



## Recycling of Tungsten

**Current share, economic limitations and future potential**

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Sorting of cutting insert scrap. Courtesy of Sandvik

# Recycling, an Important Contribution to a Sustainable Economy

Recovery of metals from scrapped products has a long tradition in the use of metals, long before this activity became popular under the names of recycling and sustainable economy. The main driving force was, and still is, the (monetary) value of metals, which makes their recovery a feasible activity. In the case of tungsten, recovery from used products can be traced back to the early 1930s, ie to times shortly after the respective material developments were made.

A more recent aspect in the recycling discussion is the concept of a circular economy, which was designed to overcome the limitations caused by the exhaustion of natural resources. An economy which relies on the use of commodities, which are not renewable and will be exhausted after a certain period of time, is considered to be unsustainable. Such an economy necessarily dies when resources are depleted or, alternatively, has to change its fundamentals to survive in a different form, for another period of time.

Because of their unique properties, metals are key commodities in today's economy and are therefore frequently scrutinised with respect to their role in the quest for a sustainable economy (society). Fortunately, they do not disappear from the planet, because they are used. Every metal atom (which is not sent into space intentionally) stays on earth and, in principle, can be used again and again. The important aspect in this case is not the frequently mentioned exhaustion of resources, as they stay with us by their very essence. It is rather the way we manage

them, namely to avoid dissipation and dilution beyond the point where it becomes increasingly difficult to access them again for (economic) reuse. When we look at tungsten, it is worth noting that recent technology allows us to extract tungsten from natural sources (so called primary tungsten) with concentrations as low as 0,06% in an economically feasible way [1]. Many of the tungsten products used nowadays can be collected after the lifetime of these products at much higher concentrations and the technologies to convert them into raw materials and new products are numerous.

One concept about how to use a valuable raw material the best possible way, is the application of the **"3R" approach**:

**Reduce:**

doing more using less material, which addresses the efficiency in the use (ie better performing cutting inserts with multiple cutting edges and smaller size).

**Reuse:**

which in the case of tungsten may mean reconditioning worn tools and using them again (ie regrind a worn rotary cutter to a slightly smaller diameter and give it a second life; or re-sharpen the cutting edge of a drill to use it again)

**Recycling:**

recover tungsten from used products.

This article will further focus on the recycling aspect of the "3R" approach. There are numerous activities in the tungsten industry to address the aspects of efficient use of tungsten and reuse of tungsten products and it is the combination of all three aspects which leads to the responsible and sustainable use of tungsten.

## Definitions for Products, Scrap and Recycling

A product is made to serve a certain purpose. When talking tungsten products, the expression "product" is further subdivided into **first-use products** and **end-use products**. Examples of first-use products are hardmetal rods or hardmetal drill bits or any other tungsten containing materials, which need further production steps to be ready for an end-use. First-use products are also sometimes referred to as semi-finished products. To become an end-use product (sometimes also called finished product), mentioned examples of first-use products have to undergo additional manufacturing steps. The hardmetal rod may be ground to

become a metal cutting drill or an endmill; many of the drill bits may be shrunk into a steel part to become a drill head for mining purposes. The basis for manufacturing of first-use products are the so-called **intermediates** (or intermediate products which in the case of tungsten are: ammonium paratungstate (APT), ammonium metatungstate (AMT), tungsten oxide (WO<sub>3</sub>), tungsten metal (W) and tungsten carbide (WC) powders, as well as ferrotungsten (FeW) and ultimately the **raw materials** (concentrate or primary raw material and scrap or secondary raw material).



Figure 1: Examples of cemented carbide old scrap. Tungsten products after their end-of-life. Courtesy of Wolfram Bergbau und Huetten AG

As soon as a product is no longer fit for purpose, it becomes **scrap**. The hardmetal drill may break and the drill head be worn out. When this happens to an end-product, the resulting scrap is called **old scrap** (Figure 1). When it happens to a first-use product, the scrap is called **new scrap** (sometimes also called primary scrap or production scrap). Examples of new scrap are grinding sludge from hardmetal drill production, sintered hardmetal rods or drill bits (or even the manufactured end-products) which do not pass quality checks (for all sorts of reasons, ie metallurgy, dimensional failure, porosity etc) (Figure 2).

**Recycling** stands for a process to extract one, several or all constituents from scrap for reuse in the production of first-use products, which need such components as raw materials (not necessarily the same first-use products for which they were used before they became part of the scrap). This sounds complicated, but is easy to understand with some examples:

A hardmetal drill scrap (old scrap) may be recycled by a chemical process to extract both tungsten and cobalt (the constituents of such a hardmetal). The resulting tungsten oxide may be converted to tungsten metal powder and used to produce a heavy metal alloy (first-use product) for counterweights (end-use product) in airplanes. Thus tungsten from a scrapped drill becomes part of a counterweight but the end-use is different as the tungsten is used for an end-use product where the genuine properties of tungsten are essential for the application. The cobalt, recycled from the drill scrap, may be used to produce lithium cobalt carbonate (first-use product) and finally a lithium ion battery (end-use product). Again a very different product as compared to the hardmetal drill, but as cobalt is essential for the function of the battery, it is a proper recycling of cobalt. In this example both tungsten and cobalt are recycled.

Now let us consider what may happen to the scrapped drill head. This is a product which, looking at the weight (not



Figure 2: Examples of tungsten carbide new scrap, also called primary or production scrap. Scrap generated during manufacturing of tungsten products. Courtesy of Wolfram Bergbau und Huetten AG

necessarily the value), consists mainly of steel. It may end in a collection tray for steel scrap and be used to produce structural steel. In this case tungsten and cobalt are not recycled, but diluted and thus lost (loss by dilution) as they have no function and are even considered to be impurities. Sometimes this is referred to as **downcycling** or **non-functional recycling**, the latter expression being a contradiction in itself, as the very essence of recycling is to recover a constituent to make use of its *function*. There is of course the possibility to separate the hardmetal drill bits from the steel body and recycle the tungsten and cobalt too, but this is a complicated and costly process and its economic feasibility depends on prevalent commodity prices.

In the case of tungsten, the expression recycling is further divided into **direct recycling**, **indirect recycling** (also called **chemical recycling**) and **semi-direct recycling** (a

combination of both), which is explained in more detail in a separate “Newsletter” dealing with recycling technologies. Nevertheless it is worth a mention here that indirect recycling is capable of recovering tungsten without any loss of performance (function). Tungsten products manufactured from 100% scrap by chemical (ie indirect) recycling have exactly the same properties and performance as tungsten products made from 100% tungsten concentrate (primary raw material) due to the purification steps in the process.

Another important point to be clear about when talking about recycling is the calculation of the **recycling rate** or, in other words, the **share of recycling**. In this article two different recycling rates are used and explained. The expression **recycling input rate** is the percentage of scrap (old and new scrap) used for production of the intermediates and the term **end-of-life recycling rate** is the percentage of end-use products (old scrap) recycled.

## Current Share of Recycling

Based on recent studies performed by ITIA [2,3], the global tungsten flow has been mapped for the year 2016 (**Figure 3**). The total input for production of intermediates was 108,500 t (metric tons tungsten content) from which 37,500 t were scrap (new and old scrap), which results in a **recycling input rate of 35%**.

98,000 t of tungsten were consumed in end-use products and based on the estimate for old scrap generated (29,000 t) an **end-of-life recycling rate of 30%** can be calculated.

Thus, tungsten belongs to the group of metals with a recycling input rate above 25% (ie 35%) which, according to a recent UNEP Report [4], is only achieved by one third of the sixty metals investigated.

Today, the tungsten processing industry has developed technologies to treat nearly every type of oxidic, metallic or carbide scrap generated in the production and end-use cycle. As these technologies were adapted to the materials made from tungsten and these materials are reflected

