

GENERAL CONSIDERATION ON RECYCLING OF METALS

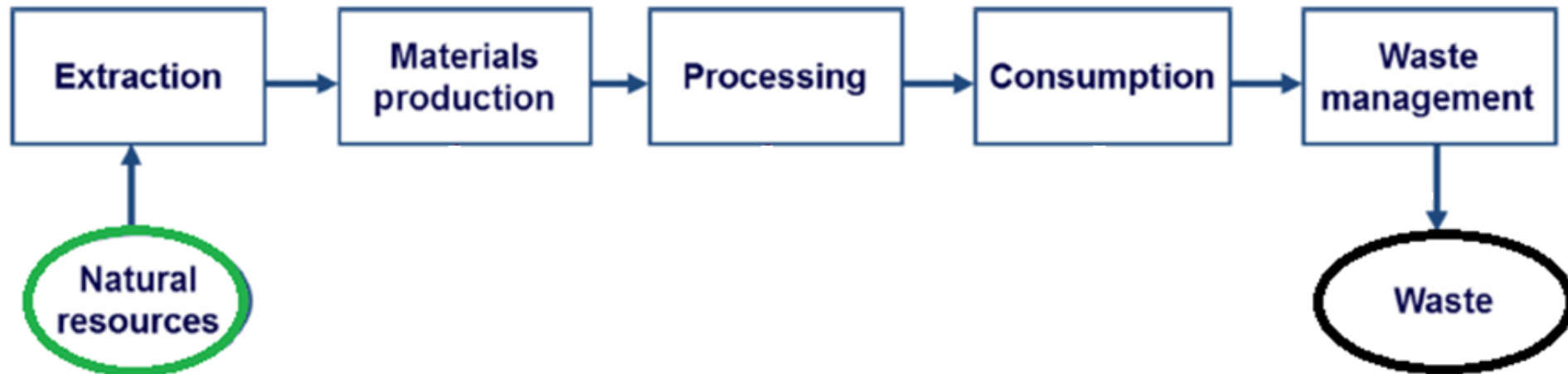
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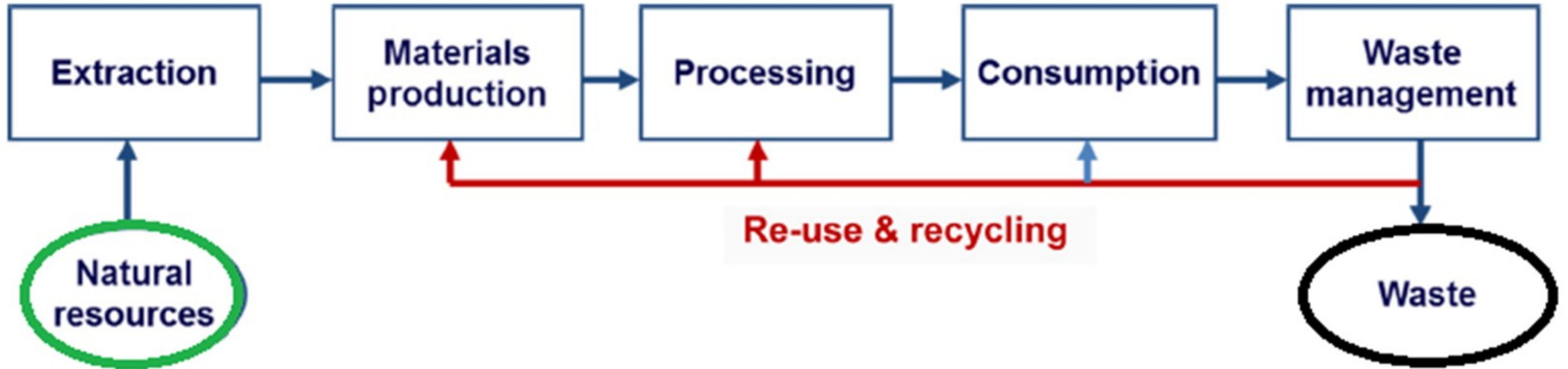
Historically, industry has operated as an open system, transforming resources to products that are eventually discarded to the environment.

