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Pgm Market Report

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Supply and Demand in 2018

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- Investment demand fell steeply, with significant ETF liquidation in Europe and South Africa.
- A steep decline in European diesel car output hit platinum consumption in autocatalysts.
- Jewellery demand remained weak, as platinum lost market share to karat gold jewellery in China.
- However, consumption in the chemical, glass and petroleum sectors was exceptionally strong, reflecting Chinese capacity expansions.
- Primary supplies were flat, while recycling growth was dampened by capacity constraints at secondary refiners.

Platinum Supply and Demand '000 oz

Supply	2017	2018	2019
South Africa	4,450	4,467	4,565
Russia	720	687	668
Others	953	959	956
Total Supply	**6,123**	**6,113**	**6,189**
Gross Demand			
Autocatalyst	3,248	3,051	3,128
Jewellery	2,400	2,269	2,227
Industrial	2,117	2,459	2,322
Investment	361	67	858
Total Gross Demand	**8,126**	**7,846**	**8,535**
Recycling	-2,047	-2,105	-2,219
Total Net Demand	**6,079**	**5,741**	**6,316**
Movements in Stocks	44	372	-127

The platinum market moved further into surplus in 2018. Gross platinum demand fell by 3%, due to a steep fall in investment purchasing, lower jewellery demand, and a decline in platinum consumption on European diesel cars. Nevertheless, purchasing by industrial consumers remained extremely buoyant, with double-digit growth rates in the Chinese glass, chemicals and petroleum sectors. Combined primary and secondary supplies were little changed, with growth in autocatalyst recoveries slower than anticipated due to rationalisation and outages at secondary refineries, which in turn led to delays in secondary metal being returned to the market.

World primary supplies of platinum were flat in 2018. South African shipments increased marginally, as the impact of shaft closures was outweighed by the ramp-up of new and expanding operations, but Russian sales declined due to a steep fall in alluvial platinum production.

In South Africa, underlying mine output rose by around 1% in 2018, despite the closure of two mines in late 2017 and further rationalisation at some older mines on the western Bushveld. At Anglo American Platinum's flagship Mogalakwena mine, improved productivity and the mining of a high-grade area of ore lifted production by 7% to nearly half a million ounces of platinum. Royal Bafokeng Platinum reported a 13% increase in platinum output, reflecting the ramp-up of its new Styldrift mine (pgm from which is refined and marketed by Anglo), while the Kroondal joint venture between Anglo and Sibanye-Stillwater had a record year, producing nearly 300,000 oz of platinum.

Fluctuations in refined and pipeline stocks have obscured the trend in underlying mining production over the last two years. In the second half of 2017, the refining and sale of some additional pgm ounces from semi-processed inventories added to supplies. In contrast, the first half of 2018 saw an increase in pipelines; while some of these excess pgm stocks were released during the second half, in-process inventories remained higher than normal at the year end. As a result, refined shipments of platinum by South African producers increased only marginally compared to 2017.

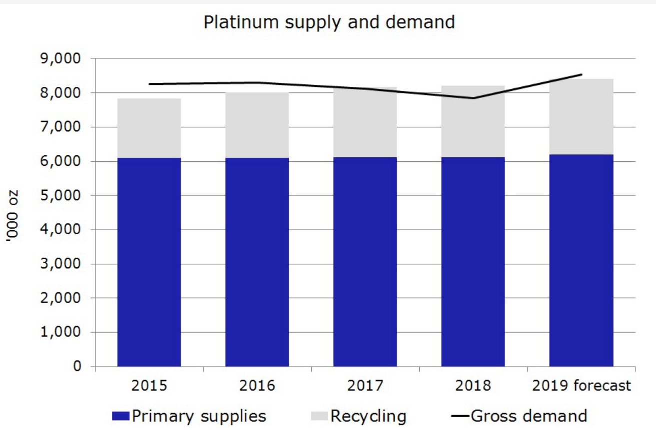
In Russia, the volume of ore mined at the Norilsk-Talnakh mines was stable, but pgm grades declined slightly, reflecting a fall in output of pgm-rich massive sulphide ore, and a corresponding increase in lower-grade disseminated ore. However, Norilsk Nickel has continued to supplement its mine output by processing surface materials, particularly stocks of old copper concentrate purchased from the state enterprise Rostec in 2017. This contributed to a 4% increase in Norilsk's output of platinum in the January to September 2018 period. However, full-year production figures were affected by a build-up in pipeline inventory at the Krasnoyarsk Precious Metals Refinery during the final quarter, leaving annual platinum production flat.

Alluvial platinum production in Russia dropped steeply in 2018, due to declining grades at placer operations in the far east of the country. In the past, these operations contributed as much as 150,000 oz of platinum annually, but output is now below 20,000 oz a year. As a result, total Russian supplies declined 5% to 687,000 oz.

Both Zimbabwe and North America saw small increases in platinum output in 2018. Anglo American Platinum's only Zimbabwean operation, Unki, lifted platinum output by 15% following improvements in mining productivity and efficiencies, while production from Zimplats and Mimosa was broadly stable. The commissioning of Anglo's new Zimbabwean smelter began in the third quarter of 2018 and this new furnace will treat Unki's concentrate output in future. However, the final refining of all pgm produced in Zimbabwe continues to take place in South Africa (although we report it separately in our tables).

In the USA, Sibanye-Stillwater's Blitz expansion project made its first meaningful contribution to production last year, lifting the company's US platinum output. Sibanye-Stillwater's Montana mines are the only primary pgm producers in the USA, although small amounts of byproduct platinum are derived from base metals mining.

We estimate that platinum production from Canadian ores fell in 2018, reflecting depletion of higher-grade ores at the Sudbury mines owned by Vale and Glencore. However, the positive outlook for nickel demand has improved the likelihood that replacement reserves will be developed in future. Vale and Glencore announced in December 2018 that they are cooperating on a feasibility study of using infrastructure at the Nickel Rim South mine to exploit other nearby deposits.



"The platinum market moved further into surplus in 2018. Gross demand fell by 3%, while supplies were little changed."

Platinum Demand: Industrial '000 oz			
	2017	**2018**	**2019**
Chemical	463	540	569
Electrical	233	266	269
Glass	366	478	376
Medical & Biomedical	218	221	227
Petroleum	230	372	288
Other	607	582	593
Total	**2,117**	**2,459**	**2,322**

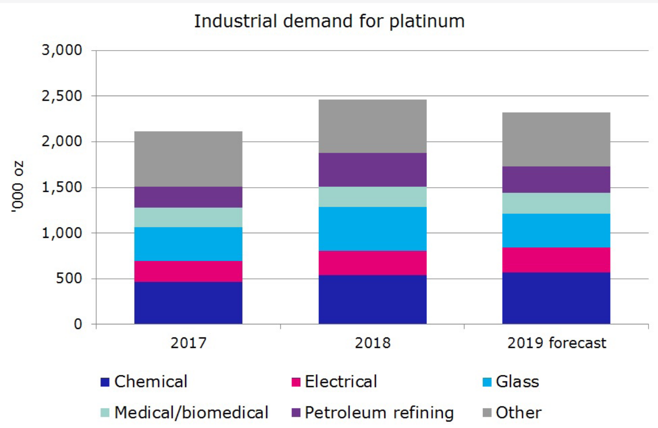
Overall, global primary supplies of platinum were little changed in 2018 and our final estimate is very close to the number we published in our February report. However, it has become clear that our preliminary estimate of 2018 secondary supplies was too optimistic. Although there has been substantial growth in the volume of spent autocatalyst collected from scrapped vehicles, some of the contained metal was not refined in 2018. The recent closure of two European refineries has reduced pgm refining capacity at a time of rapid growth in the volume of spent autocatalyst collected. The outcome has been an increase in lead times and in-process stocks, and we have therefore cut our estimate of 2018 secondary supplies. This is discussed further on page 20.

The rise of China as a major producer of bulk petrochemicals has supported demand from the chemicals industry at historically high levels over the past decade. This sector posted further gains in 2018, despite signs of a slowdown in the global economy, with exceptionally large purchasing of platinum process catalyst for new paraxylene units in China and the Rest of World region. In China, this represents a first wave of buying related to the construction of several very large integrated crude oil refining and petrochemical complexes, designed to improve the country's self-sufficiency across a range of bulk chemicals.

The construction of these integrated complexes has also generated significant demand for platinum catalysts used in petroleum refining processes such as reforming and base oil production. We have increased our estimate of platinum consumption in the Chinese petroleum industry to account for rising sales of petroleum refining catalyst to privately owned operations, known as 'teapot' refineries.

In May 2018, one such independent operation in China was given approval to import 400,000 barrels per day of crude oil – the largest such quota ever authorised – ahead of the commissioning of its new facility. Two other independents are also bringing significant new crude refining capacity on stream. Between 2017 and 2019, we estimate that the commissioning of new petroleum refineries by state-owned and independent companies will lift total Chinese reforming capacity by nearly a quarter.

Demand from the nitric acid industry was also up. The nitric acid process involves the use of a platinum catalyst gauze, from which metal is lost due to volatilisation over the course of a production campaign. Manufacturers



"New petrochemical complexes in China generated significant platinum demand in 2018 in petroleum refining and chemical processes."

Platinum Demand: Autocatalyst '000 oz (Gross)			
	2017	2018	2019
Europe	1,711	1,468	1,407
Japan	358	354	353
North America	348	352	363
China	157	146	229
Rest of World	674	731	776
Total	**3,248**	**3,051**	**3,128**

often employ a palladium 'catchment' gauze to capture this lost platinum but, as palladium prices have risen above those of platinum, fewer plants are being equipped with catchment systems. As a result, platinum losses from the nitric acid process are increasing gradually, although to date the impact on demand has been small.

Last year also saw exceptionally buoyant demand for platinum from the glass industry. Purchases by the glass fibre sector set a new record high: manufacturers, particularly in China, are investing heavily in new production capacity to meet anticipated growth in the electronics, construction, renewable energy and automotive sectors. There was also an increase in platinum purchasing for new display glass facilities, as companies invested in equipment to produce next-generation LCD glass panels required to make large-screen televisions over 60 inches. However, production efficiencies have improved in recent years and demand in the display glass segment remains well below the 2011 peak.

In the electrical sector, consumption of platinum in hard disks proved resilient, due to strong demand for hard disk drives (HDDs) from the enterprise and nearline sectors, which require low-cost data storage media with high reliability and extremely large capacities. While HDD sales continue to contract, as they are displaced from consumer electronics by solid-state memory, the trend for platinum demand remains positive due to growth in the number and size of disks in the average hard drive.

The fuel cell sector also enjoyed strong growth, especially in China, where the government's New Energy Vehicle (NEV) programme has stimulated the market for electric vehicles, including those powered by fuel cells (FCEVs). There has been significant investment in fuel cell stack production capacity in China, and local manufacturers have developed new FCEV platforms for passenger cars, buses, logistics trucks and trams.

While industrial applications remained buoyant, consumption of platinum in autocatalysts fell by 6% in 2018. World output of light duty diesel vehicles contracted by around 4%, due to a 10% drop in European production that was only partly offset by growth in some Rest of World diesel markets. In addition, there was a decline in average platinum loadings, primarily due to a reduction in the pgm content of European diesel aftertreatment systems. While there was moderate growth in platinum consumption in heavy duty applications, this was not enough to offset falling demand in the light duty sector.

Globally, consumption of platinum in heavy duty vehicle applications rose by 4% to around half a million ounces, due to higher truck production in North America and increasing catalyst fitment rates in China and India in advance of stricter legislation which will be rolled out over the 2019–2021 period. This more than compensated for a fall in platinum usage in Europe, where wider adoption of vanadium-based selective catalytic reduction (V-SCR) technology has allowed average platinum loadings on diesel oxidation catalysts to be thrifted. V-SCR bricks are used exclusively on heavy duty diesels and, to date, Europe is the only region to see significant penetration of this technology.

In contrast to rising heavy duty demand, platinum consumption in light duty vehicle applications fell by 9% in 2018. This was mainly due to a sharp contraction in the diesel car market in Europe, where production volumes fell by nearly a million units to the lowest level since 2013.

Platinum loadings on European diesel cars also declined last year, reflecting changes in catalyst fitment strategies adopted by European automakers to comply with Euro 6d-TEMP regulations. The implementation of on-road testing under Real Driving Emissions (RDE) conditions has resulted in wider use of non-pgm selective catalytic reduction (SCR) for NOx conversion, in place of platinum-containing lean NOx traps (LNTs). At the same time, there has been increased adoption of SCRF technology, which combines the functions of the diesel particulate filter and SCR on a single non-pgm brick.

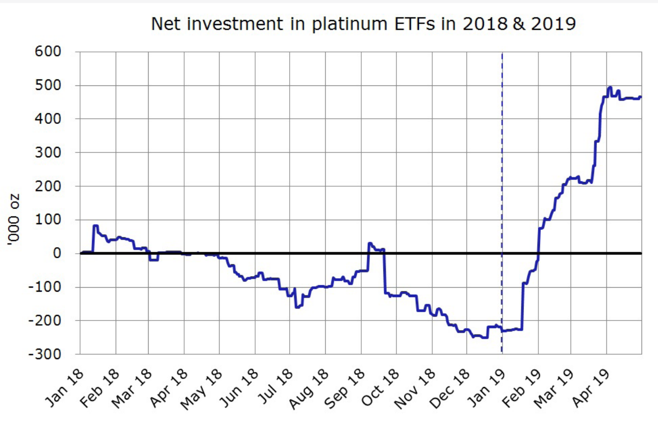
Overall, we estimate that consumption of platinum in the European light duty diesel sector fell by over 10% in 2018. This was partly offset by some modest gains in demand in some Rest of World countries, including India, Thailand and Russia, where light duty diesel output increased. Emissions legislation in most Rest of World countries is currently equivalent to Euro 4 or earlier, so catalyst systems on cars sold in these markets tend to be less complex, based on older technology, and typically contain less pgm than European diesel aftertreatment systems. Of these countries, India moves to Euro 6-equivalent legislation from April 2020, which will lead to a rise in average platinum loading per vehicle (see page 11).

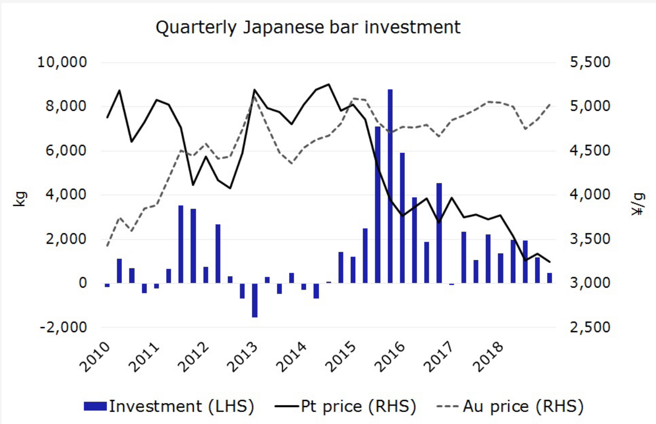
Demand for platinum in exchange traded funds (ETFs) was negative in 2018, although changes in total holdings were moderate compared with the consistent heavy liquidation seen in palladium. Over the last three years, platinum ETF holdings have fluctuated in a relatively narrow range around 2.5 million ounces, with the majority of holders 'out of the money' and reluctant to sell their positions at a loss. Nevertheless, some investors liquidated their positions as the platinum price fell first through $900 and then $800. This selling was concentrated in Europe and South Africa; in contrast, there was some buying by US ETF investors during the second half of 2018.

