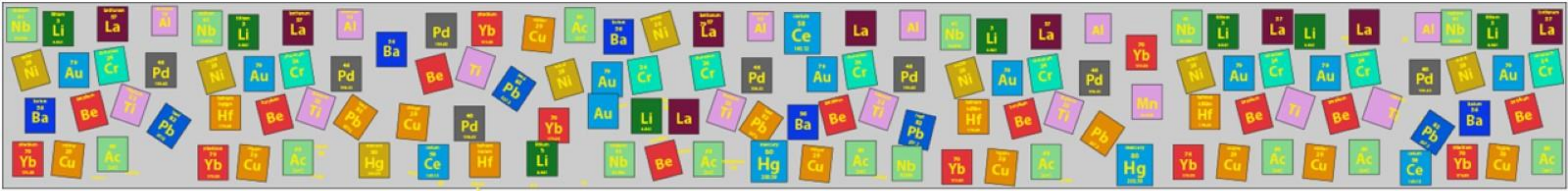
Bernd E. Langner

Non-Ferrous Metals for a Sustainable Future

… and the important Role of Copper



Energy:

Energy saving
Energy generation, transformation and transportation
Energy storage

Source: Enercon

Saving resources:

By corrosion protection
By material strength

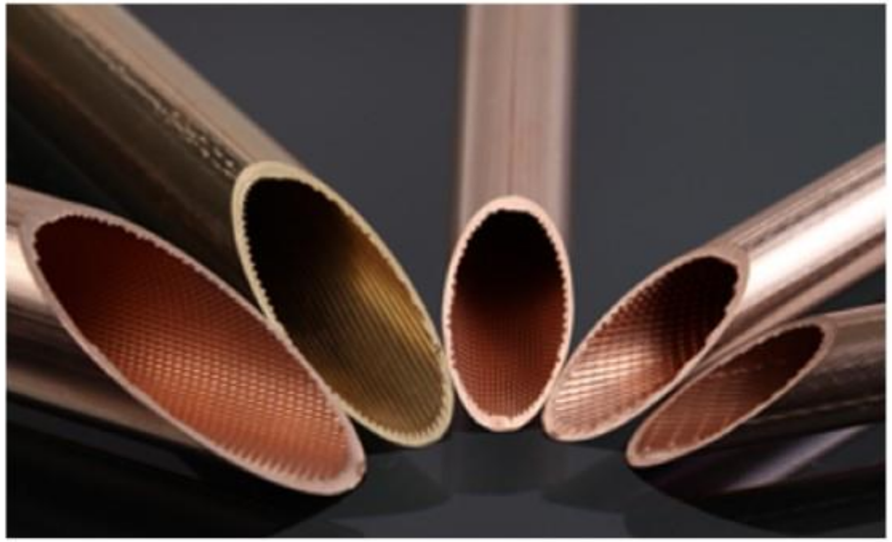
Source: Wikimedia Commons

Recycling

Source: Author at Aurubis

High thermal conductivity
=> more efficient heat transfer

Material	Therm. Cond. (W/m/K)
Silver	430
Copper	385
Aluminium	235
Steel	45
Stainless Steel	15
Graphite (anisotropy)	10
Plastics	<0.5



Source: KME

Non-Ferrous Metals: Mainly aluminium, copper

Applications (examples): residential heating, ACR (Air Conditioners and Refrigerators), heat pumps

But steel and plastics are often much cheaper, and heat transfer depends also on flow conditions !

High temperature resistance => more efficiency from heat to mechanical energy

$$\text{Efficiency: } \eta = 1 - T_{Cold}/T_{Hot}$$

Example 1: T_{hot} = 1000 C, T_{cold} = 100 C -> theoretical efficiency= 71%

Example 2: T_{hot} = 400 C, T_{cold} = 100 C -> theoretical efficiency= 45%

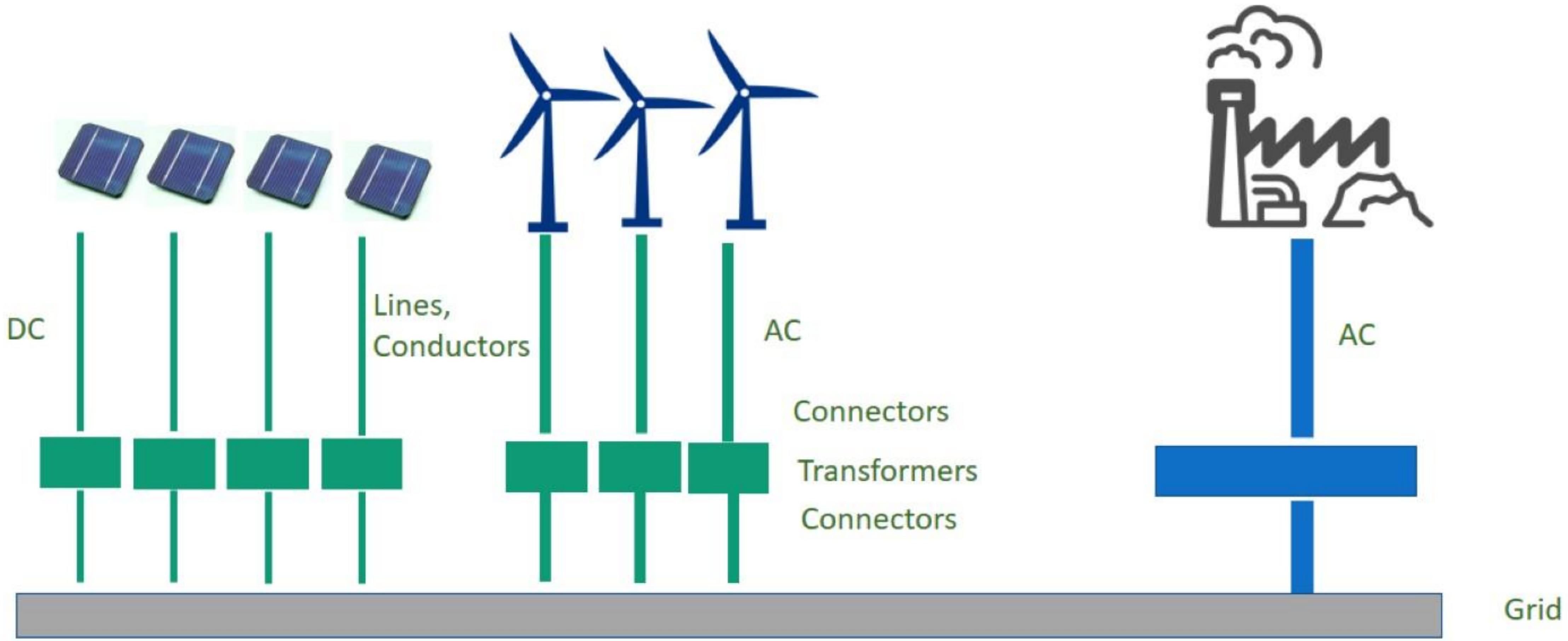
Source: Wikimedia Commons
Siemens Turbine

