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Recycling the Platinum Group Metals: A European Perspective

Effective recycling systems for pgm-containing materials will ensure sustainable supply

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The high technical recyclability of platinum group metals means that over 95% recovery can be achieved once pgm-containing scrap reaches a state-of-the-art refining facility. Technical challenges exist, but the main barriers to recycling pgms lie in ensuring the collection of scrap and in the capacity and technical capabilities of recycling chains around the world. Economic and legislative drivers are also significant. The "seven conditions" for effective recycling and their impact within Europe are discussed in this article; industrial applications are found to lead the way in terms of recycling rates while automotive and particularly electronic areas are currently some way behind. New business models are recommended, to enable precious metal-containing waste to be seen as a valuable resource and ensure the sustainability and security of pgms supply for the future.

Introduction

Platinum group metals (pgms) play a key role in modern society, as they are of specific importance for clean technologies and other high-tech equipment. Important applications beyond the well-known areas of chemical process catalysis and automotive emissions control include information technology (IT), consumer electronics, and sustainable energy production such as photovoltaics (PV) and fuel cells, among others (**Table I**). Driving forces for the booming use of pgms are their extraordinary and sometimes exclusive properties, which make them essential components in a broad range of applications which can play a part in building a more sustainable society.

Competition between applications leads to increased pressure on supply. One way to ensure adequate supplies is to increase exploration and extraction of geological deposits of the pgms (1, 2). Increasing the efficiencies in the primary supply chain may offer some additional gains and much has been achieved here already, but comprehensive recycling efforts are a vital part of effective life cycle management to enable the increased use of secondary (recycled) metals in the future.

Table I
Some Important Application Areas for Platinum Group Metals

Application area	Platinum group metal				
	Platinum	Palladium	Rhodium	Iridium	Ruthenium
Catalysts	✓	✓	✓	✓	✓
Electronics	✓	✓		✓	✓
Fuel cells	✓	✓	✓		✓
Glass, ceramics and pigments	✓		✓		
Medical/dental	✓	✓		✓	
Pharmaceuticals	✓	✓			✓
Photovoltaics					✓
Superalloys					✓

Recycling the Platinum Group Metals

Metals are not consumed. Instead, they are only transferred from one manifestation into another. Metal combinations in products often differ from those in primary deposits, which results in new technological challenges for their efficient recovery.

Mass produced consumer components such as computer motherboards contain around 200–250 grams per tonne (g t^{-1}) of gold and around 80 g t^{-1} palladium; mobile phone handsets contain up to 350 g t^{-1} gold and 130 g t^{-1} palladium; and automotive catalytic converters may contain up to 2000 g t^{-1} pgm in the ceramic catalyst brick, the active part of the converter. This is significantly higher than the gold or pgm content in primary ores (on average < 10 g t^{-1}). The high intrinsic metal values make recycling attractive from an economic point of view, and due to the much higher concentration compared to mining of ores, it also helps to reduce the environmental burden of metal supply significantly, especially with respect to the impact on climate. Even more valuable for recycling are pgms used in jewellery, as these are typically concentrated at an even higher level.

Technical and Market Challenges

Such challenges exist, especially for complex products such as vehicles and computers. Effective recycling requires a well-tuned recycling chain, consisting of different specialised stakeholders, starting with the collection of old products, followed by sorting/dismantling and preprocessing of relevant fractions, and finally recovery of the metals. The latter requires sophisticated, large-scale metallurgical operations. For example, Umicore, at its integrated smelter-refinery in Antwerp, Belgium (**Figure 1**), currently recovers and supplies back to the market *via* its main process route

Fig. 1. Umicore, at its integrated smelter-refinery in Antwerp, Belgium

seven precious metals as well as ten base and special metals. Further metals are recovered in special processes from rechargeable batteries or high grade photovoltaic residues (3, 4). Johnson Matthey, at its refineries in Brimsdown and Royston, UK, recovers platinum, palladium, iridium, rhodium and ruthenium along with gold and silver from secondary materials using the traditional refining route. It also uses Smopex® to recover other metals where process economics require, or in the cleaning of effluent (5, 6).

Recycling technology has made significant progress (**Figure 2**) (7–9). Further improvements are constantly being made to increase the yields from the recycling process, as well as to extend the range of metals that can be recycled.