In Japan, investment demand primarily occurs in the form of 'over-the-counter' sales of platinum bars and has historically been associated with periods of weak price. In 2015–2016, a combination of sharp downward movements in the yen platinum price and a significant widening in the discount to gold resulted in massive demand for platinum bars, totalling over half a million ounces in each of those years. In 2017–2018, a continuing downward trend in the yen platinum price failed to stimulate investment to the same extent, perhaps because investors have become accustomed to platinum trading at a wide discount to gold. Nevertheless, net bar demand remained in positive territory in 2018, slightly exceeding the levels seen in 2017.

We have made a downward revision to our 2018 estimate of platinum jewellery demand in its main market, China. Johnson Matthey's biannual survey of Chinese jewellery factories suggests that the contraction of the market accelerated last year after a relatively stable year in 2017. This reflects a trend towards karat gold in the fashion jewellery market, driven initially by margin considerations in the manufacturing and distribution chain, but increasingly by consumer trends.

Younger consumers, who are key fashion jewellery purchasers, no longer have a specific preference for





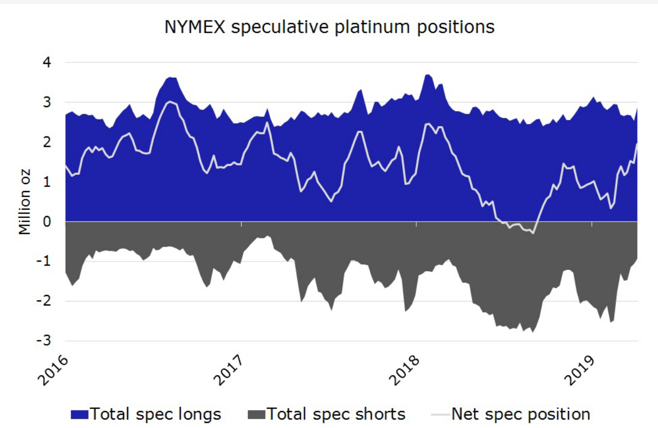
Platinum Demand: Jewellery '000 oz									
	Gross			Recycling			Net		
	2017	2018	2019	2017	2018	2019	2017	2018	2019
Europe	176	191	192	-5	-5	-5	171	186	187
Japan	305	298	299	-222	-196	-179	83	102	120
North America	238	230	231	0	0	0	238	230	231
China	1,470	1,316	1,250	-515	-526	-531	955	790	719
Rest of World	211	234	255	-4	-4	-4	207	230	251
Total	**2,400**	**2,269**	**2,227**	**-746**	**-731**	**-719**	**1,654**	**1,538**	**1,508**

platinum; purchasing decisions are more likely to be motivated by the availability of attractive designs or specific gemstones. In response to these changes in consumer behaviour, manufacturers and retailers have expanded their ranges of karat gold jewellery, which is typically priced per piece rather than per gram, and which enables both fabricators and distributors to earn better margins.

The capital cost of switching from platinum to karat gold production is relatively low, so there is little incentive for established platinum jewellery makers to defend platinum's share of the market, and many factories have switched part of their production to karat gold. There have been some efforts to introduce per piece pricing for platinum jewellery, but to date this does not appear to have been successful.

The decline in the Chinese jewellery market was partly offset by expanding demand in India, where consumption of platinum in jewellery is still growing at double-digit rates, albeit off a relatively small base. Overall, after accounting for recycling, net world platinum jewellery demand fell by 7%.

With weaker demand in the automotive, jewellery and investment sectors, the platinum market moved to a surplus of around 370,000 oz last year. Investor sentiment became increasingly negative during 2018, and this was reflected in a significant build-up in speculative short positions on the futures markets. The net long position on NYMEX declined by over 2.7 million ounces between February and September 2018, and during the third quarter, speculative positioning was consistently 'net short' for the first time since 2004. This drove the platinum price downwards, from the year's high of $1,020 per ounce in January to a low of $772 in September. During the final quarter, speculators reduced their short positions, and the price staged a modest recovery, ending the year just below $800.



"Increasingly negative investor sentiment in 2018 was reflected in a build-up in speculative short positions on the futures markets."

Platinum Outlook

Supply and Demand in 2019

- A dramatic turnaround in investor sentiment stimulated heavy buying of platinum ETFs in early 2019.
- Investors were motivated by supply disruption risks and an improving outlook for auto demand.
- The implementation of stricter heavy duty emissions limits will boost platinum consumption in China and India over the next two years.
- High palladium prices could boost platinum use in diesel catalysts, at the expense of palladium, but substitution in gasoline applications is more challenging.
- Industrial demand will be supported by Chinese capacity expansions but will fall short of 2018's exceptional total.
- Net demand for platinum jewellery will fall again, with subdued retail demand and rising scrap rates in China.
- Auto recycling will also rise again, although processing capacity constraints may check growth.
- The release of pipeline stocks should lift South African supplies by 2%, assuming no production disruption occurs.

The platinum market is expected to move into deficit in 2019, with a resurgence in investor activity outweighing modest falls in industrial and jewellery demand. We also expect a tentative recovery in autocatalyst consumption, as stricter heavy duty emissions legislation is enforced first in China and then in India. We forecast a modest increase in primary supplies, but this could be tempered by electricity shortages and, potentially, industrial action in South Africa, while growth in recycling may be dampened by processing capacity constraints in some regions.

During the first quarter of 2019, investors took advantage of low platinum prices to purchase nearly 700,000 oz of platinum ETFs. The steep climb in the palladium price since August 2018 has led some investors to conclude that platinum appears under-priced, in view of its potential to substitute for palladium in automotive applications in future. At the same time, the outlook for pgm mining in South Africa is increasingly uncertain, with producers facing steep increases in electricity prices, periodic disruption to power supplies, and a risk of industrial action during forthcoming wage negotiations. The result has been a dramatic turnaround in sentiment, particularly among European and South African ETF investors, who together bought 637,000 oz of platinum between January and March 2019. This appears to be net new investment in pgm, rather than investors switching out of palladium into platinum.

This reversal in sentiment and the recent improvement in price do not yet reflect any significant, fundamental changes in platinum consumption in automotive or industrial applications. Despite the recent surge in ETF buying, our estimates suggest that the platinum market will be in only a modest deficit in 2019. Excluding investment, we think that demand will fall marginally this year, mainly due to weakness in the Chinese platinum jewellery sector.

There is clearly some short-term downside risk to primary supplies, which could continue to support both price and investor sentiment. There is also some upside risk to demand. High palladium prices have, to date, had only a very limited impact on platinum consumption, but in the last year several new test programmes on platinum-containing three-way catalysts have been initiated. Although there are technical challenges to overcome, we think there may be potential for additional platinum use in gasoline applications within a two- to three-year timeframe.

It is impossible at this stage to predict how durable the recent surge in investment will prove. We observed in our February report that liquidation of platinum ETFs in the last four years has been limited because most investors were 'out of the money'. This suggests that there may be potential for any price rallies to trigger 'pent up' selling by ETF investors, partly offsetting new purchasing. Our forecast includes the 700,000 oz of platinum purchased in the first quarter but takes a neutral view of the rest of the year, assuming that any further buying will be offset by profit taking.

In Japan, investors have historically taken advantage of periods of negative market sentiment to buy into falling platinum prices; this means that Japanese investment demand often runs counter to trends elsewhere in the world. Between 2015 and 2018, as the retail platinum price moved down through ¥4,000 and then ¥3,500 per gram, and to a historically wide discount to gold, Japanese investors acquired over 1.5 million ounces of platinum in the form of bars purchased over the counter from bullion houses.

Looking forward, the outlook for Japanese bar demand is more subdued. Demand should remain in positive territory while the retail price remains below ¥4,000 per gram, while any downward price corrections still have the potential to stimulate additional buying. However, if the price moves above ¥4,000 per gram we think there could be some net selling back to the market.

Platinum supplies are forecast to rise modestly in 2019, assuming the South African pgm industry can navigate obstacles such as power shortages, electricity cost increases and potential strike action. Although platinum price weakness has resulted in significant rationalisation of the pgm mining industry in recent years, to date this has had surprisingly little impact on pgm output. Shaft closures have been broadly offset by the ramp-up of some newer, more profitable operations, along with an increase in the amount of metal recovered from the retreatment of chrome and pgm tailings. While there are some further shaft closures to come, we think that the South African pgm industry can probably maintain mine output at levels close to those seen in 2018 for at least one more year. In addition, there is currently some excess pgm in refinery pipelines which should be released during 2019.

Eskom, South African's state-owned electricity supplier, initiated regular load shedding during the first quarter of 2019, to allow the domestic grid to cope with a shortage of generating capacity. During load shedding, miners and refiners are required to reduce their electricity consumption, which is typically achieved by reducing power to processing plants rather than by halting mining operations. This means that the impact on mine production has so far been limited, but fluctuations in electricity supply may have affected producers' ability to draw down their processing backlogs during the first quarter. At the time of writing, in early April, load shedding had been suspended, allowing processing operations to return to normal. Our forecast assumes that producers will be able to release most of their excess pipeline inventory by the year end.

With some South African producers about to enter wage negotiations, and fierce labour union opposition to the takeover of Lonmin by Sibanye-Stillwater (due to conclude this year), there is potential for industrial action to impact supplies. In 2014, a six-month stoppage at western Bushveld operations owned by Anglo American, Impala Platinum and Lonmin resulted in the loss of over one million ounces of platinum production. Should future strike action affect the same operations to the same extent as in 2014, it could cut platinum output by up to 40,000–45,000 oz per week. However, our current forecast for 2019 does not make any allowance for widespread strike action.

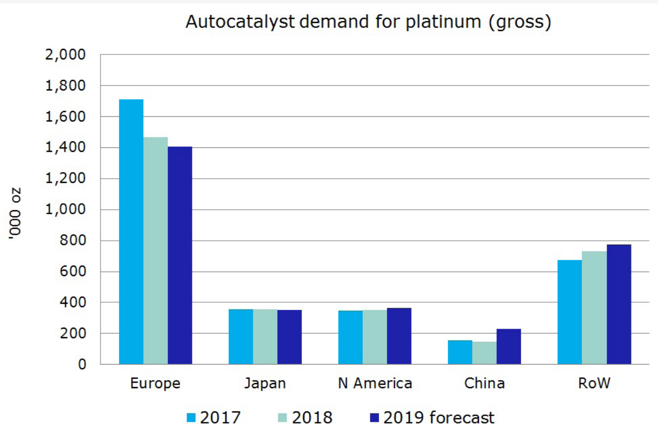
We do not expect any significant changes in Russian platinum production this year. The pgm grade of ores mined at Norilsk continues to decrease gradually, reflecting an increased reliance on lower-grade disseminated ores. However, output will be supported for at least one more year by the refining of old copper concentrate. This material originates from historic pgm mining activities in the Norilsk-Talnakh area and was purchased from the state corporation Rostec in 2017. Norilsk has used it to replace production from stored pyrrhotite concentrate, which was an important source of pgm for a number of years until stocks were exhausted in 2017.

We believe that the platinum to palladium ratio in the Rostec copper concentrate is lower than in pyrrhotite concentrate, and that this explains why Norilsk Nickel expects platinum output to remain stable while palladium production reaches ten-year highs. Looking further ahead, Norilsk is evaluating a large open-cast expansion at its 'Southern Cluster' mining operations, but this is unlikely to contribute to production before about 2023.

We expect secondary supplies to rise by around 5% this year, reflecting underlying growth in the autocatalyst recovery sector, and assuming that some of the metal that built up in processing pipelines during 2018 is released. However, refinery capacity constraints could continue to dampen growth in secondaries in the short term. For platinum, capacity issues have been exacerbated by the fact that most refiners can handle only limited quantities of diesel particulate filter scrap, because of its silicon carbide content. Scrap with an elevated silicon carbide grade must usually be blended with other scrap materials to limit the carbon content of smelter feed.

Combined primary and secondary supplies are forecast to rise by 2% this year. However, supply growth will be outpaced by 9% gains in gross demand, primarily due to the surge in ETF investment, discussed above. In addition, we expect a modest recovery in purchasing by automakers, and consistently strong demand in industrial applications. However, there will be a further contraction in the Chinese platinum jewellery market.

After setting a five-year low in 2018, autocatalyst demand is forecast to recover modestly this year, as an increase in catalyst fitment on heavy duty trucks in China and India offsets a further fall in diesel car production in Europe. Consumption will also be supported by a small increase in global average platinum loadings on light duty diesels; loadings are increasing in India to meet Bharat Stage VI (BSVI) legislation which will be enforced starting in 2020, and in North America, where increasing numbers of vehicles meet US Federal Tier 3 limits. In Europe, the platinum



"Autocatalyst demand is forecast to recover modestly this year, as increases in China and India offset a further fall in Europe."

content of diesel aftertreatment systems has stabilised after two years of decline.

Demand for platinum in heavy duty catalysts is forecast to rise significantly over the 2019–2021 period, as the implementation of China VI then BSVI emissions regulations results in the addition of advanced platinum-containing aftertreatment systems to all trucks sold in China and India. In the past, many vehicles sold in these countries were not equipped with pgm-containing aftertreatment systems, while those which did carry catalysts typically had low platinum loadings.

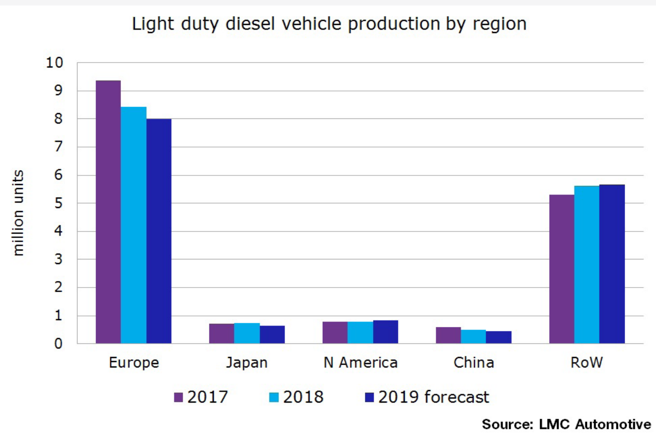
In China, the proportion of heavy vehicles equipped with pgm-containing catalysts is expected to rise sharply this year. The government's 'Blue Sky Protection' plan has seen the early rollout of China VI legislation in a number of cities and provinces, with the result that trucks sold in these areas will be equipped with advanced aftertreatment systems from July 2019. The new standards will apply to all vehicles nationwide from the middle of 2021.

While there is already quite widespread use of catalysts in the Indian truck market, these aftertreatment systems currently have low platinum loadings or contain no pgm at all. This is set to change over the next two years, as the market transitions directly from BSIV (equivalent to Euro IV) to BSVI (equivalent to Euro VI) standards starting in April 2020. This step change in emission limits will have a significant impact on aftertreatment system complexity and on catalyst loadings.

In contrast, global use of platinum in light duty vehicle catalysts is forecast to contract by around 2% this year, as the impact of a shrinking European diesel market is softened by gains in some Rest of World countries. European diesel car production fell by 10% in 2018 and is expected to retreat by a further 5% this year, to a ten-year low of under eight million units. This represents a 17% contraction in European diesel production volumes since the post financial crisis peak in 2016. Platinum demand has fallen faster than diesel car output: consumption in European light duty diesel applications this year will be about 22% lower than in 2016, despite the implementation of successive phases of Euro 6 legislation.