Non-Ferrous Metals: Superalloys: cobalt, nickel, tungsten, chromium, rhenium platinum metals and others

Applications (examples): turbines in thermal power plants, jet air planes, military

Renewable electrical energy
=> More conductors, connectors, transformers

From centralized to decentralized energy generation

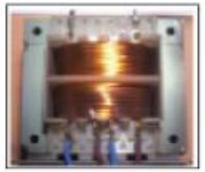


Beside Lines of aluminium and copper a lot of non-ferrous metals are involved

Silicon (crystalline, amorphous), CdTe, CuInSe (thin layer),
TCO (cond. layer), molybdenum, silver (paste), tin (connection), aluminium (frame),
copper (connections, lines and transformers)

Neodymium, dysprosium, copper (electro-magnets), copper (lines),
molybdenum, chromium, nickel, manganese (stainless steel) , zinc (corrosion protection)

Connectors: copper alloys - CuNiSi, CuBe, CuMg ... (base), tin, gold, silver (corrosion protection)



Transformers: copper, aluminium

Electronics: GaAs, silicon, tantalum, manganese, indium
(semiconductors) tin, lead (soldering)

The best solution would be to use renewable energy without storage but:

- In the night zero solar electrical energy
  (only about 800 – 2000 h/year full energy from 8760 h/year)

- The wind is not always blowing
  (only about 2500-4500 h/year full energy from 8760 h/year.

Therefore electrical energy has to be stored:

- Short-term: when there is unbalance between supply & demand
- Long-term: for seasonal balancing

Storage of electrical energy leads always to Losses

The best Solution would be to use renewable energy without storage

Primary batteries (used only once)

Zinc carbon: Zinc (beaker-anode), manganese

Alkaline: Zinc(anode), manganese

Zinc zir: Zinc (anode), cobalt-nickel, cobalt, Pt-metals (catalysts)

Secondary batteries (rechargeable)

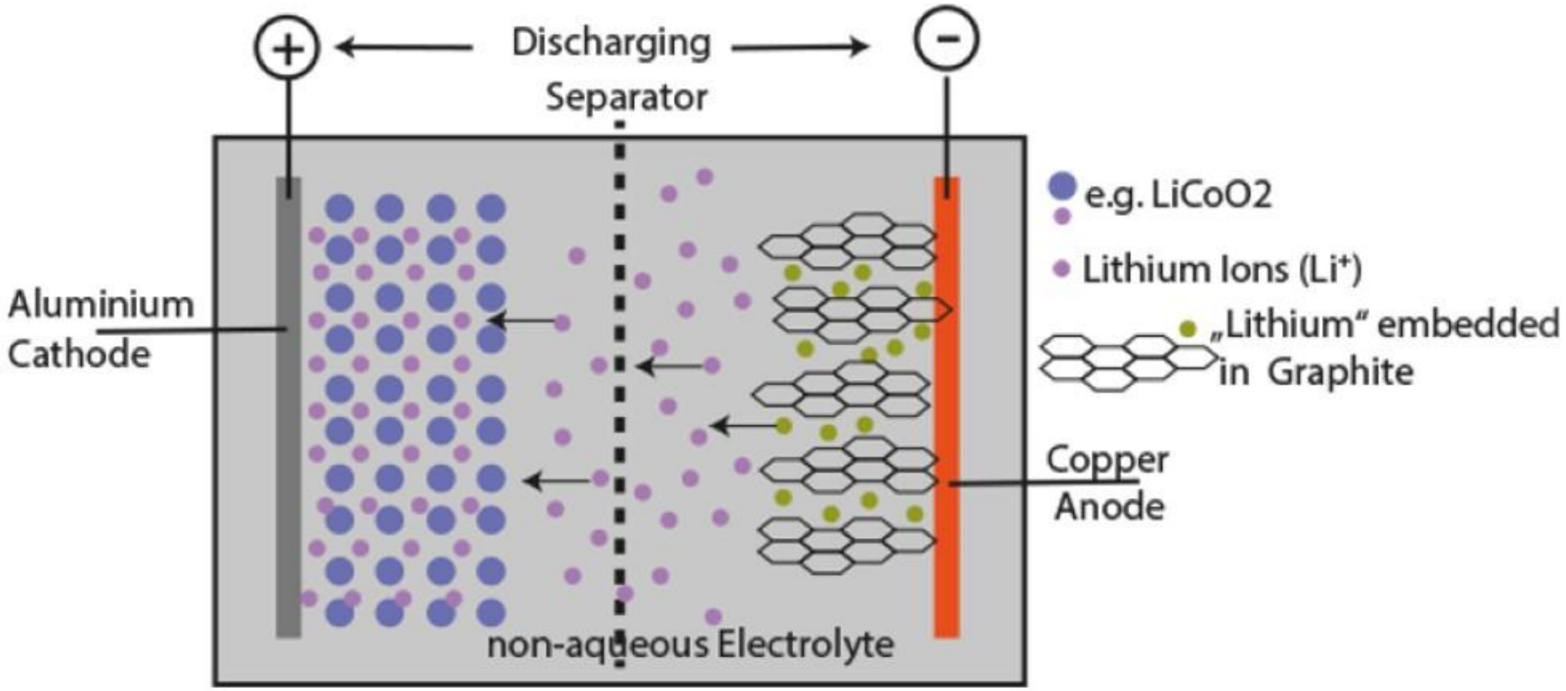
Nickel-cadmium: Nickel, cadmium

Nickel-metal hydride: Nickel, lanthanum, titanium, cobalt et al.

Lithium: Lithium, cobalt, manganese et al.