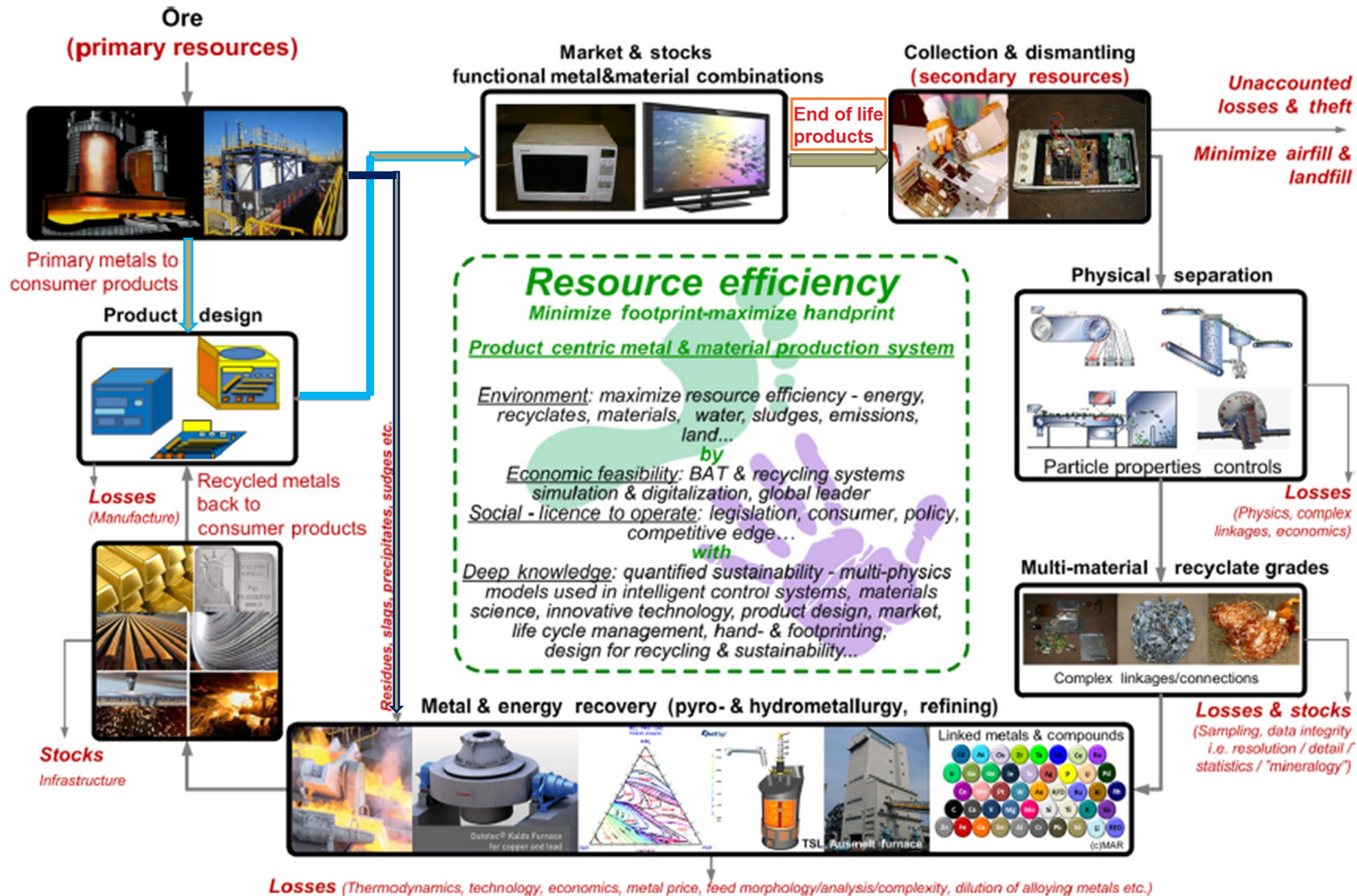


Linear economy extracts resources from the environment and discharges the wastes in the environment



circular economy





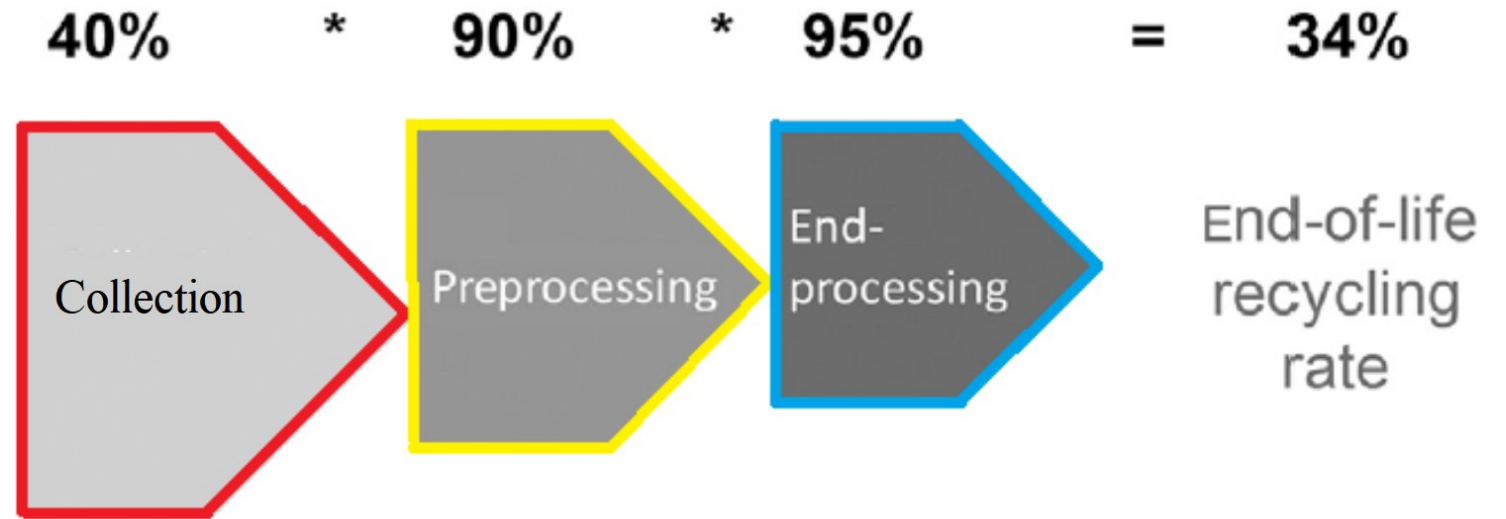
- Recycling aims at recycling the materials contained in the products that are recovered from the waste stream.
- The fraction of a material that can reenter the life cycle will depend both on:
 - the material itself;
 - the initial product in which the material is contained;

The quality and purity of the recovered material determine its future applicability.

Recycling involves different stages:

- Collection
- Preprocessing
- End-processing

During recycling, losses occur at every stage, and generally the stage with the lowest recycling efficiency is the very first: collection.



The steps involved in the recycling sequence

Recycling is expressed by three main metrics:

1. old scrap ratio (**OSR**),
2. recycled content (**RC**),
3. end of life recycling rate (**EOL-RR**).

1.The **OSR** describes the fraction of old scrap to the overall scrap market, which includes new scrap from manufacturing.

2. The **RC** is the fraction of secondary metal (old and new scrap) in the total metal input to the total metal production. RC is sometimes also referred to as recycling input rate (RIR).

3.The **EOL-RR** refers to the amount of old scrap in the product reaching their EOL (EoL=End of Life).

It refers to functional recycling only that is “the portion of EOL recycling in which the metal in a discarded product is separated and sorted to obtain secondary materials”.

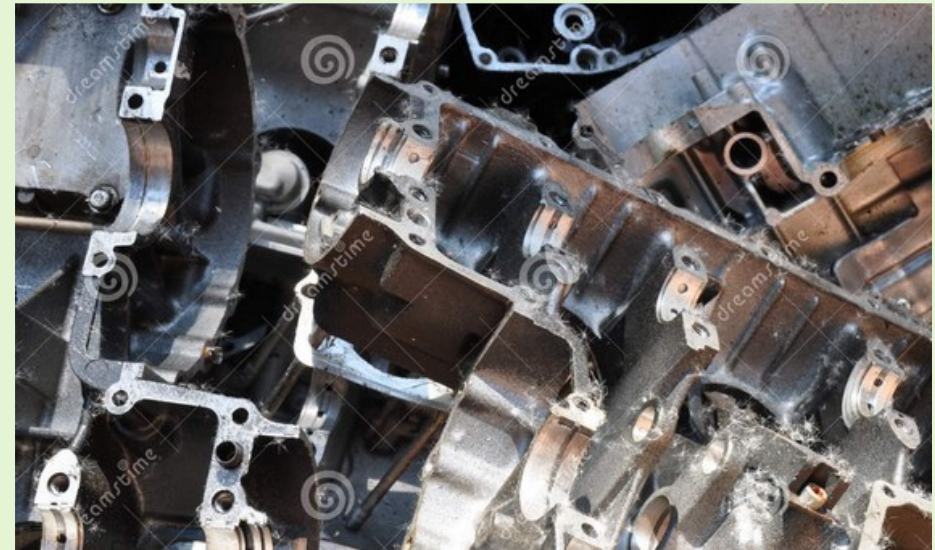
TYPE OF SCRAPS:

- home scrap (from the production of the material)
- new scrap (pre-consumer, from manufacturing of products)
- old scrap (post-consumer, at end-of-life)

- **Home scrap:** scrap material arising internally in production sites or mills as rejects, e.g. from melting, casting, rolling or other processing steps.