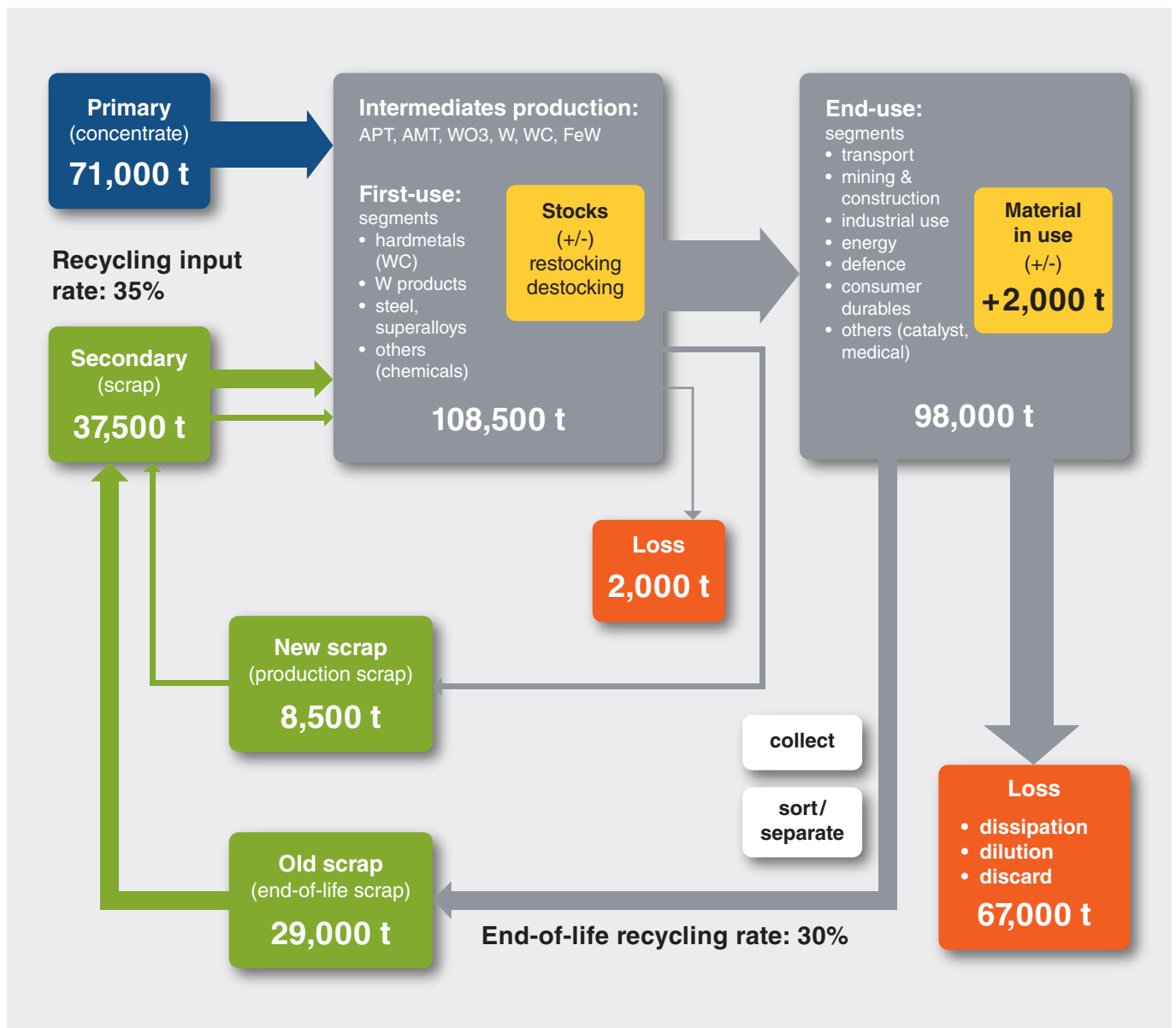


Figure 3: The global tungsten flow 2016. Source: ITIA 2018

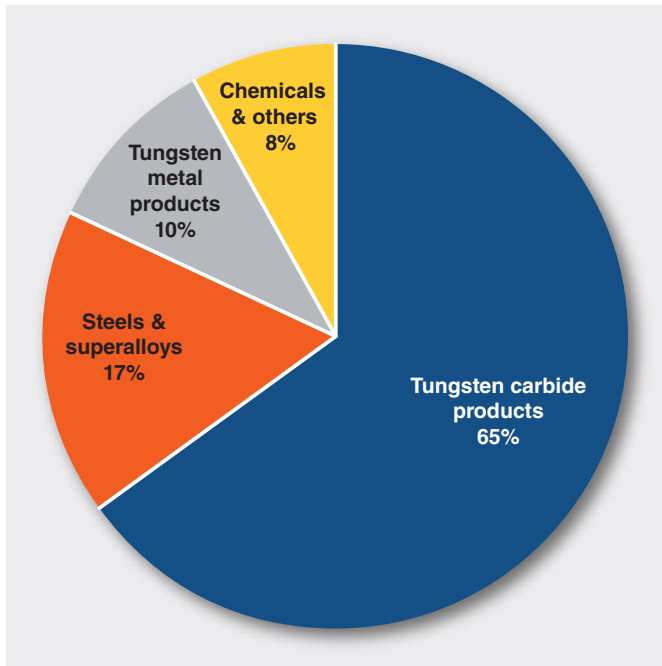


Figure 4: Global breakdown of first-use segments for tungsten in 2016

in the first-use segments, it is worth studying the global breakdown (**Figure 4**) and the recycling efforts in each segment better to understand the current state of recycling and future potential.

### Tungsten carbide products

From the first-use analysis (Figure 4) it is evident that the tungsten recycling rate is mainly influenced by its use in Tungsten Carbide Products (mainly as hardmetal or cemented carbide, an alloy of tungsten carbide and cobalt), which represents two thirds of the global tungsten use. This share has increased over time and still has the potential to grow further. This segment also exhibits a large number of uses which, for ease of understanding, can be divided into different groups of application areas, such as:

- Cutting tools
- Mining, construction, and energy
- Wear parts and chipless forming

The estimate for the current overall global recycling rate of tungsten carbide products is 46%.

Based on feedback from large cemented carbide producers and tungsten carbide powder manufacturers, the share is the largest for cutting tools, with an average of 55%, but rates above 80% are considered possible by globally

working producers. This high efficiency in recycling is due to the local accumulation of scrap at large producers and users (for example in the automotive or aerospace industry), which makes this scrap more readily available and thus easier to collect. In addition, large producers are offering buy-back programmes and scrap traders are very active collecting these valuable materials. Cemented carbide cutting tool scrap is small-sized and therefore easier to handle in current recycling technologies. Scrap pre-sorting (sorting by material composition) by the end-user contributes to a higher recycling efficiency. Carefully sorted scrap can be used in direct recycling technologies, which are more energy and cost efficient.

The global recycling rate is lower in the two other cemented carbide segments, both of which are estimated at 40% current rate. The high number of differently shaped, sized and composed cemented carbide products, which are in many cases attached or even brazed-on or cast-into steel parts (**Figure 5**), is the main reason for the lower recycling rate. Increased processing costs due to the required multi-stage separation operations and high labour costs frequently makes recycling economically unfeasible at prevailing metal prices.

### Steels and superalloys

Tungsten in melting metallurgy for production of steels and Superalloys is the second largest use for tungsten (17% globally), but follows a quite different recycling route. Production scrap originating from smelting, casting and forming can directly be re-melted in-house and is therefore not considered in the calculation of the recycling rate. In-house re-melting is even possible with partly oxidised scrap, as the oxygen is removed during this process.

Tungsten steel scrap generated by the toolmaker and machine shops (used parts, blanks and turnings, **Figure 6**) is collected in a similar way as in the case of cemented carbides. In particular large toolmakers and users collect the scrap sorted by grades, in which case the scrap can be added directly to the respective tungsten steel melt for recycling.

Metal traders are working hand-in-hand with high speed tool mills and refineries, providing them with the majority of their raw material feed stock. However, at small sites the tungsten-bearing steel might end up in the metal collection container and thus will not be recycled, but diluted to other steels.



Figure 5: Collected old scrap stemming from end-use in mining and construction. The tools consist of cemented carbide and steel. They are stored for dismantling and cemented carbide separation. Courtesy of M Sicho, GTS - Global Tungsten Solution s.r.o., Czech Republic



Figure 6: Tungsten high-speed steel (HSS) scrap, blanks and turnings, as collected by the toolmaker (new scrap) for recycling in an HSS smelter. Courtesy of W D Schubert



Coils



Wires

Figure 7: Powder metallurgical (PM) tungsten new scrap. Courtesy of W D Schubert

No information is currently available on the recycling rate of low-tungsten-containing steels, such as cast-steels, heat resisting steels or stainless steels.

Recycling rates are reported to be very high in the case of superalloys (which makes sense due to the high material value), but again no definite figures are currently available.

Rates of recycling of stellites can be assumed to be significantly lower, as “stellited” steel parts (to increase wear and corrosion resistance of the tool) will readily be dissipated or simply “disappear” in ordinary steel.

There is no information on reliable recycling rates in this field (which falls somehow out of the “tungsten commodity family”). The estimate for the current global recycling rate of tungsten in the steel and superalloy segment is 15%, mainly based on earlier investigations [5].

### Tungsten metal products

Tungsten metal products, sometimes also referred to as tungsten mill products, cover the area of PM (powder metallurgical) tungsten for lighting, electronics, high-temperature applications, electrical contacts, heavy metals and alloys for high performance switches (W-Ag, W-Cu, WC-Ag). These products are made almost exclusively by powder metallurgical methods, hence the name, and represent 10% of global tungsten use.

The estimated global recycling rate in this segment is rather low at 22%. The highest individual recycling rate within this

segment is achieved in the field of heavy metal products at 30%. By far the greatest proportion of heavy metal scrap, in turn, is production scrap generated during manufacturing (turnings from shaping), and the bulk of that is recycled for reuse within this product area [6].

The majority of PM tungsten scrap is new scrap, such as coils, mesh, wires, blanks, trim, turnings, rods, switches, contacts and sinter-bar ends (**Figure 7**). In contrast to the situation in the tungsten steel and superalloy field, in powder metallurgy such new scrap cannot be recycled directly to produce PM products again. But as some of this scrap is of very high purity, it is perfectly suited for direct addition in superalloy manufacturing, for which application the highest scrap prices can be achieved. Alternatively, less pure scrap can be either used to make cast eutectic carbide (WC-W<sub>2</sub>C), which is a hardfacing material, or for the manufacturing of tool steel which has a higher tolerance for impurities in scrap [7]. The amount of old scrap collectable from the end-use is comparatively small, which results in a low recycling rate. Contaminated parts can easily be recycled by oxidation and subsequent alkaline digestion.

### Chemicals and others

The smallest segment is chemicals and others at 8% on a global base. This group comprises tungsten chemicals, used for catalysts (hydrocracking, DENOX), pigments, lubricants, semiconductors, photovoltaic cells, etc.

Hydrocracking catalysts can be re-activated at the catalyst producer (reuse) but this is commonly not considered



as recycling. Chemical recycling of non-reusable catalyst is generally possible (such as oxidation and leach – eg US Patent 4,514,368/1985 – *Leaching Nickel, Cobalt, Molybdenum, Tungsten, and Vanadium from Spent Hydro-processing Catalysts*), but economic feasibility remains questionable, in particular at low metal prices and low tungsten levels. The same is valid for DeNOx-catalysts (containing up to 10 wt% WO<sub>3</sub>). Such catalysts can have an end-of-use period of up to 30 years, and catalyst regeneration is done by washing, gel coating and reuse of the modules. At the end of life (due to poisoning, masking, sintering and volatilisation), they are frequently contaminated to such a large extent (by V, P, As, Hg, Tl, etc.) that on alkaline or acidic leaching (for example: German Patent

DE 4242978 A1/1994 – *Verfahren zur Aufbereitung von deaktivierten DENOX-Katalysatoren*) the separation of the contaminants is becoming a crucial economic factor. Sometimes downgrading of the ceramic catalyst by mixing with other ceramics for heat storage vessels is the more economical way; alternatively deposition on a hazardous waste disposal site.