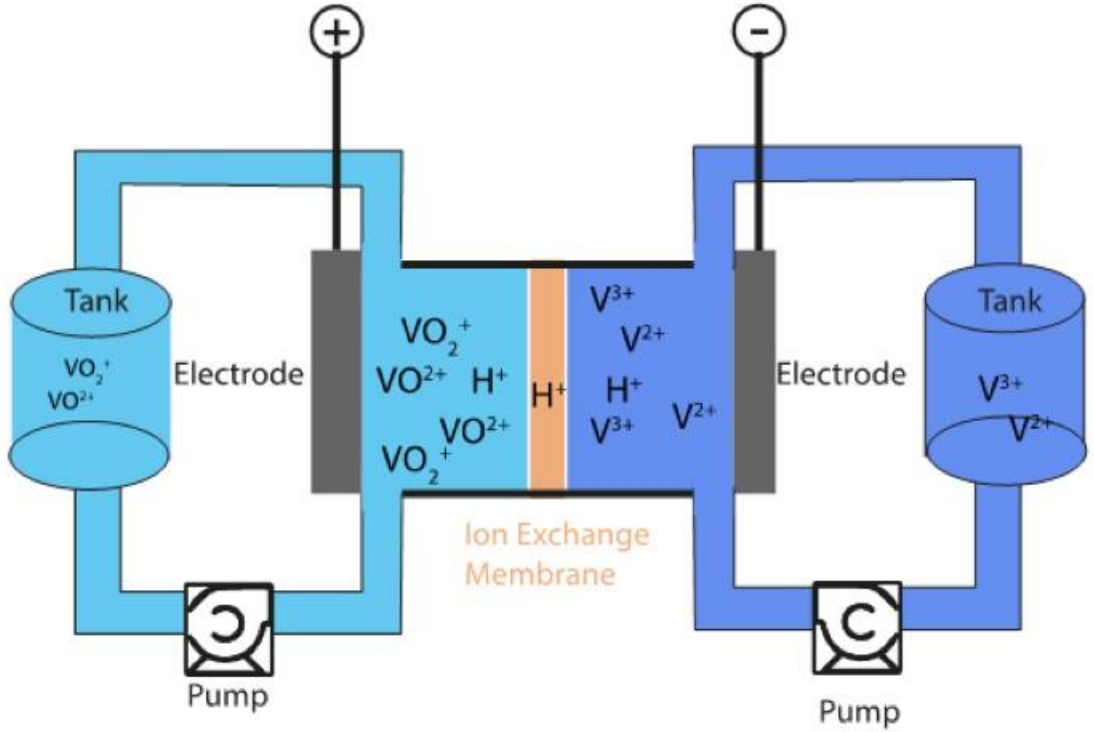
Lead acid battery: Lead (anode, cathode), calcium, antimony, selenium (alloying), copper (contact)

Lithium battery: Lithium (electrolyte, anode), cobalt, nickel, aluminium (cathode)



Sodium sulfur battery: high temperature, solid electrolyte Aluminium oxide (electrolyte), sodium

Redox flow battery



Total different principle:
Anolyte and catholyte are solutions
Needs metal ions with different oxidation states

Mainly vanadium is used:
On the cathode: V^{3+} <-> V^{2+}
On the anode: V^{4+} <-> V^{5+}

Advantages:
Easy upscaling of capacity by increasing volume
Easy upscaling of current density by increasing surface of the membrane

Disadvantages:
Low energy density because of solubility of the vanadium compounds
Only useful in stationary systems

Electrical Energy Storage: Comparison of Batteries

	Primary		
Type of Cell	Zinc-Carbon	Alkaline	Zinc Air
Voltage (Volt)	1.5	1.5	1.5
Energy Density (Wh/kg)	30-40	85-190	440
		Secondary	
Type of Cell	NiMH	Nickel -Cadmium	Lead Acid
Voltage (Volt)	1.2	1.2	2.0
Energy Density (Wh/kg)	60-120	45-80	30-50
	Lithium Cells (Secondary)		
Type of Cell	Cobalt	Manganese	Phosphate
Voltage (Volt)	3.6	3.8	3.3
Energy Density (Wh/kg)	150-190	100-135	90-120
	Special Cells (Secondary)		
Type of Cell	Redox Flow (V)	Sodium-Sulfur	Fuel Cell
Voltage (Volt)	1.25	2	0.5-0.8
Energy Density (Wh/kg)	15-25	>200	not appl.

Disadvantages of batteries:

Huge resources necessary:

Example for a calculation:

Germany consumes more than 400 TWh electrical energy per year

If energy had to be stored for 2 weeks in winter this would be 400 TWh/26 = 15 TWh

Assumptions:

15 TWh have to be stored. Energy density: 15 KWh = 160 kg (E-Car) about 160 $*10^9$ (Trillions (US), Billions(EU) tons batteries (active material)

+ electric-cars:

20 million cars with 70kWh battery = 14 Mio. tons batteries (active material)

+ heat pumps + ….

And that is only Germany!

Solution: you have to produce a fuel from renewable electric energies
Even if you loose efficiency
(or much more pumped-storage power plants or other storage systems)

Energy Storage: Hydrogen with Fuel Cells

Works like a battery with anodic and cathodic process on different locations

Charging: Hydrogen production from water **$2\ H_2O \rightarrow 2\ H_2 + O_2$ Electrolysis**

Discharging: Water from hydrogen by oxidation **$2\ H_2 + O_2 \rightarrow 2\ H_2O$ Fuel cell**