This decline in demand reflects a move towards non-pgm SCR technology for NOx control, combined with increasing use of SCRF, which combines SCR and particulate filter functions on a single non-pgm brick. Although the implementation of the final phase of Euro 6d legislation will begin in January 2020, further limiting permitted NOx emissions during real driving emissions testing, we expect the resulting growth in SCRF adoption to offset increases in platinum loadings elsewhere in the aftertreatment system.

India is the second largest world market for light duty diesel cars, but with local light duty emissions legislation



"European diesel car production is expected to retreat by a further 5% this year to a ten-year low of under eight million units."

currently equivalent to European stage 4, diesel catalyst loadings are typically light. This is set to change with the implementation of BSVI (similar to Euro 6) emissions standards next year. The new limits for NOx and particulate matter are significantly tighter than under BSIV, and will result in the fitment of particulate filters and additional NOx aftertreatment.

We expect some models sold this year to meet these stricter standards, lifting the average platinum content of an Indian diesel car significantly in 2019. There should be further double-digit growth in loadings over the next couple of years, but these gains could be partly offset by declining diesel car production. The gap between diesel and petrol prices is narrowing, while the cost of BSVI aftertreatment systems could make smaller diesel cars uncompetitive.

With palladium prices setting new records in the first quarter of 2019, and the premium over platinum widening to over $600 per ounce on average, there has been increased speculation about the potential to move away from palladium and towards platinum in some autocatalyst applications. However, to date, recent palladium price gains have not had any measurable impact on automotive pgm demand. Looking forward, there may be near-term potential to replace some palladium with platinum in the light duty diesel sector. Substitution in gasoline three-way catalysts will take longer to achieve and will require significant improvements in technology.

All light duty diesel aftertreatment systems incorporate one or more platinum-containing bricks: diesel oxidation catalysts (DOCs), diesel particulate filters (DPFs) and NOx traps. Between 2005 and 2013, both for technical reasons and to reduce cost, there were sharp increases in the palladium content of diesel catalyst systems, displacing some platinum. This was particularly true in North America, where the average platinum to palladium ratio in light duty diesel applications is currently around 1:1, compared to 3:1 in Europe.

More recently, there has been a modest reversal of this trend, though this has been for technical rather than economic reasons: a higher platinum content can help optimise the exhaust gas stream for downstream NOx conversion over the SCR brick. Looking forward, there may be some potential to accelerate this move back towards platinum in diesel catalysts, especially in DOCs, although palladium will still be required to provide thermal stability. We think that this could add a few tens of thousand ounces of platinum demand in the short to medium term.

In the longer term, there may also be some potential for substitution in gasoline applications. High palladium prices have led to an intensification of programmes to develop and test platinum-containing three-way catalysts. However, it remains difficult to match the performance of existing palladium-rhodium catalysts, especially in hotter 'close-coupled' (close to the engine) configurations, because palladium has better thermal stability than platinum under typical gasoline exhaust temperatures. Even if platinum-rich three-way catalysts can demonstrate equivalent performance, any meaningful substitution is likely to take at least two to three years. Automakers are already devoting enormous technical resources to meeting tightening legislation, while the introduction of real driving emissions (RDE) testing in major markets is inciting the adoption of more conservative emissions strategies that prioritise compliance over cost.

Consumption of platinum in industrial applications is forecast to be slightly lower than last year's record total but will nevertheless be the second highest level on record. Buoyant demand is primarily due to structural factors, with glass, petroleum and chemicals companies adding capacity to meet growing demand for products such as fibreglass, plastics and silicones. Platinum's low price compared to other pgm has not been an important factor in most industrial applications, where pgm demand is generally insensitive to price.

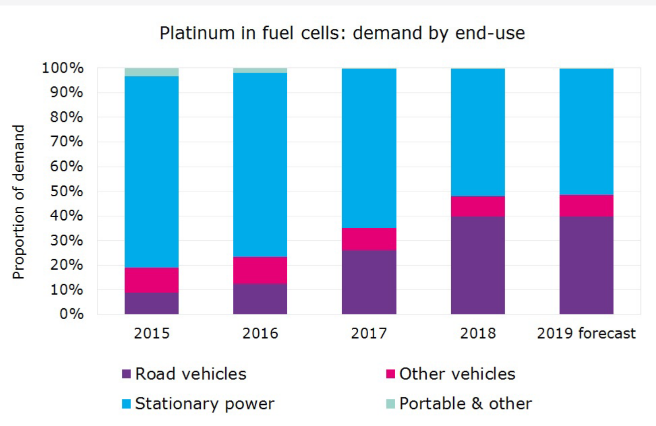
The exception is the glass industry, where high rhodium prices are stimulating an increase in the platinum content of platinum-rhodium alloys used in fibreglass bushings, at the expense of rhodium. However, to date this has had only a modest impact on platinum usage. Most glass demand is a consequence of capacity increases, stimulated by rising global fibreglass consumption in the construction, automotive, renewable energy and mobile communications sectors.

Purchases of petroleum refining catalyst should remain buoyant in 2019, with further capacity increases in the 'teapot' (independent) crude refinery sector in China to provide feedstock for downstream petrochemicals plants. There is also potential for some additional consumption in novel petroleum refinery applications, where the use of platinum catalysts in place of established processes can be justified by improved safety, superior product quality and a better environmental profile.

Purchasing of platinum catalysts by the chemicals industry is forecast to set new highs over the next two years, as the construction of several large integrated petrochemical complexes in China approaches completion and catalyst charges are installed. These complexes typically incorporate large paraxylene units which may require an initial charge of several tens of thousands of ounces of platinum.

In the electrical sector, demand for platinum in hard disks is forecast to be flat to slightly down this year. Solid-state drives (SSDs) have taken a significant share in consumer applications but have in the past been too expensive to displace hard disk drives (HDDs) in the enterprise and nearline data storage sectors. However, the SSD market moved into oversupply in the second half of 2018, and prices have fallen sharply. This has enabled SSD to gain a foothold in enterprise applications and it may even begin to encroach on the nearline ('cloud') market in future. Going forward, this will tend to moderate growth in platinum demand in HDDs, although in the medium term there is potential for the commercialisation of next-generation hard disk technology to boost platinum consumption.

Consumption of platinum in fuel cells is expected to see another year of double-digit gains in 2019, although we expect the pace of growth in the Chinese fuel cell vehicle (FCEV) market to slow following a cut in central government subsidies. This subsidy reduction could eliminate some of the smaller market participants, but it may provide a base for more sustainable market development going forward. Under the new policy, part of the subsidy will be paid after the vehicle is registered, with the remainder due once the vehicle has operated for 20,000 km. However, the subsidy may be withdrawn completely for registered FCEVs which fail to reach this requirement within two years. This should provide an incentive for Chinese local government authorities to invest in hydrogen refuelling infrastructure to support local FCEV producers. The new central government policy explicitly permits local authorities to offer support for the development of charging and hydrogen infrastructure, and also allows them to provide a local purchase subsidy for FCEVs (and battery electric buses, but not battery electric cars). Several local governments



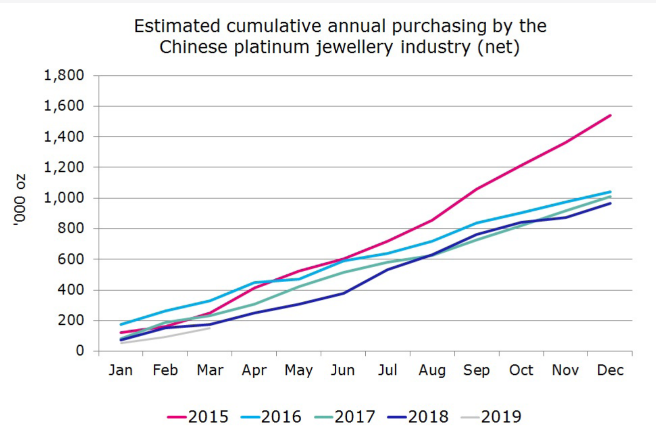
"Platinum consumption in fuel cells should see another year of double-digit gains in 2019, although the pace of growth in China will slow."

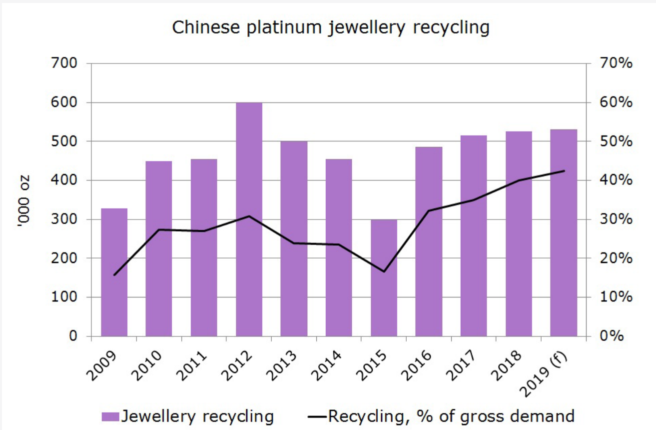
have recently announced plans to provide support for the FCEV sector.

While the outlook for investment, industrial and automotive demand is largely positive, this is less true for the jewellery sector. The Chinese platinum jewellery market had a very slow start to 2019: based on trade data and Shanghai Gold Exchange (SGE) statistics, net purchasing of platinum for jewellery manufacture appears to have fallen sharply in the first quarter. However, we believe that the picture may have been distorted by purchasing by individuals and companies connected to the jewellery sector, which occurred during the second half of 2018, but which we did not include in our demand estimates for last year. As platinum prices rose in early 2019, it is possible that this metal was sold on to jewellery fabricators.

Our forecast envisages a further 5% decline in gross platinum jewellery fabrication in China, reflecting a combination of economic uncertainty, a shift in consumer preferences towards karat gold jewellery, and the relative ease with which manufacturers can switch their production between the two metals to maximise margins. With only minimal capital investment and staff retraining required to switch from platinum to 18 karat gold, many platinum jewellery fabricators have chosen to diversify their output.

Chinese jewellery manufacturers continue to source a significant percentage of their metal needs from scrap. Traditionally, there was no cash market for platinum jewellery scrap in China: consumers returned unwanted jewellery pieces to retailers, exchanging them for new designs. However, recent years have seen the development of a network of independent scrap collectors who purchase old jewellery for cash, and jewellery retailers in some cities have now begun to offer this service. Looking forward, we think that the proportion of jewellery fabrication demand that is supplied from old scrap will continue to rise, and we therefore anticipate further declines in net platinum consumption, even if retail demand for platinum jewellery stabilises.





Special Feature:

Emissions Legislation in Europe

An evolving context for pgm demand

The years since 2017 have seen something of a revolution in European light vehicle emissions legislation. The roots of this date back over ten years, but much of the shakeup was catalysed by the 2015 emissions scandal. Occasionally obscure, and certainly not as high-profile as the consequences of the scandal for the automakers under investigation, the legislative developments are nonetheless having a considerable practical impact on aftertreatment design and vehicle loadings.

This will not be confined to Europe: developments to vehicle test procedures are being coordinated by the UN and will be implemented in other major markets, notably China, with the implications for demand in those regions yet to play out.

This article is an overview of the progress in European light vehicle emissions legislation presently underway. Although necessarily a summary and a simplification, the aim is to provide some context for the upward pressure on automotive pgm demand in Europe.

Addressing the real-world gap

European regulators had been aware of the discrepancy between laboratory test results and real-world emissions for years before the emissions scandal broke, with the inadequacy of the NEDC (New European Driving Cycle) laboratory test identified as the cause. As a result, the Euro 5 and 6 regulation published in 2007 already made provision for future amendments to the laboratory test cycle, and the incorporation of emissions generated by 'real' driving. The amendments were slow to come, however, and in 2015 automakers were still only required to demonstrate emissions compliance on the NEDC.

Shortly after 'Dieselgate', the European Parliament set up an inquiry into emission measurements in the automotive sector, known as the EMIS Committee, to investigate how the emissions scandal could have happened. The Committee's final report was published in March 2017; it considered that the inadequacy of the NEDC was only partly to blame. Nor was the fault to be found with any limitation in emissions control technology. Rather, it concluded that a lack of political will in implementing legislation had contributed to a situation where real-world emissions could consistently exceed limits, despite compliance with laboratory tests.

Following the results of the EMIS inquiry, several amendments were made to the EU's Type Approval Framework; the new Framework Agreement was published in June 2018 and enters into force next year. It allows for inclusion of results from recognised third-party testing organisations. Also, as previously, Member States are required to impose penalties on manufacturers found to not be meeting requirements, but a new clause allows the Commission to impose a fine of up to €30,000 per non-compliant vehicle if the Member State does not act sufficiently robustly. These were strong signals of growing legislative intolerance for non-compliance, sent just as the long-awaited amendments to the test cycles were finally being implemented.

Replacing the NEDC

The WLTP is a laboratory testing method, developed as a global programme under the United Nations Economic Commission for Europe (UNECE) as a more realistic laboratory driving test. (The WLTP is the World Light Duty Test Procedure, which is the complete framework of the test procedure, test conditions and test cycle. The WLTC is the World Light Duty Test Cycle, which forms part of the procedure.) This was primarily done to address the gap between reported type-approval CO_2 and fuel economy figures with those observed in real life, with the secondary aim of reducing various loopholes in the testing of vehicles.

The new protocol (or parts of it), will be used in several major automotive markets: Japan adopted the test from 2018 but is not including the extra high speed portion of the test since it is higher than its national speed limit; China will use the WLTP from China 6a in 2020. The US Environmental Protection Agency has been involved in all WLTP discussions but at this stage has no plans to adopt it, as it believes the current US test procedures are more representative of real driving conditions than the test cycles in use elsewhere.

In Europe, the WLTP applied to emissions testing of all new type approvals (new models) from September 2017, and to all new vehicle registrations from September 2018 (first to passenger cars, and then to all new light commercial vehicles a year later).

Compared to the NEDC, the WLTC is a hotter, more transient cycle. It is also a longer cycle, running for thirty minutes rather than twenty, which can be helpful for compliance in that it provides more dilution of cold-start emissions when averaged over the whole cycle. However, the characteristics of the cycle mean that high-speed NOx emissions can be higher, as average exhaust flow rate is higher. In theory, this could mean more catalyst volume is necessary, but can also be addressed through adjustments to engine calibration and urea dosing strategies.

As the WLTP mandates that every variant of a vehicle must be individually tested to determine the effect of modifications such as sunroofs and alloy wheels on emissions, it has greatly increased the number of tests

	NEDC	WLTP
Duration	20 minutes	30 minutes
Distance	11 kilometres	23.25 kilometres
Average speed	33.6 km/hour	46.5 km/hour
Maximum speed	120 km/hour	131 km/hour
Driving phases	2 phases	4 phases
	66% urban/34% non-urban	52% urban/48% non-urban
Durations (rounded percentages)	Stop 24%	Stop 13%
	Constant driving 40%	Constant driving 4%
	Acceleration 21%	Acceleration 44%
	Deceleration 15%	Deceleration 40%
Test mass	Kerb weight + 100 kg	Kerb weight + 100 kg + extras + payload
Gear shift strategy	Fixed gear shift points	Vehicle-specific gear positions

A comparison of the NEDC and WLTP laboratory tests, showing key differences

(Source: adapted from wltpfacts.eu and International Council on Clean Transportation) manufacturers have to run, stretching testing resources and initially causing some backlogs. On its own, it does not appear to be having a major impact on vehicle pgm loadings in Europe – for that, we must look to RDE.