Rolling scrap



Casting scrap

- **New (pre-consumer) scrap:** scrap from fabrication of the material into finished products.

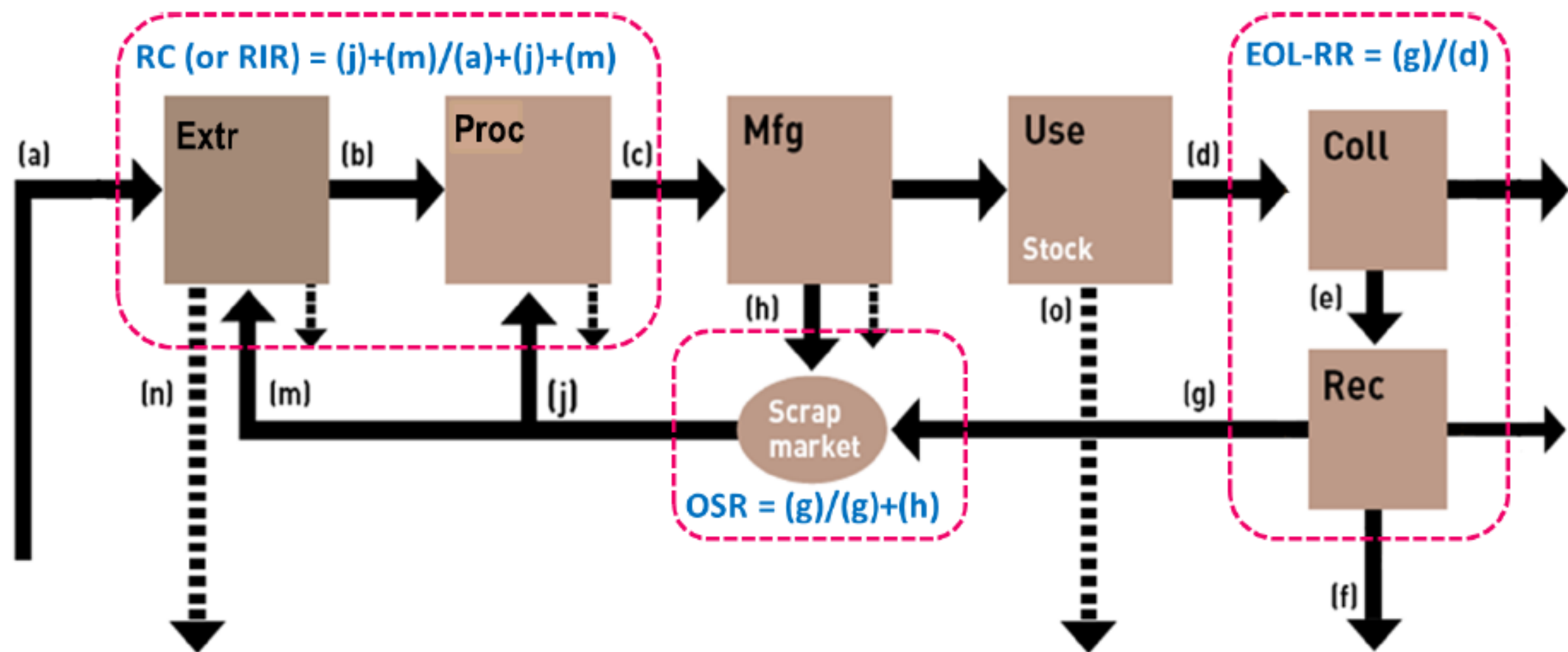


Scrap from
fabrication

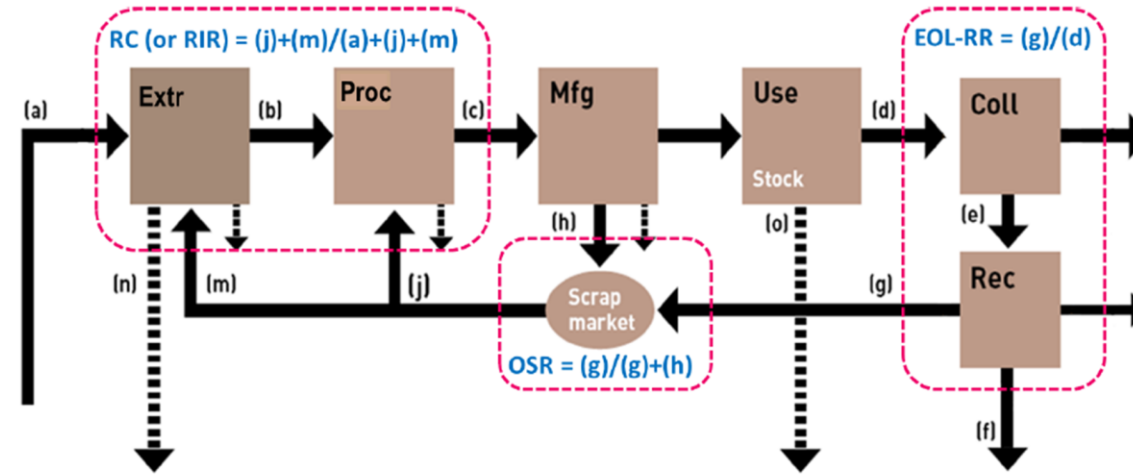


Old (post-consumer) scrap: scrap from obsolete products that is recovered, traded and sold to plants for recycling.





