Global Tungsten Mining and Processing

Environmental and Social Impacts



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History of Tungsten

- The discovery of tungsten minerals dates to the middle ages in the tin mines of Saxony-Bohemia and Cornwall, where **tungsten was infamous for its adverse influence during tin production**[1]
- This is the origin of the name “Wolfram”[1] and the **chemical abbreviation W**
- Tungsten was first isolated much later in 1783[1] and given its current name which comes from “heavy stone” in Swedish[2]

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Elemental Properties

- Tungsten's unique properties include the highest melting point of all metals[3], the lowest coefficient of thermal expansion and the lowest vapor pressure of any non-alloyed metal[4]
- In addition, tungsten is among the heaviest metals with a density similar to that of gold and presents a high modulus of compression, high wear resistance, high tensile strength and high thermal and electrical conductivity[4]
- And finally, there is high hardness of certain tungsten compounds (such as tungsten carbide, which is close to diamond) which makes it valuable for a variety of applications[2]

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Tungsten Uses

- Tungsten is irreplaceable in a wide range of applications, including:
  - in **cemented carbide**, a ceramic providing a suitable combination of both hardness and toughness that is widely used for producing various machine tools[5] (60-65%)[6]
  - **super alloys and high speed steels**, increasing their durability, hardness and corrosion resistance in cutting and drilling tools[5] (10-15%)[6]; and
  - several applications in the **chemical industry**[5] (<10%)[6]

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Tungsten in Smartphones

- **Tungsten has two primary uses in consumer electronics**[7]:
  - **smart phone vibration motors** (a small electric motor used to notify the user of an incoming connection) and
  - **vias** (opening in an oxide layer that allows conductive connection between layers) in integrated circuits (ICs)
- Due to its high density, **tungsten enclosed in the vibration motor of a cell phone enables large vibration within a small form factor** (approximately 1g)[7]
- **Much of the tungsten used in the fabrication of vias is lost during chemical and mechanical polishing**[7]
- Overall, **tungsten's use in electronics is small compared to other uses, estimates put it at less than 0.1% of 2013 market share**[7]

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Ores

- **Tungsten is not abundant in the earth's crust (54th element in abundance)**[8]
- Scheelite ($CaWO_4$) and wolframite ($(Fe, Mn)WO_4$) are the only tungsten minerals mined commercially[9]
- Scheelite is more common and is found in approximately 65% of known tungsten deposits[10]
- **The tungsten content in these ores is quite low; only 0.3%–1.5% is WO_3** [2]

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Deposits and Reserves

- Tungsten was identified in 2012 as being amongst the five elements that have the least data amount of material flows data available[4]
- Globally, there are more than 30 countries that contribute to the global supply of tungsten[11]
- **China supplies more than 80% of tungsten mine production in the world, even though it has about 60% of tungsten reserves**[12]
- Based on the data by the USGS (2009–2018), the main reserves of tungsten are located in China (~60%), Russia (~8%), US (~4%), Canada (~8%), Bolivia (~2%), and other countries (~18%) including Austria, Australia, Mongolia, Spain, United Kingdom, and Vietnam[12]

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Supply and Demand

- In an assessment of materials important in Europe, tungsten was named in 2013 as the raw material with the highest economic importance and with a medium supply risk[5]
- Similarly, the British Geological Survey (2012) also ranked tungsten at the top of their metal "Risk List", immediately after the rare earth elements[5]
- **China has adopted stricter pollution control and safety regulations on tungsten production and shut down numerous tungsten mining facilities starting in 2017**[13]
- **This resulted in a reduced supply of tungsten to the world market and high volatility in prices for tungsten commodities**[13]

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Mining Process

- Mining techniques for W-containing ores can be divided into underground and surface mining categories, chosen depending on the mineral properties and the physical peculiarities of the ore body[2]
- Some valuable metals such as molybdenum (Mo), copper (Cu) and bismuth (Bi) are associated with tungsten ores in the form of sulphides[9]
- **The mining methods required to exploit underground vein-type deposits such as tungsten deposits are among the most expensive**[4]
- Most scheelite and wolframite deposits occur **with such low levels of WO_3 (0.1–2.5%) that is not economically viable to apply directly metallurgical methods to extract the metal**[14]

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Mining Process (cont.)

- With the progressive exhaustion of wolframite ore in last several decades, **scheelite, sometimes mixed with wolframite, is the chief raw material to extract tungsten. This makes the tungsten extraction process more complex and challenging**[12]
- For example, only scheelite is readily amenable to flotation. Wolframite, in contrast to scheelite, is paramagnetic[9]
- **Enrichment of the ore is necessary in order to produce a concentrate containing 60%–75% WO_3** [2]

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Tungsten Processing

- For the treatment of wolframite ores or tungsten ores with high impurities, a pure synthetic scheelite is first produced through alkali roasting or digesting[12]
- A fraction of tungsten concentrate flows directly towards the tungsten carbide production step, while another concentrate fraction is used directly in the manufacturing of steel and alloys[4]
- **A larger portion of tungsten concentrate is chemically converted to ammonium paratungstate (APT),** which is an intermediate compound used in the production of tungsten chemicals and tungsten metal powder[4]
- APT is usually obtained by treating tungsten concentrates with either caustic soda or hydrochloric acid[12]
- Tungsten metal powder is commonly employed to manufacture tungsten forms, ferrotungsten and tungsten carbides[4]

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Tungsten Processing (cont.)

