PLATINUM ESSENTIALS

End of life autocatalysts are a key source of recycling supply, however, only at economically viable PGM prices

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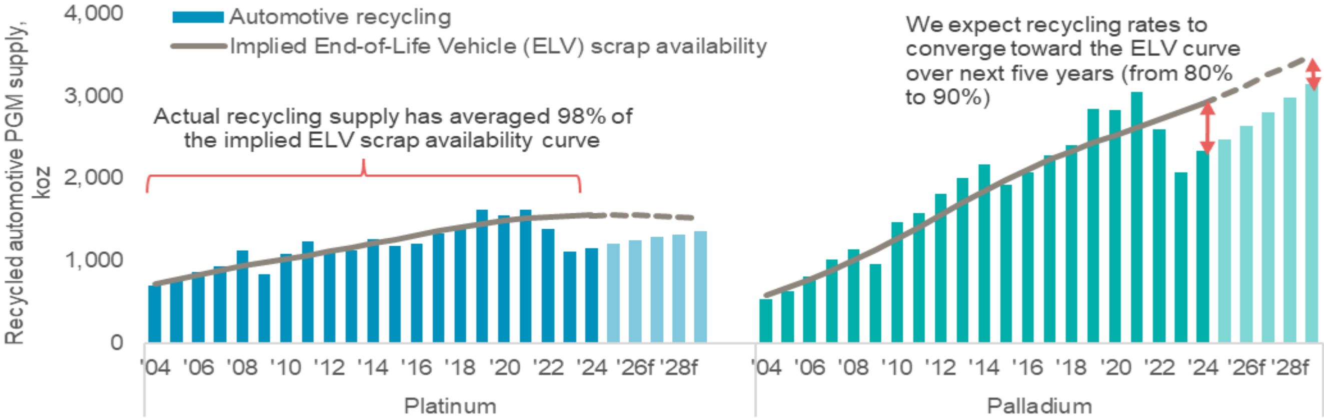
In this Platinum Essentials, we assess the value chain associated with recycling platinum group metals (PGMs) within the automotive industry. Recycled automotive PGM supply has recently been more price elastic than traditionally believed, explaining why recycling supply forecasts heavily undershot from 2022 to 2024. Higher PGM prices in 2025 are supportive of supply growth. However, platinum automotive recycling supply will not recover above peak levels reported in 2021 and we expect this to contribute to expected platinum market deficits to 2029f.

PGMs are, for the most part, infinitely recyclable, which supports their use in sustainable circular economies. With the first autocatalysts fitted to cars in the 1970s, significant quantities of "in-use" PGMs have accumulated and are theoretically able to support future supply requirements. Globally, legislation does promote recycling and the PGM industry has a mature recycling supply stream. However, in practice, we consider 1) the availability of spent autocatalysts and 2) the economic incentive to recycle autocatalysts to be the fundamentals that underpin PGM recycling volumes. Notably, the economic performance of recycling PGM supply may often be overlooked, in part because the value chain is opaque. Market participants may assume recycled PGM supply is completely price agnostic because refiners of scrap material generate stable margins through price cycles. This simplified assessment of recycling supply ignores the different gearing to PGM prices faced by scrapyards and aggregators that impact on recycled supply volumes. This impact should be considered together with mine supply risks. Our analysis highlights that recycling supply is price elastic. The decline in the PGM basket price from 2022 to 2024 materially reduced recycling supply leading to persistent downgrades in forecasts. Conversely, high PGM basket prices supported upgrades to automotive recycling forecasts from 2019 to 2021.

Recycled automotive PGM supply is price elastic and low PGM prices from 2022 to 2024 have disincentivised recycling supply. Recent PGM price increases have improved recycling economics. However, supply growth may be capped by palladium's expected transition towards a surplus market.

Consequently, within our five-year outlook to 2029f, we have downgraded our annual automotive recycling supply forecasts by 66 koz (-5%) for platinum and 226 koz (-7%) for palladium. However, we still expect automotive recycling supply to increase by 3.3% CAGR and 6.2% CAGR from 2024 to 2029f for platinum and palladium respectively. This is underpinned by the increasing availability of spent autocatalyst supply and the year-to-date rise in the basket price. However, since automotive PGM recycling supply is price elastic, growth in platinum recycling supply could be capped by the transition of palladium markets (dominant metal in recycling economics) into surplus from 2026f. Accordingly, we expect platinum automotive recycling supply to recover to only 90% of the available supply implied by end-of-life vehicle (ELV) scrappage curves (vs. 80% from 2022 to 2024 and 110% from 2019 to 2021).

Figure 1. PGM automotive recycling supply is forecast to trend higher



Source: Johnson Matthey (2004-2012), SFA (Oxford) (2013-2018), Metals Focus (2019-2025f), WPIC Research

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Introduction

Recycling forms a core component of platinum group metal (PGM) supply, accounting for an average of 24% of total platinum supply over the five years to 2024. The physiochemical recyclability of platinum and its sister PGMs is extremely high, with the efficiency of scrap collection systems the primary limitation of recycling recovery rates. Notably, PGMs retain their functional properties after recycling which means that recycled metal is interchangeable with mined metal in end-use applications. This allows PGMs to play an important role in the circular economy and sustainable design practices. Moreover, the recyclability of PGMs is becoming increasingly key to overall platinum supply, as developed economic mine reserves deplete; primary 3E supply has declined at a -0.7% CAGR since 2015.

Recycled automotive PGM supply is price elastic and depressed prices during 2023 and 2024 have weighed on volumes.

Total recycling supply consists of automotive recycling supply, the recovery of PGMs from catalytic converters from end-of-life vehicles (ELVs), jewellery recycling, and industrial recycling (from open cycle applications, primarily electronics). Automotive recycling makes up three-quarters to 84% of total PGM recycling supply, depending upon the metal.

This research will unpack key aspects of automotive PGM recycling for platinum, palladium and rhodium. Our analysis suggests the two key factors necessary for a healthy recycling industry are:

1) The availability of spent autocatalysts, and
2) The economic incentive to recycle autocatalysts.

There is a common misconception that automotive PGM recycling is price agnostic. We find that recycling profitability and therefore recycling supply are leveraged to prices. However, that leverage occurs at the upstream of the recycling value chain (i.e. scrapyards) which makes it more difficult to track since most publicly available financial reporting occurs downstream (i.e. processing and refining). We believe that automotive PGM recycling supply is reasonably price elastic and that lower PGM prices from 2022 to 2024 likely curtailed output.

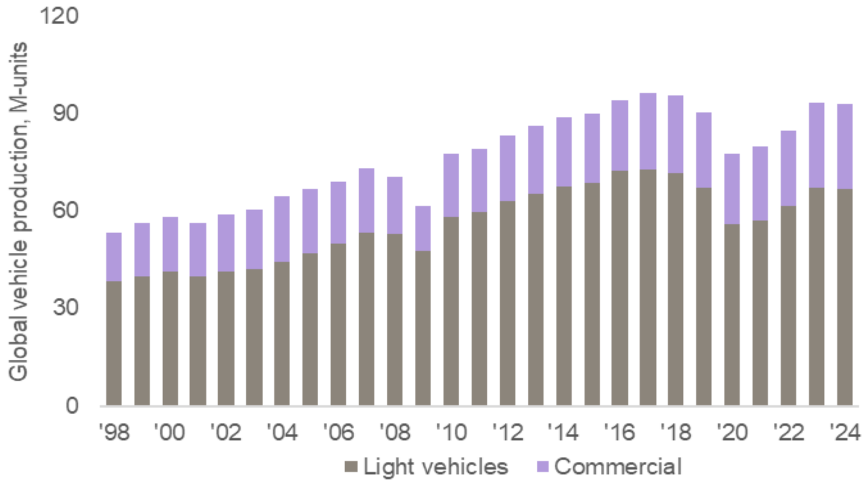
Looking forward, automotive platinum and palladium recycling has the capacity to increase as we expect the availability of spent autocatalysts to improve. However, this recovery may face downside risks if the uptick in PGM prices through the second quarter of 2025 is not sustained.

PGMs in autocatalysts

Emissions legislation was first introduced in 1966 in California, United States to combat rising smog levels in large metropolitan areas. The catalytic convertor, or autocatalyst, was a key technological development allowing vehicles to meet emissions legislation. The majority of automotive emissions control technologies are based on PGMs – primarily platinum, palladium and rhodium – due to their catalytic properties which enable reductions in harmful pollutants such as carbon monoxide (CO), nitrous oxide (NOx) and unburnt hydrocarbons (HC).