(a): primary metal input; (b): refined metal; (c): intermediate products (e.g. alloys, semis); (d): EOL products (metal content); (e): EOL metal collected for recycling; (f): EOL metal separated for non-functional recycling; (g): recycled EOL metal (old scrap); (h): scrap from manufacturing (new scrap); (j) scrap used in fabrication (new and old scraps); (m): scrap used in production (new and old scrap); (n): tailings and slag); (o): in-use dissipation. Extr: Extraction; Proc: Processing; Fab: Fabrication; Mfg: manufacturing; Coll: collection; Rec: recycling



RC or RIR (Recycled Content / Recycling Input Rate)

Formula: $(j+m)/(a+j+m)$

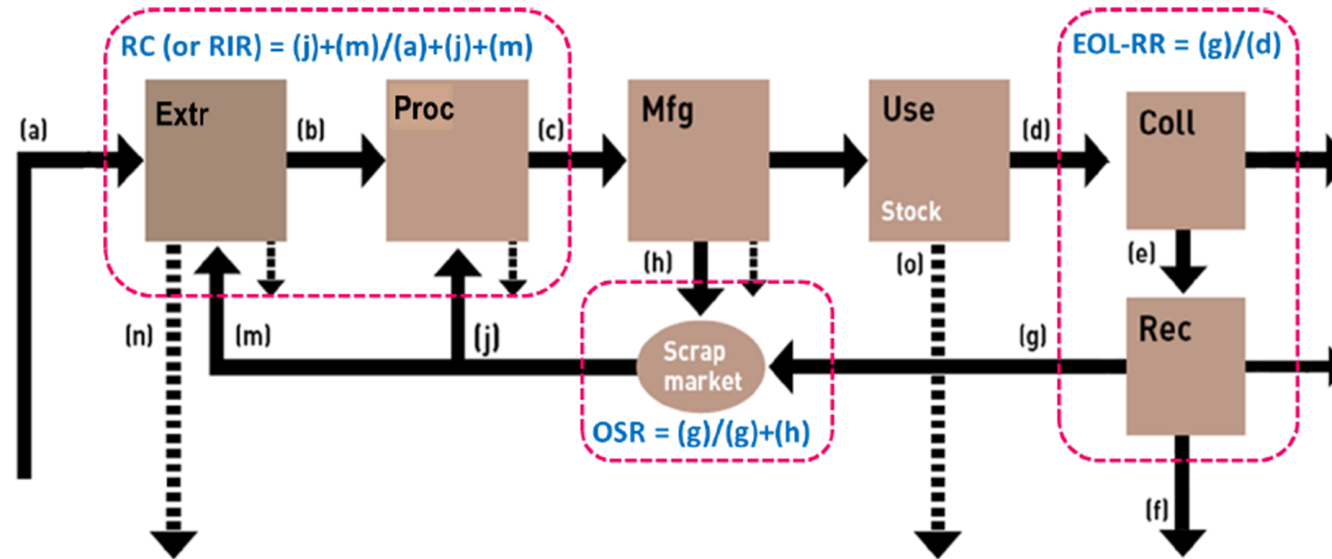
What it measures: how much of the total metal used in production (both in fabrication and in primary production) comes from recycled material, compared to the total (recycled + virgin primary material).

In simple words: "When we manufacture new products, how much of that metal comes from recycled sources instead of newly mined ore?"

Practical example: if producing new steel uses 100 tonnes of virgin ore and 25 tonnes of recycled scrap, the RC is $25/125 = 20\%$.

👉 This indicator reflects **how much production still depends on virgin material** versus recycled material. A high RC means less pressure on natural resources.

⚠️ **Important conceptual point:** a metal can have a very high EOL-RR (well recycled at end-of-life) but still a low RC, because demand for that metal grows very fast (e.g., copper): even recycling almost everything available isn't enough to meet new demand, so a lot of virgin material is still needed.



EOL-RR (End-of-Life Recycling Rate)

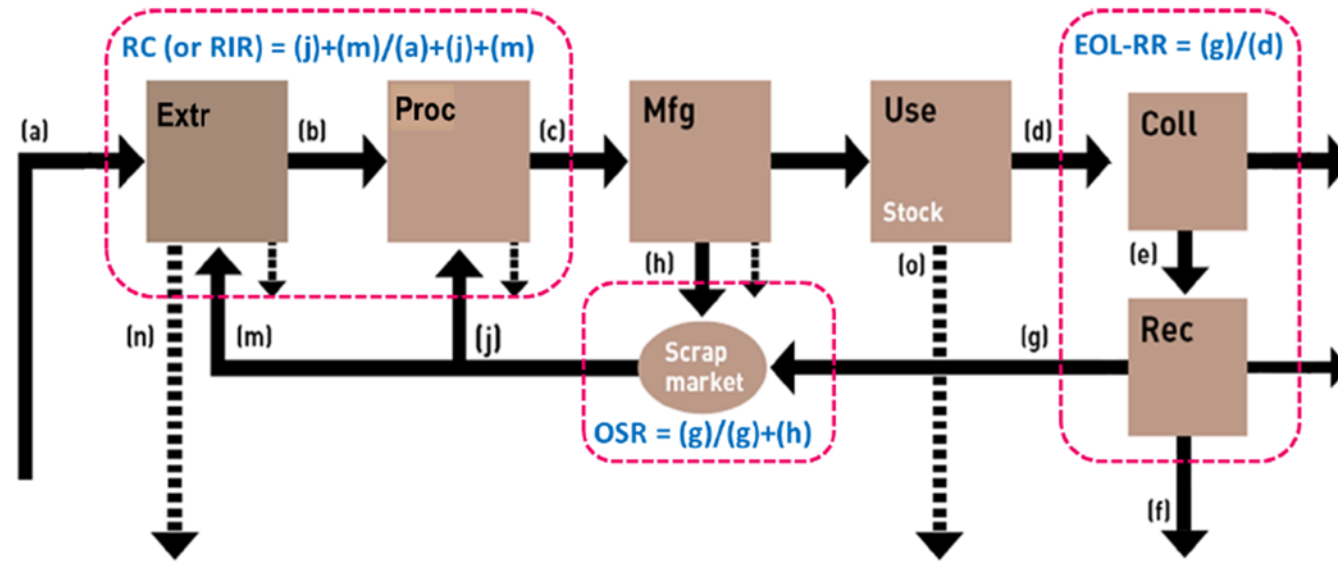
Formula: g/d

What it measures: the percentage of metal contained in end-of-life (EOL) products that is actually recovered and recycled.

In simple words: "When a product reaches the end of its life (e.g., a car, a phone, an appliance), how much of the metal it contains is actually recovered and recycled, instead of being lost or sent to landfill?"

Practical example: if there are 100 kg of steel in old scrapped cars, and 70 kg are actually collected and recycled, the EOL-RR is 70%.

👉 This is the indicator most closely linked to **how efficiently we "close the loop"** at the end of a product's life.