- The properties of tungsten also result in significant challenges during final product production[1]:
  - The **high melting temperature** of tungsten makes processing methods, such as casting, unfeasible
  - Its **high ductile-to-brittle transition temperature** severely limits its workability at room temperature which in turn, limits the performance of methods such as forming and machining

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Acid Mine Drainage (AMD)

- **Acid mine drainage (AMD) can be generated from tungsten tailings storage**[13]
- For example, the Panasqueira mine, the largest Sn–W deposit in Western Europe, had stored a significant amount of tungsten tailings in tailing dams with low pH, leaking into the nearby river[13]
- The Lianhuashan tungsten mine, one of the largest tungsten mines in southern China, was closed in 1991 and left a huge amount of untreated tailings, which during the rainy season were released into the ambient environment as AMD[13]

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Heavy Metals

- In addition to AMD, **the presence of heavy metals in tailings - often arsenic - are a risk from tungsten mining**[15]
- **A mine abandoned almost 100 years ago in the English Lake District still found presence of tungsten and other heavy metals such as copper, zinc, and arsenic**[16]
- Other examples of tailings polluting the surrounding water supply exist in places like Brazil[18]
- While tungsten has previously been considered an immobile metal, recent reports describe elevated concentrations in ground and surface water, bioaccumulation in ecosystems, and adverse effects on various organisms[17]
- **The US EPA did claim tungsten as an emerging toxicant after reports of adverse health associated with environmental tungsten exposure**[3]

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Other Environmental Impacts

- The intermediate compound APT is mainly produced via a decomposition procedure with NaOH. Consequently, **tungsten residue from the procedure has high alkalinity** and may be categorized as a basic pollutant[19]
- In addition, tungsten production results in the **consumption of large volumes of water[12] and the subsequent discharge of large volumes of high-salinity wastewater**[12]

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Waste

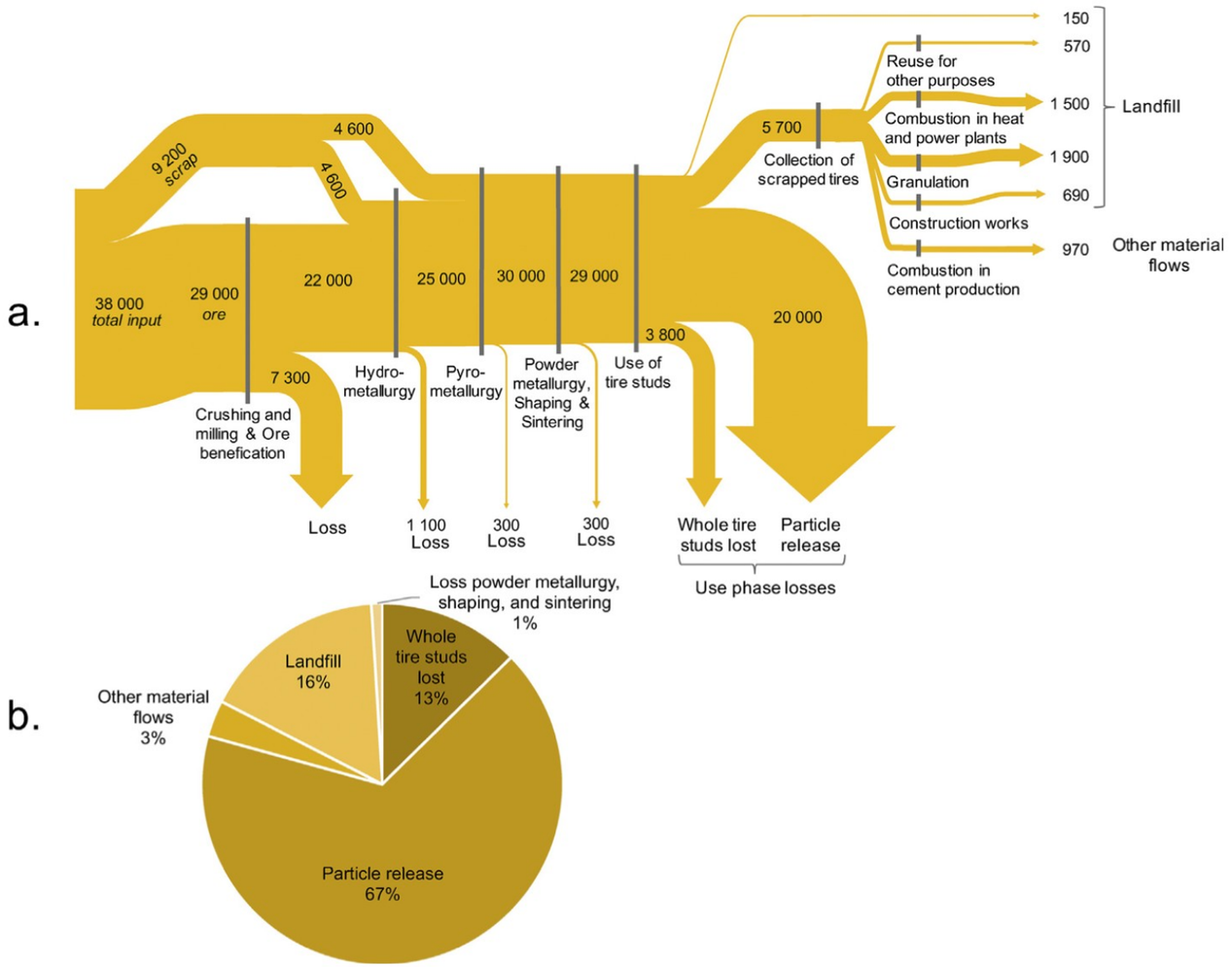


Fig. 2. Results for the base case giving (a) tungsten flows [kg/year] related to the use of tire studs in Sweden in 2015 and (b) dissipation profile for the tungsten outflows between manufacturing (i.e. powder metallurgy, shaping and sintering) and waste management.