The biggest challenges to overcome are the insufficient collection of consumer goods and inefficient handling within the recycling chain. The life cycle structure for consumer goods differs fundamentally from that of industrial pgm products such as process catalysts. For the latter, ownership usually remains with the industrial user, the product location is well known, and handling throughout the life cycle is conducted in a professional, transparent way. This is known as a "closed loop" recycling system.

In contrast, ownership of consumer items tends to shift frequently, goods such as mobile phones and cars are moved around the globe, manufacturers lose track of their devices and the flow of products becomes impossible to trace. This forms an "open loop" in which recycling cannot be guaranteed. Even after an item reaches the recycling chain, the first steps in particular are not always handled by reputable agencies.

The Seven Conditions for Effective Recycling

For effective recycling of a product, material or metal, seven conditions must be met:

(1) **Technical recyclability** of the material or metal combination. All precious metals and many other metals can be recovered from, for example, a printed circuit board if state-of-the-art processes are used.

(2) **Accessibility** of the relevant components. An underfloor automotive catalyst or personal computer (PC) motherboard is easily accessible for dismantling, whereas a circuit board used in car electronics (for example, in the engine management system) usually is not. As long as such circuit boards are isolated or dismantled before the car is put through the shredder, the precious metals they contain are easily recyclable.

(3) **Economic viability**, whether intrinsically or externally created. A dismantled PC motherboard has a positive net value, therefore recycling is viable by itself. In contrast, a dismantled ultra-thin pgm-coated PC hard disk usually has a negative net value due to the cost of processing it. Recovering the platinum and/or ruthenium from it would currently not be economically viable unless paid for externally or subsidised.

(4) **Collection mechanisms** to ensure the product is available for recycling. If collection mechanisms

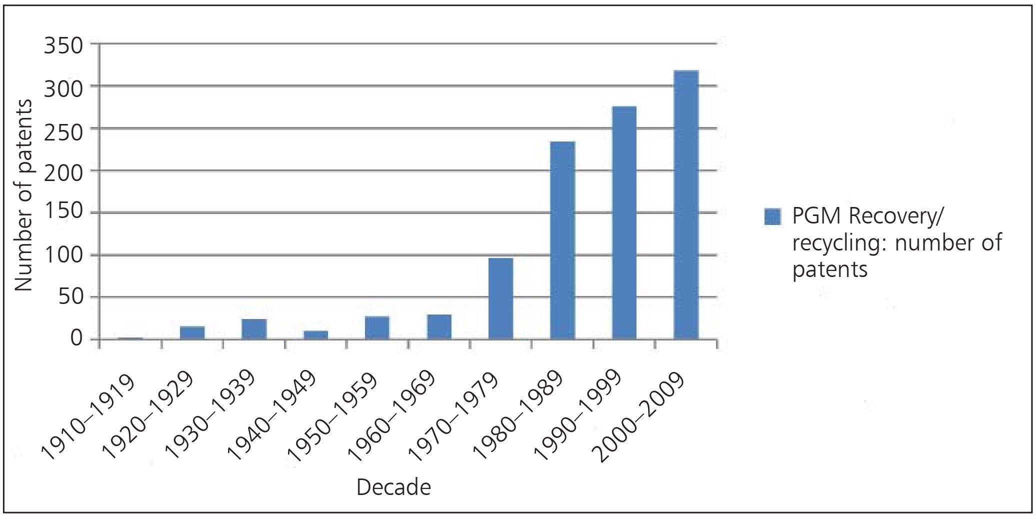

Fig. 2. PGM recovery/recycling: number of patents in the last ten decades

are not in place, items such as old PCs or mobile phones may end up being stored in households or discarded into the waste bin for landfill or municipal incineration. The precious metal they contain would effectively be lost to the recycling chain.

(5) **Entry into the recycling chain** and remaining therein up to the final step. Items such as PC motherboards, mobile phones or cars containing catalysts are often sent (either legally or illegally) to countries without the proper infrastructure for recycling at their end of life. This can also result in precious metals being lost to the recycling chain.

(6) **Optimal technical and organisational** set-up of this recycling chain. Comprehensive recycling chains exist within Europe, though it is important that items such as PCs or mobile phones are not mixed with other low grade electronic waste and channelled into a shredder process without prior removal of the precious metal-containing circuit boards. The same applies to the pgm-containing catalyst in a car or fuel cell.