Tungsten used in electronics is present as ultra-thin layers in the electronic component and is not recycled. Tungsten pigments in paint are not recycled either. As a result of these considerations, a very small global recycling rate of 5% is estimated for this segment.

## Losses by Dissipation, Dilution and Discard

The discussion of the current share of recycling (actual at 30% end-of-life recycling rate and 35% recycling input rate) leaves us with the question about how far this share could eventually be pushed in the future and what would be the limits, set by technology and the economy. To address this key question, the loss – the part of the tungsten leaving the circular flow – has to be analysed. In this context the concept of dividing these losses into three categories, as used by Smith [5] and Kieffer [6], proved to be very helpful:

### Dissipation

Dissipation is a type of loss which is linked to certain products and applications and occurs **during the use** of the tungsten containing product. The most important example is wear. Due to its extremely high hardness tungsten carbide is used in many abrasive applications. And even though it is much more wear resistant than many other materials, a certain amount of the material is lost during such applications (ie rock drill bits, road milling chisels [Figure 8], water jet cutting nozzles, ..).

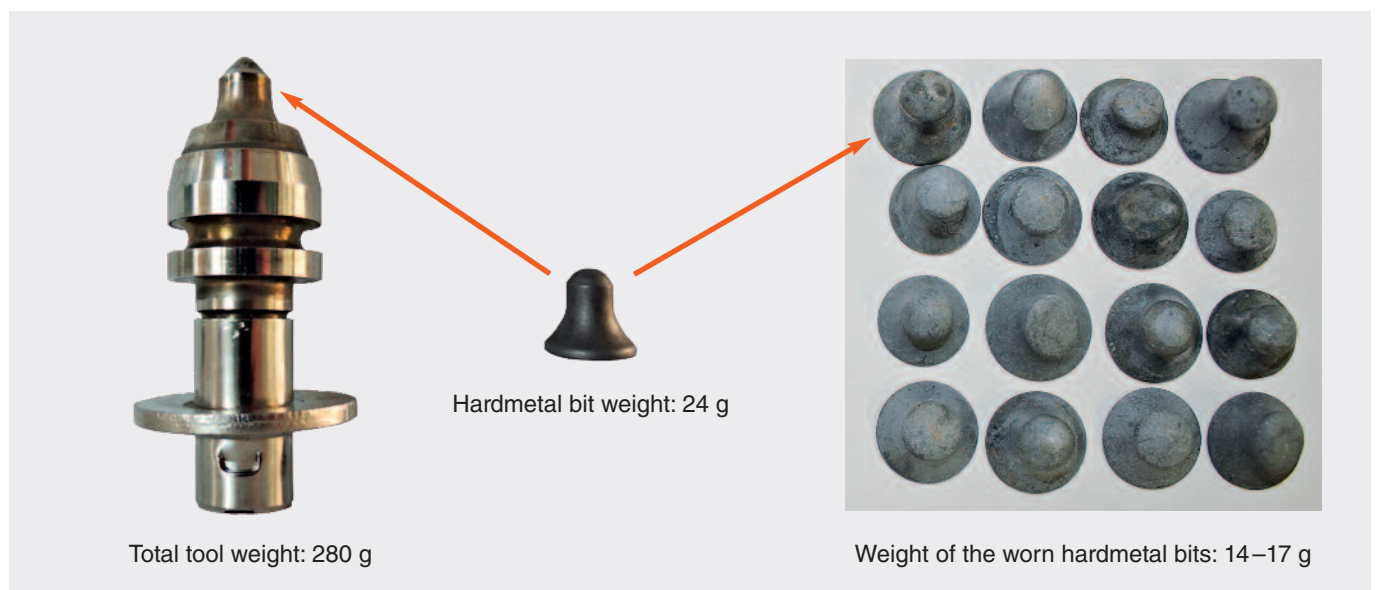


Figure 8: Wear of road-milling chisels, an example of loss by dissipation. Only 60–70% of the original bit weight is still available for recycling. Courtesy of W D Schubert (left) and M Sicho, GTS - Global Tungsten Solution s.r.o., Czech Republic (right)

Electric arc erosion, as it occurs on electrical contacts is another example for loss by dissipation. Tungsten-containing products used in corrosive environments may suffer from loss by chemical dissipation.

If a solid tungsten carbide hardmetal drill breaks apart during use, this is not dissipation, as the individual fragments are still big enough to be collected. An important aspect of dissipation is the formation of extremely low tungsten concentrations, which prohibit recycling attempts of the lost material.

### Dilution

Products which have low tungsten concentration or in which tungsten-containing parts are dispersed and it is difficult (ie not economically feasible) to separate the tungsten-containing part from the product may be recycled for other elements, rather than tungsten. Where the main components consist of steel, such products will be recycled by the steel industry. In such a case, the tungsten is diluted and becomes a trace impurity in steels where it has no function.

## Economic Limitations

Whether end-of-life products are recycled or not is influenced by several parameters. Inter alia, environmental issues or legal requirements can play an important role. Gutowski [8] suggested using thermodynamic considerations as an objective evaluation tool for recycling processes. A more pragmatic approach is to use economic factors as a criterion for recycling. Under open market economy conditions, recycling will only take place if it is economically viable. The two main steering parameters are, on the one hand, the processing costs and, on the other hand, the revenues of the recyclates. Thus, metal prices are key drivers directly affecting collection and processing efficiencies in recycling [9]. Limits are often set by the economic value of the metal and by the volumes involved. Metal concentration plays a crucial role in the viability of recycling [10].

The basic relationship between concentration and price has already been described, in 1959 by Thomas Sherwood [11]. In a double-log depiction of dilution of materials in ores over their market prices, a more or less linear relationship, the so-called Sherwood line, exists. It was in 1994 when Allen and Behmanesh used the Sherwood plot to explain whether a material is recycled or not [12]. According to the authors, materials will be recycled if they are above the

Sometimes this is called down-cycling, but as tungsten has no function any longer it is a real loss. This loss occurs **after the use** of the tungsten containing product.

### Discard

Any tungsten-containing product at the end-of-life can be subject to discard. The reasons could be manifold. If there is no recognition of the intrinsic (tungsten) value of the product it could simply be trashed. There may be logistic and economic limits to the feasibility of collection of tungsten products or difficulties in the separation of the tungsten containing parts from the scrapped product which can lead to disposal rather than recycling. Depending on where such products are disposed finally, there could be a fair chance to recycle them in the future when improved systems for collection or separation are developed and/or increased commodity prices make it economically feasible. Loss by discard occurs **after the use** of the product, but this loss does not have to be for ever. Depending on the circumstances of the disposal, discarded tungsten products still could be recycled in the future.

Sherwood line, meaning that the materials show either a high concentration in a specific product and/or show a high market price. Johnson et al. carried out an elaborate study in 2007 [10], demonstrating that the recyclability of materials is a function of price and dilution for different product groups such as mobile phones, printed wiring boards, personal computers or automobiles.

The study further revealed that in some cases the relationship is apparently not valid and metals are recycled even if they are situated clearly below the Sherwood line. The reason for this deviation from the rule is the fact that these metals are concentrated (separated) from the waste stream. As the dilution is significantly decreased, recyclability is increased. This effect was demonstrated in a Sherwood plot for automobile waste (**Figure 9**). The selected metals Pb, Cr, Cu, Ni and W are situated in the non-recycling area. Only Pt can be found above the Sherwood line. It is striking that Cr, Cu, or Ni are recycled to a large extent. In practice, it is economically viable to dismantle components such as the battery, the catalytic converter, the exhaust system or the wiring, and to recycle the mentioned metals from the disassembled components. As in these parts the concentrations of Pb, Ni or Cr are tremendously increased,