- Specifically, note **high tungsten losses during initial crushing and milling, where current global losses estimated at 10–40%**[4]
- These losses are mostly attributed to the brittle nature of tungsten ore, which leads to the excessive generation of fine particles during grinding and crushing to liberate tungsten from the rest of the ore materials [4]

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Waste (cont.)

- **Scheelite losses are exacerbated when extracted from low grade ores, as this type of rock requires even finer grinding to liberate scheelite from gangue material, leading to higher losses of tungsten as fine particles in slimes**[4]
- In 2016, tungsten slag was listed in the National Hazardous Waste List of China according to the latest environmental law. **A million tons of tungsten slag has accumulated in dumps located near metallurgical plants in China the past decades, and >70,000 tons of tungsten slag continues to be produced every year there**[21]

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Conflict Minerals

- Tungsten is known as a conflict mineral, along with tantalum, tin, and gold
- With only about 50 smelters worldwide, the tungsten industry was one of the last sectors to participate in the conflict-free sourcing program[22]
- One reason for the delay in this sector is that **less than 3% of global tungsten is mined in the DRC**, with the bulk of mineral originating and processed in China[22]
- The first tungsten company achieved compliance in 2014[22]
- In 2015, approximately half of the upstream producer companies were listed as actively engaged or progressing toward conflict-free validation[22]
- Consumer electronics, particularly the cell phone, have been highlighted as connected to the demand for these minerals from the conflict areas of the DRC[7]
- However, **in 2015 a study estimated that consumer electronics are responsible for no more than 5% of the total of tungsten conflict minerals**[7]

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Recycling Sources and Rates

- As of 2016, according to the International Tungsten Industry Association, **approximately 30% of world tungsten demand was met through tungsten scrap recycling**[13]
- **23% of which is post-consumer scrap, and the remainder production scrap**[23]