Real Driving Emissions testing

RDE – 'Real Driving Emissions' – mandates on-the-road testing of new vehicles for the first time in Europe, in addition to the WLTP lab test. It is being implemented in two phases under Euro 6d: an initial phase called Euro 6d-TEMP, followed by full or final implementation of Euro 6d.

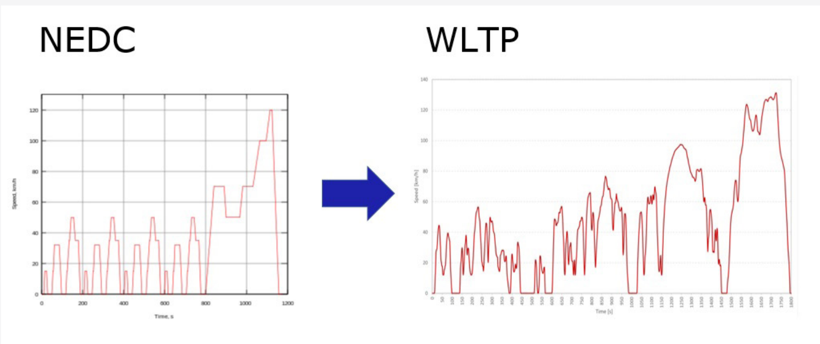
The implementation dates for new models/all new vehicles, passenger cars/LCVs, and nitrogen oxides (NOx)/particle number (PN) emissions are staggered, as summarised in the table on page 18. Automakers have in some cases moved to RDE compliance more quickly than these dates suggest, so that formal implementation is somewhat lagging the rise in average vehicle loadings.

The original Euro 6 regulation, published in 2007, stated that emissions limits are to be met in 'real' driving, providing the legal basis for the later adoption of both RDE and WLTP and allowing for ongoing technical adjustments to the testing process. Euro 6d legislation has been negotiated and agreed in four packages of such adjustments, the last of which was only adopted in May of last year; a fifth package is not expected as the Commission has now stated that Euro 6d is complete. However, future adjustments to RDE testing can be expected. Automakers are thus subject to a procedure that is no longer fixed, but constantly evolving.

The four packages are:

- **Package 1** (published in the Official Journal of the European Union in November 2015): Established the basic RDE test procedure and emissions measurement methodology using portable emissions measurement system (PEMS).
- **Package 2** (published April 2016): Gave details on the timetable for implementation, determination of conformity factors (CFs), plus further technical features for determining a valid RDE test.
- **Package 3** (published May 2017): Set the test method and conformity factors for PN emissions; provisions for testing plug-in hybrids (PHEVs); procedure to include hot and cold starts and catalyst regeneration events (such as when soot is periodically burned off filters).
- **Package 4** (published May 2018): Applies from the start of 2019. Implements in-service conformity testing; second-stage CF for NOx tightened to 1.43 (conformity factors are discussed in more detail below); revised procedure for determining a valid RDE test; further provision for testing of PHEVs.

Laboratory test cycle evolution:



WLTP Class 3 cycle shown (Images: Orzetto/Jmcc500)

In-service conformity testing, as brought in under Package 4, means that automakers now also need to ensure that vehicles can demonstrate emissions compliance in independent RDE testing up to 100,000 km, regardless of how they are driven during their lifetime. Catalyst ageing profiles must therefore be carefully characterised during development testing.

What makes RDE so different?

The challenge of RDE is not just that it takes vehicle testing onto the road for the first time. Vehicles are driven according to random acceleration and deceleration patterns, and the range of parameters that constitute the definition of a 'valid RDE trip' has been set broadly, to encompass as many real-world conditions as possible.

The test window is considerably wider than it ever has been in the laboratory, even with WLTP, greatly expanding the set of conditions that catalysts must work under. Previously, also, emissions control systems could legally be calibrated to operate differently outside of the test window if necessary to protect the catalyst or engine, but the area of engine operation that now falls outside of every conceivable test condition has shrunk to such proportions that it has effectively eliminated the opportunities for protective calibration. Emissions control must now be able to ensure compliance in virtually all parts of the engine map, and catalysts must be more robust.

The unpredictability of RDE is an important consideration for vehicle manufacturers. Due to the broad test window, there is no such thing as a 'typical' RDE cycle. Every trip can vary. When vehicles are subject to independent, third-party testing, this means that an automaker could choose to test its vehicles on a particular RDE route within a certain set of conditions, but must still allow for independent testing on routes that it can't predict and that can be very different. 'Designing to the test cycle' is a thing of the past.

Application of conformity factors

RDE tests measure vehicle NOx and particle number emissions using PEMS loaded onto the back of the vehicle. Because PEMS technology is a relatively recent development, and in acknowledgement of the difficulty of accurately measuring emissions on the road, RDE has initially been brought in with 'conformity factors' applied to the emissions limits. The conformity factor is intended to reflect the measurement error using PEMS and acts as a multiplier of the emissions limit. So, if PEMS measurement uncertainty is determined to be around 50%, a CF of 1.5 is applied – effectively increasing the emissions limit in RDE by 50%.

The main difference between Euro 6d-TEMP and Euro 6d is the NOx conformity factor, which was set at 2.1 for Euro 6d-TEMP and has been reduced to 1.43 for the second stage of RDE. For particle number emissions,

Conditions for a valid RDE trip*

Trip specifications		Provision
Total trip duration		90 to 120 minutes
Distance	Urban	>16 km
	Rural	>16 km
	Motorway	>16 km
Duration	Urban	29% to 44% of distance
	Rural	23% to 43% of distance
	Motorway	23% to 43% of distance
Speed	Urban	<60 km/hour (average 15 to 40 km/hour)
	Rural	60 to 90 km/hour
	Motorway	>90 km/hour (>100 km/hour for at least 5 minutes)

Parameter		Provision
Payload		up to 90% of maximum vehicle weight
Altitude	Moderate	0 to 700 metres
	Extended	700 m to 1,300 m
Altitude difference		<100 m between start and finish
Cumulative altitude gain		1,200 m per 100 km
Ambient temperature	Moderate	0°C to 30°C
	Extended	From -7°C to 0°C and 30°C to 35°C
Stop percentage		6%–30% of urban time
Maximum speed (depends on local limits)		145 km/hour; 160 km/hour for 3% of motorway time
Use of auxiliary systems		Free to use

(Source: adapted from International Council on Clean Transportation)

*not a comprehensive definition

the CF is currently set at 1.5 for both stages. (A particle number limit for gasoline has been implemented under the Euro 6c regulation, bringing gasoline particle number emissions down in line with diesel. This applied to all new passenger cars from September 2018 and will apply to all new light vehicles from September of this year; its effect has been to force the fitment of gasoline particle filters to almost all gasoline direct injection vehicles. The GPFs may or may not have a pgm coating – for more information see page 22).

The European Commission has stated that its intention is to bring the CFs to 1 as soon as possible, and by no later than 2023, which would mean that NOx and PN limits apply in RDE testing without any alteration. However, despite the technical justification for the use of these factors, their existence has been controversial, and has been challenged in the European Court. Although the Court found that the European Commission had effectively altered the emissions limit by introducing conformity factors, and that it did not have the legal power to do so, the Commission is now putting forward a formal co-decision process through the European Parliament to provide a legal basis for the factors as currently set. (It is also appealing the ruling.)

Future emissions regulation

Whether the conformity factors are set to 1 from next year or a couple of years later (depending on the outcome of the above legal process), further tightening of permitted emissions in RDE testing is imminent. The UN process on the WLTP and RDE continues, and both these procedures will evolve further, making the tests themselves more exacting. (China expects to implement RDE in 2023 but has not yet outlined exactly how this will be defined, so the UN process could influence this.)

And then there is 'Euro 7' which, although not named as such or defined yet in any form of regulation, is already featuring in automakers' planning. With expected implementation dates ranging from 2023 to 2025, there is not that much time to prepare, particularly as much tougher emissions limits are anticipated.

Impact on pgm demand

The impetus for higher loadings is, as it has always been, increasingly tough legislation. As this article has discussed, this increasing toughness is now not just a question of degree, but also of kind. Previously, the legislation has focused on reducing emissions by tightening limits. While tightening emissions limits will feature again in future, the key aspect of the current stringency is that it is being driven by changes to the way vehicles are tested. In fact, Euro 6d-TEMP and its successor Euro 6d implement no changes to emissions standards. Yet, as the numbers in this report show, they are resulting in significant growth in pgm consumption on European gasoline vehicles.

Applicable dates for the various regulations discussed here (simplified):

Regulation	Vehicle types	Date
WLTP	PCs new vehicle types	1st September 2017
	PCs all new vehicles	1st September 2018
	LCVs new vehicle types	1st September 2018
	LCVs all new vehicles	1st September 2019
Euro 6c	PCs all new vehicles	1st September 2018
	LCVs all new vehicles	1st September 2019

Regulation	Vehicle types	Date	NOx CF	PN CF
Euro 6d-TEMP	PCs new vehicle types	1st September 2017	2.1	1.5
	PCs all new vehicles	1st September 2018		1.5
		1st September 2019	2.1	
	LCVs new vehicle types	1st September 2018	2.1	1.5
	LCVs all new vehicles	1st September 2019		1.5
		1st September 2020	2.1	
Euro 6d	PCs new vehicle types	1st January 2020	1.43	1.5
	PCs all new vehicles	1st January 2021	1.43	1.5
	LCVs new vehicle types	1st January 2021	1.43	1.5
	LCVs all new vehicles	1st January 2022	1.43	1.5

Palladium Summary

Supply and Demand in 2018

- Although the market deficit narrowed, palladium prices surged to record levels in 2018 and lease rates peaked at over 30%.
- Producer stock sales, higher recycling and heavy ETF liquidation were not enough to support market liquidity.
- Auto demand rose by 2%, despite lower Chinese car output, as stricter vehicle testing lifted European loadings.
- Industrial demand was supported by exceptionally strong consumption in the chemicals industry.
- Higher auto scrap volumes boosted secondary supplies by 9%, despite pgm refinery capacity constraints
- Primary supplies were also up 9%, with sales from producer stocks augmenting shipments.

Palladium Supply and Demand '000 oz

Supply	2017	2018	2019
South Africa	2,547	2,543	2,744
Russia	2,452	2,976	2,792
Others	1,409	1,458	1,460
Total Supply	**6,408**	**6,977**	**6,996**
Gross Demand			
Autocatalyst	8,532	8,721	9,496
Jewellery	173	157	156
Industrial	1,827	1,918	1,812
Investment	-386	-574	-310
Total Gross Demand	**10,146**	**10,222**	**11,154**
Recycling	-2,863	-3,124	-3,349
Total Net demand	**7,283**	**7,098**	**7,805**
Movements in Stocks	-875	-121	-809

The palladium market deficit narrowed in 2018 with selling from producer stocks, higher recycling and further heavy liquidation of ETF holdings. However, there remains an underlying, long-term discrepancy between primary production and net industrial consumption, mainly due to relentless expansion in autocatalyst demand. Last year, purchases by automakers rose by a further 2% to a record 8.7 million ounces, while there was also unusually strong activity in the chemicals industry. Heavy consumer buying kept the physical market exceptionally tight: lease rates peaked at over 30% in late 2018, and the price set a new high of $1,274 in December.

Last year marked the seventh consecutive year of deficit in the palladium market. Although our estimates suggest that the deficit in 2018 was relatively small, at only 120,000 oz, market liquidity worsened dramatically during the second half of the year, with short-term lease rates spiking above 15% in June and peaking at over 30% in December. Following a period of price weakness in mid-year, when investors were spooked by concerns about a US-China trade war, the palladium price climbed steeply during the September to December period, from an annual low of under $850 in August to $1,270 per ounce at the year end.

Russian government selling during the 1990s and 2000s led to the accumulation of large market stocks of palladium, some of which were held in vaults in the UK and Switzerland as part of the market clearing system. However, this inventory has been heavily depleted in recent years: since 2007, we estimate that around 11.6 million ounces of palladium has been withdrawn from Swiss and UK stocks. This total is larger than our estimate of the cumulative market deficit over this period, suggesting that this drawdown was partly due to the relocation of metal. Regardless of their location, remaining stocks of palladium – including unknown quantities of palladium produced during the Soviet years which have ended up in the ownership of the Russian Central Bank – do not appear to be readily available to the market.

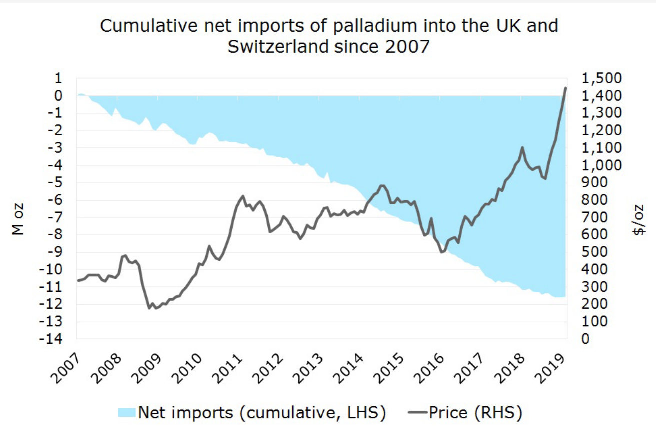
Although our headline figures suggest a market in only a modest deficit, two factors which are not fully captured by our supply and demand measurements may have contributed to unusual market tightness. Firstly, we consider autocatalyst demand to occur at the time of vehicle production, because the precise timing of physical metal acquisition is not easy to determine. During periods of sharply rising loadings – as is the case in Europe and China at present – there may be significant increases in manufacturers' work-in-progress inventories of pgm ahead of vehicle production. As a result, when step changes in legislation occur, our figures may underestimate physical demand in any single annual period.

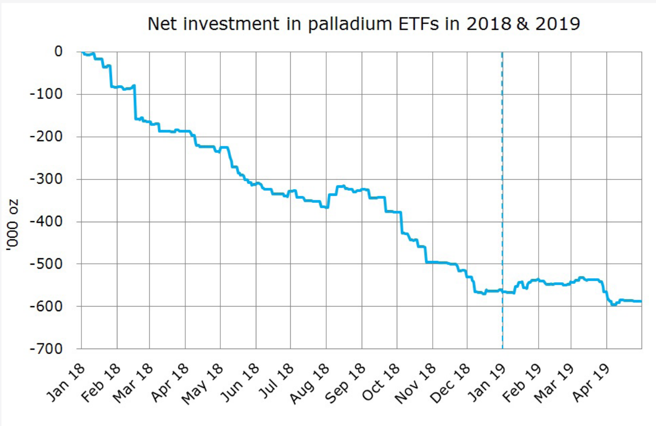
Secondly, we believe that recent refinery closures have led to a shortage of secondary refining capacity, resulting in a lengthening of processing lead times for recycled pgm, and a corresponding increase in semi-refined inventories. We have adjusted our estimates of autocatalyst recovery to allow for longer processing times. However, our figures may still underestimate the wider impact of very high capacity utilisation rates at pgm refineries. Most industrial applications involve a continuous 'closed-loop' cycle in which pgm-containing materials (such as spent chemical process catalyst) are regularly replaced and recycled. These closed-loop recycling circuits have also been affected by extended lead times, but this effect is difficult to quantify.

Last year's extreme market tightness occurred despite substantial injections of liquidity in the form of stock sales by primary producers and further disinvestment. Sustained liquidation of ETF holdings returned over 550,000 oz of palladium to the market during 2018, as high prices stimulated profit taking in virtually all palladium ETF products in all regions. South African investors were the largest sellers, as gains in the dollar price were amplified by exchange rate movements, lifting palladium to a series of record rand-denominated prices during the final quarter.