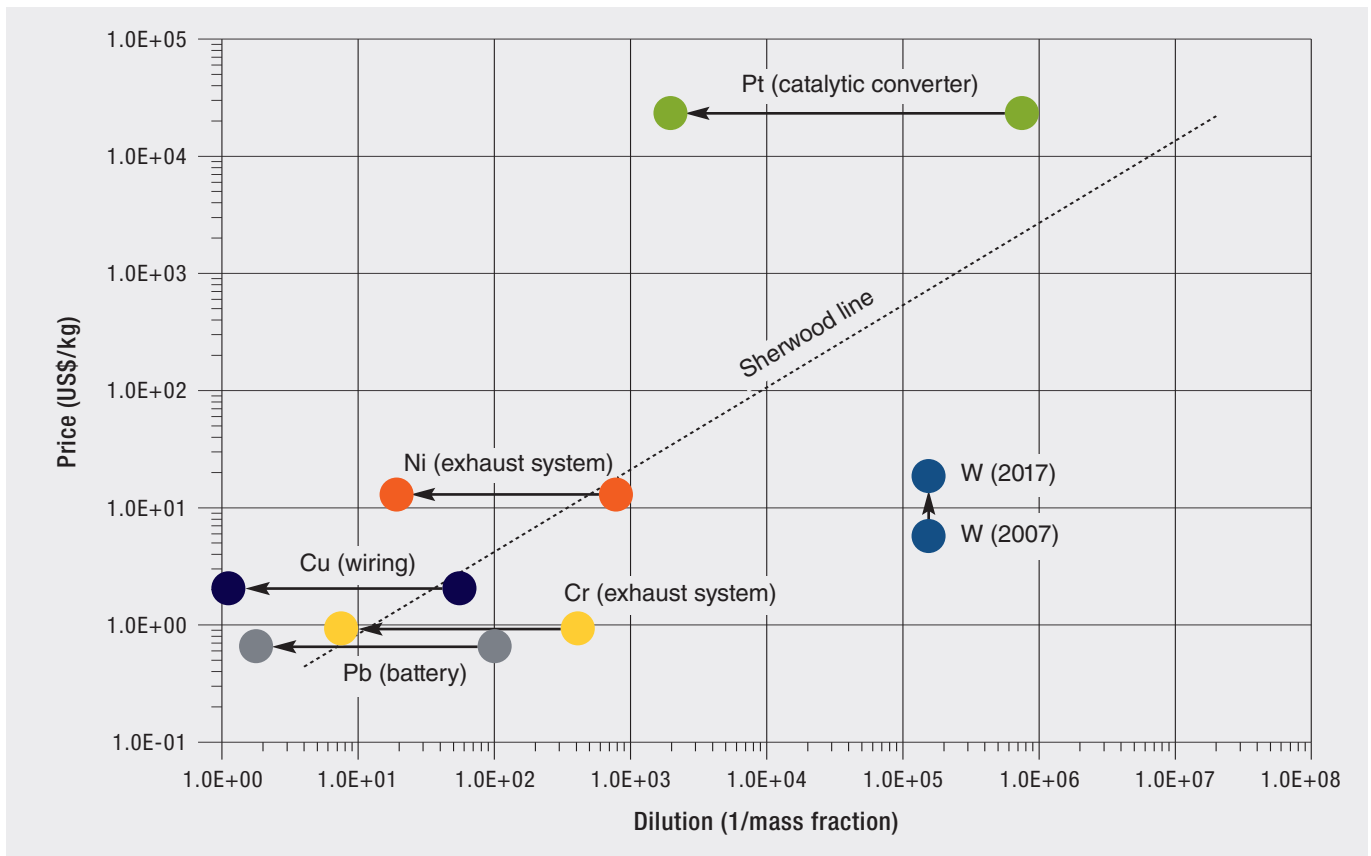


Figure 9: Sherwood plot for selected metals in a vehicle [10]

they cross the border of the Sherwood line and are thus situated in the recycling area of the plot. Pt moves further to the left indicating that recycling is economically viable. Tungsten parts are not separated from the car and thus remain “diluted” and unrecycled.

As mentioned above, the position in the plot is determined by concentration and price. In principle, a distinct increase in the metal price could move a metal across the Sherwood line. Figure 9 plots tungsten according to the scrap price for 2007 [10] and the Q3/2017 scrap price of US\$ 18–20/kg

[13]. Even if over the last decade tungsten with such high a degree of dilution moved closer to the recycling area, theoretically speaking it would only cross the Sherwood line at a hypothetical value of US\$ 1,000/kg plus.

**Small tungsten parts** (coils, electrodes, vibration alarms, computer chips, etc.), which are “distributed” in complex multi-material systems, such as lamps or electronic devices, are prone to the same economic limitations for their recycling. **Table 1** shows examples of such tungsten containing items. For instance, the ball of a pen with a diameter of

Table 1: Examples of small tungsten-containing items

Item	[g]	W bearing part	[mg]	Dilution (1/concentration)	W value <sup>+</sup> [cent]
Energy-saving lamp*	263	Coil	20	13,150	0.04
Pen**	10	Ball	2.5	4,000	0.005
Phone***	152	Unbalance motor	400	380	0.76
Unbalance engine	1	Unbalance weight	400	2.5	0.76

\* Philips Tornado 60 Watt 865 E27

\*\* Approximate mass of plastic pen according to authors' own measurement

\*\*\* Samsung Galaxy S7

+ based on the Q3/2017 scrap price of US\$ 18–20/kg [13]

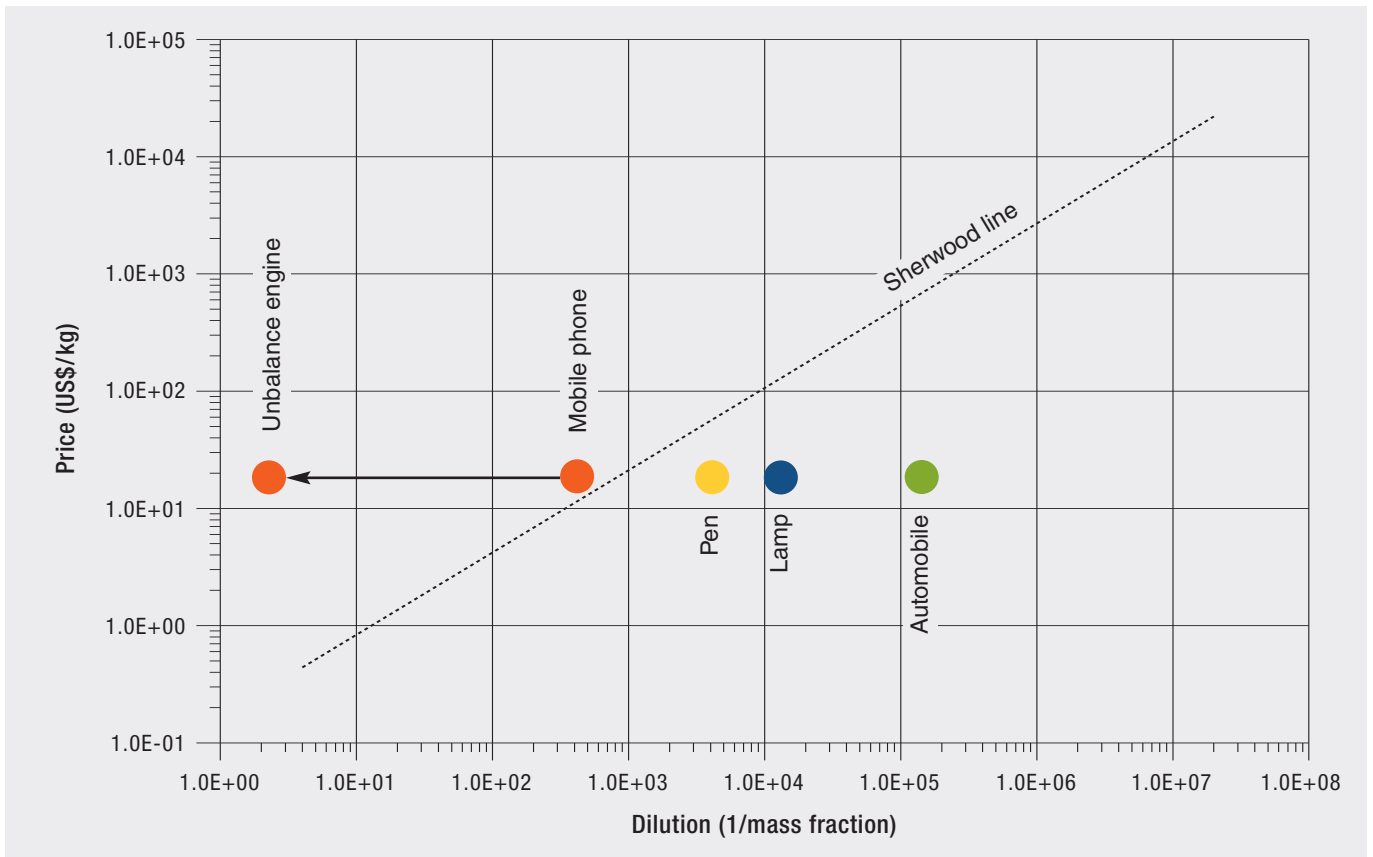


Figure 10: Sherwood plot for tungsten in selected products; data from Table 1 and [10]

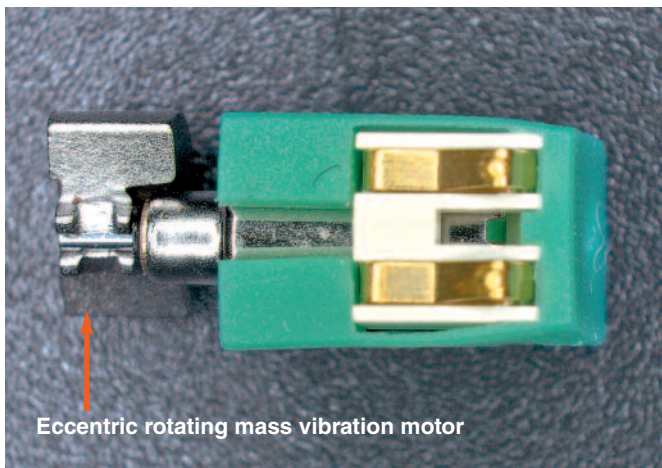


Figure 11: The unbalanced mass is composed of a W-FeNi heavy metal part, chemically coated with Ni/P. Length of motor: 12 mm; weight: 1 g; weight of the heavy metal part: 0.4 g; actual tungsten scrap "value": 0.76 cent. Courtesy of W D Schubert

about 0.7 mm is commonly manufactured from cemented carbide. Other examples are the coil in an energy saving bulb or the weight of an unbalanced motor as used in mobile phones. In such cases, the tungsten part weighs only a small share of the overall weight of the device. Table 1 shows that the dilution is extremely high which means that the items are situated on the right side of the Sherwood plot in the non-recycling area (**Figure 10**). Only a mobile phone is in the recycling area but close to the Sherwood line.

Table 1 further shows the value of tungsten per device. As the total mass of tungsten per unit is extremely small, the material value is also extremely low. The tungsten value of such parts can be as low as <0.01 cent. At such low material value, it is not possible to render economically viable collection and recycling systems as the collection, per se, and subsequent separation need then significantly more energy as is represented by the low material weight. As a result of this, several hundred tons of tungsten will be lost by discard globally, as the small parts are distributed over the globe.

The necessary extensive manual disassembly efforts needed for such material combinations push up the recycling costs which makes such activities often economically unfeasible in industrialized countries. It might, however, be viable in emerging economies, where the lower personnel cost is advantageous [9]. After collection of such parts, they have to enter a series of pre-processing steps, including repeated sorting (manually or automated), dismantling, and physical and chemical separation [9]. As already shown for vehicles, a disassembly of certain parts makes recycling easier as the dilution of metals is decreased (Figure 9). A similar case is demonstrated in **Figure 11** for a mobile phone from which the unbalanced motor could be disassembled. Thus, the dilution of tungsten is significantly reduced, and the item is shifted to the left side of the Sherwood plot. In practice, recycling tungsten from mobile phones does usually not take place as the material value of tungsten is below 1 cent, which is too low to pay for an expensive dismantling process. In the future, however, development of robotized disassembling lines may change the situation if it is possible to collect enough devices to run such lines economically. First steps in this direction are advertised

by end-use industries (for example: <https://www.apple.com/recycling/>).