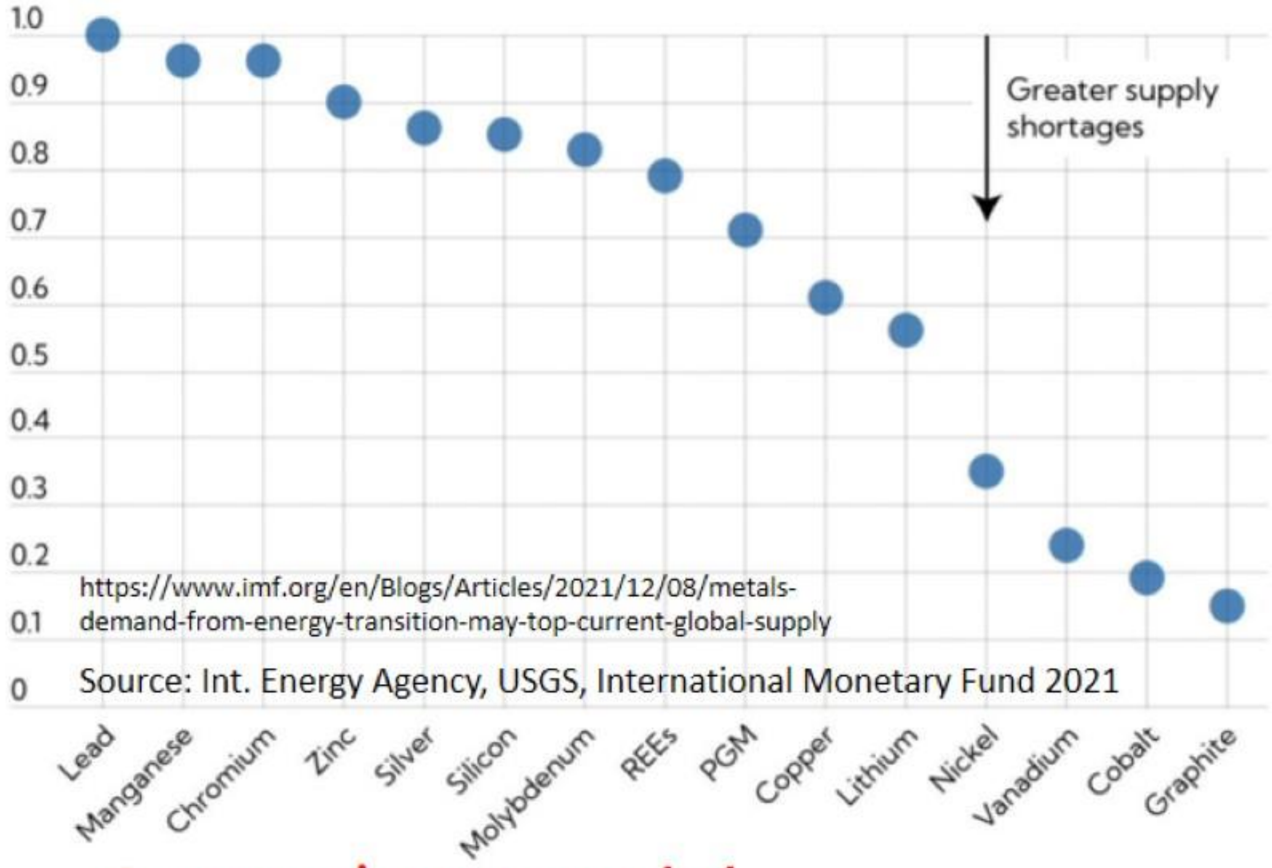
Needs non-ferrous metals only as catalysts: mainly platinum metals, nickel, lanthanum etc.

But loss of Energy :
in hydrogen production: 30%
In fuel cell: 40% In total about 50% , becomes better when generated heat is used.

My opinion: This could be the long term solution (compared to batteries as an interim solution)
Especially for seasonal imbalances, long haul transport, substitution for fossil fuels as Reactants

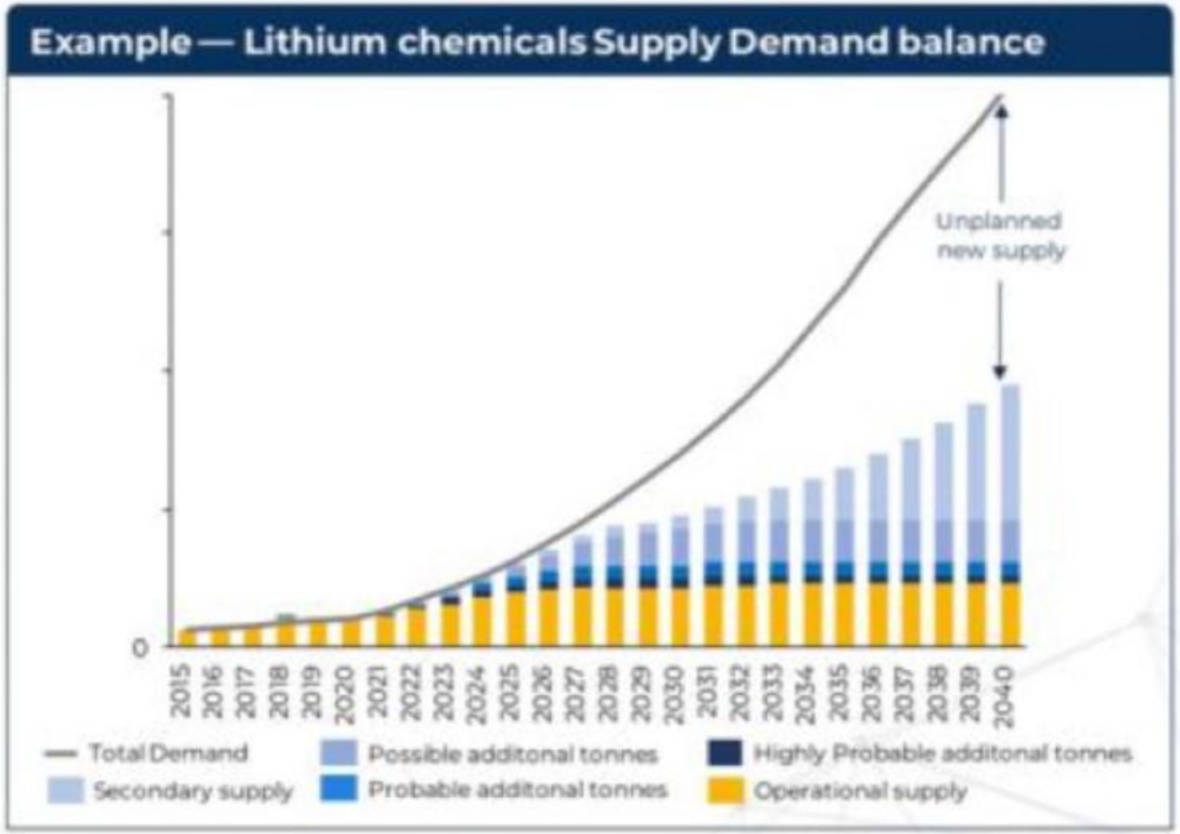
Generation and Storage of Electrical Energy
Huge Demand for Non-Ferrous Metals

Supply/demand ratio for a a net-zero scenario
Supply = cumulative production volume 2021-2050, based on production 2020
Demand = total demand 2021-2050 for a net-zero-demand