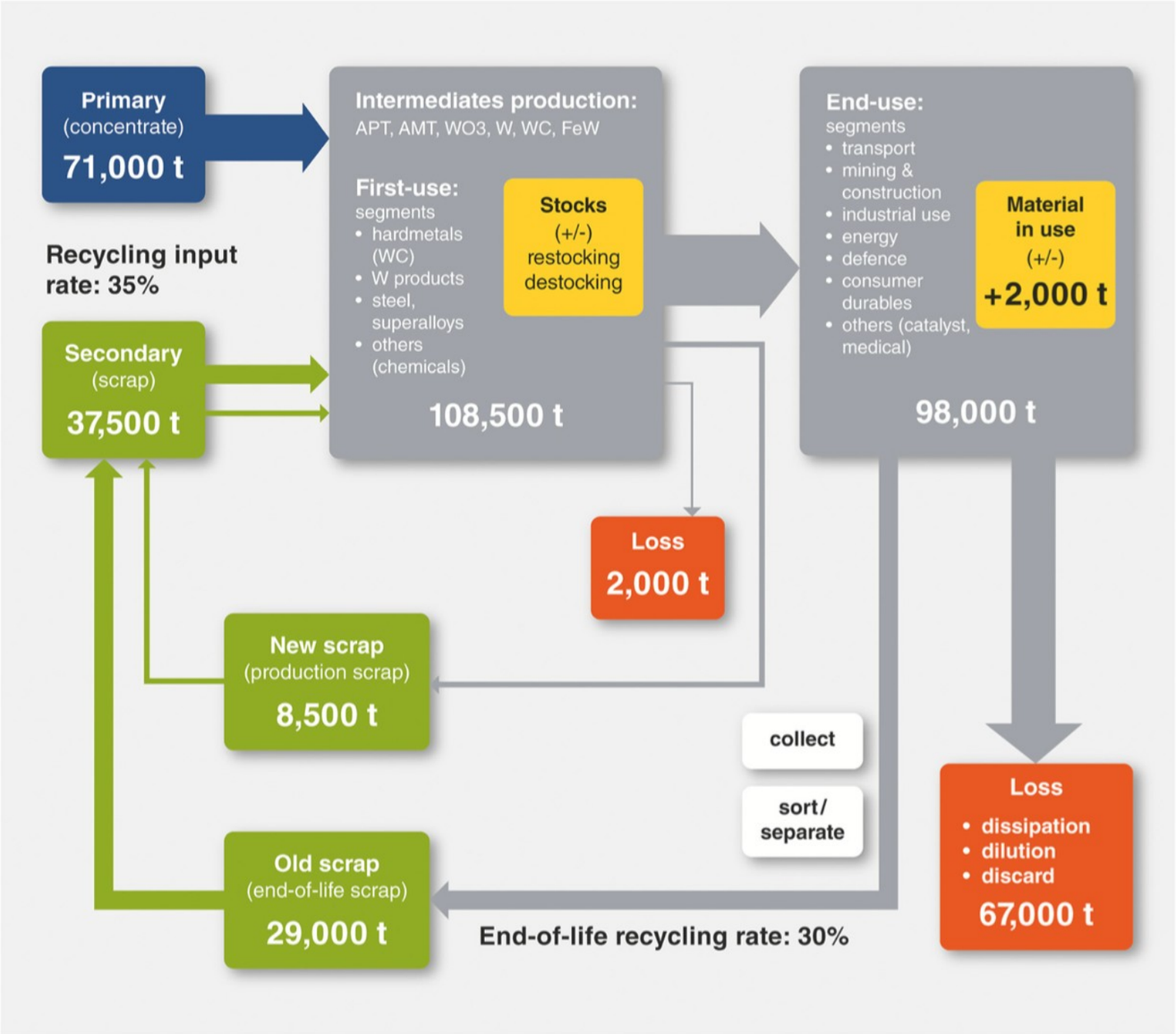


Fig. 3. The global tungsten flow 2016. Source: ITIA 2018.

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Recycling Sources and Rates (cont.)

- **The effectiveness of recycling secondary tungsten strongly depends on the origin of the feed materials**. For example, the recycling of tungsten-containing high-speed steel is more favorable for recycling than tungsten used in lamps and electrodes, due to its higher tungsten content[2]
- Some tungsten uses (e.g. the wearing down of tungsten-carbide tools, or tire studs) are dissipative, and cannot be practically recovered for recycling[23]

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Recycling Process

- A wide variety of tungsten scrap recycling methods are used globally[13]
- For cemented carbides (at least 50% of post-consumer tungsten products recycled[4]), for example:

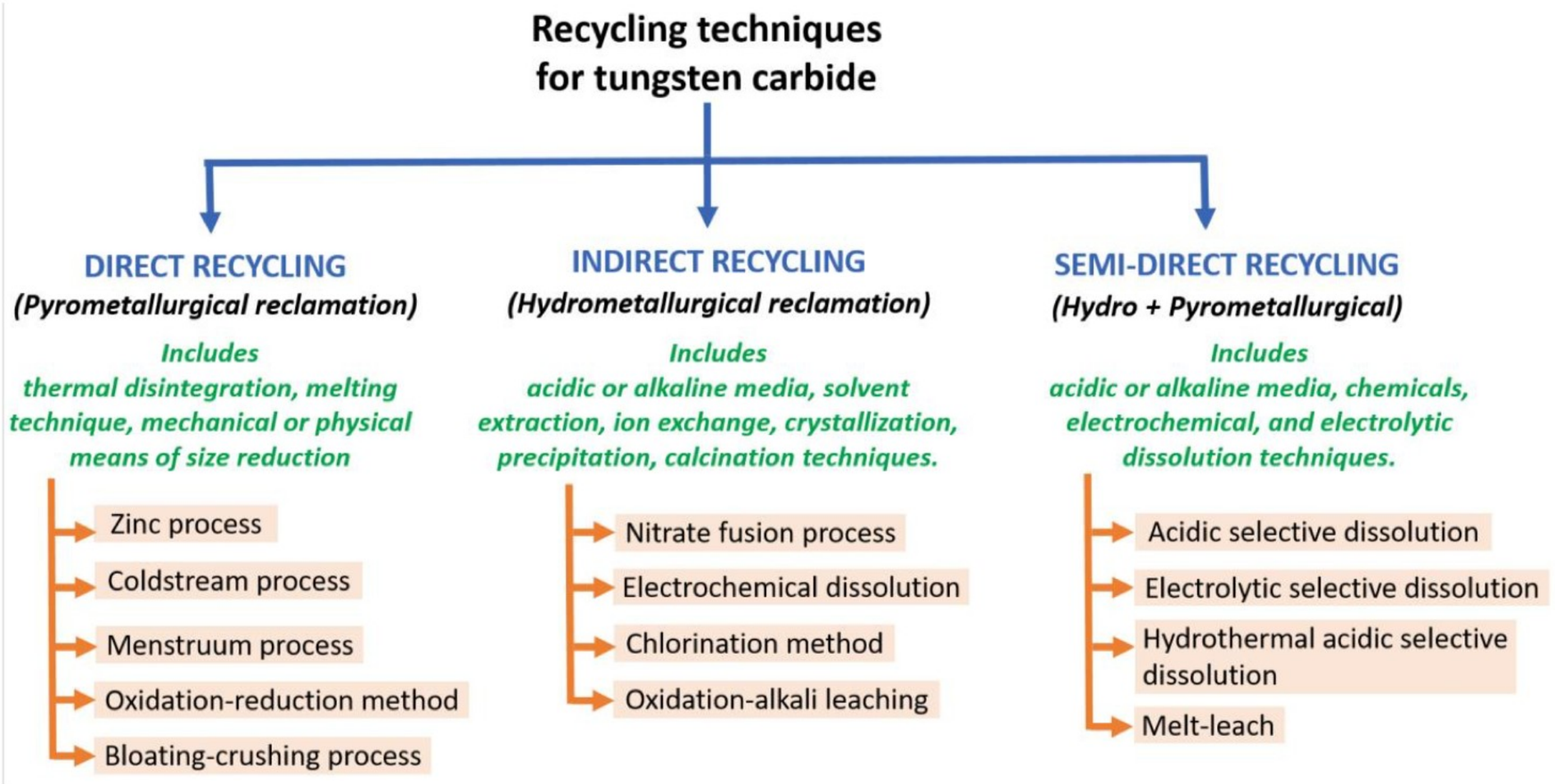


Figure 12. Classification of different types of tungsten (cemented carbide) recycling methods [22,25,47,51,54,85,89–98].