The steadily **growing complexity of tools** is another economic challenge for recycling. Large wear parts for mining and construction, oil & gas well-drilling and metal forming are commonly composed of two materials, cemented carbide and steel. If the cemented carbide parts were originally pressed into the steel matrix, they can later be easily separated from the steel part by a thermal treatment, and thus be recycled. In the case of brazed parts, the solder has to be removed prior to processing. However, quite often the steel part of the tool and/or the cutter of the rotating drill bit or chisel is protected from wear by tungsten-containing hardfacing materials, which are either sprayed-on, welded-to or infiltrated onto the steel part or surface of the cutters (**Figure 12**). In this case, economic limitations can result from the high cost of (manual) pre-processing (transport, dismantling, material separation, removal of solders, etc.) although in this case the tungsten value is comparatively high.

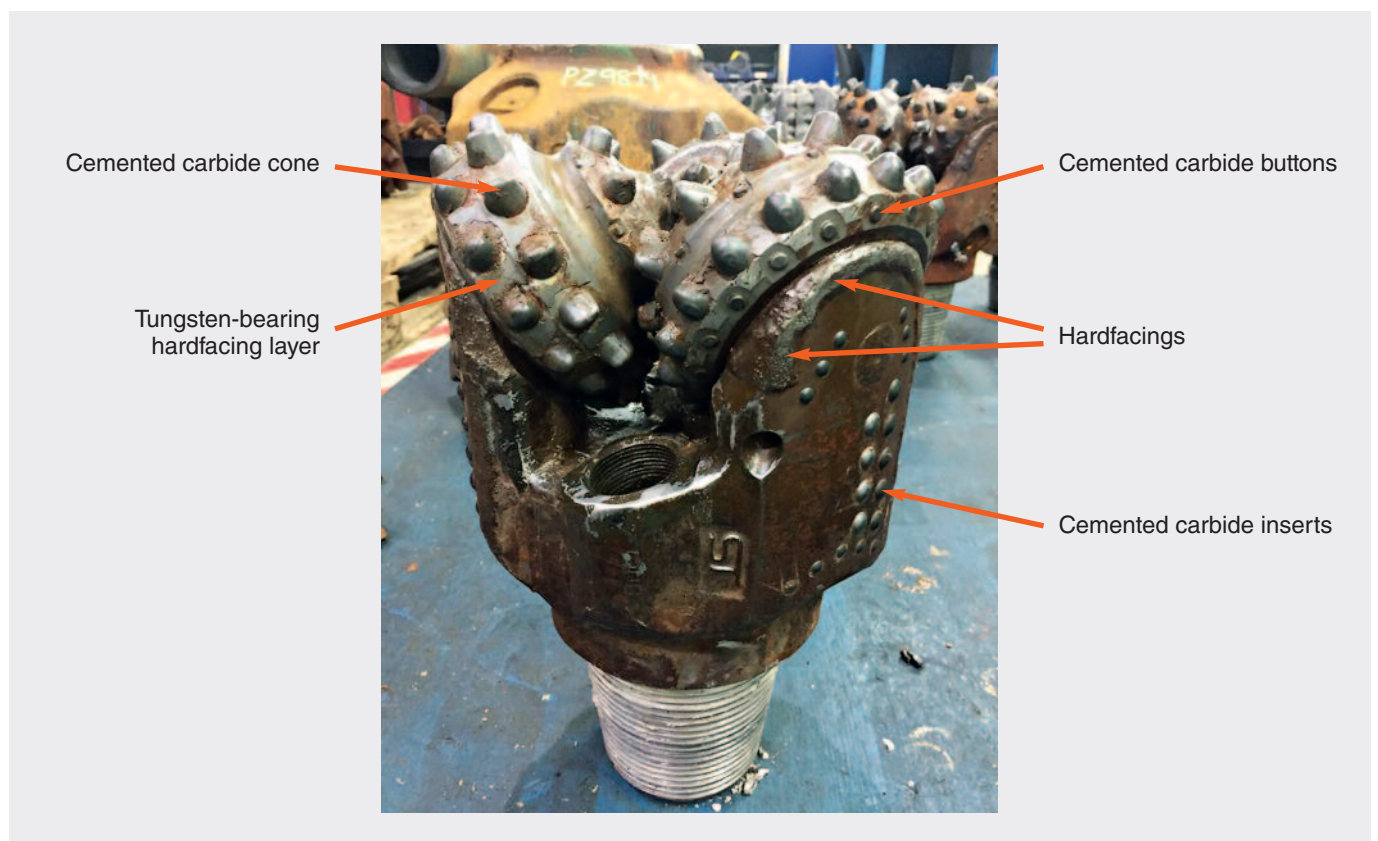


Figure 12: Roller cone bit used for drilling through rock. The cutting structure of the bit varies with rock formation. The surface of the cones is strengthened by a tungsten-bearing hardfacing layer to make them more resistant to abrasion and erosion. Hard facing of the shirt tail area and tungsten carbide inserts in the leg area improve the wear resistance of the steel part. Courtesy of Smith Bits

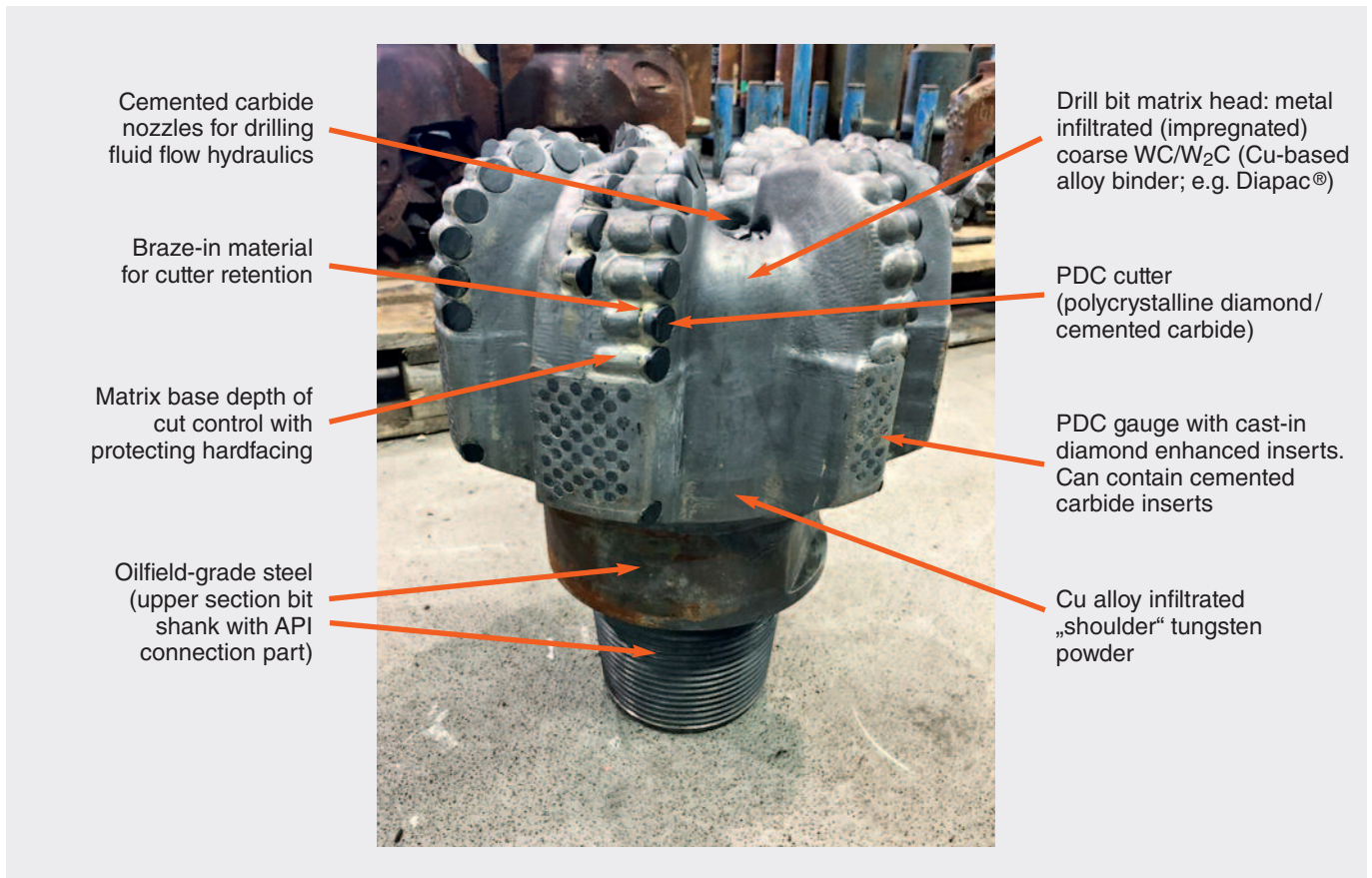


Figure 13: PDC matrix drill bit used for oil & gas drilling. Modern drills are composed of several materials forming a complex material compound. These combinations currently prevent an economic recycling of all tungsten valuables. New recycling strategies are demanded. Courtesy of Smith Bits

PDC (Polycrystalline Diamond Compact) cutters have changed the oil and gas exploration industry. They have reached a market share of 75–80% [14]. These high performance bits consist of a copper alloy-infiltrated coarse WC or cast carbide drill body, cemented steel parts, PDC cutters bonded to tungsten carbide substrates, cemented carbide nozzles, solders and a series of complex hardfacing layers or parts, based on cemented carbides and/or diamond (**Figure 13**). Every drill bit is “crafted” for its specific use and requirements which reduces the overall costs through longer tool life and more dependable drilling operations. Any mechanical and chemical treatment to separate such a multi-component system prior to recycling is extremely elaborate and expensive. As a matter of fact, in practice, such drill bits are usually only partly recycled. Parts, easy

to dismantle, such as the PCD cutters are separated from the drill head but the large remaining body (containing a big mass of WC, cast carbide and W metal) remains untouched. New recycling strategies and technologies are demanded for these complex material combinations to increase the share of recycling.