OSR (Old Scrap Ratio)

Formula: $\frac{g}{(g+h)}$

What it measures: among all the recycled material used in production processes, what percentage comes from **old post-consumer scrap** (i.e., from end-of-life products) compared to **new scrap** (i.e., manufacturing/fabrication scrap, such as offcuts and production waste that never reached the consumer).

In simple words: "Of the recycled material we use, how much really comes from products that consumers actually used and discarded (old), versus just factory waste that never even reached the end user (new)?"

Practical example: if the scrap market has 40 tonnes of scrap from old cars (old scrap) and 20 tonnes of production offcuts from factories (new scrap), the OSR is $\frac{40}{60} = 67\%$.

👉 This indicator tells us **how much recycling is "true" post-consumer recycling**, as opposed to material that never even reached the end user.

Indicator	Key question
EOL-RR	"How much do we recover from what we throw away?"
RC	"How much of total production is made with recycled material?"
OSR	"Does the recycled material really come from used products, or just from factory scrap?"

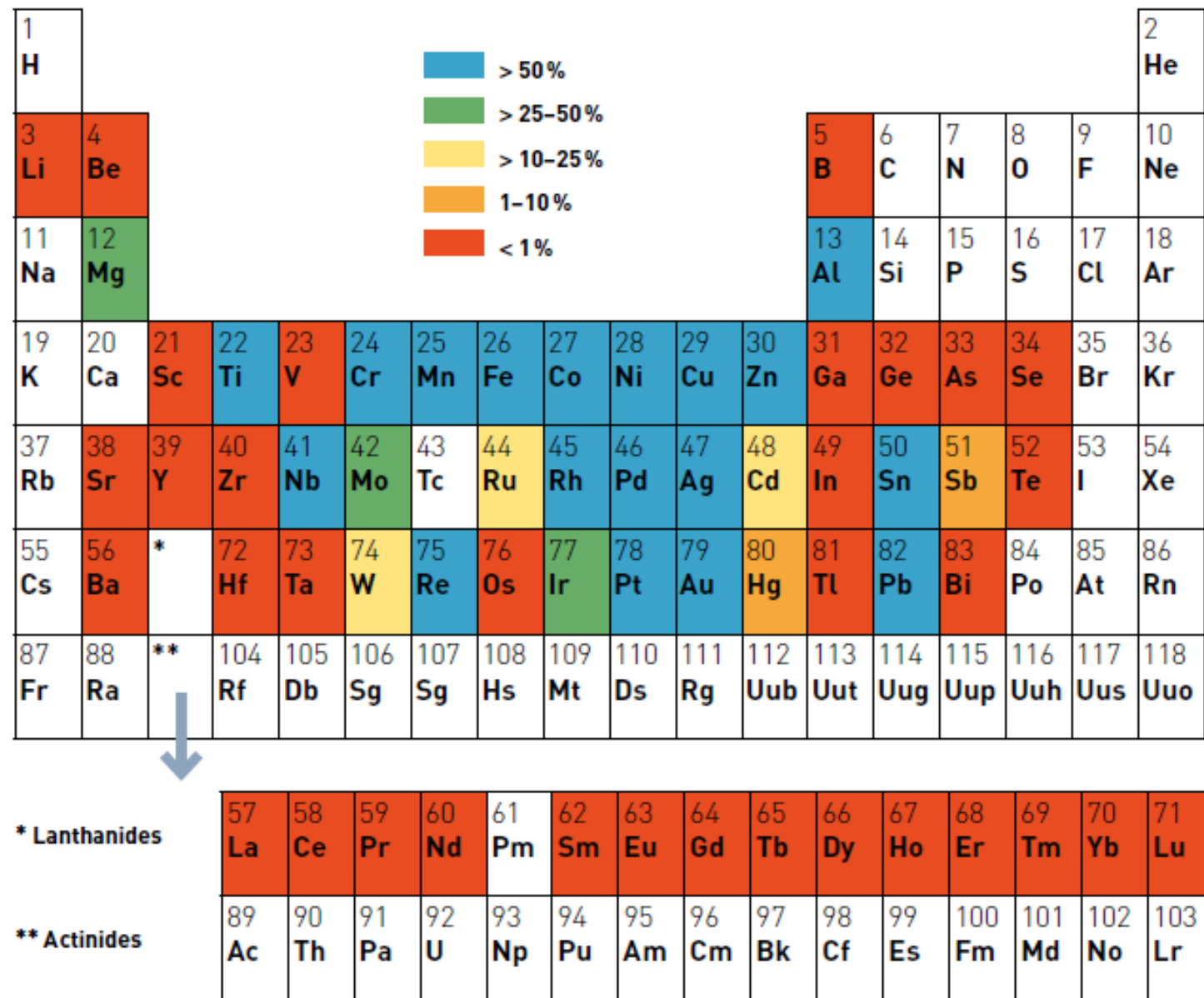
This Figure provides the EoL recycling rate (EoL-RR):

- the metal percentage from EoL products that returns to the manufacture of new products.

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.