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Recycling Benefits and Challenges

- **Each type of recycling has its limitations and benefits, and each works best with certain types of scrap[23]**
- For example, for tungsten carbide (WC) hard metal scraps[24]:

Table 2. Comparative assessment of direct, indirect, and semi-direct recycling of WC scraps [47,52,85, 92,104,111,126].

	Direct	Indirect	Semi-Direct
Scrap type/Recyclate	Clean, sorted, same sized	Any	WC-Co scrap with other carbides
Final product	Same composition as of scrap	Pure virgin 'W'	Pure virgin 'W' and other constituents
Chemical/Reagent use	No or minimal	High	High
Recycling cost	Reasonable	High	High
Recycling time	Less	High	High
Waste by-product	None	High	Medium
Energy utilized	High	Low	Low
Final product property	Better	Chemical degradation	Chemical degradation
Environment damage	Low	High	Low

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This table covers tungsten carbide (WC) hard metal scraps[24]:

Table 1. A comparative assessment of requirements, advantages, and disadvantages associated with direct, indirect, and semi-direct recycling of WC scraps [47,85,95,101,102,111].

	Requirements/Conditions	Advantages	Disadvantages
Direct	• Composition of scrap should match that of the end product. • High purity of scrap. • Applicable for WC-Co scrap without any other carbide/nitride additives. • May include thermal disintegration, melting technique, mechanical or physical means of size reduction techniques.	• Results in high quality powders. • Excellent grain size control. • Less chance of product oxidation (except oxidation-reduction method).	• Only fits for WC with single binding phase. • Incomplete segregation of tungsten carbide from the matrix phase. • High energy consumption. • Needs specialized equipment.
Indirect	• WC-Co scrap that contain other carbide/nitride additives may be used. • Applicable for grinding sludges, floor sweepings, contaminated powder qualities, solids, etc. • Encompasses use of acidic or alkaline media, solvent extraction, ion exchange, crystallization, precipitation, calcination techniques.	• Results in virgin pure tungsten. • Low energy consumption.	• Extended processing times. • Comprises numerous conversion stages. • High regent intake.
Semi-direct	• WC-Co scrap that contain other carbide/nitride additives may be used. • Not applicable for grinding sludges, floor sweepings, contaminated powder qualities, solids, etc. • Encompasses use of acidic or alkaline media, chemicals, electrochemical, electrolytic dissolution techniques.	• Low energy consumption. • Low environmental influence. • Retrieval of WC and binder metals.	• High regent intake. • Recovery of WC and binder metal.

Recycling Smartphones

- **From the perspective of smartphones, tungsten isn't always focused on as a material to be recycled**[25]:
- Current recycling of tungsten needs a minimum of 75% content of tungsten. Parts without shredding should have thicknesses of less than 1 mm, according to recyclers. **This would be true for most tungsten parts from the vibration actuators, but not for the complete actuator assemblies**[25]