Automotive PGM demand is functionally underpinned by annual vehicle production and autocatalyst loadings (i.e. the mass of PGMs per autocatalyst). Over the past 25 years, global vehicle production, including light commercial vehicles (LCV) and heavy duty (HD) commercial vehicles, has increased by c.2% CAGR to 93M units (Fig. 2).

Figure 2. Rising global vehicle production has supported higher automotive PGM demand

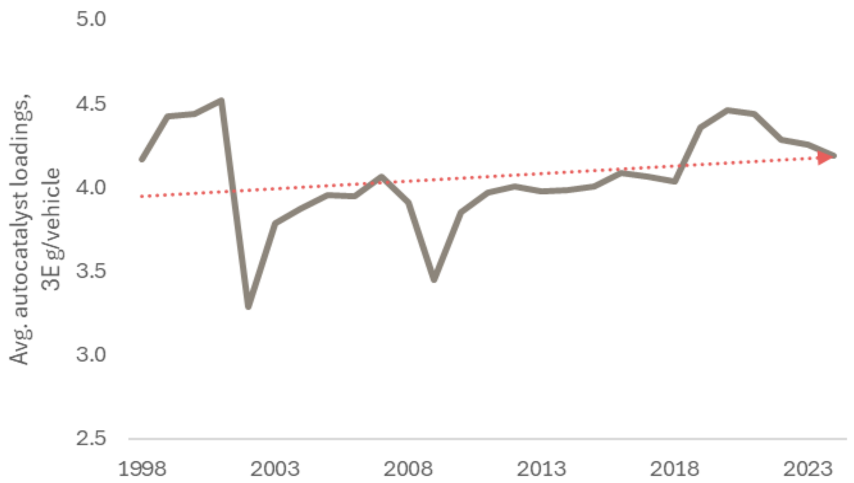


Source: OICA, WPIC Research

Automotive PGM demand is functionally underpinned by annual vehicle production and autocatalyst loadings.

In conjunction with rising vehicle production, more stringent emissions legislation has, on average, led to rising per vehicle PGM loadings (Fig. 3). However, vehicle loadings are cyclical where loadings rise with new legislation and subsequently decline with thrifting (i.e. optimising metallurgical design to reduce metal requirements whilst still achieving emissions parameters).

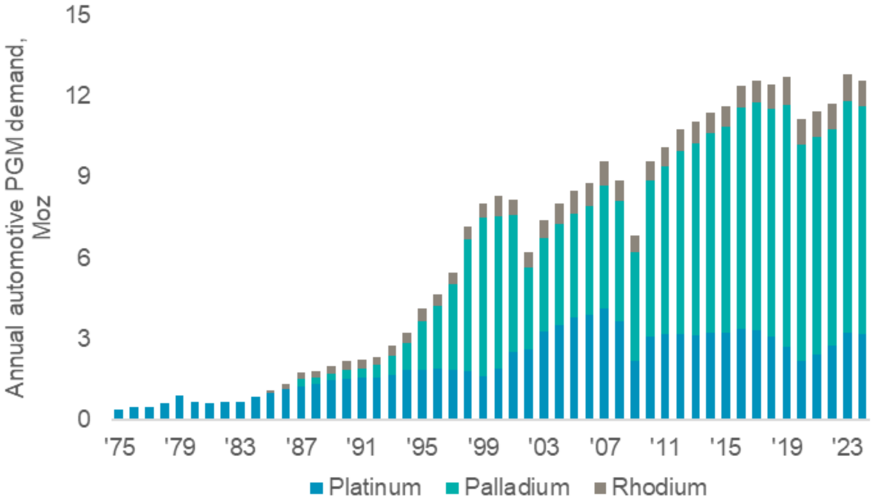
Figure 3. Autocat loadings have generally risen and supported higher automotive PGM demand even though cycles of tightening emissions legislation typically boost loadings followed by technology-driven thrifting



Source: WPIC Research

The combination of rising vehicle production and autocatalyst loadings has led to automotive PGM demand doubling to around 12 Moz (3E) in 2024 from around 6 Moz in 2000 (Fig. 4). On average, the automotive industry accounts for ~35% of annual platinum demand and over 80% of both annual palladium and rhodium demand.

Figure 4. Autocatalysts began getting fitted to vehicles in the 1970s, as a consequence of poor air quality and the introduction of emissions legislation



Source: Johnson Matthey (1975-2012), SFA (Oxford) (2013-2018), Metals Focus (2019-2024), WPIC Research

Recycling spent autocatalysts

Recycling timeline

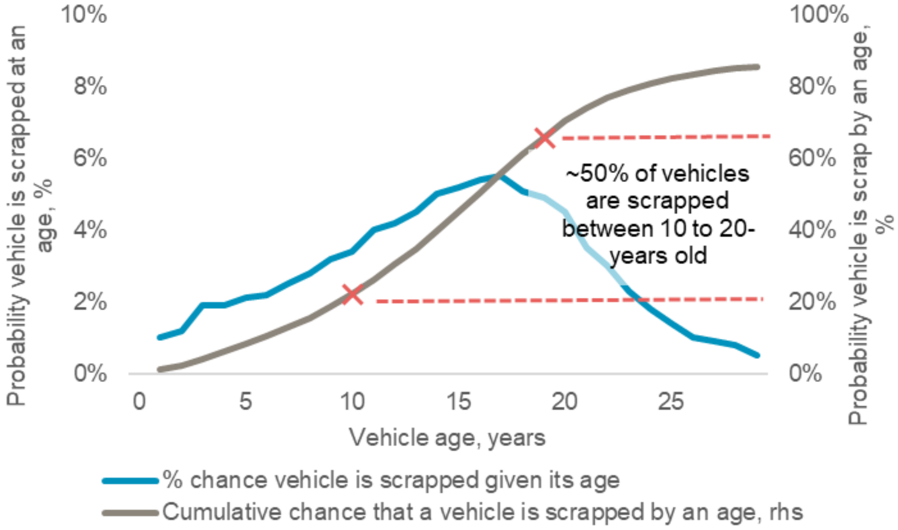
PGMs are highly recyclable and are recovered from end-of-life vehicles by recycling spent autocatalysts. Recoveries are well over 95% when using the correct process such as pyro and/or hydrometallurgical methods. However, before recyclers can get access to used autocatalysts, vehicles need to reach the scrap yard.

The use of PGMs in autocatalysts for over fifty years has enabled autocatalyst recycling or "urban mining" to support future metal supply.

A vehicle reaches its end-of-life when the economic cost of maintaining or restoring its roadworthiness is higher than outright replacement. In general, as a vehicle is used and ages, the accumulation of wear and tear increases the maintenance requirements which in turn increases the likelihood it gets scrapped. Between the ages of 10 years and 20 years, a vehicle has the highest chance of being scrapped with around half of all vehicles being scrapped within that period. Newer vehicles may also be deemed end-of-life if they have been in a serious accident.

With decades worth of historical data, market participants have developed scrappage curves which assigns a probability of a vehicle being scrapped in each year of its life. As a vehicle ages, the cumulative probability increases that it will get scrapped (Fig. 5). By applying the applicable probabilities within a scrappage curve against historic vehicle sales for individual years, one can broadly estimate how many vehicles are likely to get scrapped each year. This information is valuable since it gives new car manufacturers an idea of how many vehicles to produce for replacement purposes and provides the after-market with insight on volume and time to stock spare parts.

Figure 5. Cumulative survival probability distributions for US passenger vehicles (2003, 2011 and 2019)



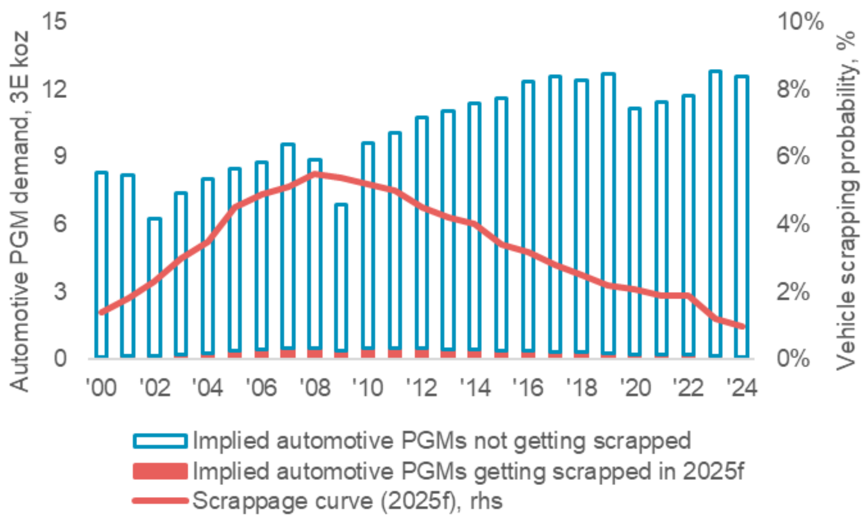
Source: Statistical Estimation of Trends in Scrappage and Survival of U.S. Light-duty Vehicles (DL. Greene, B Leard), WPIC Research

Passenger vehicles are most likely to be scrapped from ten and twenty years old.