=> more mines are needed

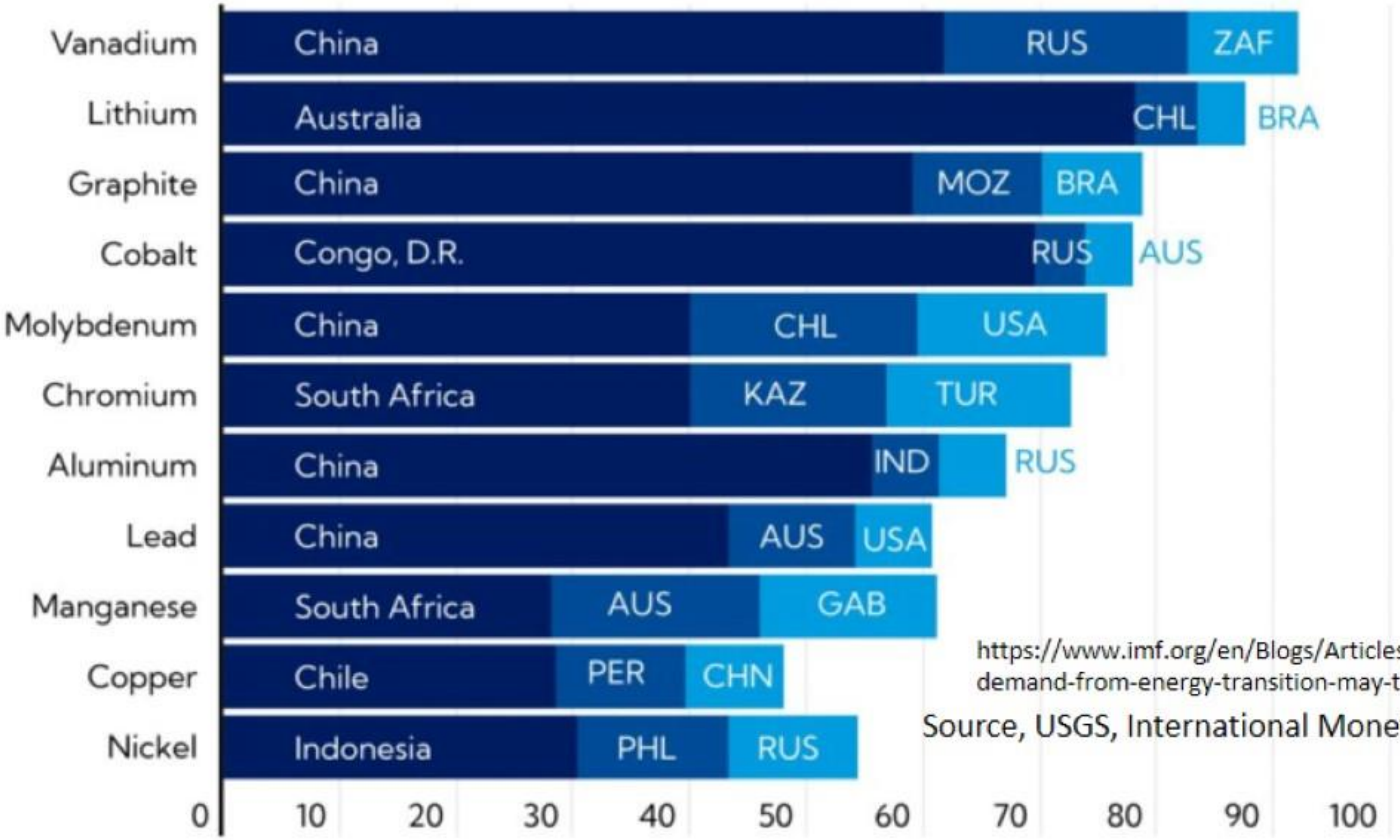
Electrical Energy Storage: Huge Lithium Demand



Benchmark Mineral Intelligence 2021 From Linkedin

It is not the question: Is there enough Lithium in the earth?,
But: How fast can you realize new production capacities?

Europe only plays a Minor Role in the Production of Many Metals



https://www.imf.org/en/Blogs/Articles/2021/12/08/metals-demand-from-energy-transition-may-top-current-global-supply

Source, USGS, International Monetary Fund 2021

=> production of several metals is in the hand of only few countries

Important Metals are mined only as a By-Product

Commodity	By-product	Share of total production that is mined as by-product (%)
Pb	Largely (Zn, Ag, Au, Cu, Sb)	84%
Au	In small part (Cu, Zn, Pb)	5%
Cd	Exclusively (Zn, Cu, Pb)	100%
Pd	Largely (Ni, Cu)	-
Ge	Exclusively (Zn)	100%
Ag	Partially (Zn, Pb, Cu)	70%
Mn	No	0%
Pt	Partially (Ni, Cu)	-
Sn	No	0%
V	Largely (co-product or by-product of iron ore)	-
Mo	Partially (Cu)	60%
Cr	In small part (chromite recovered from PGM tailings)	14%
In	Exclusively (Zn, Cu)	100%
Ga	Exclusively (Al, Zn)	100%
Te	Exclusively (Cu electrolytic refining mainly)	100%
Ir	Exclusively (as co-products of Pt & Pd)	100%
Sc	Exclusively (ores or tailings of Fe, Ti, REE, Zr, Ni, U, W)	100%

Source :KU Leuven Metals for Clean Energy , April 2022

Increasing by-metal (often also minor total value) needs to increase main metal with main total value

We need new Mines in Europe

But new mines for special metals carry big risks:

- Especially for battery technologies:
  Technical development is faster than the lifetimes of new mines
- Do we need much more cobalt in batteries in future?
- Do we need much more rare earth metals in future?

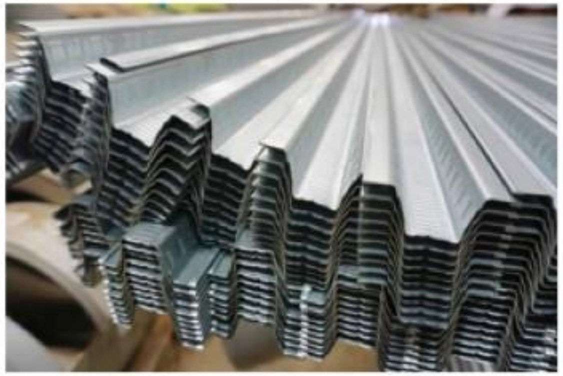
The problem: Batteries need metals for storing the energy
The Solution: Hydrogen technology needs metals only as catalyst (the energy is stored in hydrogen)

But what can be sure: there will be more need for copper as copper connects all technologies, which produce electrical energy

Preventing of corrosion:

Coating corrosively sensitive metals like Steel but sometimes also copper e. g. with tin or zinc by electroplating or hot dip coating.