(7) **Sufficient capacity** along the entire chain to make comprehensive recycling happen. Once Conditions 1–6 are met, the only requirement is to ensure that there is sufficient capacity to process the volume of material available for recycling. Precious metal refiners are willing to invest in building up such capacities provided there is sufficient security of feed later on. Conditions 5 and 6 are thus crucial to trigger timely investments in a principally growing market for (precious) metals recycling.

End of life products and materials will reach various steps in this sequence of conditions; the higher they get, the easier it will be to find appropriate measures to make use of this recycling potential.

Figure 3 (10) shows a schematic representation of a life cycle for a typical pgm-containing product, highlighting the various points at which losses of precious metal can occur. Each of these provides an opportunity for making an improvement to the process or for adding incentives that encourage recycling to take place.

Case Studies

The following case studies briefly illustrate the current recycling rates for pgm materials from industrial,

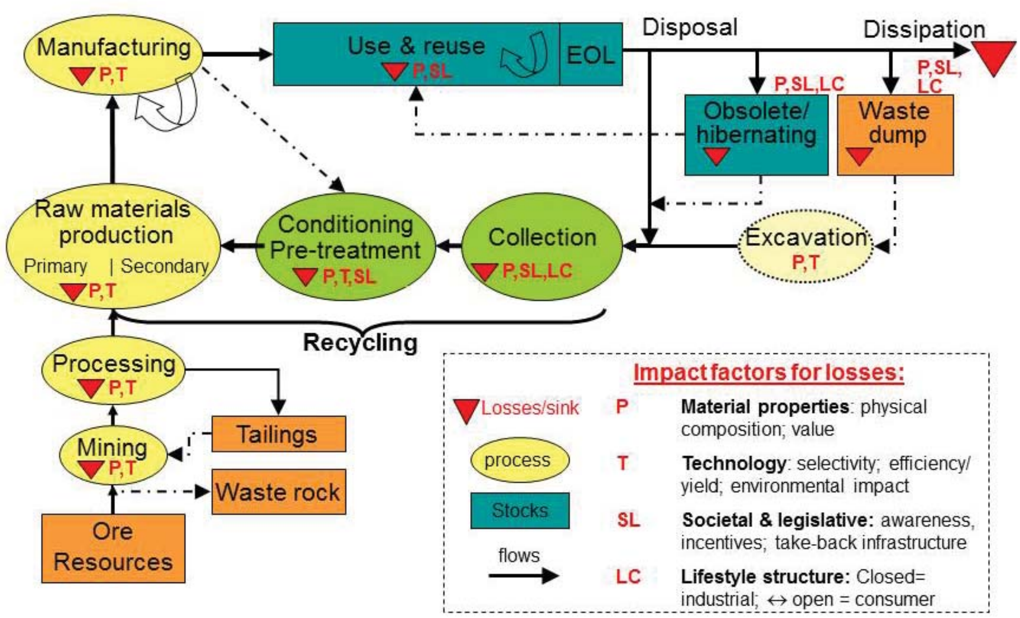

Fig. 3. Life cycle for products containing metals including the pgms, and factors impacting their loses at various stages (10)

automotive and consumer electronic applications. All numbers refer to global averages.

Case Study 1: Industrial Applications

Industrial applications such as catalysts used in fine chemicals production or petrochemical processing, and pgm equipment used in the glass industry, are the current benchmark for pgm recycling, with recycling rates of 80–90% (although catalyst lifetimes can reach several years before they enter the recycling chain). Recycling in this case is solely market driven and is an integral part of the product life cycle. Each of the Conditions 1–7 are met, strongly supported by the economic significance of the pgm materials involved. This limits the need for primary metal supply in these industries to covering the small life cycle losses and keeping up with market growth and new applications.

Case Study 2: Automotive Applications

End of life recycling rates for pgms in automotive applications reach a global average of 50–60%. A recent United Nations Environment Programme (UNEP) report (11) shows that this is significantly more than for most other metals, but it still leaves room for improvement compared to the rates of recycling seen in most industrial pgm applications. Automotive pgm recycling within Europe is partly impacted by legislation such as the EU End of Life Vehicles (ELV) Directive (12), but the dominant driver is economic. As for all pgm applications, technical recyclability is not a problem. However in automotive applications, the pgm-containing catalyst is only a subsystem of a larger product, i.e. the car, which is driven by its own market mechanisms at its end of life. European car catalyst recycling mainly fails at Condition 5 (13). Many old cars are exported to countries outside Europe which lack an appropriate recycling chain, and it is only due to the excellent recyclability and the intrinsic economic value of automotive catalyst recycling that the pgm losses here are not even higher. Better enforcement of transboundary waste shipment rules to limit the export of genuine scrap cars could give a further push to recycling rates within Europe.