Since a scrappage curve estimates a distribution of the various model years of vehicles likely to be scrapped, one is able to reconcile what the applicable emissions legislation the scrapped vehicles were subject to and therefore the likely PGM loadings in those vehicles' autocatalysts. Accordingly, a scrappage curve functionally also helps to calculate a theoretical availability of recycled automotive PGM supply.

To simplify the calculation of theoretical recycled automotive PGM supply, a scrappage curve can be applied against the applicable historic automotive PGM demand. In Fig. 6, we estimate 8.1 Moz of theoretical recycled 3E PGM availability from the cumulative sum of each of the past 25 years' worth of annual automotive demand multiplied by the probability of scrapping.

Figure 6. Cumulative survival probability distributions for US passenger vehicles (2003, 2011 and 2019)



Source: POLK, WPIC Research

It is worth noting that not all the theoretically available PGMs (determined from a scrap curve) enter the recycling value chain. Forecasts for recycled automotive PGM supply need to be adjusted to reflect:

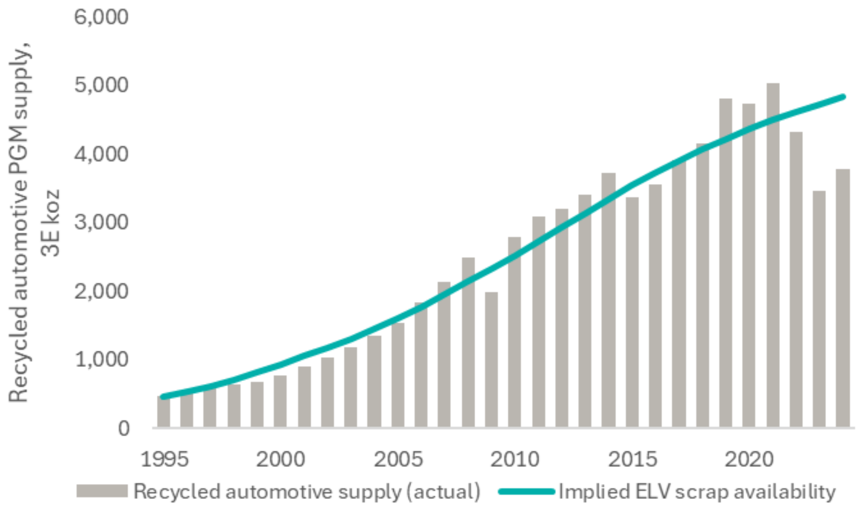
- **Loss in use (LIU):** Over the operating life of an autocatalyst, physical wear and tear can lead to minor losses of PGM-containing substrate (these losses are continually being reduced with improved catalyst design), which we estimate impacts recoveries by 5%.

- **Exports:** The automotive industry is underpinned by global trade. Trade is most associated with new parts and vehicles. However, there is also a significant trade in second-hand vehicles, typically from developed markets to emerging markets where new vehicles are often less affordable. Regions such as Africa or South America which import second-hand vehicles often lack the necessary recycling infrastructure to recover PGMs at scale. We estimate around 25% of vehicles are exported to regions without formal recycling.
- **Catalyst attachment:** Some end-of-life vehicles do not have an autocatalyst or the catalyst was inadvertently sent to landfill. WPIC estimates that 75% of scrapped vehicles have an attached catalyst.
- **Recovery losses:** There are low single-digit PGM losses (~3-5%) incurred when de-canning, smelting and refining spent autocatalysts.
- **Other scrap inclusions:** Aftermarket parts for maintenance and repairs (as well as to replace stolen catalytic converters) over a vehicle's useful life is additive to catalyst volumes and total recoveries (~15%).

Further to the above, one should also consider that there are wide regional variations in recycling, where for example Japan is a large exporter of used vehicles relative to a market like North America. Accordingly, one could apply a geographic overlay to the above-mentioned factors to calculate an end-of-life scrap quantity. For the purposes of this report (which is intended to be educational), we have opted to express the discussed concepts at an aggregated global level. Cumulatively, downward adjustments of around 40% to 45% should be made to the theoretical recycled automotive PGM supply derived from a scrappage curve (a recovery factor). Back-checking forecasts against actual automotive recycled PGM supply since 1995 indicates that actual supply has been 98% of forecast implied End-of-Life Vehicle (ELV) scrap availability (Fig. 7), validating our recovery factor.

While PGMs are highly recyclable, theoretical recoveries must be adjusted for real world considerations (-40% to -45%) as not all metal returns through recycling value chains.

Figure 7. Historical recycled automotive PGM supply (as reported) is around 98% of recycled automotive PGM supply estimated using an End-of-Life Vehicle scrappage curve adjusted for loss factors



Source: POLK, Johnson Matthey (1995-2012), SFA (Oxford) (2013-2018), Metals Focus (2019-2024), WPIC research

The implied End-f-Life Vehicle (ELV) scrap recovery has averaged 98% of reported recycled automotive PGM supply since 1995.

Deviations from the scrap curve

Over the last thirty years, recycled automotive PGM supply has, in general, aligned quite well with implied scrap availability from an ELV curve. However, the deviation between actual supply and the implied availability has clearly increased from 2019 to 2024. Whilst we have explained the theory of recycling using scrappage curves, in practice automotive PGM recycling can deviate from expectations if there are shocks to 1) the physical supply of spent autocatalysts and 2) economic incentives to recycle.

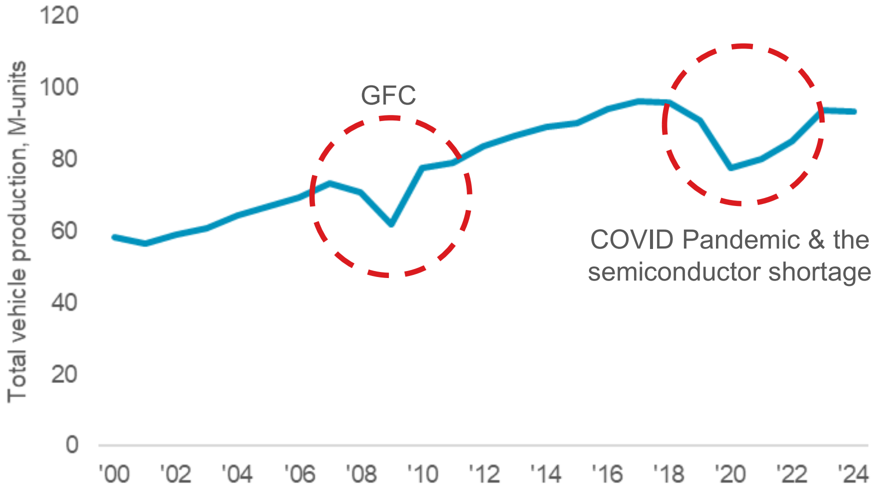
Physical supply shocks:

We have explained how a scrappage curve predicts the probability of a vehicle reaching its end-of-life. Scrappage curves are based on historical data and accordingly underestimate trends in the new car market. However, vehicle scrapping, used car markets and new car markets are not strictly independent, and two such instances in recent history where the interplay between these markets impacted PGM recycling were during the Global Financial Crisis (GFC) and the COVID pandemic.

Lower new car supply has knock on effects for the used car market and scrapping economics.

During the GFC and the height of the pandemic, new vehicle demand collapsed (Fig. 8) with economic uncertainty leading to consumer caution over large expenses such as new vehicles. Furthermore, during the pandemic, lockdowns and subsequent work-from-home trends reduced annual mileage and deferred vehicle depreciation. The result of economic caution and less driving was that consumers held onto their current vehicles for longer, which in turn reduced the supply of used vehicles for recycling. In addition, automakers over-estimated the downturn in demand for new vehicles as a result of the pandemic, cutting their orders of semiconductors, which were then diverted into other sectors (predominantly consumer electronics). When they tried to respond to higher-than-expected demand they found themselves unable to procure sufficient semiconductors which further constrained new vehicle production and added to deferred consumer scrappage decisions. Reflecting the shortage of new vehicles, used vehicle prices increased by as much as 50%.