Limits in recycling also appear when strongly **contaminated** tungsten-bearing materials (for example: DeNOx-catalysts) have reached their end-of-life period. In this case, hydro-metallurgical multi-stage processing to separate the valuable from the contaminated material is often more expensive than deposition of the waste on a hazardous waste disposal site.

## Future Potential

From the tungsten flow model (Figure 3) it is obvious that the production of intermediates, first-use and end-use products is already optimised with respect to recycling. The amount of material treated in 2016 was 108,500 t and led to an output of 98,000 t tungsten content in end-use products. The difference is 10,500 t from which 8,500 t are recycled as new scrap. This equals a recycling rate of 81% and only 2,000 t are lost. The majority of this loss occurs in the APT production during the digestion step of concentrates where the yield is slightly below 100% and some tungsten stays in the digestion residues. Worldwide regulation for such residues ensures they are disposed of in a well-organised manner. According to our definitions for loss categories, this would be loss by discard. Where the residues are collected and disposed at defined spots, there is the option to use them as future resources for tungsten when technological progress and the market make it technically possible and economically feasible. Slags from ferrotungsten production are a similar case but, due to the lower tonnage of tungsten processed via this route, not as important for the total flow.

As a matter of fact this part of the tungsten flow, which is under full control of the tungsten industry, has a closed recycling loop (everything that can be recycled, is recycled) and losses are managed in a way that they may serve as future resources.

On the end-use side of the tungsten flow, the situation is more complex. 98,000 t of tungsten went into end-use products in 2016. The end-of-life recycling rate was estimated at 30%, which equals 29,000 t of old scrap being recycled and a total of 67,000 t assigned to “loss”. Despite the fact that tungsten is among the metals with comparatively high recycling rates, it is obvious that there is potential for further improvement.

In order to be able to estimate the theoretical maximum, in-depth knowledge of the end-use products, industries and markets is needed. ITIA started an end-use analysis project in 2016 and first results were available by the end of 2017. **Figure 14** shows the relevant end-use industries for global tungsten consumption.

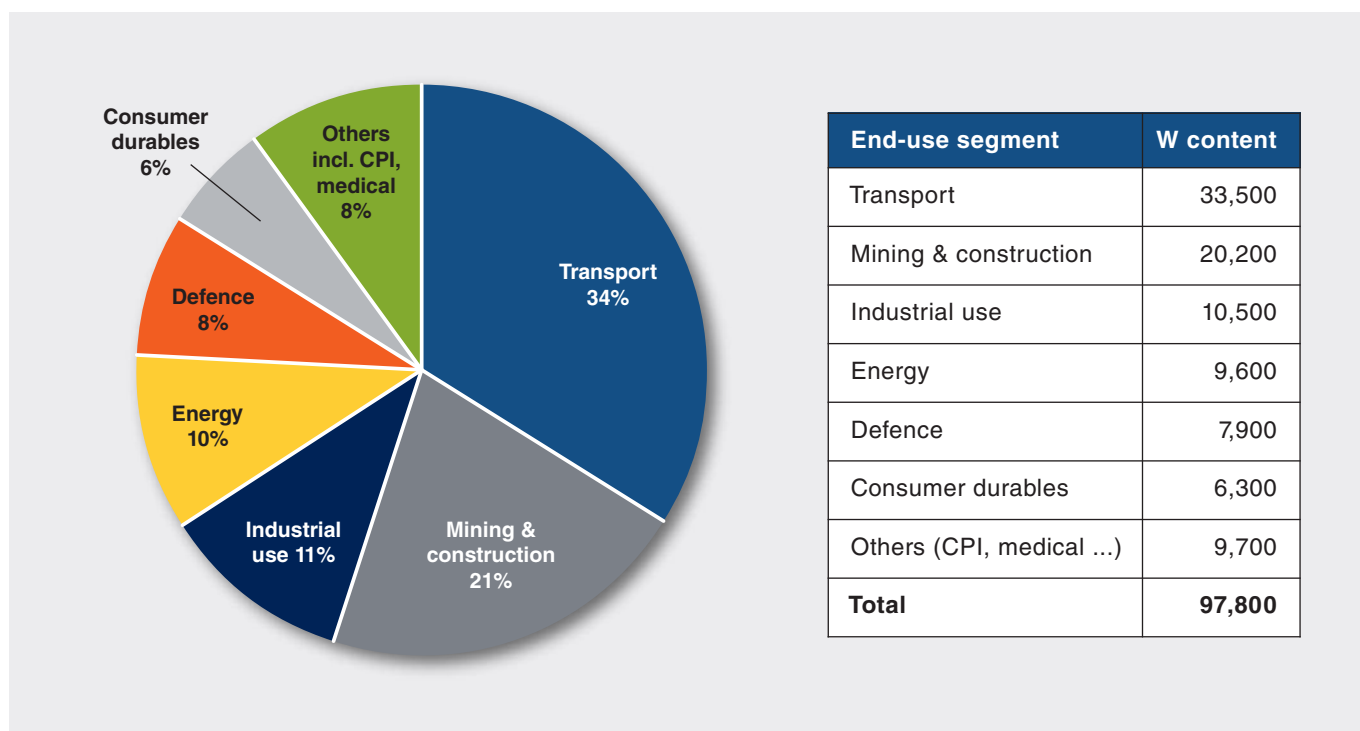


Figure 14: Global breakdown of end-use segments for tungsten in 2016

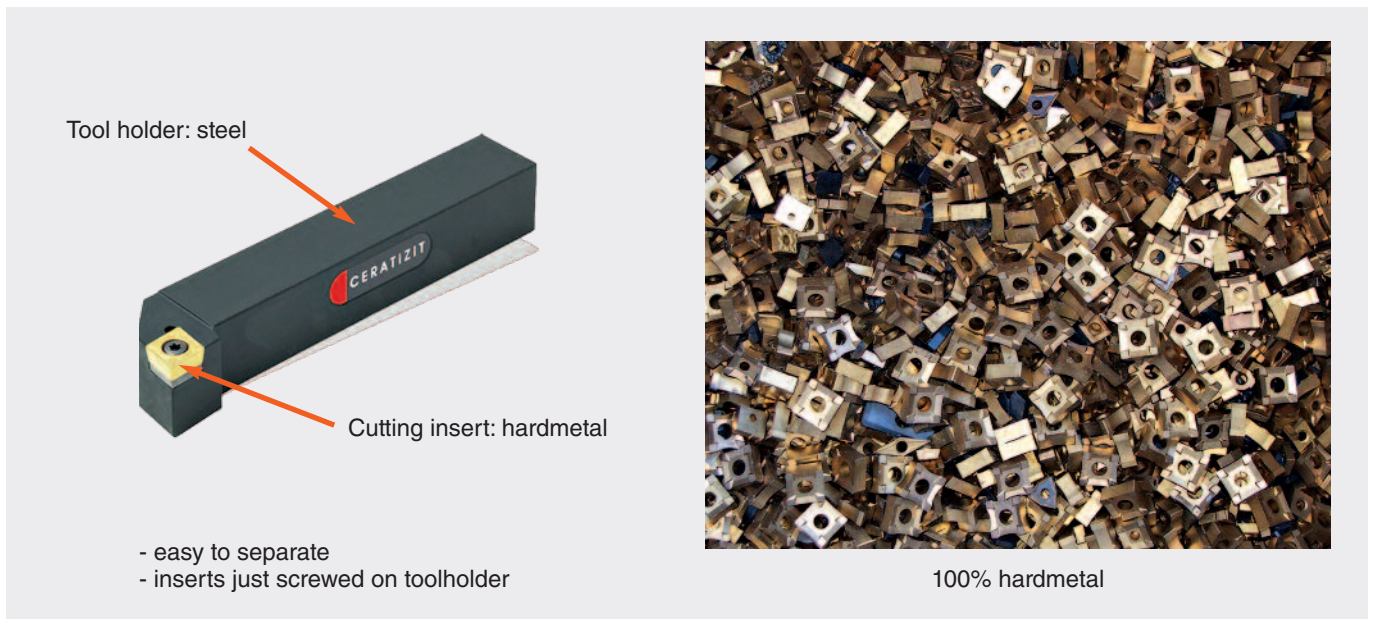


Figure 15: Tools for the transport end-use segment, which are easy to collect and to recycle. Courtesy of CERATIZIT and Wolfram Bergbau- und Huetten AG

The transport segment is the biggest single consumption segment with one third of the whole tungsten consumption. In this segment there is a high percentage of tungsten carbide hardmetal cutting tools used. These tools (**Figure 15**) are either based on the use of cutting inserts or solid hardmetal round tools. Tooling systems based on cutting inserts are designed for quick and easy insert change and the percentage of tungsten in the inserts is very high (typically above 80%). The same is true for solid round tools, which are very easy to recycle (high tungsten concentration in the tungsten parts and tungsten parts easy to separate from the product). The transport industry (especially the most important sub-segment, the automotive industry) is a consolidated industry with big global players involved, which offers favourable conditions for the collection logistics of the tungsten scrap. As a consequence, the recycling rate in this segment is very high already, which leaves less potential for further improvement. Due to the products involved, there is very low loss by dissipation.

Mining and construction is the second biggest end-use industry, which represents 21% of the global tungsten consumption. From a recycling perspective, this industry is more challenging. Unlike the automotive industry, tools in the mining and construction industry are used at remote

sites and collection logistics is more difficult. Moreover mining and construction tools are complex designs with hardmetal parts shrunk or brazed to steel bodies or tungsten being part of new material combinations and hardfacing layers. Separation at site is impossible which means that the whole part has to be transported to a site for separation first and finally to the recycling factory. Additional costs for transport and separation set the economic limits for recycling in mining and construction.