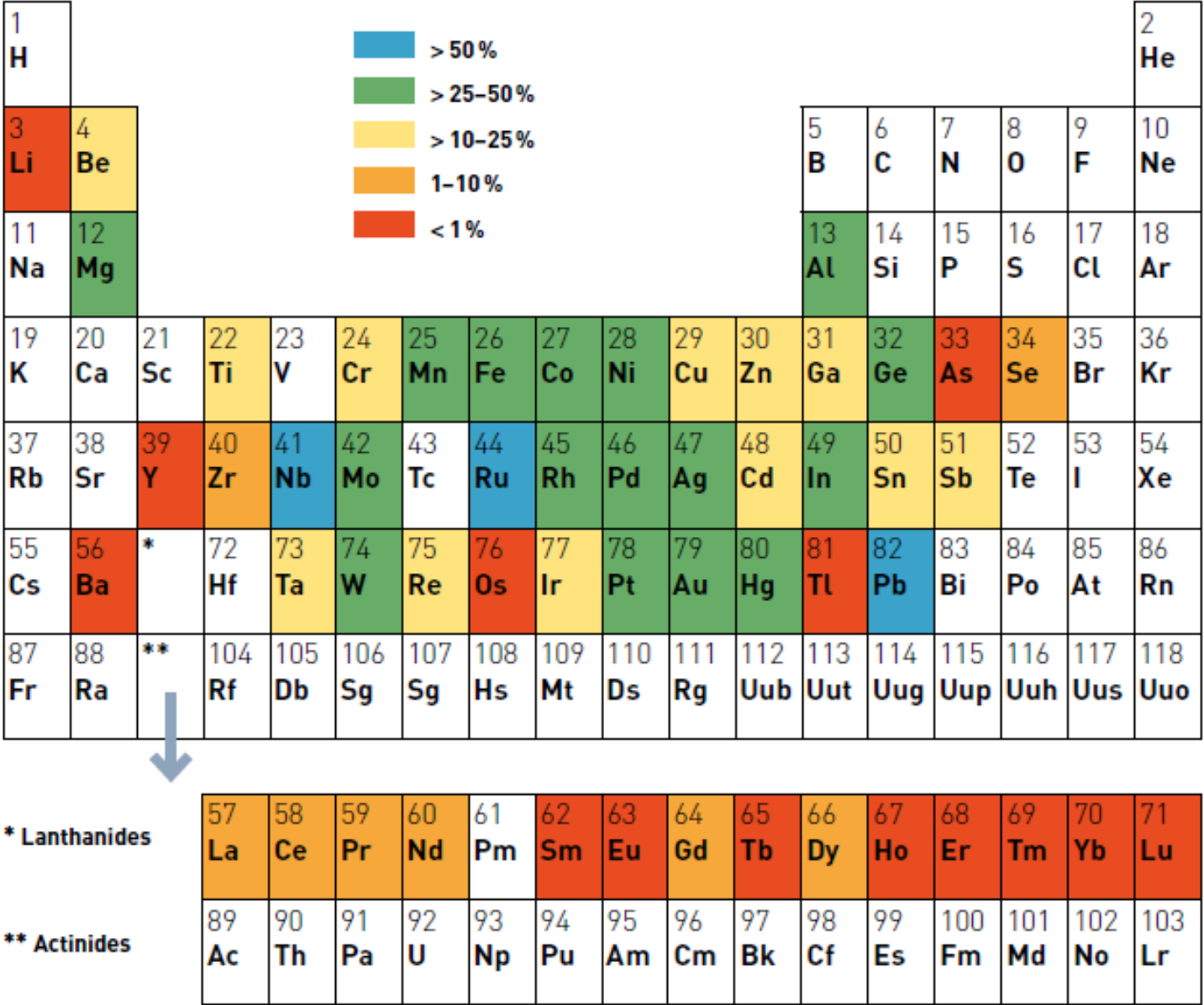
Unfilled boxes indicate that no data or estimates are available, or that the element was not addressed as part of this study. These evaluations do not consider metal emissions from coal power plants.

- For cases in which relatively high EOL-RR are derived, the impression might be given that the metals in question are being used more responsibly than those with lower rates.
- In reality, rates tend to reflect the degree to which materials are used in large amounts in easily recoverable applications (e.g. lead in batteries, steel in automobiles).
- In contrast, where materials are used in small quantities in complex products (e.g. tantalum in electronics), recycling is much less likely, and the rates will reflect this challenge.

This figure shows Recycled Content (RC), or the share of recycled metal of the total metal produced.

Lead, ruthenium, and niobium are the only metals for which RC >50%, but 16 metals have RC in the 25-50% range.

This indicates a combination in several cases of efficient reuse of new scrap as well as better than average EOL recycling.

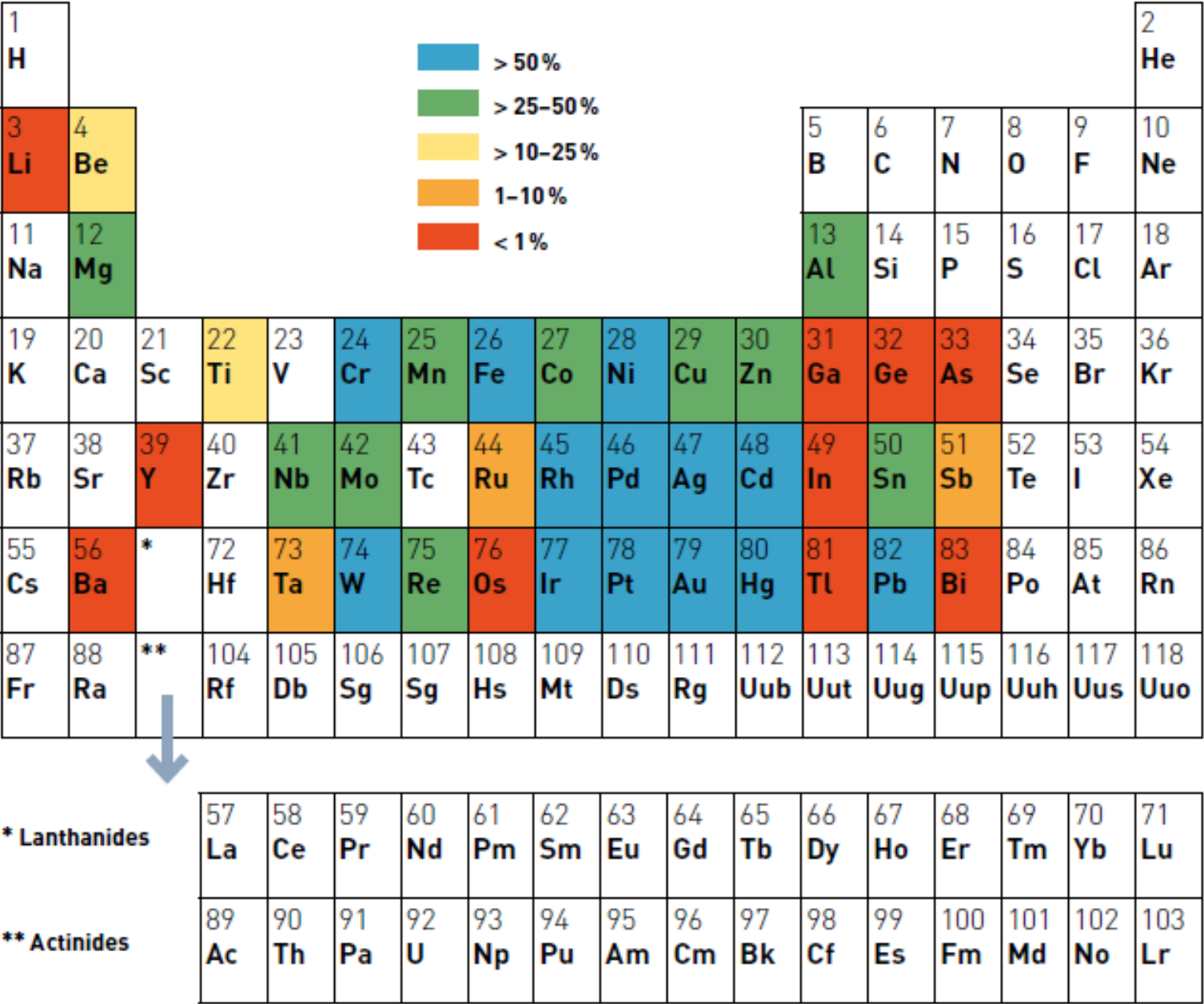


This figure shows the OSR (old scrap ratio), or the share of post-consumer recycled metal in the total recycled metal flow.