Figure 8. Shocks to new vehicle markets can impact the pipeline of used car recycling



Source: OICA, WPIC research

Economic incentives to recycle:

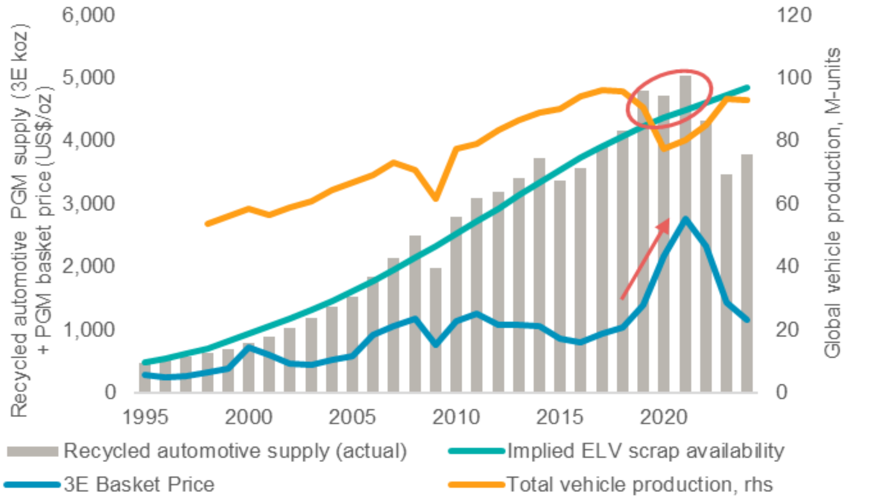
A scrappage curve can help forecast how many spent autocatalysts will enter scrapyards in a given year. However, scrappage curves do not tell us whether it is economically attractive to actually recycle those autocatalysts. Based on prevailing markets, automotive PGM recycling may increase with higher PGM prices or decrease with lower PGM prices.

Palladium is the largest economic driver of automotive PGM recycling.

Notably, in 2019, 2020 and 2021, recycled automotive PGM supply exceeded estimates from the ELV scrappage curve by an average of 10%. It appears that sharply higher palladium and rhodium prices (Fig. 9) offered a greater economic incentive to increase recycling rates despite the COVID pandemic weighing on the physical supply of used vehicles for scrapping. Controversially, the higher prices paid for spent catalytic converters also incentivised increased theft of catalytic converters off vehicles on the road.

As the prices of palladium and rhodium began receding from 2022, recycled automotive PGM supply undershot estimates from the ELV scrappage curve by an average of 18% between 2022 and 2024.

Figure 9. Elevated Pd and Rh prices 2019-2021 supported a record basket price (3E) offering the economic incentive to boost automotive recycling

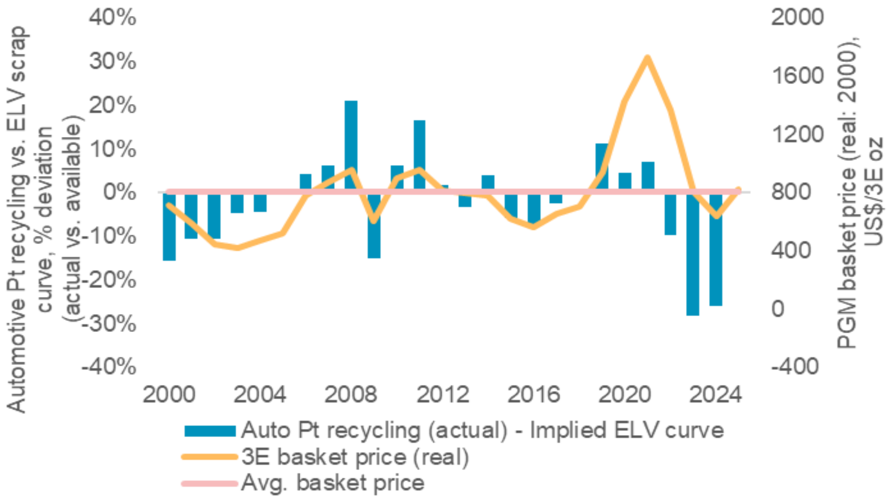


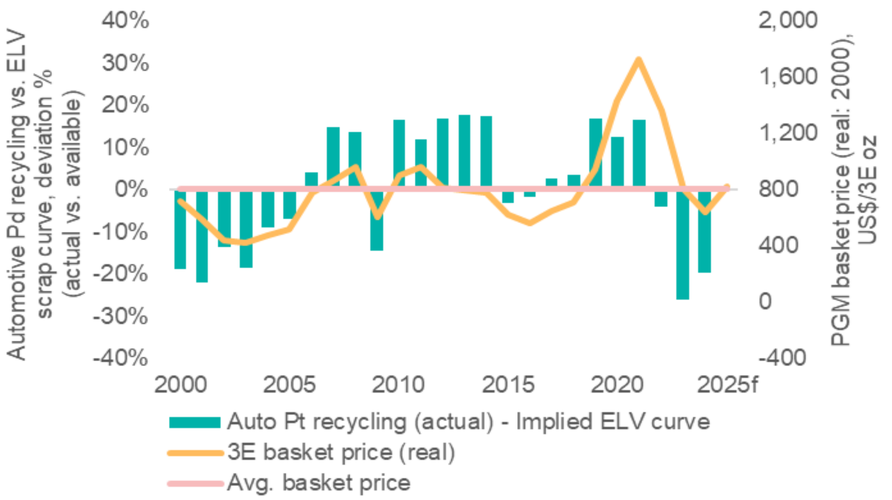
Source: OICA, Bloomberg, Johnson Matthey (1995-2012), SFA (Oxford) (2013-2018), Metals Focus (2019-2024), WPIC research

Automotive recycling volumes respond to prices and typically overshoot the ELV curve in periods of higher PGM prices.

Expressing actual recycled automotive platinum and palladium supply against their respective ELV scrap availability curves (implied) further reinforces scrap's supply elasticity to prices (Fig. 10). In general, where real basket prices are below their historic average price, recycled automotive PGM supply underperforms expectations from the implied ELV scrap curve.

Figure 10. Excess/depressed automotive recycling volumes (vs. implied ELV curve) occur during periods of elevated/below average PGM prices





Source: Bloomberg, WPIC research

What drives recycling?

Regulations which require vehicles to enter a formal scrappage scheme can be an enabler for increasing recycling rates. Other incentives to increase recycled PGM supply would be de-risking procurement. OEMs can diversify their PGM supply chain away from primary mining which is concentrated in geopolitically riskier geographies such as South Africa, Zimbabwe and Russia. Moreover, recycled PGM supply carries a lower carbon footprint and is recovered in a safer operating environment compared to mining.

Notwithstanding external drivers to increase PGM recycling, it appears evident that PGM prices are a significant driver of recycled automotive PGM supply. Explaining why PGM prices are the key driver underpinning recycled automotive PGM supply requires an understanding of the automotive PGM recycling value chain.

The physical value chain

The upstream segments of recycling are fragmented with many market participants, while smelting and refining is concentrated amongst fewer firms.

The structure of the recycling value chain can in general be summarised by the following key steps;

1. **Vehicle scrapping:** End-of-life vehicles are sent to scrapyards where dismantlers strip down the vehicle into its constituent parts, including the spent autocatalyst.
2. **Collection and sorting:** Aggregators will collect autocatalysts from scrapyards and thereafter sort them, typically into categories determined by whether they have metallic or ceramic honeycombs (the substrates that are coated with the PGM-based catalysts). Catalysts are assayed to measure PGM content and establish their value for the scrapyards.
3. **De-canning:** The autocatalyst is stripped of its outer metallic housing to access the PGM containing honeycomb substrate.
4. **Crushing and sampling:** Substrates are crushed and aggregated into a fine powder to ensure a consistent feed material which is sampled and assayed to measure PGM content and measure value for the aggregators.
5. **Metal recovery:**
    a. *Pyrometallurgical:* Crushed feed is smelted in furnaces typically at temperatures above 1,200ºC to separate metallic from non-metallic materials.
    b. *Hydrometallurgical:* Hydrometallurgy is often done in conjunction with smelting to concentrate metallic feeds and increase PGM recoveries. The process utilises chemical leaching which draws out the various underlying PGMs into solution.
6. **Refining:** is the chemical separation process of removing final impurities and converting the incoming PGMs into their final product forms, be it sponge or salts. The refining process involves a series of solvent extraction, evaporation, precipitation and filtration. Refined PGMs from recycling feedstocks have the same physio- chemical properties as mined PGMs and can be used interchangeably in end-markets.

The transactional value chain

Having laid out the value chain to get from a scrapped vehicle to recycled PGMs, to understand why recycled automotive PGM supply is price elastic, we further need to understand the transactional steps across the recycling value chain. This is best done by starting at the desired final output, that is, determining the value of the PGMs within a spent catalyst for the refiners.