→ **Longer Lifetime**



Galvanized steel:
Source: Crossroads Galvanizing

Thinner constructions:

By alloying of steel and aluminium with non-ferrous metals, tensile strength can be increased much.
This leads to less weight of the construction material for the same construction

→ **Less Material**

Aluminium alloy construction:
Source: AlCircle. www.alcircle.com

Myth of Recycling:
Can it Help the next 30 Years?

What does "recyclability" of a product mean?
The real recycling rate often cannot be measured

NOT SO MUCH

Is it really collected, separated, cleaned to recover the plastics with a value similar to the value of the original plastics?

?

Source: www.fastcompany.com (Colgate Tubes)

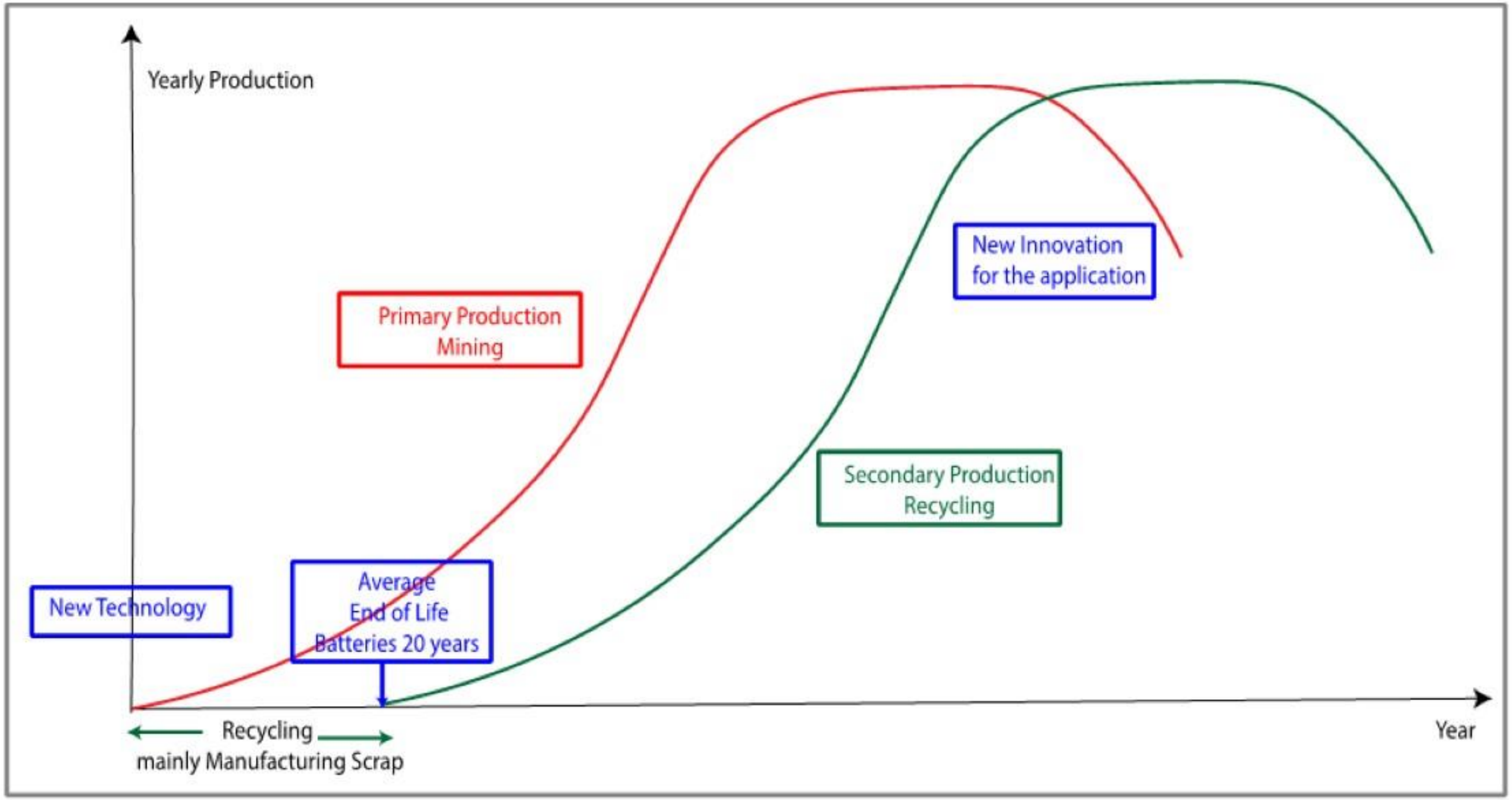
Recyling makes sense:

Economically: If cost of recycling is less than cost of mining (+ waste disposal of EoL material) and value of the recycled product.

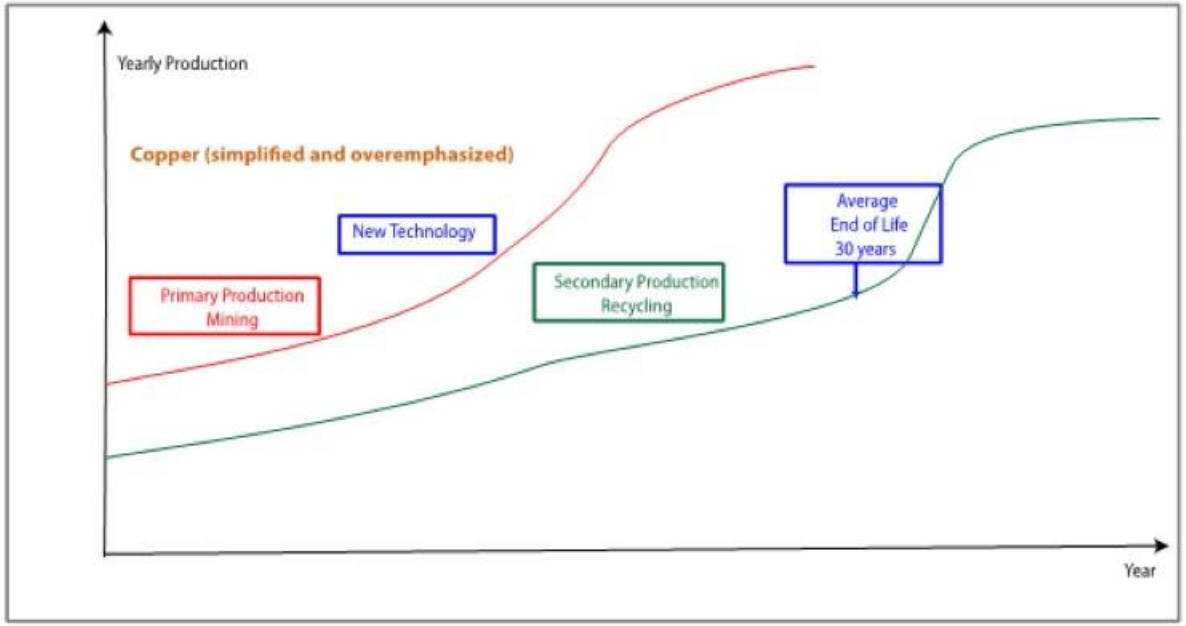
Ecologically: If CO_2 emission is lower than mining