There is a fair amount of wear in these tools during use which causes loss by dissipation. The material lost by dissipation sets the theoretical upper limit for potential future recycling, apart from any economic considerations (Figure 8).

New developments in oil and gas drilling increase the rate of penetration (ROP) of a new drill head by up to 10 times that of older drill bits [14], which leads to lower specific loss by dissipation (Figure 13), but eventually creates material combinations which would need new approaches from the technological side to actually be able to extract the tungsten from these products. Alternatively, they may be lost by dilution to the steel industry or discarded until such technologies become feasible.



The mining and construction industry has already created networks to address the more challenging recycling conditions (**Figure 16**), but these alliances are vulnerable to fluctuations in market conditions. There is clear upward potential for the future.

These examples show the high degree of sophistication of the present tungsten recycling industry. The prevailing recycling input rate of 35% is representative for the leading upper third of industrially used metals, as stated in a recent UNEP report [4].

Any further step forward will need more efforts than the previous one, as the involved collection logistics become more challenging and the separation of the tungsten parts from the products (to cross the Sherwood line of recycling

economy) has to be mastered. The critical task is the economical collection and separation of tungsten parts to achieve sufficiently high concentration and tonnage to be able to treat them with the processes to recover tungsten. A wide variety of these processes is available in industry, eagerly “waiting” for suitable feedstock.

In-depth understanding of the end-use products and markets is necessary to develop the appropriate collection and separation networks, which will be key to any future increase of the share of recycling compared to today and to evaluate the technological and economic limits for the maximum possible recycling rate. The end-use analysis has just finished the first year of a three years’ approach, which will then cover the entire industry exploring all the diverse applications of tungsten.

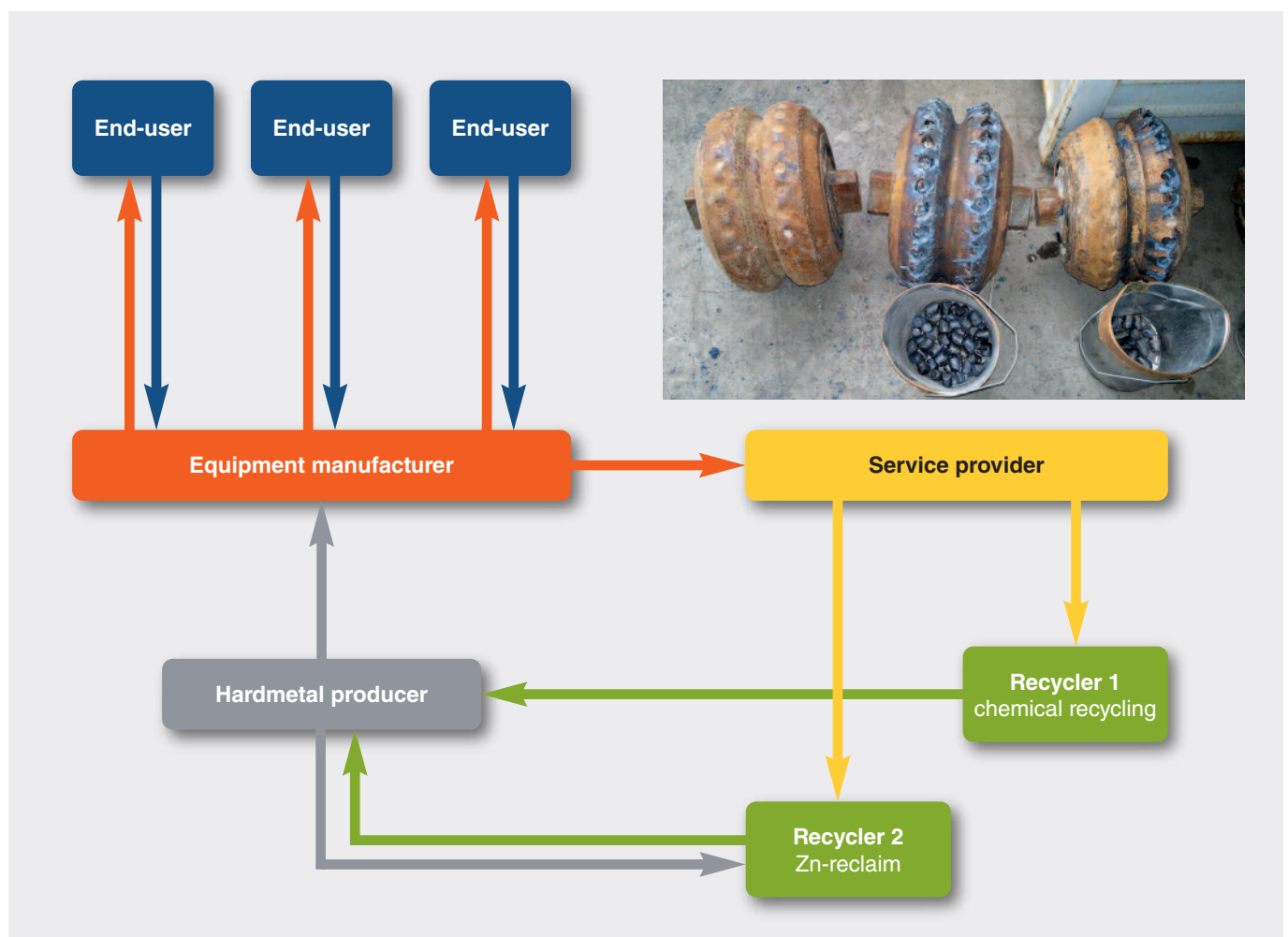


Figure 16: Example of a recycling network to address challenging collection, separation and reclaim aspects, as used in the mining and construction end-use segment. Image: courtesy of M Sicho, GTS - Global Tungsten Solution s.r.o., Czech Republic

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# Results of the Hardmetal Epidemiology Study – an International Investigation

*The following article is an overview of the background and results of the study by Dr Gary Marsh, Professor of Biostatistics, Epidemiology and Clinical & Translation Health Science, and Director of the Center for Occupational Biostatistics and Epidemiology at the University of Pittsburgh, Graduate School of Public Health. Dr Marsh served as the principal investigator of the international study of hardmetal workers that was sponsored by three member companies of International Tungsten Industry Association (ITIA), with one non-member company and the Cobalt Institute (formerly Cobalt Development Institute) adding their support. The study began in 2011 and was completed in 2017. Final results of the study were presented by the various country-specific investigators at the EPICOH 2017 conference held in Edinburgh, Scotland.*

The Hardmetal Epidemiology Study (Epi Study) was prompted by the decision of the International Agency for Research on Cancer (IARC) in 2006 to classify tungsten carbide with a cobalt binder (WCCo) as a probable human carcinogen based on limited evidence in humans and sufficient evidence in animals that WCCo acted as a lung carcinogen. A review of the scientific basis for the IARC decision revealed significant limitations in the earlier studies of French and Swedish workers on which it was based. The Epi Study was designed to overcome the methodological limitations of earlier studies by including a comprehensive, quantitative exposure assessment conducted by the University of Illinois at Chicago (UIC), country-specific cohort mortality studies in the United States, Austria, Germany, Sweden and the United Kingdom and methods to determine if smoking could be responsible for any observed elevations in lung cancer risk.

The Epi study included 32,354 workers from several companies with 17 manufacturing sites in five countries (8 US sites, 3 German sites, 3 Swedish sites, 2 UK sites, and 1 Austrian site), each independently conducted under the direction of country-specific occupational epidemiology experts. UIC conducted an assessment of historical exposure levels to tungsten, cobalt and nickel for each of the 17 study sites. The University of Pittsburgh (UPitt) served as the coordinating center for the overall study and also performed an analysis which combined the data from each country, called a pooled analysis. This study was larger, more robust and more definitive than any hardmetal epidemiology study done to date.

A primary goal of the pooled analysis was to evaluate the relationship between the level and duration of tungsten, cobalt and/or nickel exposure and mortality from lung cancer with adjustment for potential confounding by smoking. Also evaluated were mortality rates for other cancer and non-cancer cause-of-death categories. The results of the exposure assessment, the country-specific studies and the pooled cohort analysis were presented in a series of eight online articles in the Journal of Occupational and Environmental Medicine in December 2017 (Volume 59, Issue 12). The weblink to this volume is: <https://journals.lww.com/joem/toc/2017/12000>. The following is a summary of the key methods and findings from the pooled analysis.

The study methodology involved evaluating lung cancer mortality risks in the pooled cohort using external mortality comparisons, where mortality rates among workers are compared to the mortality rates of the general population in the area surrounding each facility. Also used were internal mortality comparisons, where lung cancer rates among workers more heavily exposed to tungsten, cobalt or nickel were compared to workers with the lowest levels of exposure to these agents.

The pooled cohort analysis revealed no consistent evidence of elevated lung cancer mortality risks overall. No consistent evidence was found of elevated lung cancer mortality risk by demographic factors, like age at hire or sex, nor among exposure-based subgroups. Consistent deficits in lung cancer mortality were found when comparing workers

with the greatest potential for risk (eg, employed more than 5 or more than 10 years, and followed for 20 or more or 30 or more years) with workers without these risk potentials.

The analyses of lung cancer rates in relation to the duration, average intensity and cumulative exposure to tungsten, cobalt and nickel indicated that none of these agents was a risk factor for lung cancer mortality. These findings were consistent with the observation that the median average intensity of exposure to each agent (calculated across all workers in the pooled study) were well below the 2016 Threshold Limit Values (TLVs) for tungsten, cobalt and nickel, and indicate that workers exposed to these levels are not at an increased risk for lung cancer. The findings of decreased lung cancer risk estimates were unaffected by statistical adjustments for the smoking history of workers.

The pooled and country-specific results were generally not consistent with the results from the earlier epidemiology studies conducted in France and Sweden. The earlier studies revealed elevated and mostly statistically significant overall elevations in lung cancer mortality. Deficits in deaths were found in all countries except Sweden. The elevated lung cancer rate in the Swedish study was limited to short-term workers, who worked at the facilities for less than one year. Causes of death included for example cancer, heart disease, cirrhosis of liver, as well as accidents, suicides and homicides. The higher mortality is not considered to have resulted from their short time in the hardmetal industry, but instead from differences in behavior and lifestyle characteristics, or from exposures received before or after employment in the hardmetal industry. Higher mortality among short-term workers is commonly seen in similar worker studies.