A refiners' point of view

Our scrappage curves highlight that vehicles entering scrapyards are around 12 to 16 years old on average. Emissions legislation at the time would imply these vehicles had average PGM loadings of between 2 to 6 grams. In the table below (Fig. 11), we highlight that the value of contained PGMs in an autocatalyst would therefore have ranged from US$85 in China to US$250 in North America due to regional variations in emissions standards and therefore loadings (we'll ignore differing PGM metal combinations within catalysts for now), assuming:

There are significant geographic differences in recycling economics.

- Average PGM prices for 2024, and
- Vehicles from 2010 (i.e. 14-year-old vehicles).

Figure 11. Geographic emissions legislation and vehicle preferences dictate the PGM loadings which underpin the value of a spent autocatalyst

		North America	Europe	China
Avg. loadings (2010 model-year)	**g/vehicle**	**5.8**	**5.4**	**2.2**
Platinum		*1.3*	*2.7*	*0.2*
Palladium		*4.0*	*2.3*	*1.9*
Rhodium		*0.6*	*0.4*	*0.1*
Contained metal value (2024 prices)	**US$ / catalyst**	**250**	**211**	**84**
Platinum	*(US$957/oz)*	*39*	*84*	*5*
Palladium	*(US$982/oz)*	*126*	*73*	*61*
Rhodium	*(US$4,640/oz)*	*85*	*54*	*18*

Source: Bloomberg, WPIC estimates

Simplistically, the value of contained metal in an autocatalyst would be the revenue a PGM refiner would achieve after purchasing scrap feedstock from an aggregator. Hence, working backwards from the contained metal value in a catalytic convertor, one can infer rough estimates for,

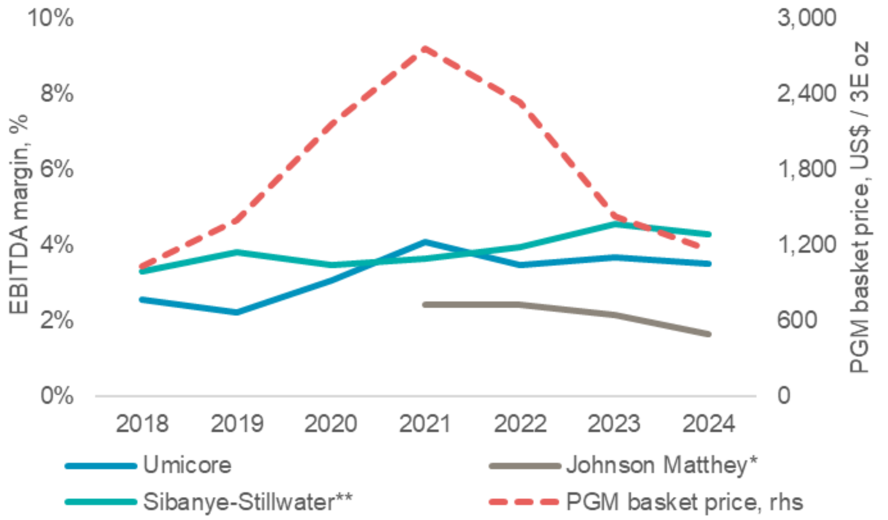
- The prices paid by a PGM smelter/refiner for that catalyst feed to an aggregator, and
- A breakeven offer price that an aggregator could offer a scrapyard to purchase the catalyst before incurring a loss. *We note that several collectors offer mobile apps which provide live pricing for spent catalysts based off a database of catalyst details including PGM loadings.*

Offer price from smelter/refiner to scrap aggregator:

Through hedging, PGM refiners generate stable margins through price cycles.

The business model for secondary PGMs refiner is to achieve a spread between the price paid for spent autocatalyst feedstock and the price achieved for selling refined PGMs (typically market prices). These are low margin businesses, with the spread covering the largely controllable and known costs of smelting and refining recycling feedstock. Refiners use hedging to avoid price risks and are therefore able to lock-in stable margins through PGM price cycles (Fig. 12).

Figure 12. Smelting and refining recycled PGMs generates broadly stable margins through price cycles



*Source: Company data, Bloomberg, WPIC Research, * JM reports an EBIT margin, ** Sibanye-Stillwater operates a smelting only autocatalyst recycling business*

Since we know that 1) refined PGMs are sold at market prices, and 2) refiners achieve stable margins, the price paid by the refiner to the aggregator for autocatalyst feedstock can be backed out at between 90% to 95% of the value of the contained PGMs.

In other words, whereas a PGM smelter and refiner (e.g. Johnson Matthey or Umicore) recognises the purchase of aggregated scrap feedstock as an input cost, the actual scrap aggregators would record this as revenue (Fig. 13).

Through hedging, PGM refiners generate stable margins through price cycles.

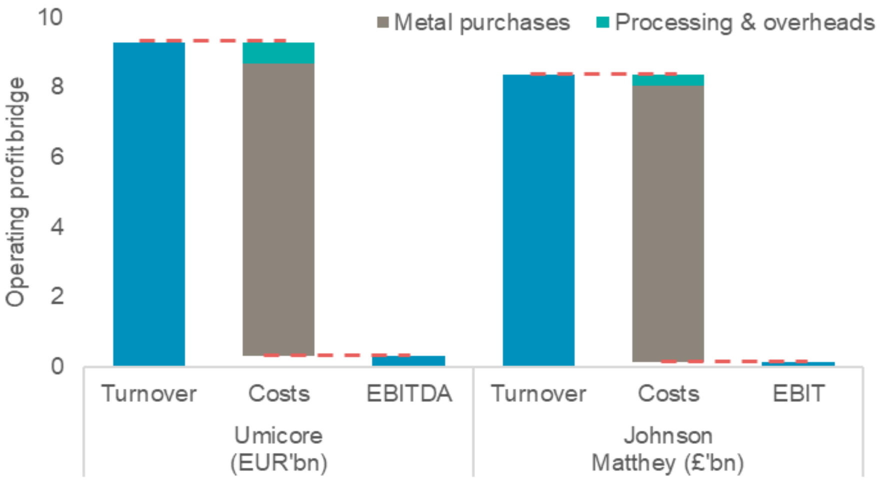
Figure 13. Scrap collectors sell aggregated autocatalyst material (de-canned and shredded) for ~90% of the value of the contained PGMs

		North America	Europe	China
Contained metal value (2024 prices)	**US$ / catalyst**	**250**	**211**	**84**
Processing losses	%	2.0%	2.0%	2.0%
Refiner offer	%	92.5%	92.5%	92.5%
Aggregator revenue receipt	**US$ / catalyst**	**227**	**191**	**76**

Source: WPIC estimates

The common misconception that PGM recycling is price agnostic arguably arises at this juncture in the value chain. There is a lack of reported financial data from the fragmented scrap aggregation industry. In contrast, recycled PGM smelting and refining supply is derived from a reasonably consolidated set of market participants which includes Johnson Matthey, Umicore, BASF and others. These company's recycling business units typically report stable margins through the cycle (Fig. 12). As noted above, the margin stability of refiners is because ~90% of the input costs is purchasing recycled feedstock (Fig. 14), which is linked to market prices, and then future selling prices are hedged.

Figure 14. Purchasing PGM-containing recycled feedstock is the largest component of a smelter and refiner's cost base



Source: Company data, WPIC Research

It costs an estimated US$90 to US$200 to collect, de-can, crush and assay a spent autocatalyst ahead of its sale to a PGM refiner

Break-even price for aggregator to avoid losses:

Unlike PGM refiners, scrap aggregators' processing and overhead costs are not a nominal proportion of their total costs. We estimate that it costs an aggregator between US$90 and US$200 (depending on the geography) to collect, de-can, crush and assay a spent autocatalyst ahead of its sale to a PGM refiner (Fig. 15).

The costs an aggregator incurs to prepare autocatalyst feedstock for PGM recycling are largely fixed. These costs are also over and above the costs to purchase spent autocatalysts from scrapyards, which are variable.

Low PGM prices during 2023 and 2024 have meant that the value of contained PGMs in a spent autocatalysts is less than the costs of recycling.