Norilsk Nickel sold 2.97 million ounces of palladium in 2018, of which we estimate that around 250,000 oz were sourced from stocks of primary metal, produced but not sold in 2017 and held temporarily in the company's Global Palladium Fund. The purpose of this fund is to improve the security of supply for Norilsk's industrial customers; as well as primary metal, it also holds palladium acquired from pre-existing market stocks (the sale of which we do not count as fresh supply).

Underlying refined production from Norilsk Nickel was unchanged at 2.73 million ounces, with palladium production from the company's mines once again





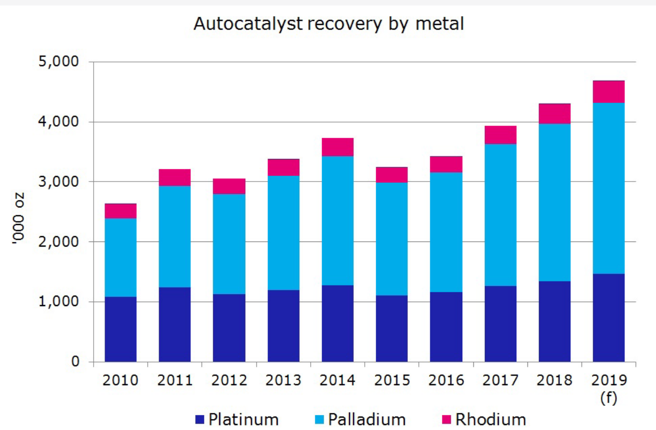
supplemented by the processing of surface materials. These include old copper concentrate, derived from mining activities in the Norilsk area during the Soviet era, and purchased from the state-controlled corporation Rostec in 2017. The company originally planned to treat this material over a four-year period, but we believe that it has been processed at a faster rate than initially planned.

Shipments of palladium from South Africa were also flat, despite an exceptionally strong performance from the palladium-rich Mogalakwena mine. While total mine output of palladium improved slightly, this was offset by an increase in inventories of semi-processed palladium in refinery pipelines. In North America, output of byproduct palladium from nickel smelters was subdued. However, supplies were boosted by Stillwater's Blitz expansion project, which delivered significant quantities of metal for the first time, while North American Palladium also lifted output at its Lac des Iles mine. Overall, we estimate that primary supplies rose by 9% to 6.98 million ounces.

We have reduced our figure for secondary supplies to reflect capacity issues in the secondary refining sector discussed above, although our figures still show growth of 9% in secondary palladium recoveries, to 3.12 million ounces. The volume of spent catalyst removed from scrapped vehicles rose significantly last year, as the market continued to recover from a period of weak vehicle recycling activity during 2015 and 2016. At the same time, the palladium content of spent catalysts continued to rise in line with historic trends in palladium loadings, especially in the US market, where palladium-rich three-way catalysts – often very highly loaded by modern standards – were in wide use from the 1990s. This rapid increase in both scrap volumes and contained pgm has created some bottlenecks in the collection, smelting and refining network, which have been exacerbated by recent rationalisation in the secondary refining industry.

The automotive scrap collection network is primarily a cash business: collectors purchase spent catalyst from scrap merchants for cash but receive payment for the contained pgm only several weeks or months later. As a result, the rise in metal prices has created a financing constraint for some market participants, who have had to turn business away. While we do not believe that large stocks of unwanted catalyst scrap have accumulated, it is likely that some lower-grade or more contaminated scrap is taking longer than in the past to move from the scrap yard to the final refiner.

Refineries are also operating close to their capacity limits. This has led some market participants to become more selective about the materials they accept for treatment, and has also contributed to an increase in average smelting and refining lead times across the industry. In view of increased inventories of unprocessed and semi-processed pgm across the autocatalyst recycling sector, we have downgraded our estimate of growth in palladium



"Despite constraints in secondary refining capacity, the volume of spent autocatalyst continued to recover last year from the weak recycling activity during 2015 and 2016."

Palladium Demand: Autocatalyst '000 oz (Gross)			
	2017	**2018**	**2019**
Europe	1,700	1,889	2,042
Japan	829	857	902
North America	2,106	2,109	2,117
China	2,179	2,081	2,558
Rest of World	1,718	1,785	1,877
Total	**8,532**	**8,721**	**9,496**

recoveries from automotive scrap to 11% in 2018 (versus 13% in our February report).

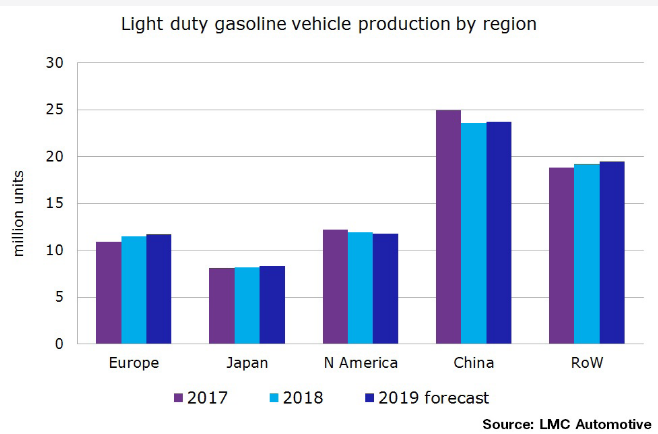
Gross demand for palladium rose by 1% to 10.2 million ounces, as growth in the auto and chemicals sectors outweighed redemptions by ETF holders. Automotive demand recorded a new high of 8.72 million ounces, up 2.2%, even though there was a slight decline in global light duty gasoline vehicle production. Gains in automotive palladium use in 2018 were mainly due to significant growth in palladium loadings on European gasoline catalyst systems.

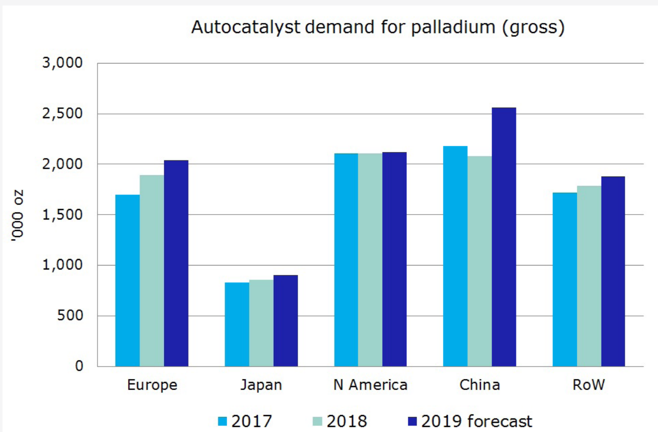
The progressive enforcement of Euro 6d-TEMP legislation has been highly positive for palladium loadings on gasoline vehicles. The new regulations extend emissions compliance for PN and NOx from the laboratory to the real world, via 'real driving emissions' (RDE) testing using portable emissions measurement equipment. The phase-in of Euro 6d-TEMP began in September 2017, initially applying only to new passenger car models; these standards will extend progressively to all new light vehicles by September 2020.

In addition, a more stringent laboratory test, known as the WLTP (Worldwide Harmonised Light Vehicle Test Procedure), was introduced in September 2018, replacing the less demanding NEDC cycle (see page 15). This has also increased the testing burden for automakers, although it is a less dramatic change for emissions compliance than the implementation of RDE.

Because vehicles are now being tested under a wider range of conditions, emissions control has become significantly more challenging. This has resulted in an increase in both the complexity of aftertreatment systems, and their pgm content. In particular, there has been a significant rise in average loadings on three-way catalyst bricks.

The introduction of a particle number limit under Euro 6c – with a phase-in period that overlaps that of Euro 6d-TEMP – has also had consequences for aftertreatment system design. In particularly, many gasoline direct injection (GDI) models are now being fitted with gasoline particulate filters (GPF) in addition to three-way catalysts. The pgm content of GPFs is extremely variable: some filters do not have a pgm coating, while others have relatively light pgm loadings to assist with the 'regeneration' process during which captured soot particles are periodically burnt off. However, some GPF bricks are designed to provide additional three-way pollutant conversion capacity in addition to functioning as a filter. These bricks may have loadings similar to those on a three-way catalyst.





Palladium Demand: Industrial '000 oz			
	2017	2018	2019
Chemical	449	565	502
Dental	391	364	328
Electrical	843	807	795
Other	144	182	187
Total	**1,827**	**1,918**	**1,812**

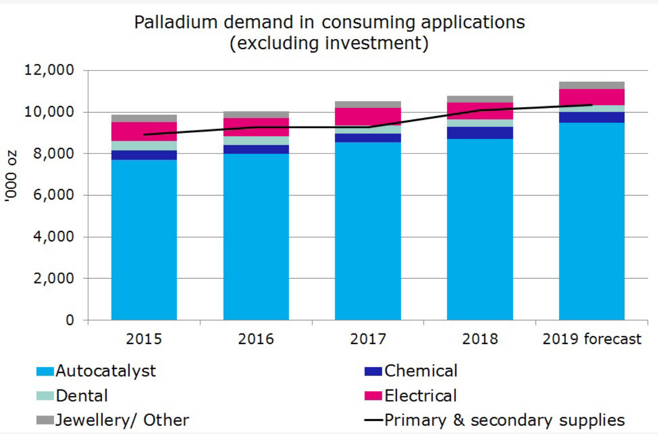
Because of the phase-in schedule, only a minority of vehicles met Euro 6c and Euro 6d-TEMP standards in 2018, but this was enough to lift European palladium loadings by more than 10% last year, reversing the thrifting seen since 2014 and lifting average palladium loadings on European gasoline cars to their highest level since the early 2000s. Please refer to page 14 for more information on Euro 6 emissions legislation.

In contrast, demand in the two largest palladium autocatalyst markets was lacklustre. Consumption by North American automakers was flat; although there was a modest increase in palladium loadings on gasoline vehicles, due to the continuing phase-in of Tier 3 US Federal emissions legislation, this was offset by a decline in light duty vehicle production.

In China, demand for palladium was hit by a sharp contraction in car production, with light duty gasoline output falling by nearly 1.4 million units (6%) – the first annual decline for at least ten years. Although Chinese car sales have slowed slightly, in line with slowing economic growth, this drop in vehicle production was primarily a reaction to excess inventory levels in the distribution chain. In addition, there was a modest decrease in pgm loadings on gasoline catalysts, as automakers took advantage of a final opportunity to thrift the pgm content of China 5 catalysts, ahead of the phase-in of China 6 legislation starting in July 2019.

Going forward, both these markets are expected to see increases in palladium loadings as legislation tightens over the next few years; in China, these changes will be particularly significant. The impact of forthcoming China 6 emissions legislation is discussed on page 25.

The use of palladium in industrial applications rose slightly in 2018. Purchasing by the chemicals sector exceeded half a million ounces, with strong investment in new capacity for the production of hydrogen peroxide and purified terephthalic acid. However, dental and electronics applications continue to be impacted by thrifting and substitution. In the dental sector, ceramics continue to take market share from palladium dental alloys, but during the final quarter of 2018 – as the palladium price approached that of gold – there was also some substitution with high-gold products.



"There is a long-term discrepancy between supply and demand of palladium, mainly due to expansion in autocatalyst demand."

Palladium Outlook

Supply and Demand in 2019

- Gross palladium demand is set to rise by 9% in 2019, as lower industrial use is offset by a surge in automotive consumption.
- Combined secondary and primary supplies will increase by 2%, mainly due to higher auto scrap volumes.
- The implementation of China 6 legislation will result in a step change in palladium use on Chinese cars.
- Electrical and dental demand will fall, as higher prices stimulate thrifting and substitution.
- Net investment was close to zero in the first quarter of 2019, but there is still potential for ETF profit taking.
- However, remaining ETF holdings are no longer sufficient to fill the market deficit.

The deficit in the palladium market looks set to widen dramatically in 2019, with stricter emissions legislation forecast to trigger a step change in demand from Chinese automakers. Although recoveries from autocatalyst scrap should rise again, the rate of growth in secondary supplies is likely to be lower than in 2018, while primary shipments are expected to be flat. ETF holdings stabilised in the first quarter after four years of heavy liquidation but, in any case, these funds no longer hold enough metal to bridge the gap between industrial demand and supplies.

At their height in 2014, ETFs held nearly 3 million ounces of palladium. In the four years since then, the redemption of these holdings has added more than 2.2 million ounces of liquidity to the market; by the end of last year, just 710,000 oz remained. However, in early 2019 – as the palladium price set a series of new records on its way to a peak of over $1,600 in March – ETF selling all but dried up. Net ETF investment in the first quarter was close to zero.

Late March saw a significant correction in the palladium price, which retreated to trade between $1,350 and $1,400 for much of April. Nevertheless, almost all palladium ETF holders are still 'in the money' and it is possible that some investors who did not take profits during previous price spikes will be looking to sell into any future upward price move.

While there has been some sporadic ETF purchasing even at prices above $1,500, we take the view that there is more potential for further liquidation than for new investment, and that ETF demand is therefore likely to be negative for a fifth consecutive year. If we are wrong, and ETF holders do not return metal to the market this year, then the deficit could exceed 1 million ounces.

On the demand front, tightening emissions legislation and stricter vehicle testing regimes are now driving palladium autocatalyst loadings higher in most major vehicle markets. This year, the focus will be on China, where the phase-in of China 6 emissions legislation will result in a step change in gasoline catalyst loadings compared to current China 5 systems. The European market is also seeing growth in the palladium content of gasoline aftertreatment systems, as testing becomes more stringent.

According to the official nationwide timetable, China 6 emissions legislation is due to be enforced in two phases, with China 6a limits mandated from July 2020 and China 6b standards – including RDE testing – from July 2023. However, a number of provinces and cities will adopt China 6 limits in July 2019, under the 'Blue Sky Protection Plan'. We estimate that around one third of light duty gasoline vehicle production this year will be models meeting China 6 emissions standards, and that this will generate double-digit growth in average loadings, lifting palladium demand from the Chinese auto industry by nearly half a million ounces to 2.56 million ounces.

There could be further growth in the pgm content of catalyst systems once RDE testing is rolled out. The exact requirements for RDE in China are not yet known, but will be challenging to meet, as China 6b emissions limits are even tighter than Euro 6 standards.

Trends in Chinese vehicle output are unlikely to be a major factor in the trajectory of palladium demand in 2019. First-quarter volumes were down compared with the previous year, as automakers cut production due to excess inventories of unsold cars, but output should improve as the year proceeds. For the full year, current expectations are that light duty vehicle production will be flat to slightly up compared with 2018.

Palladium purchases by European car makers are forecast to rise by a further 8% in 2019, following an 11% gain last year, reflecting the implementation of the next stages of Euro 6 legislation. From September 2019, all new passenger cars will be required to meet Euro 6d-TEMP standards, which require vehicles to demonstrate NOx and particle number (PN) emissions compliance in RDE testing (on the road) as well as in laboratory tests. The final phase of Euro 6d will be phased in starting in January 2020, further limiting permitted NOx emissions during RDE testing as the 'conformity factor' tightens. (Please refer to the special feature on page 14 for more details on RDE testing and conformity factors.)

In addition, new rules for in-service conformity (ISC) testing applied from the start of 2019. Previously, ISC tests were only carried out by automakers on their own vehicles but from now on they will also be performed by the type approval authority, which will undertake RDE testing on vehicles with up to 100,000 km on the clock, and a laboratory test on vehicles up to 160,000 km. This means that vehicles are required to meet type approval standards for almost their entire working life, increasing the emphasis on catalyst durability.