In conclusion, the pooled analysis of country-specific cohort data from the Epi Study of an international study of hardmetal production workers provided no consistent evidence that work in this industry is associated with an increased risk of lung cancer, as suggested in the earlier French and Swedish epidemiologic studies. No evidence were found that duration, average intensity or cumulative exposure to tungsten, cobalt or nickel, at levels experienced by the workers examined, increases lung cancer mortality risks. No evidence was found that work in the US or EU hardmetal industry increases mortality risks from any other cause of death. The results of the pooled cohort analysis, which were

consistent with the country-specific study findings, should help guide risk management efforts for workers exposed to hardmetal so that exposures are maintained below levels where increased risks may occur.

*Dr Marsh's report concluded with grateful acknowledgement for the cooperation and assistance of representatives from the ITIA and the participating member companies, as well as to his co-investigators and associates in the US and Europe whose professionalism, hard work and dedication contributed to the success of the Hardmetal Epi Study of hardmetal workers:*

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# ITIA News

## The 30<sup>th</sup> Annual General Meeting, 27–28 September 2017, Moscow

In her opening address, Ulrika Wedberg, the ITIA President and President of Wolfram Bergbau, welcomed 202 delegates from 87 companies and 27 countries to the 30<sup>th</sup> AGM in Moscow. She warmly thanked Mr Servatinsky Pavel Vadimovich, Director of the Metallurgy and Materials Department at the Ministry of Industry and Trade of the Russian Federation, and Mr Michael Gorbachev, founder of Wolfram Company JSC, for taking the time to deliver welcome speeches to delegates.

Wedberg said it was the first ITIA meeting in Russia – suitably enough in the year celebrating the 100<sup>th</sup> anniversary of the October Revolution – and extended her gratitude to Denis Gorbachev and his colleagues in Wolfram Company JSC, celebrating its 20<sup>th</sup> anniversary this year, for hosting the 30<sup>th</sup> AGM and inviting delegates to a reception and dinner in the famous Metropol Hotel and for permitting visits to their Refractory Metals and Ferro-Tungsten Plants in Unecha.

Wedberg recalled that Moscow had only been restored as Russia’s capital in 1918 by Lenin, the government having been moved to St Petersburg in 1712 by Peter the Great. And speaking of “The Great”, Wedberg reminded delegates about Empress Catherine, the longest serving (1762–1769) and most famous female Russian Leader who came to power in a coup d’état after the assassination of her husband, Peter III. Russia was revitalised under her reign, growing



Denis (right) volunteered to translate the welcome speech by his father, Michael Gorbachev, at the Metropol dinner

larger as well as stronger in military terms and becoming recognised as one of the great powers of Europe. She was proud to comment on how far female power could already bring a country 250 years ago!

Expressing the hope that delegates would find time to explore the city, Wedberg noted that Moscow was not only the greenest capital in the world, with 40% of its area covered by greenery but also the biggest city on the European continent with some 13 million inhabitants. Its architecture was world-renowned, being the site of Saint Basil’s Cathedral,



A group photo before leaving the Unecha Refractory Metals Plant



Lavish performances – folk dances, songs, accordion players from different regions of Russia – and the last stunning Caucasus dance with striking drums was an unforgettable ending to Wolfram CJS's dinner at the Metropol Hotel

with its elegant onion domes, as well as the Cathedral of Christ the Saviour and Stalin's skyscrapers, more popularly known as the Seven Sisters, a set of seven skyscrapers built in the 40s and 50s in Russian and Gothic baroque style. In order to provide housing for everyone, Moscow has continued to build skyscrapers with at least 9 floors and it is estimated that Moscow has over twice as many elevators as New York City and four times as many as Chicago.

On a personal note, Russia was of course famous for the arts, particularly literature and music, but on a personal note Wedberg said that the heroes of her youth were the Russian ice-hockey team which became World Champions 13 times between 1970 and 1990 – and always beat her fellow Swedes!

In conclusion, Wedberg, who was presiding over her last meeting after serving two years as President, thanked

ITIA members and delegates for their contributions to the meeting, her colleagues on the Executive and the HSE Committees for their devotion to ITIA activities, and the ITIA staff and consultants for their diligent work. In particular, she was looking forward with much curiosity to the presentation by SMR (to ITIA member only) regarding the Tungsten End-Use Analysis. She expressed the hope that members would give Gao Bo, the new President, the same strong level of support as she herself had received.

On behalf of all members, Gao expressed the Association's gratitude to Mrs Wedberg for serving as President and to Wolfram Company for hosting a very successful event. He looked forward to seeing delegates at the 2018 AGM in Chengdu, the provincial capital of Sichuan so famous for its sizzling spicy dishes, the good humour of its people and Giant Panda breeding.

## Election to the Executive Committee and Election of Officers

Members at the AGM unanimously approved the election of Mr Akihiko Ikegaya, Managing Executive Officer of ALMT Corp and Mr William Thalman, Vice-President & General Manager, Advanced Material Solutions of Kennametal, to the Executive Committee.

The AGM unanimously agreed to elect Mr Gao Bo, Vice-President, China Tungsten & Hightech Materials Co Ltd, to serve as President in 2018 and 2019 and Mr Dominic Heaton, Director & Chairman of the Sustainable Development Committee, Masan Resources, to serve as Vice-President.

# 31<sup>st</sup> Annual General Meeting, 26–27 September 2018, Chengdu

The 31<sup>st</sup> AGM will be held in the Shangri-La Hotel in Chengdu on Wednesday 26 and Thursday 27 September, jointly hosted by Zhuzhou Cemented Carbide Group and Zigong Cemented Carbide Co. The event will be followed by visits to Zigong's plants located in Chengdu on 27 September and to Zhuzhou Cemented Carbide's plants in Zhuzhou on Friday 28 September.

There will be the markets papers covering markets in China, the EU, Japan and the US, a technical paper on Development of Indexable inserts in China and a panel discussion on Tungsten Recycling (again!) focusing on technology, market trend and capacity.

Further details of this annual event, at which the worldwide industry gathers, can be found on our website - [www.itia.info](http://www.itia.info) and will be updated to include the expanded programme and registration form in May. Companies which are not ITIA members may attend (there is a fee) and receive presentations on a variety of industry and general topics.

The provisional programme is as follows:

Date	Meeting / Function
Monday 24 Sept	<ul style="list-style-type: none"><li>• ITIA HSE Committee</li><li>• Tungsten Consortium Technical Committee</li></ul>
Tuesday 25 Sept	<ul style="list-style-type: none"><li>• Tungsten Consortium Steering Committee</li><li>• ITIA Executive Committee</li><li>• Reception and Dinner</li></ul>
Wednesday 26 Sept	<ul style="list-style-type: none"><li>• AGM</li><li>• Dinner hosted by Zhuzhou Cemented Carbide Group and Zigong Cemented Carbide Co Ltd</li></ul>
Thursday 27 Sept	<ul style="list-style-type: none"><li>• AGM</li><li>• Visit to Zigong Cemented Carbide's plant in Chengdu</li><li>• Depart Chengdu to Changsha for plant visits of Zhuzhou Cemented Carbide Corp</li></ul>
Friday 28 Sept	<ul style="list-style-type: none"><li>• Plant visits to Zhuzhou Cemented Carbide Corp</li></ul>

## ITIA Membership

Welcome to:

**Advanced Corp for Materials & Equipments Co Ltd, China** – a manufacturer of advanced heating equipment and furnaces  
**Sandvik Hyperion, USA** – a provider of innovative cemented carbide, diamond and cubic boron nitride solutions.

For a full list of ITIA members, contact details, and products or scope of business, please refer to the ITIA website – [www.itia.info](http://www.itia.info).

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## First reports of the Tungsten End-Use Analysis

In recent years, the Executive Committee and the Secretary-General have been discussing the best way to develop more extensive intelligence about the tungsten market. ITIA performs (primary) supply-focused statistical analyses but it has become evident that in-depth knowledge of the end-use industries and markets, where tungsten is used, must be developed in order to be able to evaluate the impact (both opportunities and threads) of future technological changes on tungsten demand. Such end-use analyses would enable the association to pursue its mission to promote tungsten and would provide ITIA Members with a powerful tool to perform their own analyses on the feasibility of their strategies. The decision finally made in 2016 was to employ an external consultancy firm, SMR GmbH (Steel & Metals Market Research), to prepare an extensive annual End-Use Analysis exclusively for ITIA members. The choice was based on the fact that SMR had developed a comprehensive data-base on all critical end-use markets and was able to provide experts who were familiar with the various applications of tungsten in these markets – a rare combination.

The complexity of such analysis and the degree of detail aimed for, makes it a three-year exercise to investigate all end-use segments. The first year started with the end-use segments “Transport” and “Mining and Construction”,

to which priority was given by the Executive Committee. In transport, for instance, there was great interest in the possible impact of the development of electric vehicles on tungsten consumption. The underlying fundamentals in terms of specific tungsten consumption for fuel-powered and electric vehicles were developed which, together with the growth expectations for these industries, enabled a calculation of scenarios for a potential impact on the tungsten industry.

The 2016 data were analysed and a ten-year forecast to 2026 was presented by SMR in 2017. The focus areas for 2018 will include “Oil and Gas” (part of “Energy”), “Electronics” (part of “Consumer Durables”) and “Defence”. After 2019, when all end-use segments have been covered in detail, SMR will update the report on an annual basis to follow developments and to compare them with previous forecasts. Deviations will be explained and new forecasts will be based on the improved understanding of the market. Access to the full reports is limited to ITIA member companies.

The Executive Committee is confident that this new service for the ITIA membership will be of great benefit to better understand and further develop the industrial use of tungsten.