Figure 15. Scrap aggregators incur significant fixed costs preparing spent autocatalysts for eventual sale to PGM smelters and refiners

		North America	Europe	China
Aggregator costs		**193 + ?**	**167 + ?**	**89 + ?**
Processing costs	**US$ / catalyst**	**193**	**167**	**89**
Logistics/handling		*100*	*80*	*50*
Sampling		*30*	*30*	*20*
De-canning/shredding		*10*	*10*	*5*
Storage		*5*	*5*	*2*
Overheads		*15*	*15*	*5*
Financing/hedging		*33*	*27*	*7*
Autocatalyst purchase price	**US$ / catalyst**	**?**	**?**	**?**

Source: WPIC estimates

Because the costs an aggregator incurs to purchase autocatalysts from scrapyards is unknown, we simplify the interpretation by referring to this as the break-even price. The break-even price is the highest price an aggregator could offer a scrapyard for the spent autocatalyst before its total costs exceed the revenue it would receive from a PGM smelter and refiner for the feedstock.

Consolidating our analysis (Fig. 16) highlights that during 2024 in North America and Europe, the break-even offer an aggregator would make to a scrapyard would be around US$30 per autocatalyst. The Chinese break-even price is estimated to have been negative in 2024 due to the country's lower historic PGM loadings. In reality, aggregators operate to turn a profit and **thus the price an aggregator would offer a scrapyard would be lower than the break-even price**, which further compresses economic incentive to recycle PGMs from spent autocatalysts.

Figure 16. Low to negative implied break-even prices highlight the financial constraints facing the upstream segments of the automotive PGM recycling value chain

		North America	Europe	China
Avg. loadings (2010 model-year)	**g / vehicle**	**5.8**	**5.4**	**2.2**
Platinum		*1.3*	*2.7*	*0.2*
Palladium		*4.0*	*2.3*	*1.9*
Rhodium		*0.6*	*0.4*	*0.1*
Contained metal value (2024 prices)	**US$ / catalyst**	**250**	**211**	**84**
Platinum	*(US$957/oz)*	*39*	*84*	*5*
Palladium	*(US$982/oz)*	*126*	*73*	*61*
Rhodium	*(US$4,640/oz)*	*85*	*54*	*18*
Processing losses	%	2.0%	2.0%	2.0%
Refiner offer	%	92.5%	92.5%	92.5%
Aggregator revenue receipt	**US$ / catalyst**	**227**	**191**	**76**
Aggregator processing costs	**US$ / catalyst**	**(193)**	**(167)**	**(89)**
Logistics		*100*	*80*	*50*
Sampling		*30*	*30*	*20*
De-canning/shredding		*10*	*10*	*5*
Storage		*5*	*5*	*2*
Overheads		*15*	*15*	*5*
Financing/hedging		*33*	*27*	*7*
Implied breakeven	**US$ / catalyst**	**34**	**24**	**-13**

Source: WPIC estimates

Low PGM prices during 2023 and 2024 have meant that the value of contained PGMs in a spent autocatalysts is less than the costs of recycling.

Recycling is more attractive in regions which have high PGM loadings on their vehicles.

If the above table is amended to reflect average PGM prices during 2021 (i.e. the most recent cyclical peak), we can highlight how leveraged scrapyards are to PGM prices given the implied break-even offer from aggregators would have been around ten times higher than in 2024 (Fig. 17).

Figure 17. The implied break-even price which an aggregator could pay a scrapyard is highly leveraged to PGM prices

		North America	Europe	China
Avg. loadings (2010 model-year)	**g / vehicle**	**5.8**	**5.4**	**2.2**
Platinum		*1.3*	*2.7*	*0.2*
Palladium		*4.0*	*2.3*	*1.9*
Rhodium		*0.6*	*0.4*	*0.1*
Contained metal value (2021 prices)	**US$ / catalyst**	**719**	**509**	**231**
Platinum	*(US$1,089/oz)*	*45*	*95*	*6*
Palladium	*(US$2,392)*	*307*	*178*	*148*
Rhodium	*(US$20,080/oz)*	*367*	*235*	*77*
Processing losses	*%*	*2%*	*2%*	*2%*
Refiner offer	*%*	*92.5%*	*92.5%*	*92.5%*
Aggregator revenue receipt	**US$ / catalyst**	**652**	**461**	**210**
Aggregator processing costs	**US$ / catalyst**	**(250)**	**(204)**	**(94)**
Logistics		*100*	*80*	*50*
Sampling		*30*	*30*	*20*
De-canning/shredding		*10*	*10*	*5*
Storage		*5*	*5*	*2*
Overheads		*15*	*15*	*5*
Financing/hedging		*90*	*64*	*12*
Implied breakeven	**US$ / catalyst**	**402**	**257**	**116**

Source: WPIC estimates

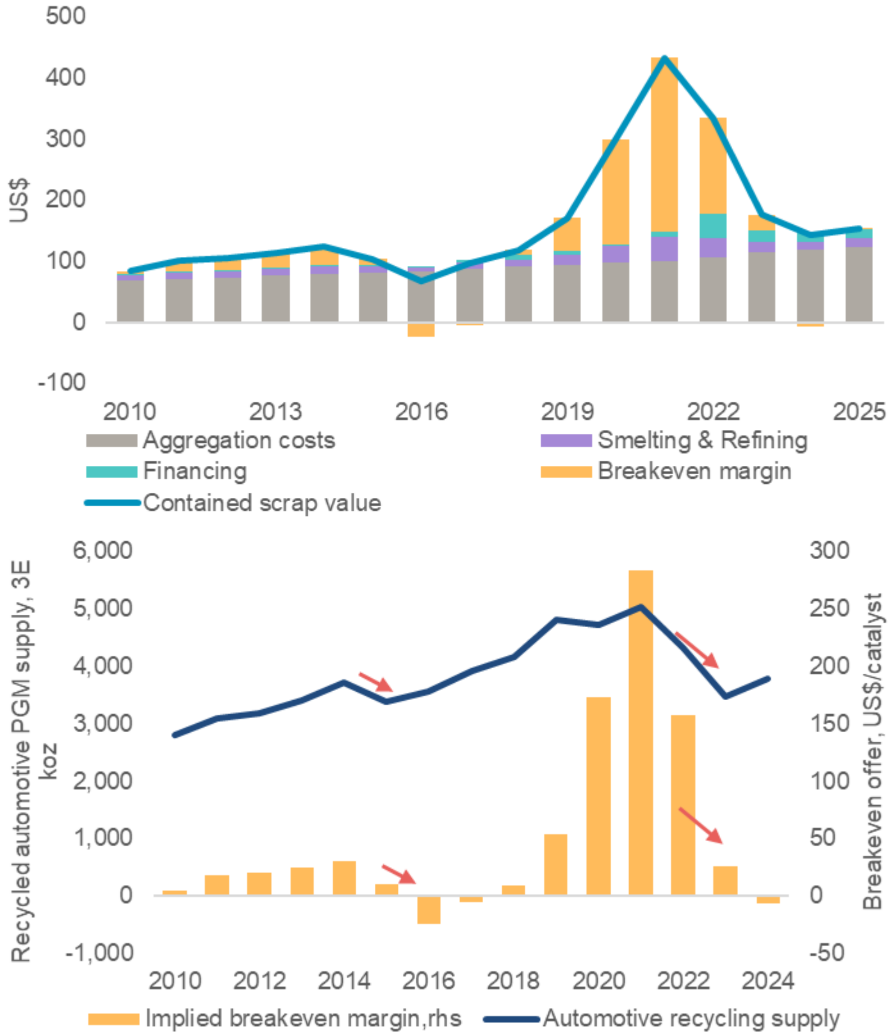
Scrapyards could be hoarding spent autocatalysts (thereby constraining supply) hoping for PGM prices to return to 2020 to 2022 levels.

Supply does respond to prices:

The sharp reduction in offer prices from aggregators to scrapyards between 2021 and 2024 could explain reports that scrapyards are hoarding spent autocatalysts in expectation of higher future prices. Notably, scrapyards can hoard autocatalysts because they recognise multiple revenue streams from recycling vehicles with everything from steel, fabrics and used engine oil getting recycled when a vehicle is scrapped.

Since 2010, we estimate that the break-even margin for automotive recycling was at times negative in the mid-2010s and through late 2023 and 2024 (Fig. 18-1). Plotting 3E automotive PGM recycling supply (Fig. 18-2) against the implied break-even margin highlights that supply shows some degree of price elasticity. It can be seen that recycled PGM supply increases with rising break-even prices and declines with lower break-even prices.

Figure 18. Purchasing PGM-containing recycled feedstock is the largest component of a smelter and refiner's cost base



Source: Bloomberg, WPIC estimates

Recycled automotive PGM supply has reduced with declining breakeven margins for aggregators.