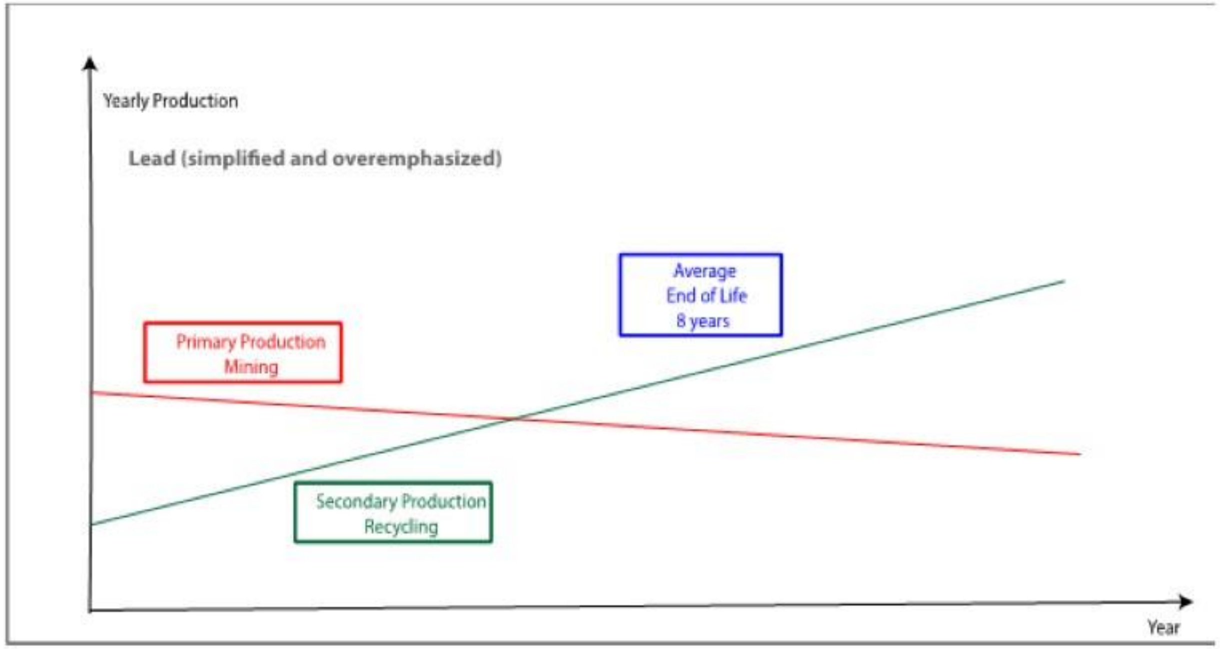
Lithium Battery Recycling does not help much in the next years

Liftetime of a battery for storing electrical energy is about 15-20 years



Myth of Recycling:
Recycling is important in Mature Industries





For base metals, recycling is an important factor, but percentage is reduced with new technologies, which use the base metal

Substitution of metals may lead to higher recycling rates than a metal is needed

Myth of Recycling:
… and partly in Short Life Products

For example big potential for

Electronic scrap

Small batteries

But the biggest obstacle is separate collecting

Myth of Recycling:
Prerequisits for Economical Recycling

1. Collecting of metal containing EoL materials

2. Dismantling/separation components

3. Separation of metals

   Optional:
   Enrichment
   Refining

4. Reshaping/remelting

Myth of Recycling: Separate Collection biggest Problem

Ideal collection: Separated, big and valuable
Examples mainly one Metal: (most of) copper, aluminium, steel, lead
Examples but, many Metals: old cars, big electronic components

Or small, very valuable and separated:
Precious metals in jewelry or catalysts

Collected by industry or craft

Problems as not separated, small and only partly valuable:
Small electronic scrap, small batteries

Domestic waste collected by household

Problems also low concentration of valuable metals:
Coating of bulk, minor elements in electronic scrap

Remelting

- Needs sorting according to alloys
- Only interesting for base metals alloyed with other metals
- Mainly applied to scrap from industry or production scrap
- Only minor refining possible
- Composition can be adjusted to small extent by addition of new metal
- The composition should be near to the demand of an alloy

But Remelting is the most important and efficient Kind of Recycling for Base Metals Leading to Products with a High Value

Recycling of Metals:
Example Stainless Steel and Superalloys

60% of all new stainless steel comes from recycled material

Source: Wikimedia Commons
Compacted Stainless Scrap

Stainless steel contains non-ferrous metals
like chromium (18%), nickel (8%)

Superralloys contain cobalt, nickel, chromium +
sometimes molybdenum, rhenium etc.

Steel is only recycled by remelting and
adjusting the composition in the melt

**Because of Remelting Stainless Steel the Cobalt, Nickel et. al.
Content cannot be used e.g. for Battery Production!!**

Remelting of Metals: Example Aluminium

About 40% of all new aluminium comes from recycled material

Because of its ignoble character, alumiunium alloys cannot be refined to a pure metal - ecomically and ecologically

Only volatile material like labels on a can or hydrogen can be removed from aluminium scrap by remelting

Sorting according to alloy is essential for aluminium remelting

Source: Wikimedia Commons
Compacted can scrap

Remelting of Metals: Example Copper

Recycling rate of copper is about 30%.
About two thirds of copper recycling is done by remelting

The main alloy for remelting is brass
with about 60-65% copper and the rest zinc

Because of the noble character of copper,
copper can be refined to a certain extent
even during remelting by oxidation

Source: Austick Copper Recycling

Input material for the production of copper alloys follows price and availability of scrap

Scrap (if available) → Off-grade cathodes (if available) → Grade A cathodes

Price (Deduction or Surplus to LME)

Refining of Metals: The Unique Role of Copper

Copper is the only metal which is recycled leading to the same quality like pure copper cathodes from copper ore

From each copper source both more ignoble (like nickel) and noble (like gold) impurities can be removed (and recovered).

