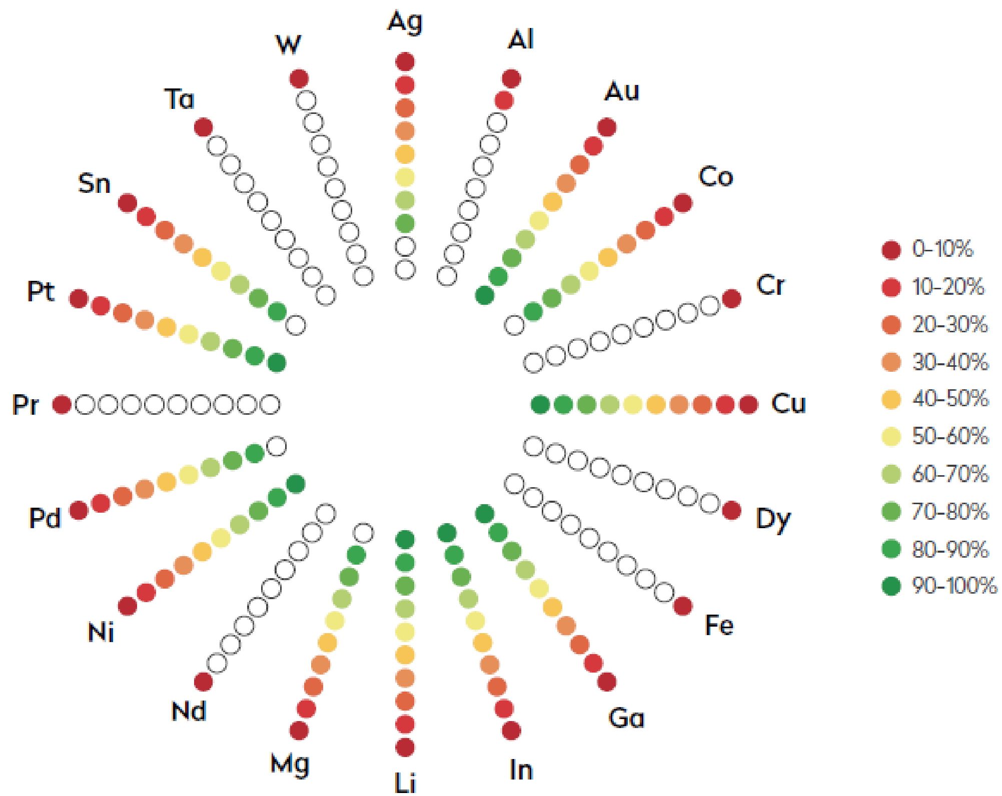
Mobile phone recycle – dismantling and selective smelting

- Route 2 delivers the widest range of recovered materials, and in contrast to route 1, also successfully recovers plastics in a usable form because the plastic case is sent directly to the plastics extruder. It also results in successful recovery of magnesium (90%), which is completely lost in the first route



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Mobile phone recycle – Shredding, physical pre-processing and metallurgy

- The final route involves removing the battery and feeding the remainder through a cutting mill, followed by separating the small pieces (scrap) into different valuable scrap fractions.
- The separation is achieved by using the physical properties of the elements, for example using the different degrees of conductivity and magnetism to separate iron and other ferrous metals from the non-ferrous non-magnetic materials (e.g. copper, aluminum and magnesium). Optical sorting is also used to separate plastic pieces from metal-rich pieces
- These fractions are processed using the appropriate technology either metallurgically, for energy recovery (mostly from burning polymers), or into plastic products