The share of post-consumer recycle metal in the total recycle metal flow tends 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 as well for the hazardous metals cadmium, mercury and lead.



IRON / STEEL (Fe) — units: Mt/year

Symbol	Value
(a) Primary metal input	1 200
(d) EOL products	500
(g) Recycled EOL metal (old scrap)	350
(h) New scrap	150
(j) Scrap in fabrication	100
(m) Scrap in production	300

- **EOL-RR** = $g/d = 350/500 = 70\%$ 
- **OSR** = $g/(g+h) = 350/500 = 70\%$ 
- **RC** = $(j+m)/(a+j+m) = 400/1600 = 25\%$ 

COPPER (Cu) — units: kt/year

Symbol	Value
(a) Primary metal input	800
(d) EOL products	300
(g) Recycled EOL metal	180
(h) New scrap	150
(j) Scrap in fabrication	40
(m) Scrap in production	100

- **EOL-RR** = $180/300 = 60\%$ 
- **OSR** = $180/(180+150) = 180/330 = 35\%$ 
- **RC** = $(40+100)/(800+40+100) = 140/940 = 15\%$ 

GOLD (Au) — units: tonnes/year

Symbol	Value
(a) Primary metal input	1000
(d) EOL products	600
(g) Recycled EOL metal (old scrap)	420
(h) New scrap	80
(j) Scrap in fabrication	150
(m) Scrap in production	250

- **EOL-RR** = $420/600 = 70\%$ 
- **OSR** = $420/500 = 84\%$ 
- **RC** = $400/1400 = 28.6\%$ 

LEAD (Pb) — units: kt/year

Symbol	Value
(a) Primary metal input	300
(d) EOL products	400
(g) Recycled EOL metal	280
(h) New scrap	30
(j) Scrap in fabrication	150
(m) Scrap in production	250

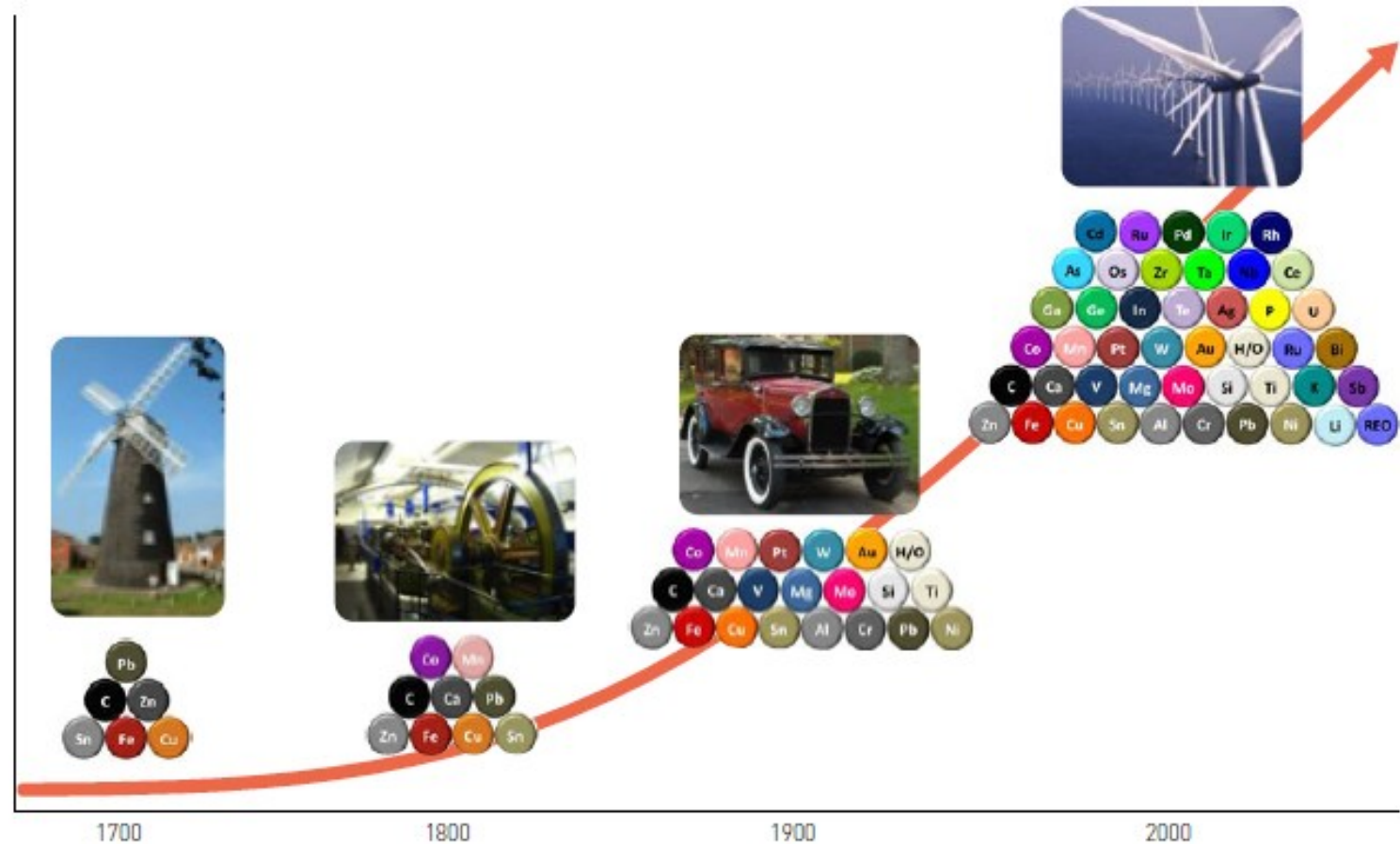
- **EOL-RR** = $g/d = 280/400 = 70\%$ 
- **OSR** = $g/(g+h) = 280/310 = 90\%$ 
- **RC** = $(j+m)/(a+j+m) = 400/700 = 57\%$ 

Metal	EOL-RR	RC	OSR
Fe (Steel)	● 70%	● 25%	● 70%
Cu (Copper)	● 60%	● 15%	● 35%
Pb (Lead)	● 70%	● 57%	● 90%
Au (Gold)	● 70%	● 28,6%	● 84%

The way in which a product is designed is a strong factor in whether recycling occurs.



the greater the degree of material complexity in a product,
the smaller the probability that recycling will occur.