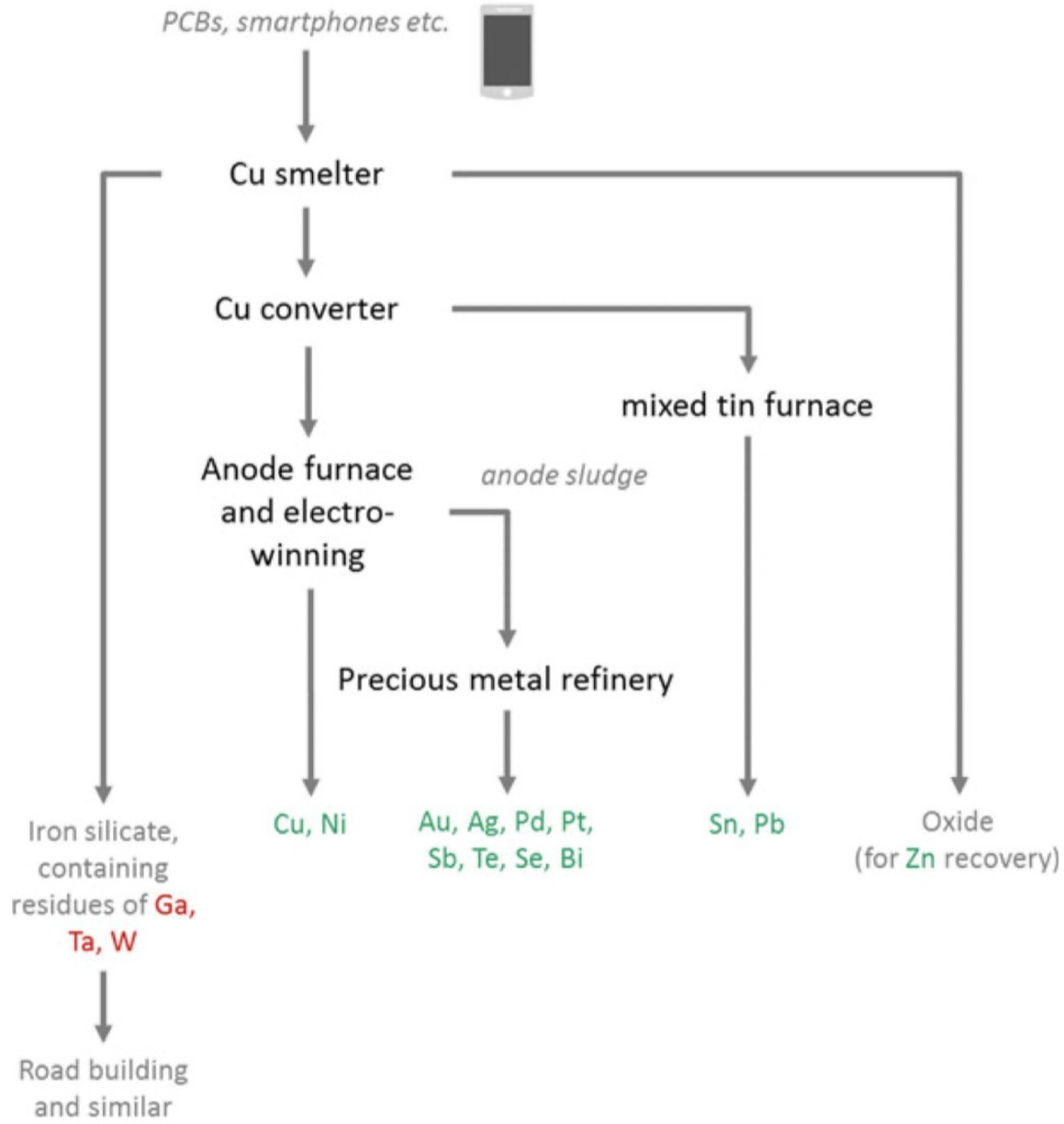


Fig. 26.1 Recovery of metals in a copper smelter

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The Sherwood Line

- Sherwood proposed a relationship between ore quality and market prices, which was later adapted for recycling[23]

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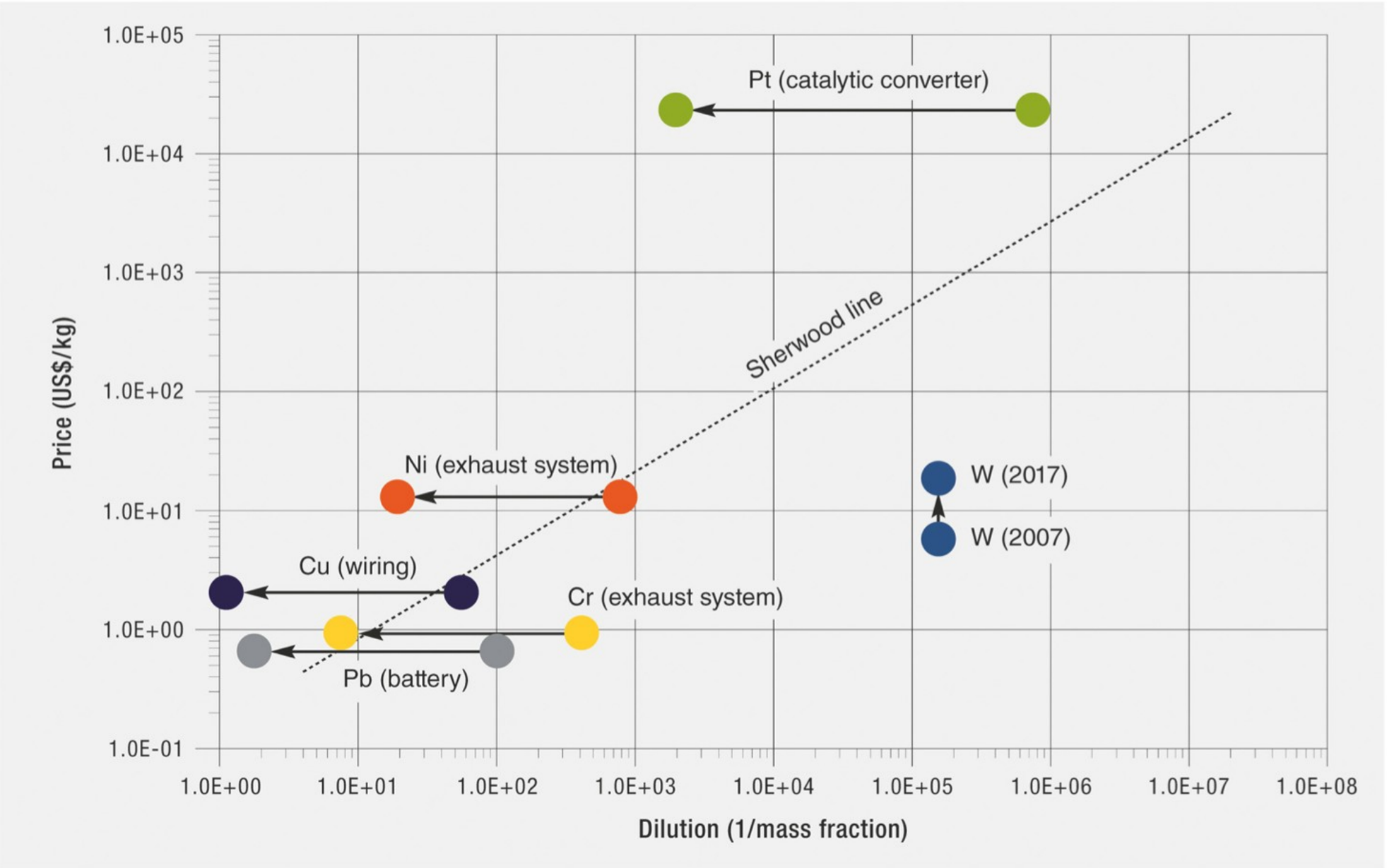