This is not possible for steel or aluminium, which are only recycled by remelting sorted by alloys

Copper cathodes:
Source: Author, at Aurubis AG

The reason is the unique electrolytic refining process

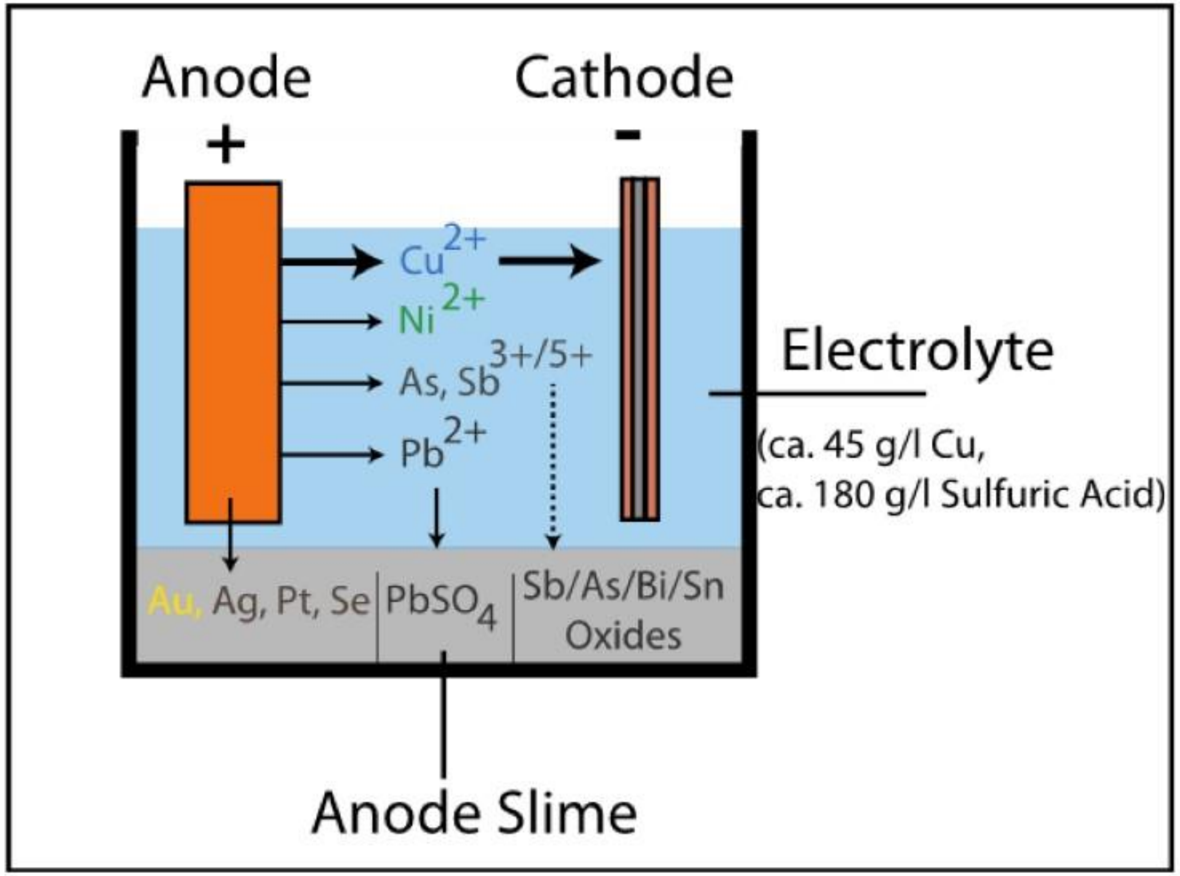
Refining of Metals: The Electrolytic Refining of Copper

The principle:

All metals which are less noble than copper (like nickel) and copper itself are going into solution from the anode.

From these metals in solution copper as – the most noble metal in solution - is deposited at the cathode

All metals which are more noble than copper (like silver) or metal compounds which are insoluble in the electrolyte (like lead-sulfate) are going to the anode slime



Products:
- Copper cathode
- From anode slime: lead, tin, selenium, precious metals
- From electrolyte: e.g. nickel

Refining of Metals: The Unique Role of Copper

Copper plays also an important role for the recycling of other metals.

Liquid copper is a collector for other metals, as many other metals are soluble in a copper melt, and can be separated afterwards by the electrolytic process

Spent automotive catalysts
Source: Thermofischer Scientific by AZO Materials

Copper can dissolve e.g. metals, which are in minor concentrations
In a ceramic matrix: dissolving platinum metals from spent automotive catalysts.

In electronic scrap: processing in a copper melt, a lot of metals can be recovered

Electronic scrap
Source: Author at Aurubis

Conclusions

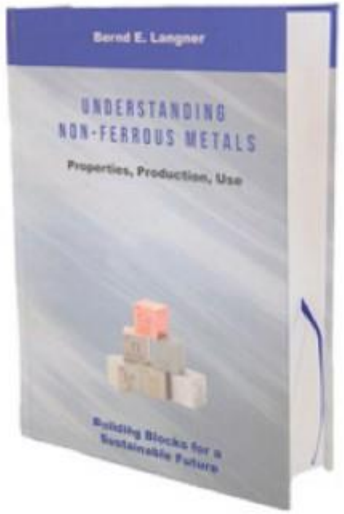
- The availability of non-ferrous metals is a determinant factor for a sustainable future: both for renewable energies and saving energy and material

- Recycling is important for base metals like aluminium and copper, but plays only a minor role at least for the next 10 years for special metals

- New mines and new metal producing plants are necessary for the next two decades. But will this be sufficient?

- Copper plays an essential role for the sustainable future both for renewable energies and recycling

THANK YOU
FOR YOUR ATTENTION



Have a look on my new book:
Understanding Non-Ferrous Metals – Properties, Production, Use
With the subtitle: Building Blocks for a Sustainable Future

www.understanding-nfmetals.com

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