Separately, the EU's type approval framework has been amended to give the EC the power to carry out its own checks on in-use vehicles and to issue fines for non-compliance, starting in September 2020. This amendment also introduces independent market surveillance of in-use vehicles by approved authorities, and the results of these controls may be used by EU member states to restrict or prohibit the sale of non-compliant vehicles.

The impact of Euro 6d legislation on pgm demand has been significant. The technical difficulty of meeting the new regulations, and the commercial risk of not doing so, mean that the average pgm content of European gasoline catalyst systems has risen by nearly a quarter over the last two years, although there is considerable variation in loadings strategies between companies.

Further tightening of the RDE conformity factors is anticipated, and many automakers are already beginning to look ahead to Euro 7. Although nothing has yet been confirmed by the legislators, this could come in as early as 2023 and is likely to bring in even stricter, and possibly more wide ranging, emissions limits. These successive phases of legislation are expected to maintain upward pressure on gasoline vehicle loadings, although there may be some scope to reduce the pgm content of some systems with very high loadings, once auto companies gain more familiarity with RDE testing.

There have also been some changes in testing procedures in other regions. The Worldwide Harmonised Light Vehicle Test Procedure (WLTP) type approval protocol (used in Europe from September 2017) is being adopted in a number of other regions. In Japan, the JC08 test cycle was replaced by the WLTP testing regime in October 2018, while China will move to WLTP for China 6.

Industrial demand for palladium is forecast to fall by 6% in 2019, due to an intensification of price-related thrifting and substitution in the electronics and dental sectors. Palladium's use in multi-layer ceramic capacitors (MLCCs) is now mainly confined to high-end products used in automotive, medical and military applications, and is not thought to be price sensitive. However, in plating applications it competes directly with gold, and at current prices some substitution is likely to occur. In the dental sector, we expect palladium-rich dental alloys to continue to lose market share to high-gold alloys and to ceramics.

This substitution will be partly offset by exceptionally strong consumption in the chemicals sector. In China, this year should see continued investment in three processes which in recent years have consumed large amounts of palladium: the production of mono ethylene glycol (MEG) in a China-specific process that uses coal as its feedstock, and the manufacture of purified terephthalic acid and hydrogen peroxide. All these chemicals are feedstocks for manmade fibres such as polyester and nylon.

Primary supplies of palladium are expected to be flat, with modest releases of metal from pipeline inventories at South African producers helping to offset a reduction in Russian sales. Production at Norilsk Nickel will continue to benefit from the processing of palladium-rich surface materials, but shipments are forecast to be lower than in 2018, when substantial stock sales occurred. Secondary supplies are forecast to increase again, but the rate of growth should moderate following two years of very rapid gains.

The 2017–2018 period saw very rapid expansion in the amount of autocatalyst scrap entering recycling circuits. As we noted on page 21, this rise in volumes coincided with rationalisation in the secondary refining industry and occurred at a time of steeply rising palladium and rhodium prices. This put parts of the collection and refining network under pressure, with the result that collection and refining lead times have risen, and there has been an increase in inventories of unprocessed and semi-refined pgm. We think that inventories should begin to normalise this year, and pgm recoveries should therefore rise at a slightly higher rate than underlying growth in auto scrap volumes.

The palladium price set a series of records in early 2019, reaching a peak of over $1,600 in late March. This acted as a 'sell' signal to the market, and over the next ten days the price plummeted by more than $200, shedding 13% of its value in the process. During April, the price stabilised, with palladium trading in a $1,350–$1,400 range for most of the month. At the same time, there does appear to have been some improvement in liquidity: short-term lease rates have fallen from over 30% in early January to around 7% at the time of writing. This suggests that availability has improved, which may be partly due to the release of pipeline inventories at primary and secondary refineries. Nevertheless, with automotive demand set to grow significantly – particularly in the second half of 2019 – we expect the market to remain tight and any dips in the price to be met by strong consumer buying.

Rhodium Summary

Supply and Demand in 2018

- The rhodium price climbed to an eight-year high of $2,600 in December 2018.
- Auto demand rose by 3%, as European car makers used more rhodium to meet stricter vehicle testing regimes.
- High prices drove thrifting in the glass sector and stimulated ETF liquidation.
- Primary supplies were flat, while shortages of refining capacity dampened growth in recycling.
- Although the market remained in surplus, liquidity was drained by higher forward purchasing from auto and industrial buyers.

Rhodium Supply and Demand '000 oz			
Supply	**2017**	**2018**	**2019**
South Africa	611	618	652
Russia	78	69	73
Others	70	70	67
Total Supply	**759**	**757**	**792**
Gross Demand			
Autocatalyst	844	869	957
Other	210	157	162
Total Gross Demand	**1,054**	**1,026**	**1,119**
Recycling	-310	-334	-371
Total Net demand	**744**	**692**	**748**
Movements in Stocks	15	65	44

Rhodium demand on autocatalysts rose by 3% in 2018, despite a slight fall in world car production, as automakers added rhodium to their gasoline catalyst systems in response to stricter testing regimes. However, consumption in industrial and other applications fell short of the unusually high levels seen in 2017. This was partly due to rising prices, which triggered some thrifting in the glass sector and stimulated profit taking by holders of rhodium ETFs. With robust growth in autocatalyst recycling and little change in primary supplies, the market moved further into surplus.

This apparent surplus is at odds with price movements and market liquidity, suggesting that market participants and perhaps consumers purchased and held rhodium that was not immediately required for industrial processes. In particular, we believe that there was an increase in forward purchasing by some automotive and industrial companies in 2018; this was accompanied by additional physical buying on the spot market to hedge these transactions. We do not count this as demand, because we measure consumption at the point when metal is used in a physical product or process (or when the consumer physically takes possession of pgm, if we can identify this). However, it is likely that this activity has removed some liquidity from the market.

Fluctuations in inventories of semi-processed rhodium at pgm refineries may also have played a role in availability and hence price movements. Some major primary producers in South Africa ended 2017 with excess in-process stocks at their smelters and refineries, and there was a further inventory build last year. We allow for this effect in our supply numbers, which show flat primary shipments in 2018 after accounting for pipeline and refined stock changes.

Outside South Africa, there has been rationalisation in the European pgm refining sector, at a time of strong growth in recycling. This meant that refining capacity utilisation was unusually high last year, and refining lead times longer than usual. In addition, a fire at Umicore's Hoboken refinery in September appears to have had a short-term impact on rhodium market liquidity.

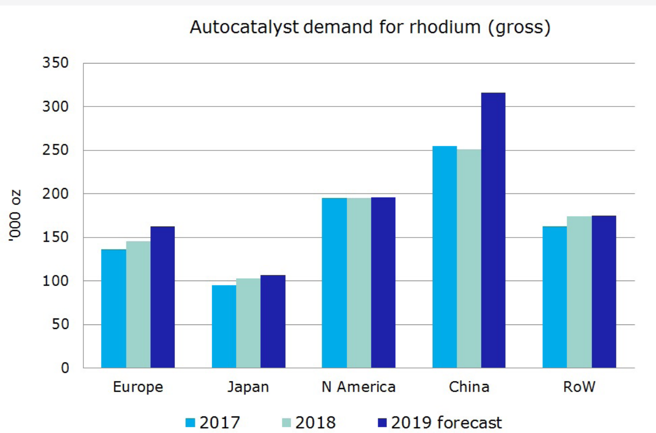
Almost all of rhodium's industrial applications involve a constant 'closed-loop' cycle in which rhodium-bearing materials such as chemical process catalysts are regularly removed, recycled and replaced. The contained metal is not returned to the market, but remains in the ownership of the industrial user, and is generally reused in the same application. We therefore measure only the 'top-up' demand that occurs due to losses in the industrial process itself and during subsequent recycling. If there are delays in recovering metal due to refinery bottlenecks, this may have a physical impact on the market that is not fully captured in our demand estimates but which may have a price effect.

In contrast, autocatalyst recycling involves an 'open-loop' process, in which metal is returned to the market via a network of scrap yards, collectors, processors, smelters and refiners, typically many years after the catalyst was originally fitted to a vehicle. Our autocatalyst recovery figures are based primarily on an estimate of the number of end-of-life vehicles reaching scrap yards, and the pgm content of the spent catalytic converters removed from them. We have adjusted our figures for autocatalyst recovery in 2018 to allow for the impact of rising lead times across the collection and pgm refining network at a time of unusually strong growth in automotive scrap volumes.

Because rhodium is a small, illiquid market, any short-term misalignment between supply and demand can have significant consequences for price and physical availability. Last year saw a steady climb in the rhodium price, from $1,690 per ounce in January 2018 to a peak of $2,600 in early December. However, in the second half of December, there were reports of increased selling from producers and investors, and the price retreated to $2,460 at the year end.

Demand for rhodium fell by 3% in 2018, under the influence of two opposing trends: a partial reversal of recent thrifting in automotive applications, offset by price-motivated changes in the composition of glass making alloys and profit taking by ETF investors (the latter is included in our 'other' demand number).

Thrifting of rhodium from gasoline autocatalysts has been a consistent feature of the auto market for the past decade: global average rhodium loadings on gasoline cars were about 40% lower in 2017 than in 2007. However, changes to emissions regulations and testing procedures have started to drive loadings higher again. The global average rhodium content of a gasoline aftertreatment system rose by around 5% last year and this helped lift



"The global average rhodium loading on gasoline vehicles rose last year, helping to lift demand in autocatalysts by 25,000 oz."

Rhodium Demand: Industrial '000 oz			
	2017	**2018**	**2019**
Chemical	71	62	63
Electrical	5	5	5
Glass	113	102	71
Other	21	-12	23
Total	**210**	**157**	**162**

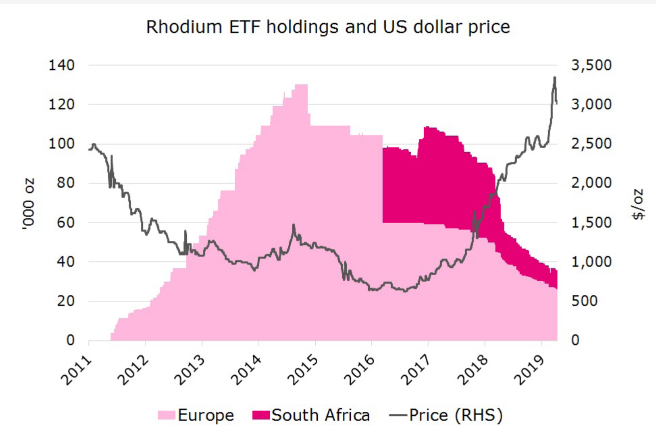
gross world demand for rhodium in autocatalysts by 25,000 oz, even though world car sales fell.

Much of this gain occurred in Europe, where the rhodium content of gasoline vehicles rose sharply as more models were equipped with aftertreatment systems capable of meeting Euro 6d-TEMP standards. While aftertreatment of NOx is less technically difficult in gasoline engines than in diesels, the implementation of RDE testing has considerably widened the range of conditions under which automakers must demonstrate that their vehicles can meet NOx (and other pollutant) emissions limits. This has been positive for pgm loadings on three-way catalysts generally and for rhodium in particular. Rhodium is an extremely effective catalyst for the conversion of NOx in the exhaust stream, and even small increases in rhodium content can result in a large improvement in catalyst performance.

Growth in auto demand was offset by a fall in rhodium consumption in industrial applications last year, in the wake of unusually heavy buying by chemical and glass companies in 2017. Lower chemical demand was primarily related to the timing of rhodium catalyst purchases for new oxo alcohol capacity, rather than a sign of weaker underlying conditions in the industry.

Purchases of rhodium by the glass sector remained at historically high levels, albeit slightly lower than in 2017. Higher rhodium prices have begun to have an impact; glass makers are among the few consumers who are able to make short-term adjustments to their rhodium usage in response to price. The rhodium content of platinum alloys used in glass making typically varies between 10% and 20%, depending partly on the relative prices of the two metals: when the rhodium price is significantly above that of platinum, it can make economic sense to thrift rhodium even if this reduces the working life of the equipment. However, it appears that glass companies have generally chosen to retain ownership of rhodium released due to alloy changes, rather than selling it back to the market. It will be used in future expansions and to 'top up' metal lost during the operation and recycling of existing glass making equipment.

Rising prices also stimulated further profit taking by ETF investors, who redeemed around 50,000 oz of rhodium ETFs last year, up from 20,000 oz in 2017. By the year end, total holdings were under 40,000 oz, down from nearly 130,000 oz at their peak in 2014. It should be noted that without this negative investment, overall rhodium demand would have risen, but the market would still have been in a modest surplus.



"Rising prices also stimulated further profit taking by ETF investors, who redeemed around 50,000 oz of rhodium ETFs last year."

Rhodium Outlook

Supply and Demand in 2019

- A step change in rhodium loadings on Chinese cars will lift autocatalyst demand by 10% in 2019.
- Other regions will also see additional rhodium use to comply with more stringent vehicle testing.
- The release of in-process inventories should lift primary rhodium supplies to a ten-year high.
- Rising auto scrap volumes will boost secondary supplies, although historic thrifting programmes will cap growth in recycling.
- Rhodium set a ten-year high of $3,345 per ounce in March 2019, before retreating below $3,000 as market liquidity improved.

Autocatalyst demand for rhodium is forecast to benefit from a step change in loadings on Chinese vehicles, as China 6 legislation is phased in under the 'Blue Sky Protection Plan' from July 2019. Elsewhere, car companies are also increasing pgm loadings in response to tighter emissions legislation and more stringent testing. Worldwide, this will boost autocatalyst demand by 10%, outweighing further thrifting in the glass industry, and lifting gross demand to record levels. However, with primary supplies expected to rise by 5% due to the release of rhodium from pipeline inventories, the market is expected to remain in a moderate surplus.

The release of rhodium from pipeline stocks at primary refineries could result in a bumper year for South African output in 2019, assuming that production is not interrupted by industrial action, technical problems or further electricity shortages. We think that supplies from South African producers could exceed 650,000 oz, a ten-year high; however, with major South African producers due to conduct wage negotiations this year, the downside risk is also greater than usual. With autocatalyst recovery set to grow again, we expect combined primary and secondary rhodium supplies to expand by 7% this year.

The secondary refining sector in North America and Europe also ended 2018 with unusually high in-process stocks of pgm. Capacity constraints are likely to keep lead times longer than usual, but we would expect excess refinery pipelines to be gradually released. This may help to improve physical availability in the short term, although we think that the market could tighten again from mid-year, as Chinese automakers begin to ramp up output of vehicles meeting stricter China 6 standards.

Looking further ahead, rhodium supplies from South Africa are forecast to contract as shaft closures at

Lonmin and Impala Platinum are implemented, and as some other UG2 operations near the end of their lives. The UG2 reef is richer in rhodium than other pgm ores mined in South Africa, so the depletion and closure of UG2 operations will be particularly significant for supplies of this metal. Growth in autocatalyst recycling may not be enough to offset future declines in mine production of rhodium. Due to past rhodium thrifting programmes, particularly on North American and European cars, the scope for growth in rhodium recovery is lower than for palladium.

In contrast, the outlook for demand is increasingly positive. Emissions legislation is tightening in most major markets, contributing to an upward trend in global rhodium loadings. In 2019, the largest changes will be seen in Europe, as a result of more stringent testing of passenger vehicles, and in China, where a new phase of legislative tightening is about to get underway.