Fig. 9. Sherwood plot for selected metals in a vehicle [10].

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The Sherwood Line (cont.)

- **Either a decrease in dilution of the element in a part to be recycled** (in this example, automotive parts)**, and/or an increase in the recycled material market prices will make the part economically viable to recycle** (i.e. "above" the Sherwood line)[23]

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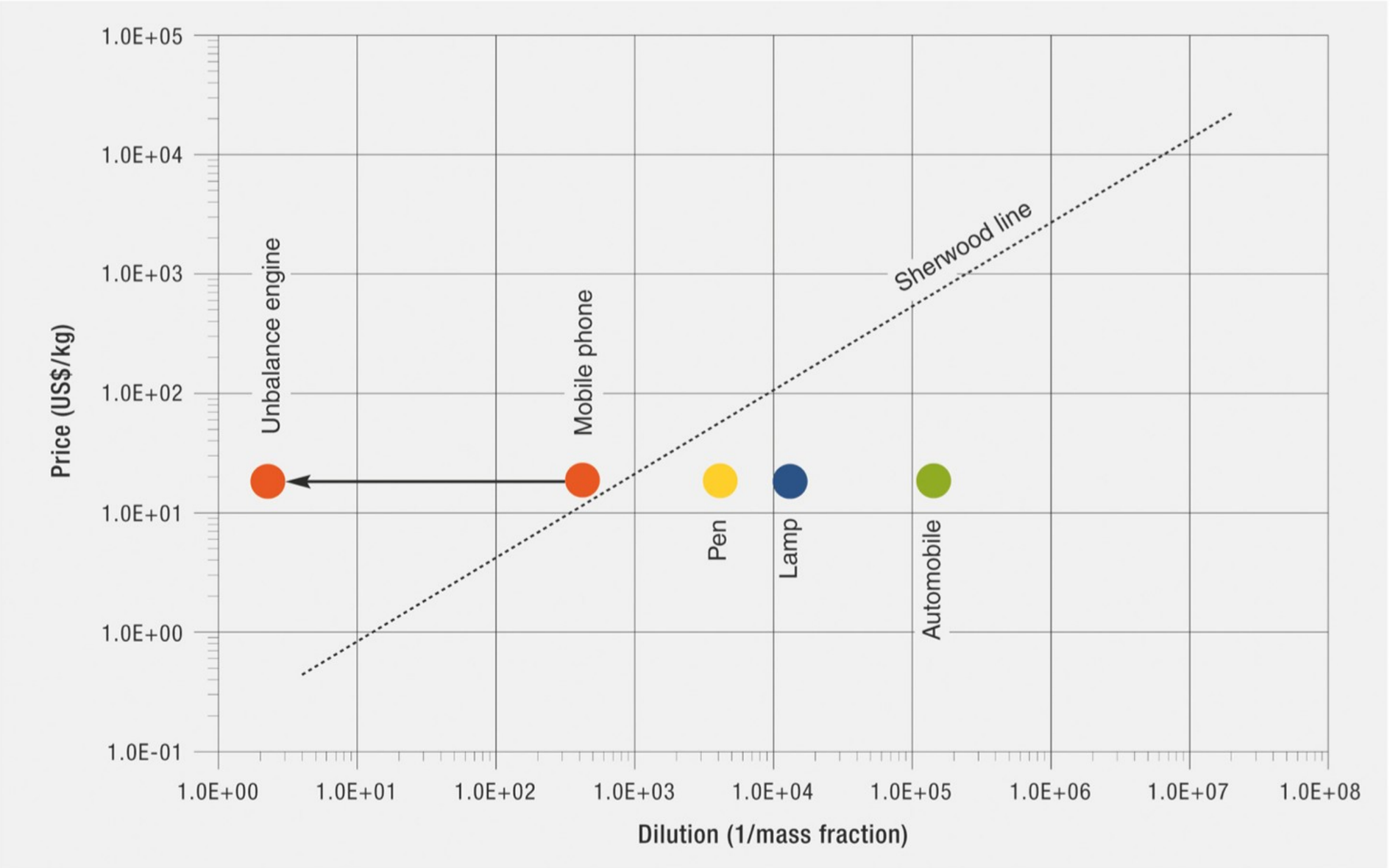


Fig. 10. Sherwood plot for tungsten in selected products; data from Table 1 and [10].