Case Study 3: Electronic Applications

Recycling rates are currently only 5–10% for pgms in electronic applications. The main driver for recycling is legislation such as the EU Waste Electrical and Electronic Equipment (WEEE) Directive (14). The largest use of pgms in electronics is palladium used in circuit boards, and market mechanisms at the end of life of products such as PCs, TVs, mobile phones, car electronics etc. play an important role in the rates of collection and recycling of the circuit boards they contain. As in the case of automotive catalysts, a big challenge occurs at Condition 5 when end of life electronics are exported out of Europe, but Condition 4 in which items are stored by consumers or disposed of through municipal waste collection is also significant. Conditions 2 and 3, the accessibility and economic viability of components for recycling, can be an issue in some cases, as can Condition 6, inappropriate handling within the recycling chain.

Legislation such as the EU WEEE Directive helps to stimulate recycling of electrical and electronic products but its enforcement is currently weak. More transparency and better monitoring of end of life chains would improve the rates of recycling of these products. And, most importantly, a shift of focus of the current legislation away from mass and towards a more pragmatic approach to the introduction of treatment standards and a certification system along the recycling chain would help to increase the recycling rates of pgms and other metals which are present in low amounts.

Differences in Recycling Rates

The main reason for the differences in recycling rates in these three case studies is less a question of market *vs.* legislative drivers, and more connected to which step a product reaches in the sequence of conditions listed above. It is important to note that in all applications the technical recyclability is not an issue, as yields of well over 95% can be achieved if the product or the pgm-containing component therein (for example, a circuit board) reaches a state-of-the-art precious metals refinery. Hence, neither pgm product manufacturers nor pgm refiners can act to improve the situation; it is the life cycle system as a whole and the interactions of the stakeholders within that system which will make the difference.

Recommendations for the Future

The potential for recycling precious metal-containing waste can be thought of as an "urban mine", and can complement the primary source of pgm supply from mining. However, in order to fully utilise this potential source of secondary supply, the following changes will need to take place:

- **Attitudes** need to change from "waste management" to "resource management" to ensure the collection and appropriate treatment of end of life products and encourage the enforcement of legislation. This is particularly important where economic or environmental drivers are currently absent.

- **Targets** need to be adapted accordingly, with emphasis on the quality and efficiency of recycling processes and the recovery of precious and other critical metals, rather than on the overall mass of materials such as plastics or steel.
- **Recycling practice** needs to reflect the new requirements. In place of the traditional structures of a scrap business, high-tech recycling can sit alongside clean-tech manufacturing and renewable energy generation in terms of company structures, appearance and stakeholder cooperation, with increased emphasis on transparency and business ethics.
- **The manufacturers' vision** needs to change. Rather than a burden imposed by legislation, recycling can be seen as an opportunity for manufacturers to sustainably increase access to the raw materials needed for their future production.

To close the recycling loop for consumer products there will need to be a gradual shift towards more industrial style practices, which means that new business models will need to be introduced to provide strong incentives for returning products at their end of life. This may include deposit fees on new products; product service systems, such as leasing; or other approaches. For emerging technologies (such as fuel cells (15) and photovoltaics), setting up "closed loop structures" from the beginning will be essential, and manufacturers that put successful models in place can secure their supply of pgms for the future.

Conclusions

Efficiently recycling our end of life products today is insurance for the future. Effective recycling systems would thus make a significant contribution to conserve natural resources of metals and secure sufficient supply of pgms and other scarce metals for future generations. It would further mitigate metal price volatility and limit the climatic impacts of metal production, which is energy intensive, especially in the case of (precious) metals mined from ores containing low concentrations of the desired metals.

The technical recyclability of the pgms combined with the structures in place within the pgm industry as a whole means that it has reached a leading position in terms of sustainable metals management and recycling, thanks in part to the high value of the pgms. In some areas further room for improvement exists, and this can be put into practice by involving all stakeholders and with appropriate political support for the relevant legislation.

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