From September 2019, all new passenger cars sold in Europe will be required to meet Euro 6d-TEMP standards, which require vehicles to demonstrate NOx and particle number (PN) emissions compliance in RDE testing as well as in laboratory tests. The final phase of Euro 6d will be implemented starting in January 2020, further limiting permitted NOx emissions. At the same time, automakers also face new in-service conformity regulations, which were introduced in January 2019 and are intended to ensure that catalyst systems meet RDE standards not just at the point that the vehicle is put into service, but for most of its lifetime. Because rhodium is a particularly effective catalyst for NOx, the impact of Euro 6d legislation on rhodium demand has been especially significant.

China is also entering a period of regulatory change. Some cities and provinces will start to implement China 6 legislation this year, ahead of its nationwide application which is officially scheduled to take place between 2020 (China 6a) and 2023 (China 6b, including RDE testing). Meeting China 6 standards will involve significantly higher palladium and rhodium loadings compared to current China 5 systems.

While autocatalyst demand is set to rise strongly, consumption in industrial applications could weaken in 2019, primarily due to lower purchasing from the glass industry, where higher prices have begun to stimulate some thrifting of rhodium. Elsewhere, demand in the chemicals sector is forecast to remain firm, while ‘other’ demand (including investment) is almost certain to rise because there is now only limited potential for further ETF selling.

Our supply and demand forecasts suggest that the rhodium market could again be in a technical surplus in 2019, although much will depend on the exact trajectory of automotive demand in China, the speed of thrifting in the glass sector, and the ability of primary and secondary refineries to manage in-process inventories. The first quarter of 2019 saw further significant gains in the rhodium price, which peaked at $3,345 in late March – the highest since October 2008. However, the price subsequently retreated to just under $3,000 during April, reflecting some improvement in market liquidity. In view of our forecast of sharply rising automotive demand in Europe and China, we expect spare metal to be readily absorbed by consumer purchasing and, potentially, by strategic buying in anticipation of future demand growth.

Ruthenium & Iridium

Summary of 2018 and Outlook for 2019

- The ruthenium price hit a ten-year high of $250 in 2018, while iridium set a new record of $1,480.
- Availability was affected by fluctuations in refinery pipelines and strategic purchasing by investors.
- However, industrial demand fell, with lower purchasing of iridium crucibles, and higher recycling of ruthenium process catalysts.
- Buoyant demand in the chemical and electrochemical sectors will boost consumption of both metals in 2019.

Ruthenium Demand: Industrial '000 oz			
	2017	**2018**	**2019**
Chemical	428	267	315
Electrical	416	429	419
Electrochemical	205	200	220
Other	173	182	188
Total	**1,222**	**1,078**	**1,142**

Iridium Demand: Industrial '000 oz			
	2017	**2018**	**2019**
Chemical	17	19	20
Electrical	73	52	59
Electrochemical	85	61	72
Other	85	89	92
Total	**260**	**221**	**243**

Demand for both ruthenium and iridium fell in 2018, reflecting an increase in recycling in the chemical and electrochemical sectors, and a drop in purchasing of iridium crucibles. Both metals remained theoretically well supplied, after accounting for recycling and sales from producer stocks. However, market liquidity has been affected by fluctuations in primary and secondary refinery pipelines, while metal has also been absorbed by strategic purchasing in Asia, which is not included in our demand numbers. These factors contributed to an increase in the prices of both metals in 2018: ruthenium reached a ten-year peak of over $250, while iridium ascended to a record $1,480 per ounce.

These price gains were steepest in the early part of the year. From mid-2018, prices stabilised, reflecting a modest improvement in market liquidity, probably due to some additional recycling activity in the chemicals sector (see below) and an improvement in refined output at some primary producers.

Industrial users of platinum group metals typically recycle pgm-containing materials at the end of their working life in a continuous 'closed-loop' cycle. This metal usually remains in the ownership of the industrial user, and metal recovered from scrap is subsequently reused in the same application. Our industrial demand figures therefore include only the 'top-up' demand that is required to replace metal lost during the industrial process or during the refining of scrap.

However, ruthenium differs from other platinum group metals because of its low price and complex chemistry. Until recently, it was common not to recover ruthenium from process catalysts. At low ruthenium prices, the cost of refining spent catalyst may exceed the value of the metal recovered; this is especially true of catalysts with a low ruthenium content or where process losses are high. During the five-year period from 2013 to 2017, the ruthenium price averaged under $100, making it uneconomic to recover ruthenium from most types of chemical scrap, and in particular from spent catalyst from bulk chemicals processes in China. Large quantities of used catalyst were therefore stockpiled in anticipation of higher prices.

The ruthenium price moved sharply higher in late 2017 and averaged around $240 in 2018. This has stimulated some additional recycling of spent ruthenium process catalyst, especially in China. There has also been an increase in recycling in the electrochemical sector, in response to higher prices for both ruthenium and iridium.

Recent rationalisation in the secondary pgm refining sector has been particularly problematic for the ruthenium and iridium markets and this may help to explain why prices remain at record levels even though industrial demand eased in 2018. Few market participants have the capability to fully refine these metals, and refining lead times are typically very long – often over 20 weeks. In addition, price-related increases in recycling of ruthenium and iridium have exacerbated the impact of capacity bottlenecks, causing lead times to be extended and resulting in growth in pipeline stocks. It is difficult to ascertain when recycled metal is returned to the market, and our demand numbers may therefore underestimate the impact of higher work-in-progress inventories at secondary refineries.

This increased recycling activity was the reason for a sharp drop in ruthenium demand from the chemicals industry in 2018. While there was continued strong purchasing of fresh ruthenium catalyst for new plants and capacity expansions, new metal demand was partly offset by increased recycling, as higher prices stimulated the recovery of ruthenium from old stocks of spent process catalyst.

Outside China, ruthenium catalysts are used in the production of a variety of speciality and fine chemicals, and in two bulk (or commodity) chemical processes: the Cativa acetic acid process and the Kellogg Advanced Ammonia Process (KAAP). Both these processes compete with other, longer-established synthesis routes which use different catalysts (rhodium for acetic acid, and an iron catalyst for ammonia). Chemicals demand for ruthenium outside China is currently stable, with little new investment in ruthenium processes.

The Chinese chemicals industry makes much greater use of ruthenium than elsewhere, largely in processes that do not involve pgm catalysts in other regions. For example, over the last few years, extremely large quantities of ruthenium catalyst have been employed in the production of caprolactam and adipic acid feedstocks for nylon and polyester production in China. Prior to 2018, it was uneconomic to recycle ruthenium used in these applications, and large quantities of spent catalyst were accumulated. However, as the ruthenium price moved through $100 in late 2017, and then $200 during early 2018, it stimulated the return of some of this scrap for recycling. This resulted in a decline in chemicals demand in 2018, even though underlying conditions in the industry remain buoyant.

Both ruthenium and iridium are used in coatings for electrodes used in electrochemical processes. Most electrochemical demand derives from the chlor-alkali industry (which produces chlorine and caustic soda), but in recent years this sector has seen increased consumption in some new applications, including purification processes such as swimming pool disinfection and ballast water treatment on ocean-going ships, as well as in electrowinning in base metal refineries. The relative quantities of ruthenium and iridium used in these applications differs, so demand for the two metals does not necessarily vary in the same direction.

In 2018, iridium demand fell in the wake of strong purchasing for electrowinning applications the previous year. Ruthenium demand rose slightly, lifted by increasing sales to the ballast water treatment sector.

Our demand estimates allow for a price-related increase in the recycling of used electrodes. However, in this application, much of the ruthenium and iridium is lost from the electrodes during use, so only a small proportion of the original metal can be recovered.

The use of ruthenium in electronic components such as chip resistors remained strong in 2018, driven by increasing use in the automotive sector, while consumption in hard disks also rose. Although they are losing share to solid-state (flash) memory in consumer products, hard disks continue to dominate large commercial data storage applications, and we continue to expect growth in this application going forward.

Demand for iridium from the electronics sector declined by 29% in 2018, primarily due to lower purchasing of iridium crucibles. The 2015–2017 period saw a wave of investment in new capacity for the production of lithium tantalate crystals, used as the substrate for filters in mobile phones. These crystals are grown or 'pulled' in iridium crucibles, which can withstand extremely high temperatures and are highly inert (and therefore do not contaminate the single crystal). However, with global lithium tantalate capacity now sufficient to meet demand, 2018 saw a sharp decline in iridium crucible purchases.

The outlook for both ruthenium and iridium is firm, although price-related increases in recycling may create a temporary brake on demand growth, especially for ruthenium. In 2019, we expect further investment in new caprolactam and adipic acid capacity in China, and there is also potential for new ruthenium demand arising from the commercialisation of new, proprietary catalytic processes. However, this will be partly offset by continued recycling of old ruthenium catalyst.

Demand for both metals should be supported by strong growth in the electrochemical sector going forward. The International Maritime Organisation's (IMO's) 'International Convention for the Control and Management of Ship's Ballast Water and Sediments' mandates the fitment of ballast water treatment technology to new ships, to prevent the spread of invasive aquatic species and damage to marine ecosystems. In the longer term, existing ships will also need to be retrofitted. Electrochemical technology, using electrodes coated with ruthenium and iridium, is one of several ballast water treatment options available to ship owners.

In the electrical sector, iridium usage in crucibles is expected to stabilise, but there will be growth in demand for iridium in organic light emitting diodes (OLEDs) used in displays for electronic devices. In an OLED, iridium organometallic complexes are sandwiched between two electrodes and produce light when an electric current is applied. Compared to screens using conventional LED technology, OLED screens consume less energy and provide better colour contrast and a greater viewing angle. This technology has already made inroads into the high-end mobile device sector and is now beginning to gain share in the TV market.

Over the 2016 to 2018 period, demand for both iridium and ruthenium exceeded mine output, but sales from producer stocks have helped to keep the markets supplied. We believe that unusually large amounts of iridium were shipped in 2016–2017, and of ruthenium in 2017–2018, but some of this metal has been absorbed by strategic purchasing in Asia, which is not included in our demand numbers.

Mine production of iridium should be sufficient to satisfy demand this year, assuming that producers do not experience any disruption to mining or processing activities, and that they sell all their output. However, iridium is a very small and illiquid market where modest increases in demand, or fluctuations in supply, can have a significant impact on availability.

In contrast, mine output of ruthenium is expected to fall significantly short of net industrial consumption this year, despite growth in the recycling of spent chemical catalyst. We believe that producers have some remaining ruthenium inventory, which we assume will be mobilised to help meet demand.

Platinum Supply & Demand

Troy ounces

PLATINUM '000 oz - Supply and Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Supply[1]	South Africa	3,546	4,572	4,392	4,450	4,467	4,565
	Russia[2]	700	670	714	720	687	668
	North America	339	314	337	329	332	332
	Zimbabwe[3]	401	400	489	466	474	483
	Others[3]	167	151	162	158	153	141
	Total Supply	**5,153**	**6,107**	**6,094**	**6,123**	**6,113**	**6,189**
Demand[4]	Autocatalyst[4]	3,063	3,263	3,344	3,248	3,051	3,128
	Chemical	576	502	476	463	540	569
	Electrical[4]	225	228	232	233	266	269
	Glass	143	227	247	366	478	376
	Investment	277	451	620	361	67	858
	Jewellery[4]	2,839	2,746	2,412	2,400	2,269	2,227
	Medical and Biomedical[5]	214	215	216	218	221	227
	Petroleum	172	140	175	230	372	288
	Other	434	480	568	607	582	593
	Total Gross Demand	**7,943**	**8,252**	**8,290**	**8,126**	**7,846**	**8,535**
Recycling[6]	Autocatalyst	-1,272	-1,109	-1,164	-1,267	-1,338	-1,462
	Electrical	-27	-29	-32	-34	-36	-38
	Jewellery	-762	-574	-738	-746	-731	-719
	Total Recycling	**-2,061**	**-1,712**	**-1,934**	**-2,047**	**-2,105**	**-2,219**
Total Net Demand[7]		**5,882**	**6,540**	**6,356**	**6,079**	**5,741**	**6,316**
Movement in Stocks[8]		**-729**	**-433**	**-262**	**44**	**372**	**-127**

Platinum Gross Demand by Region

Troy ounces

PLATINUM '000 oz - Gross Demand by Region							
						2019 numbers are a forecast	
		2014	2015	2016	2017	2018	2019
Europe	Autocatalyst	1,475	1,661	1,796	1,711	1,468	1,407
	Chemical	111	120	122	119	123	125
	Electrical	12	13	13	10	12	12
	Glass	11	11	11	11	11	15
	Investment	-73	-88	109	36	-102	268
	Jewellery	204	203	177	176	191	192
	Medical and Biomedical	72	71	70	69	68	68
	Petroleum	22	-4	3	13	31	12
	Other	108	118	169	188	169	173
	Total	**1,942**	**2,105**	**2,470**	**2,333**	**1,971**	**2,272**
Japan	Autocatalyst	448	384	360	358	354	353
	Chemical	41	43	42	38	40	41
	Electrical	31	33	32	31	35	35
	Glass	-96	4	2	25	7	8
	Investment	19	700	543	171	220	87
	Jewellery	313	314	310	305	298	299
	Medical and Biomedical	16	16	15	15	16	16
	Petroleum	3	3	3	2	2	2
	Other	71	80	79	80	80	81
	Total	**846**	**1,577**	**1,386**	**1,025**	**1,052**	**922**
N. America	Autocatalyst	356	379	360	348	352	363
	Chemical	113	114	103	112	116	118
	Electrical	18	22	26	33	38	32
	Glass	10	10	29	45	17	34
	Investment	7	-32	109	127	66	104
	Jewellery	218	227	220	238	230	231
	Medical and Biomedical	85	85	86	87	88	92
	Petroleum	21	40	36	18	17	17
	Other	125	140	151	148	148	151
	Total	**953**	**985**	**1,120**	**1,156**	**1,072**	**1,142**
China	Autocatalyst	130	136	151	157	146	229
	Chemical	155	131	121	84	126	203
	Electrical	39	38	42	44	56	57
	Glass	144	178	135	163	365	212
	Investment	0	0	0	0	0	0
	Jewellery	1,935	1,796	1,510	1,470	1,316	1,250
	Medical and Biomedical	18	19	19	20	21	22
	Petroleum	30	32	64	116	258	193
	Other	53	59	73	84	88	89
	Total	**2,504**	**2,389**	**2,115**	**2,138**	**2,376**	**2,255**
RoW	Autocatalyst	654	703	677	674	731	776
	Chemical	156	94	88	110	135	82
	Electrical	125	122	119	115	125	133
	Glass	74	24	70	122	78	107
	Investment	324	-129	-141	27	-117	399
	Jewellery	169	206	195	211	234	255
	Medical and Biomedical	23	24	26	27	28	29
	Petroleum	96	69	69	81	64	64
	Other	77	83	96	107	97	99
	Total	**1,698**	**1,196**	**1,199**	**1,474**	**1,375**	**1,944**
	Grand total	**7,943**	**8,252**	**8,290**	**8,126**	**7,846**	**8,535**