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The Sherwood Line for Tungsten

- **Note how mechanical disassembly, i.e. separating out the unbalance engine (haptic engine) from the mobile phone (where tungsten is only 1% of the overall weight) shows the tungsten more likely to be recycled**[23]
- Of course, the cost of the disassembly will factor into the economics, too, indicating **potential value in automated disassembly**[25]

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Recycling Benefits

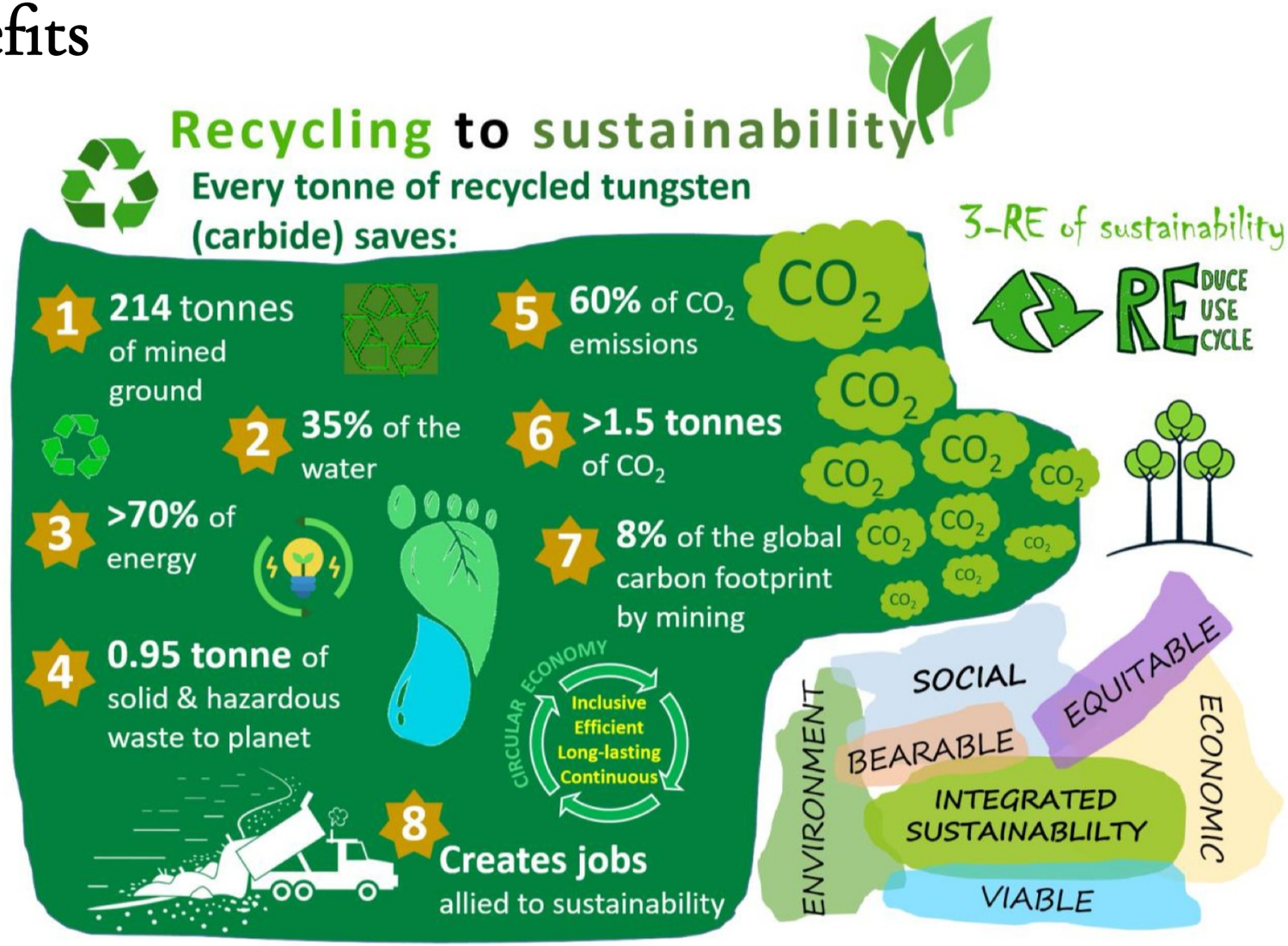


Figure 9. A scheme showing the connection between tungsten recycling and its contribution to sustainable development [26,37,74–77]. Key factors of integrated sustainability adapted from UN Global Compact Report [78].

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Summary

- Tungsten (abbreviated W) is a rare element in the earth's crust, with low-grade ores (0.3-1.5% WO3)
- However, its properties (such as the highest density of all metals) make it uniquely suited to a variety of applications - primarily the production of tungsten-carbide (cemented carbide) tools
- The natural brittleness of its ores, however, leads to a large amount of tungsten losses during initial grinding and crushing
- And the ores are co-present with heavy metals (like arsenic) and sulfides, leading to acid mine drainage when exposed to water and air
- Most tungsten today is actually mined and produced in China, despite its status as a conflict mineral in the DRC
- Recycling tungsten has multiple benefits including: energy savings (est. over 70%), emissions reductions (40%), less solid and hazardous waste creation, reduced water use
- Most post-consumer tungsten recycling today comes from tungsten carbide hard-metal scraps; mobile phones are rarely recycled for their tungsten content due to its low % of the overall mass (<1%)

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Thank you

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