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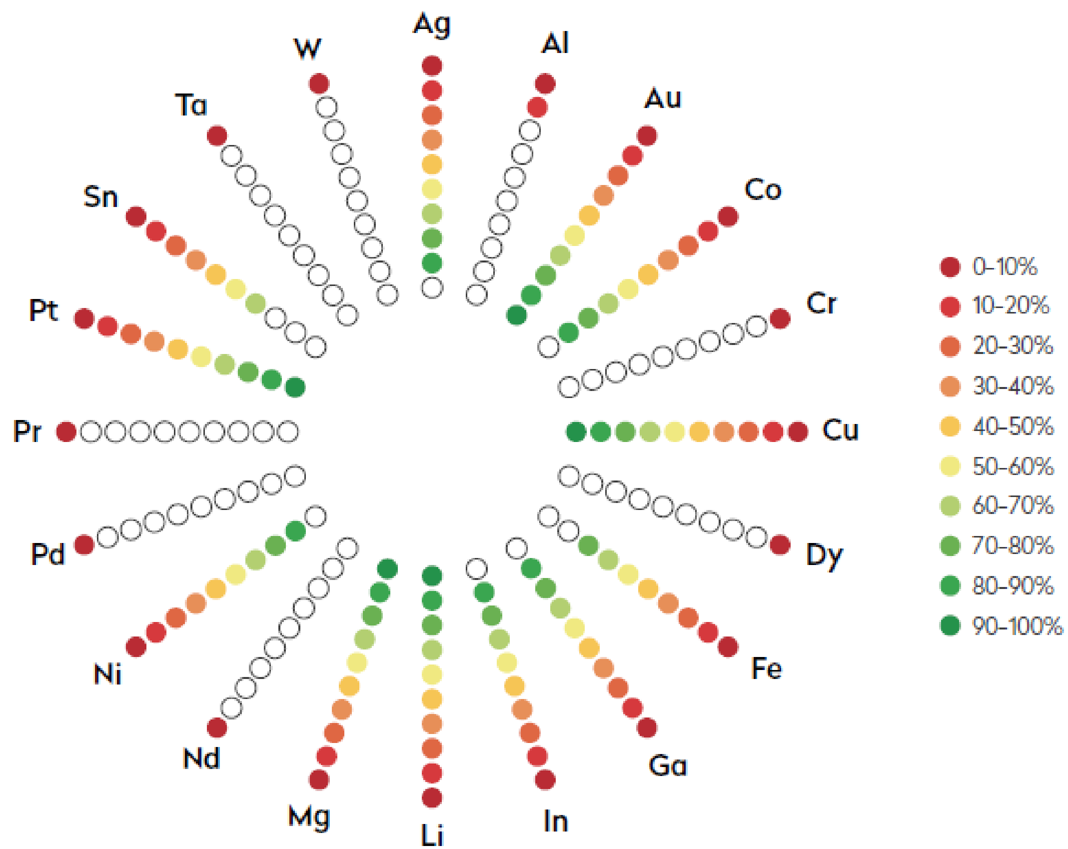
Mobile phone recycle – Shredding, physical pre-processing and metallurgy

- Route 3 is the best for recovering the most non-precious metals (e.g. Al, Mg) and results in the highest overall recovery rates by weight.
- It is less efficient in recovering valuable metals like Pd or Sn as these go lost for example in complex plastic and bulk metal scrap mixtures especially when compared to route 2. It also produces impure mixed plastic recyclate which cannot be easily reused for consumer applications



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Mobile phone recycle

- Which of the currently available recycling processes (including physical separation, metallurgical, energy recovery, plastics processing) could offer the best material recovery rates for recycling the mobile phone?
- How modularity could contribute to improving recyclability?
- Look at three metrics, (1) metal recycling rate, (2) total material recycling rate (which includes the previous) and (3) total recycling and recovery rate (materials and energy).

Mobile phone recycle

- Route 1 (smelting) offered the lowest percentage of recovered materials by weight
  - 14% metal recycling,
  - 25% total material recycling
  - 36% recovery (= recycling + energy recovery) for all materials,
  - a poor range of materials recovered.
- Route 2 (dismantling/selective smelting) offered greater recovery of materials by weight
  - 19% metal recycling,
  - 28% total material recycling
  - 31% recycling/recovery
  - the widest variety of materials recovered.

Mobile phone recycle

- Route 3 (shredding) offered the highest percentage of materials by weight
  - 22% metal recycling
  - 30% total material recycling
  - 31% recycling and recovery
  - the variety of materials recovered is more limited than route 2 due to the creation of complex mixtures, dust etc. by shredding/cutting.
- What are the optimum steps for processing of a product?
- The more separation steps, the more residues. When recycling a mono-material product, the steps are simple; for a mobile phone you need many more steps to recover as many of the 46 elements as possible.

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Mobile phone recycle

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Mobile phone recycle

- When selecting the preferred recycling route, it is insufficient to look at total weight alone, in part because the higher weight (in route 3, for example) is contributed primarily to non-precious materials.
- We also need to consider the variety of materials recovered because of the scarcity and/or potential sourcing issues of high-value (precious) metals that are present in the phone in much smaller weights.
- Based on both total weight and variety of materials recovered, recycling route 2 appears to be the best option for recycling

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Benefits from increased recycling

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Value of recovered metals

- Metal prices directly or indirectly influence the financial rewards of recovery.
- These are related to:
  - the physics of primary and recycled recovery of a metal
  - the relative abundance of the various elements in primary minerals
  - the demand for greater sustainability and other services provided by the metal
- The precious metal content of various devices can do much to boost the economic recycling of WEEE products
  - the metal value of used rechargeable batteries is significant, driven mainly by Co and Ni, which in 2010 had average prices of $45 and $21 per kg (Ni contained in one tonne of NiMH batteries has a value of about $6,000)
  - more value can be extracted from recycled batteries, if their materials are recovered as compounds instead of breaking them down to an elemental state. However, this obviously requires a market for these compounds to flow back into the products, implying that these could have a high market value and thus rendering the recycling economic

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Value of energy saved in metal production

- Improved recycling processes can be much cheaper than primary production, because they can use much less energy in production of the metals.
  - significant lowering in energy consumption required for the recycling of steel through Electric Arc Furnace smelting (9 to 12.5 GJ/tonne) compared to:
    - primary production from a Blast Furnace- Open Hearth Furnace (26.4 to 41.6 GJ/tonne)
    - Blast Furnace-Basic Oxygen Furnace (19.8 to 31.2 GJ/tonne)
    - Direct Reduction-Electric Arc Furnace (28.3 to 30.9 GJ/tonne).
  - A more sophisticated approach to recycling can help reducing the energy use of existing recycling processes, for example for steel. Scrap with impurities increases the energy required for producing metal of a required purity. Integrating new technology into existing processes may deal with some of these impurities; a metal-recycling system that capitalizes on this can maximize profits.