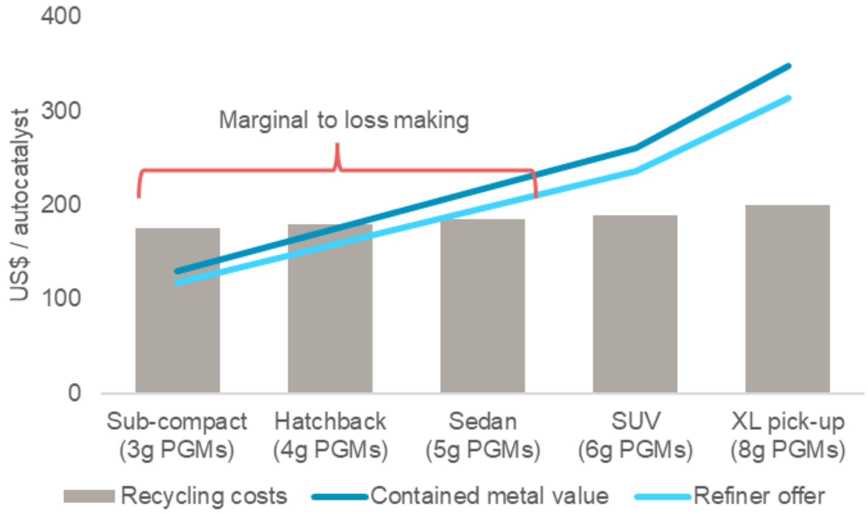
Our calculations for estimating the margins within the recycling value chain use average vehicle loadings. However, this has the effect of masking the economic incentives to recycle autocatalysts from different vehicle segments or drivetrains, and these variances may further explain depressed recycled automotive PGM supply from 2022 to 2024.

Vehicle segmentation matters:

Beyond emissions legislation, the largest single determinant of PGM loadings is engine capacity. Accordingly, PGM loadings will vary widely across different vehicle segments where a Segment B vehicle (i.e. hatchback) may have a 1.0 litre displacement engine while a Segment J vehicle (i.e. SUV) may have a 2.5 litre engine displacement. The variation in PGM loadings across vehicles will imply that some autocatalysts are more valuable than others (Fig. 19). Yet, for the most part, the cost of recycling an autocatalyst with 3.0g of PGMs is the same as the cost of recycling an autocatalyst with 7.0g of PGMs. We note that some catalyst substrates such as silica carbide increase processing complexities and costs, but these costs are not a function of loadings.

Within the broader vehicle segmentation discussion lies the notion that some larger vehicles will not have a large autocatalyst but instead have two autocatalysts operating in series (i.e. a front and back catalyst). The configuration of two autocatalysts reduces the economic incentive to recycle because now the operating costs are higher to recycle two autocatalysts.

Figure 19. Autocatalysts on smaller vehicles are more likely to be hoarded since they are less profitable to recycle given lower PGM loadings



*Source: WPIC estimates, *Estimates for loadings and costs are based on North America, **Avg. PGM prices for 2024 were used for contained metal value and refiner offer calculations*

The economic incentive to recycle any individual autocatalyst can vary widely given a vehicle's size (i.e. engine capacity) and drivetrain (i.e. loadings mix).

We believe that scrapyards are unlikely to be receiving many purchase offers for catalysts from smaller vehicles which are unprofitable to recycle (Fig. x) at current prices. In our view, this will implicitly reduce recycled automotive PGM supply and cause hoarding of low-value spent autocatalysts.

Drivetrains dictate PGM requirements:

Depending on whether a vehicle is a gasoline combustion engine or diesel, different PGMs work better at meeting emissions standards. In general, autocatalysts on diesel vehicles will primarily use platinum, while palladium is the preferred PGM for gasoline vehicles (despite recent substituting of platinum for palladium in gasoline vehicles at a 1:1 ratio). Having different ratios of PGMs in autocatalysts will again result in some spent autocatalysts being more valuable than others. For example, at current spot prices, a diesel autocatalyst with 5.0g of PGMs loaded in the Pt:Rh ratio of 90%:10% would be 13% (or US$33) more valuable than a gasoline catalyst loaded with 5.0g of PGMs in the Pd:Rh ratio of 90%. These value differences may dictate whether it is profitable or unprofitable to recycle a specific autocatalyst, which could in turn lead to hoarding of currently unprofitable, less valuable spent autocatalysts.

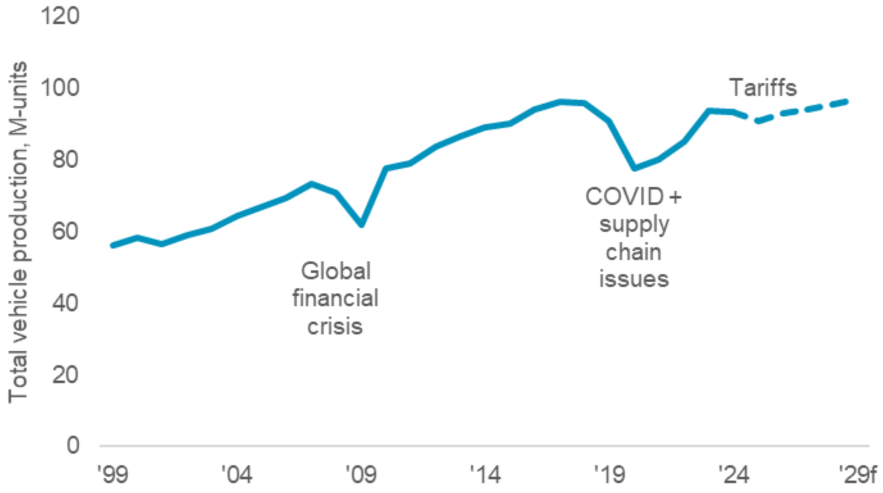
The future of automotive PGM supply

Our research has discussed two aspects which fundamentally underpin recycled automotive PGM supply. These are 1) the availability of spent autocatalysts and how this depends on both the new and used car markets and 2) the economic incentive to recycle autocatalysts.

Availability to improve

We forecast that spent autocatalyst availability will continue to improve over the medium-term. In our view, disruptions to recycling caused by COVID and the subsequent supply chain challenges, are normalising along with recovered new car sales volumes. We recognise that the US's automotive tariffs and its broad protectionist trade policies may raise new car prices and reduce demand. However, the downside risks of trade barriers appear to be limited to around 1-3 million vehicles per annum rather than the 10-20 million annual reduction seen during both 2020 and 2021 (Fig. 20).

Figure 20. Tariffs are expected to weigh on global vehicle production but to a lesser extent than occurred during the GFC or COVID



Source: OICA, WPIC research

New vehicle production has normalised after COVID and this will support an improving flow of used vehicles into scrapyards.

PGM prices off their trough

Platinum prices have increased by 43% year-to-date 2025 which will improve the profitability of automotive PGM recycling. However, in the average passenger-vehicle autocatalyst, there is around three times as much palladium as platinum which makes the palladium price (+38% YTD) a more important factor in determining recycling's economic returns. We estimate that the value of contained metal in the average passenger-vehicle autocatalyst (model year 2011, so 14-years old) has increased by 35% compared to the average of last year. The higher value of contained metal in the autocatalyst implies the average break-even price aggregators could offer scrapyards has increased from negative US$6 per catalyst in 2024 to positive US$19 per catalyst at spot (30 June 2025).

Higher PGM prices during 2025 will improve the economic incentive to recycle autocatalysts.

Figure 21. Rising PGM prices in 2025 should improve margins for recyclers

Source: Bloomberg, WPIC research

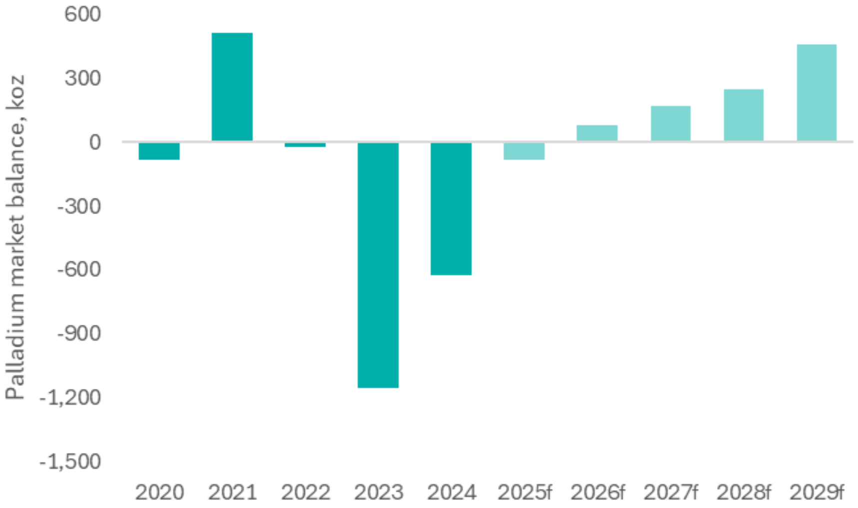
Recycling supply outlook

We had previously noted that since 1995 actual automotive PGM recycling supply has averaged 98% of forecast implied ELV scrap availability (Fig. 7). Notwithstanding the long-term validity of the ELV scrap curve, from 2022 to 2024, actual automotive recycling supply was on average 18% less than expectations (i.e. a significant deviation).