Materials within products are selected to fulfil a specific function. The increasing complexity of this functional demand has led to the use of an increasing number of elements.

Minerals processing and process metallurgy have a significant role to play in a modern resource constrained Society:

- Metal ores are formed in the process of ore genesis, and they are extracted through mining.
- Extractive metallurgy is the practice of removing valuable metals from an ore and refining the extracted raw metals into a purer form.
- Hydrometallurgy uses aqueous solutions to extract metals from ores (leaching).
- Pyrometallurgy involves high temperature processes where chemical reactions take place.
- Electrometallurgy involves metallurgical processes that take place in some form of electrolytic cell.

The application of mineral processing techniques can be used for the recovery of metal from post-consumer wastes.

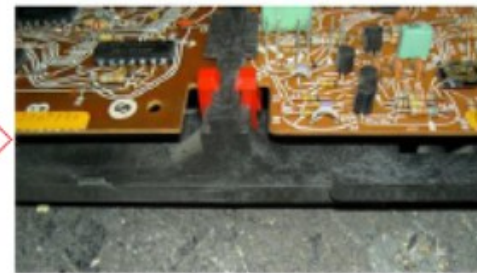
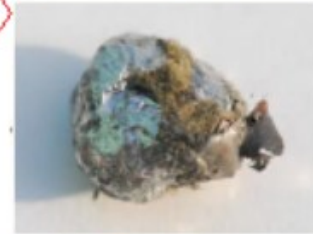
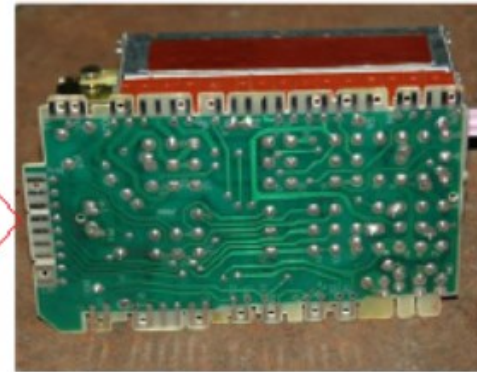
Recycling of copper from end of life products.



Geological linkages

Various copper sulphide minerals
on quartz and calcite

>15 minors e.g. Au, Ag, PGMs, Se



Product design & material combinations create new "Minerals"

>40 elements complexly linked as alloys, compounds, materials

Functional material connections

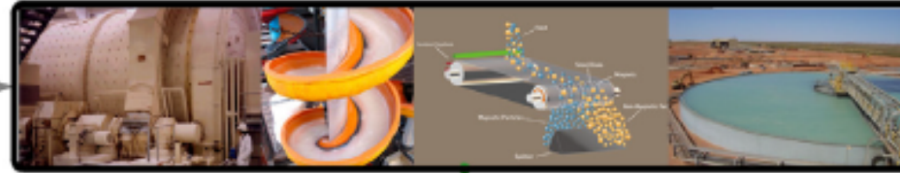
Joined materials multi-material particles

MINE

Primary resources, ores

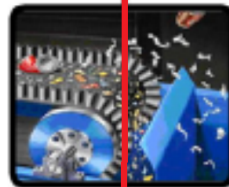


Crushing / Comminution / Thickening



URBAN MINE

Secondary Resources, Product design (DfR), Consumer Take-Back System, Designed "Mineralogy"



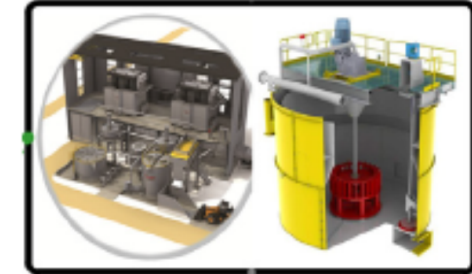
Physical Separation

Recycling

EXTRACTION OF METALS Metallurgical processes



Filtration Flotation



Three major factors determine the results of recycling expressed as a recyclability index:

- (1) the way waste streams are mixed or pre-sorted during collection;
- (2) the physical properties;
- (3) design of the end-of-life products in those waste streams.

These factors all affect the final recovery and subsequent production of high quality metal, material and alloy products.

These factors interrelate in ways that make it impossible to optimize one without taking into account the others.

It also necessary to optimize the recycling of several metals found within one product, rather than only focusing on one or two major metals (and their alloys and alloying elements) and ignoring the rest of the periodic table.

A particular attention should be paid to:

- recycling of the high-value, lower-volume metals
 - they are essential elements of today's and tomorrow's high tech products,
 - they are applied in complex multi-material design such as electronics and vehicles (also aircraft) or generation and storage of renewable energy.

These metals are often scarce but essential to sustainable growth:

- gallium,
- rare earth elements,
- platinum group elements and
- indium,

Up to now they are typically lost in current recycling processes.

Infrastructure for optimizing recycling

for optimizing recycling, the following conditions and infrastructure have to exist:

BAT: EoL, waste, and residue streams destined for recycling must be processed by Best Available Technique (BAT), according to specific performance standards and being mindful of environmental and social costs and benefits.

These BATs can differ between products and regions, and do not need to be high technology per se.

They may include hand sorting in the earlier steps of the recycling chain, thus creating jobs.

Where waste streams enter uncontrolled flows or less suitable processes, value will be lost and the environmental impact may be severe.

Infrastructure for optimizing recycling

for optimizing recycling, the following conditions and infrastructure have to exist:

POLICY: Targets must align with the economic drivers of a complete system. Policy must create the economic incentives for waste to be handled by registered BAT operations.

KNOWLEDGE: The metallurgical recycling industry has the knowledge needed for linking BAT processes so that they separate a maximum of valuable metals and create a minimum of secondary residues

Infrastructure for optimizing recycling

for optimizing recycling, the following conditions and infrastructure have to exist:

MODELLING: Physics-based-modelling and simulation of how products recycle can help designing a product that facilitates recycling, based on how products and their constituents break up and separate in BAT recycling processes. Such design goes beyond “design for disassembly” and “design for recycling”, to become “design for resource efficiency”.

INCENTIVES: Incentives can be purely legislative or purely economic, but work best as a combination of policy and profit. For example, *producer-responsibility* laws motivate a product manufacturer to innovate in recycling-process technology for meeting recycling targets.