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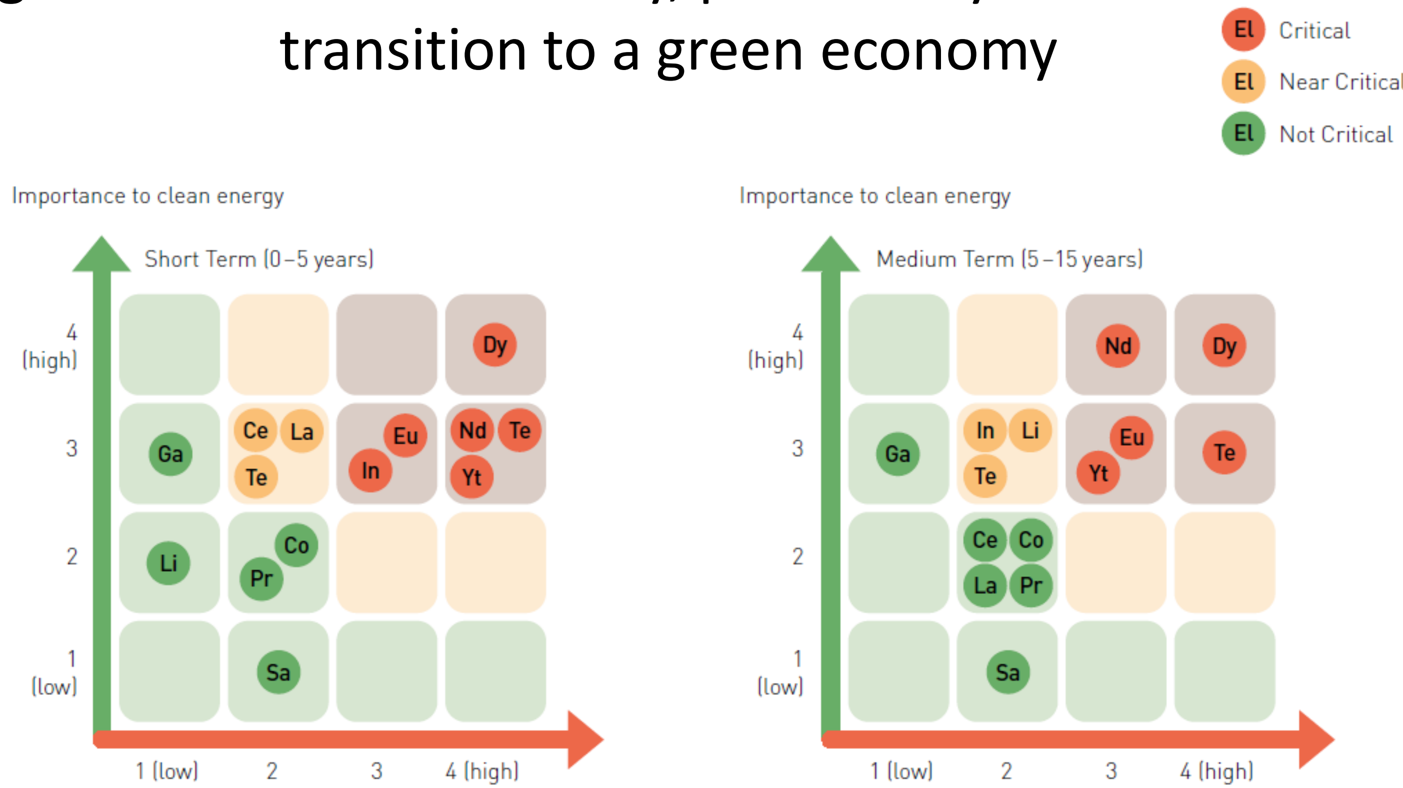
Reducing the risk of metal scarcity, particularly of metals needed for transition to a green economy



- Future supply may be compromised for CRMs due to resource depletion, poor design, a 'throw-away' society, cheap landfill costs, insufficient policy, insecurity of supply through geopolitical risks, insufficient development of current and future technologies, etc.
- Many of CRMs enable sustainability in future products and infrastructure required by a low-carbon, resource-efficient, sustainable society, including energy production (e. g. solar, wind, smart grids), water purification (e. g. enhancing water quality by using sensors, filter materials, smart water systems), transportation (e. g. electric cars, planes), and construction (e. g. various materials in eco-cities).