Looking forward, we expect recycled automotive PGM supply to trend back towards our implied ELV scrap curve given increasing scrap availability and improving recycling economics. Although we expect recycling to trend back to the implied ELV scrap curve, we do not expect it to return to the ELV curve because palladium markets are forecast to enter surpluses from 2026f (Fig. 22). If palladium markets become oversupplied, prices may be negatively impacted, and automotive recycling supply's elasticity should therefore cap output (for platinum, palladium and rhodium).

If the transition of palladium into market surpluses weighs on palladium prices, this may disincentivise automotive recycling and reduce platinum recycling supply.

Figure 22. Palladium markets are forecast to enter a surplus from 2026f due to declining automotive demand and rising automotive recycling



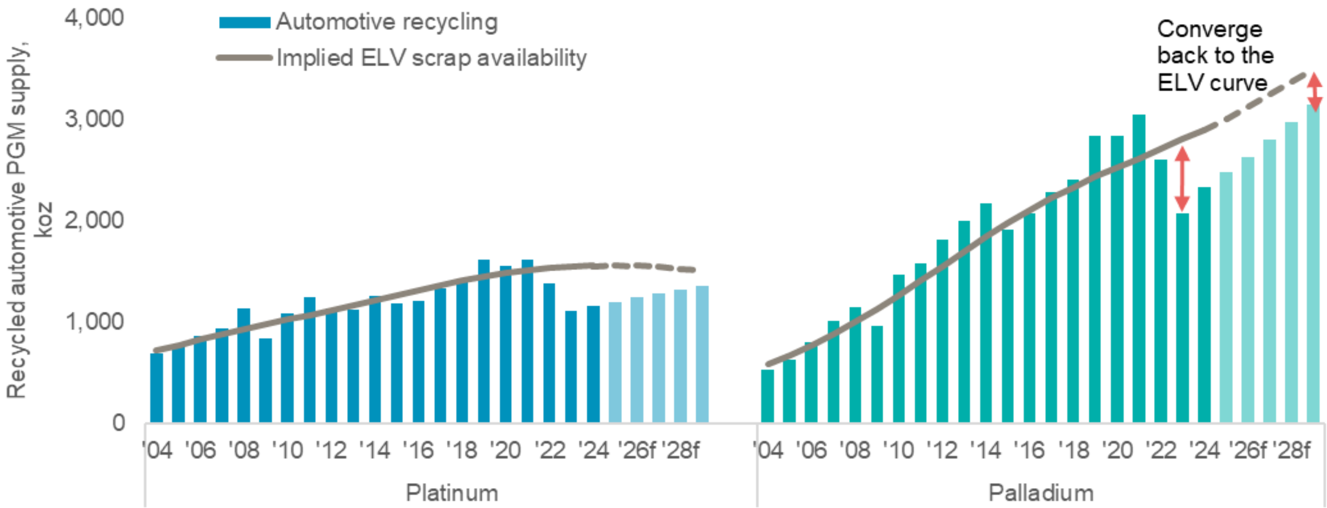
Source: Metals Focus (2020-2024f), WPIC research

We expect recycled automotive supply to retrace to only 90% of the ELV scrap curve by 2029f (Fig. 23). In our view, this creates a tension between supportive factors driving expected growth in automotive recycling, whilst potentially also limiting palladium's market surplus to 5% of demand in 2029f.

In adopting this rationale, we note that,

1. We expect recycled platinum and palladium supply to increase by 3.3% CAGR and 6.2% CAGR from 2024 to 2029f respectively, whilst
2. Our revised automotive recycling forecasts represent a downgrade in supply of 66 koz (5%) for platinum and 226 koz (7%) for palladium respectively in 2029f.

Figure 23. We expect recycled platinum supply to trend towards 90% of the implied ELV scrap curve towards the end of the decade

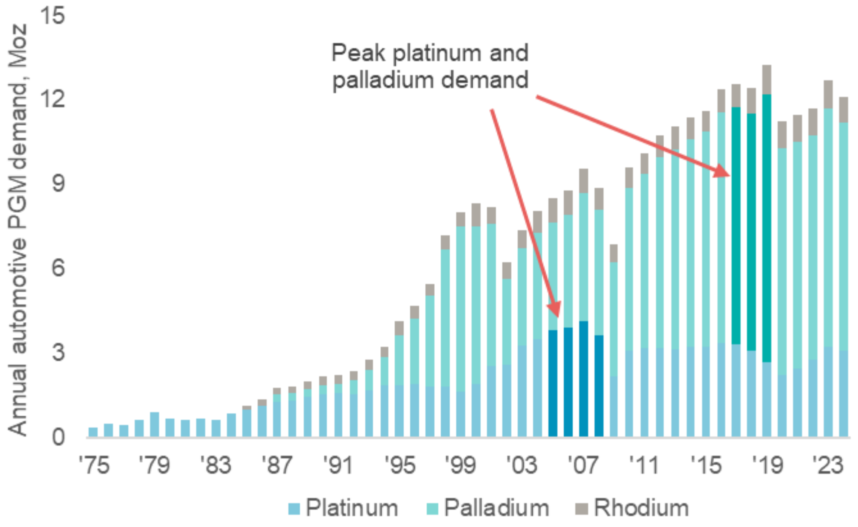


Source: Johnson Matthey (2004-2012), SFA (Oxford) (2013-2018), Metals Focus (2019-2025f), WPIC research thereafter

Within our outlook for recycled automotive PGM supply, it is worth noting the divergent trends of the platinum and palladium ELV scrappage curves. Platinum's implied ELV scrappage curve begins to taper from 2026f, whereas the palladium curve continues rising throughout our forecast period. In effect, the trends in platinum and palladium's respective ELV scrappage curves reflects past automotive demand trends where automotive platinum demand peaked in 2007 at 4.1 Moz (Fig. 24). Automotive palladium demand grew through the 2010s and peaked in 2019.

WPIC estimates that recycled automotive platinum supply peaked in 2019.

Figure 24. Automotive platinum demand peaked ahead of the global financial crisis with much of this material having been recycled already

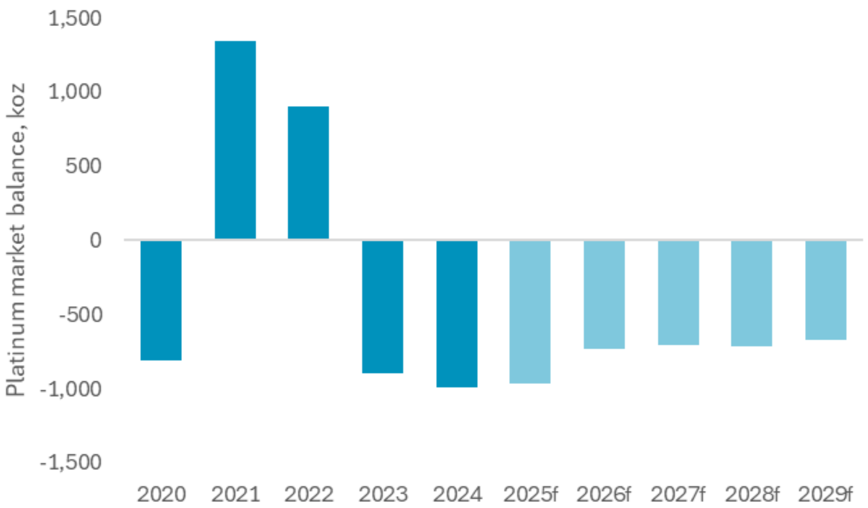


Source: Johnson Matthey (1975-2012), SFA (Oxford) (2013-2018), Metals Focus (2019-2025f), WPIC research

With automotive platinum demand peaking in 2007, many of the vehicles from that period would have already entered scrapyards and had their autocatalyst recycled. Accordingly, we believe that recycled automotive platinum supply peaked in 2021. In our view, despite the expectation for some recovery in recycling volumes out to 2029f, the declining ELV scrap curve further highlights platinum's supply side risks and reinforces our forecasts that platinum markets will record consecutive deficits to at least 2029f (Fig. 25).

Platinum markets are forecast to remain in deficit to at least 2029f given limited expectations for a supply response.

Figure 25. The platinum market is forecast to continue with consecutive deficits to 2029f



Source: Metals Focus (2020-2025f), WPIC research

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