Platinum Supply & Demand

Tonnes

PLATINUM Tonnes - Supply and Demand							
						2019 numbers are a forecast	
		2014	2015	2016	2017	2018	2019
Supply[1]	South Africa	110.3	142.2	136.6	138.4	138.9	142.0
	Russia[2]	21.8	20.8	22.2	22.4	21.4	20.8
	North America	10.5	9.8	10.5	10.2	10.3	10.3
	Zimbabwe[3]	12.5	12.4	15.2	14.5	14.7	15.0
	Others[3]	5.2	4.7	5.0	4.9	4.8	4.4
	Total Supply	**160.3**	**189.9**	**189.5**	**190.4**	**190.1**	**192.5**
Demand[4]	Autocatalyst[4]	95.2	101.5	104.0	101.0	94.8	97.2
	Chemical	18.0	15.5	14.8	14.4	16.7	17.7
	Electrical[4]	7.1	7.1	7.2	7.3	8.3	8.4
	Glass	4.4	7.0	7.7	11.4	14.8	11.7
	Investment	8.6	14.1	19.3	11.2	2.1	26.6
	Jewellery[4]	88.3	85.5	75.0	74.6	70.6	69.3
	Medical and Biomedical[5]	6.6	6.6	6.8	6.7	6.9	7.1
	Petroleum	5.4	4.3	5.4	7.2	11.6	9.0
	Other	13.5	15.0	17.7	18.8	18.1	18.5
	Total Gross Demand	**247.1**	**256.6**	**257.9**	**252.6**	**243.9**	**265.5**
Recycling[6]	Autocatalyst	-39.5	-34.5	-36.2	-39.4	-41.5	-45.4
	Electrical	-0.8	-0.9	-1.0	-1.0	-1.2	-1.2
	Jewellery	-23.7	-17.9	-23.0	-23.2	-22.7	-22.4
	Total Recycling	**-64.0**	**-53.3**	**-60.2**	**-63.6**	**-65.4**	**-69.0**
Total Net Demand[7]		**183.1**	**203.3**	**197.7**	**189.0**	**178.5**	**196.5**
Movement in Stocks[8]		**-22.8**	**-13.4**	**-8.2**	**1.4**	**11.6**	**-4.0**

Platinum Gross Demand by Region

Tonnes

PLATINUM Tonnes - Gross Demand by Region							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Europe	Autocatalyst	45.9	51.7	55.8	53.2	45.7	43.7
	Chemical	3.5	3.7	3.8	3.7	3.8	3.9
	Electrical	0.4	0.4	0.4	0.3	0.4	0.4
	Glass	0.3	0.3	0.3	0.3	0.3	0.5
	Investment	-2.3	-2.7	3.4	1.1	-3.2	8.3
	Jewellery	6.3	6.3	5.5	5.5	5.9	6.0
	Medical and Biomedical	2.2	2.2	2.2	2.1	2.1	2.1
	Petroleum	0.7	-0.1	0.1	0.4	1.0	0.4
	Other	3.4	3.7	5.3	5.8	5.3	5.4
	Total	**60.4**	**65.5**	**76.8**	**72.4**	**61.3**	**70.7**
Japan	Autocatalyst	13.9	11.9	11.2	11.1	11.0	11.0
	Chemical	1.3	1.3	1.3	1.2	1.2	1.3
	Electrical	1.0	1.0	1.0	1.0	1.1	1.1
	Glass	-3.0	0.1	0.1	0.8	0.2	0.2
	Investment	0.6	21.8	16.9	5.3	6.8	2.7
	Jewellery	9.7	9.8	9.6	9.5	9.3	9.3
	Medical and Biomedical	0.5	0.5	0.5	0.5	0.5	0.5
	Petroleum	0.1	0.1	0.1	0.1	0.1	0.1
	Other	2.2	2.5	2.4	2.5	2.5	2.5
	Total	**26.3**	**49.0**	**43.1**	**32.0**	**32.7**	**28.7**
N. America	Autocatalyst	11.1	11.8	11.2	10.8	10.9	11.3
	Chemical	3.5	3.5	3.2	3.5	3.6	3.7
	Electrical	0.6	0.7	0.8	1.0	1.2	1.0
	Glass	0.3	0.3	0.9	1.4	0.5	1.1
	Investment	0.2	-1.0	3.4	4.0	2.1	3.2
	Jewellery	6.8	7.1	6.8	7.4	7.2	7.2
	Medical and Biomedical	2.6	2.6	2.7	2.7	2.7	2.9
	Petroleum	0.7	1.2	1.1	0.6	0.5	0.5
	Other	3.9	4.4	4.7	4.6	4.6	4.7
	Total	**29.7**	**30.6**	**34.8**	**36.0**	**33.3**	**35.6**
China	Autocatalyst	4.0	4.2	4.7	4.9	4.5	7.1
	Chemical	4.8	4.1	3.8	2.6	3.9	6.3
	Electrical	1.2	1.2	1.3	1.4	1.7	1.8
	Glass	4.5	5.5	4.2	5.1	11.4	6.6
	Investment	0.0	0.0	0.0	0.0	0.0	0.0
	Jewellery	60.2	55.9	47.0	45.7	40.9	38.9
	Medical and Biomedical	0.6	0.6	0.6	0.6	0.7	0.7
	Petroleum	0.9	1.0	2.0	3.6	8.0	6.0
	Other	1.6	1.8	2.3	2.6	2.7	2.8
	Total	**77.8**	**74.3**	**65.9**	**66.5**	**73.8**	**70.2**
RoW	Autocatalyst	20.3	21.9	21.1	21.0	22.7	24.1
	Chemical	4.9	2.9	2.7	3.4	4.2	2.5
	Electrical	3.9	3.8	3.7	3.6	3.9	4.1
	Glass	2.3	0.8	2.2	3.8	2.4	3.3
	Investment	10.1	-4.0	-4.4	0.8	-3.6	12.4
	Jewellery	5.3	6.4	6.1	6.5	7.3	7.9
	Medical and Biomedical	0.7	0.7	0.8	0.8	0.9	0.9
	Petroleum	3.0	2.1	2.1	2.5	2.0	2.0
	Other	2.4	2.6	3.0	3.3	3.0	3.1
	Total	**52.9**	**37.2**	**37.3**	**45.7**	**42.8**	**60.3**
	Grand total	**247.1**	**256.6**	**257.9**	**252.6**	**243.9**	**265.5**

Palladium Supply & Demand

Troy ounces

PALLADIUM '000 oz - Supply and Demand

2019 numbers are a forecast

		2014	2015	2016	2017	2018	2019
Supply[1]	South Africa	2,126	2,683	2,570	2,547	2,543	2,744
	Russia[2]	2,589	2,434	2,781	2,452	2,976	2,792
	North America	912	874	913	890	936	951
	Zimbabwe[3]	327	320	396	386	393	380
	Others[3]	160	144	129	133	129	129
	Total Supply	**6,114**	**6,455**	**6,789**	**6,408**	**6,977**	**6,996**
Demand[4]	Autocatalyst[4]	7,523	7,696	7,986	8,532	8,721	9,496
	Chemical	315	452	418	449	565	502
	Dental	464	468	429	391	364	328
	Electrical[4]	970	903	872	843	807	795
	Investment	943	-659	-646	-386	-574	-310
	Jewellery[4]	272	220	189	173	157	156
	Other	111	134	155	144	182	187
	Total Gross Demand	**10,598**	**9,214**	**9,403**	**10,146**	**10,222**	**11,154**
Recycling[6]	Autocatalyst	-2,159	-1,882	-1,990	-2,363	-2,633	-2,862
	Electrical	-474	-475	-481	-479	-478	-476
	Jewellery	-89	-46	-21	-21	-13	-11
	Total Recycling	**-2,722**	**-2,403**	**-2,492**	**-2,863**	**-3,124**	**-3,349**
Total Net Demand[7]		**7,876**	**6,811**	**6,911**	**7,283**	**7,098**	**7,805**
Movement in Stocks[8]		**-1,762**	**-356**	**-122**	**-875**	**-121**	**-809**

Palladium Gross Demand by Region

Troy ounces

PALLADIUM '000 oz - Gross Demand by Region							
						2019 numbers are a forecast	
		2014	**2015**	**2016**	**2017**	**2018**	**2019**
Europe	Autocatalyst	1,583	1,624	1,641	1,700	1,889	2,042
	Chemical	-23	77	79	80	80	81
	Dental	77	70	65	60	51	42
	Electrical	113	101	99	96	94	92
	Investment	-74	-200	-269	-287	-141	-122
	Jewellery	60	59	58	55	52	52
	Other	25	27	24	23	30	26
	Total	**1,761**	**1,758**	**1,697**	**1,727**	**2,055**	**2,213**
Japan	Autocatalyst	794	759	787	829	857	902
	Chemical	16	15	15	17	17	17
	Dental	205	227	200	174	161	153
	Electrical	214	231	227	221	204	199
	Investment	-2	4	-3	-3	-1	0
	Jewellery	67	66	64	57	52	51
	Other	9	9	9	9	9	9
	Total	**1,303**	**1,311**	**1,299**	**1,304**	**1,299**	**1,331**
N. America	Autocatalyst	1,963	2,039	1,954	2,106	2,109	2,117
	Chemical	71	76	73	75	77	74
	Dental	156	145	138	131	125	107
	Electrical	140	131	128	124	117	114
	Investment	-205	-181	-71	-19	-87	-86
	Jewellery	44	39	36	33	33	33
	Other	43	60	46	44	43	47
	Total	**2,212**	**2,309**	**2,304**	**2,494**	**2,417**	**2,406**
China	Autocatalyst	1,608	1,654	2,038	2,179	2,081	2,558
	Chemical	160	209	156	182	200	215
	Dental	8	8	7	7	7	6
	Electrical	169	158	156	155	154	154
	Investment	0	0	0	0	0	0
	Jewellery	78	34	10	9	2	1
	Other	16	17	43	51	80	80
	Total	**2,039**	**2,080**	**2,410**	**2,583**	**2,524**	**3,014**
RoW	Autocatalyst	1,575	1,620	1,566	1,718	1,785	1,877
	Chemical	91	75	95	95	191	115
	Dental	18	18	19	19	20	20
	Electrical	334	282	262	247	238	236
	Investment	1,224	-282	-303	-77	-345	-102
	Jewellery	23	22	21	19	18	19
	Other	18	21	33	17	20	25
	Total	**3,283**	**1,756**	**1,693**	**2,038**	**1,927**	**2,190**
	Grand total	**10,598**	**9,214**	**9,403**	**10,146**	**10,222**	**11,154**

Palladium Supply & Demand

Tonnes

PALLADIUM Tonnes - Supply and Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Supply[1]	South Africa	66.1	83.4	79.9	79.2	79.1	85.3
	Russia[2]	80.5	75.7	86.5	76.3	92.6	86.8
	North America	28.4	27.2	28.4	27.7	29.1	29.6
	Zimbabwe[3]	10.2	10.0	12.3	12.0	12.2	11.8
	Others[3]	5.0	4.5	4.0	4.1	4.0	4.0
	Total Supply	**190.2**	**200.8**	**211.1**	**199.3**	**217.0**	**217.5**
Demand[4]	Autocatalyst[4]	234.0	239.3	248.4	265.4	271.3	295.4
	Chemical	9.8	14.1	13.1	14.0	17.5	15.6
	Dental	14.4	14.6	13.3	12.2	11.3	10.2
	Electrical[4]	30.2	28.1	27.1	26.2	25.1	24.7
	Investment	29.3	-20.5	-20.1	-12.0	-17.8	-9.7
	Jewellery[4]	8.5	6.8	5.9	5.4	4.9	4.8
	Other	3.5	4.2	4.7	4.5	5.7	5.9
	Total Gross Demand	**329.7**	**286.6**	**292.4**	**315.7**	**318.0**	**346.9**
Recycling[6]	Autocatalyst	-67.2	-58.4	-61.8	-73.5	-81.9	-89.1
	Electrical	-14.8	-14.8	-15.0	-15.0	-14.9	-14.8
	Jewellery	-2.7	-1.4	-0.7	-0.6	-0.4	-0.3
	Total Recycling	**-84.7**	**-74.6**	**-77.5**	**-89.1**	**-97.2**	**-104.2**
Total Net Demand[7]		**245.0**	**212.0**	**214.9**	**226.6**	**220.8**	**242.7**
Movement in Stocks[8]		**-54.8**	**-11.2**	**-3.8**	**-27.3**	**-3.8**	**-25.2**

Palladium Gross Demand by Region

Tonnes

PALLADIUM Tonnes - Gross Demand by Region							
						2019 numbers are a forecast	
		2014	2015	2016	2017	2018	2019
Europe	Autocatalyst	49.2	50.5	51.0	52.9	58.8	63.5
	Chemical	-0.7	2.4	2.5	2.5	2.5	2.5
	Dental	2.4	2.2	2.0	1.9	1.6	1.3
	Electrical	3.5	3.1	3.1	3.0	2.9	2.9
	Investment	-2.3	-6.2	-8.4	-8.9	-4.4	-3.8
	Jewellery	1.9	1.8	1.8	1.7	1.6	1.6
	Other	0.8	0.8	0.7	0.7	0.9	0.8
	Total	**54.8**	**54.6**	**52.7**	**53.8**	**63.9**	**68.8**
Japan	Autocatalyst	24.7	23.6	24.5	25.8	26.7	28.1
	Chemical	0.5	0.5	0.5	0.5	0.5	0.5
	Dental	6.4	7.1	6.2	5.4	5.0	4.8
	Electrical	6.6	7.2	7.0	6.8	6.4	6.2
	Investment	-0.1	0.1	-0.1	-0.1	0.0	0.0
	Jewellery	2.1	2.0	2.0	1.8	1.6	1.6
	Other	0.3	0.3	0.3	0.3	0.3	0.3
	Total	**40.5**	**40.8**	**40.4**	**40.5**	**40.5**	**41.5**
N. America	Autocatalyst	61.1	63.4	60.8	65.5	65.6	65.8
	Chemical	2.2	2.4	2.3	2.3	2.4	2.3
	Dental	4.8	4.5	4.3	4.1	3.9	3.3
	Electrical	4.4	4.1	4.0	3.9	3.6	3.5
	Investment	-6.4	-5.6	-2.2	-0.6	-2.7	-2.7
	Jewellery	1.4	1.2	1.1	1.0	1.0	1.0
	Other	1.3	1.9	1.4	1.4	1.4	1.5
	Total	**68.8**	**71.9**	**71.7**	**77.6**	**75.2**	**74.7**
China	Autocatalyst	50.0	51.4	63.4	67.8	64.7	79.6
	Chemical	5.0	6.5	4.8	5.7	6.2	6.7
	Dental	0.2	0.2	0.2	0.2	0.2	0.2
	Electrical	5.3	4.9	4.9	4.8	4.8	4.8
	Investment	0.0	0.0	0.0	0.0	0.0	0.0
	Jewellery	2.4	1.1	0.3	0.3	0.1	0.0
	Other	0.5	0.5	1.3	1.6	2.5	2.5
	Total	**63.4**	**64.6**	**74.9**	**80.4**	**78.5**	**93.8**
RoW	Autocatalyst	49.0	50.4	48.7	53.4	55.5	58.4
	Chemical	2.8	2.3	3.0	3.0	5.9	3.6
	Dental	0.6	0.6	0.6	0.6	0.6	0.6
	Electrical	10.4	8.8	8.1	7.7	7.4	7.3
	Investment	38.1	-8.8	-9.4	-2.4	-10.7	-3.2
	Jewellery	0.7	0.7	0.7	0.6	0.6	0.6
	Other	0.6	0.7	1.0	0.5	0.6	0.8
	Total	**102.2**	**54.7**	**52.7**	**63.4**	**59.9**	**68.1**
	Grand total	**329.7**	**286.6**	**292.4**	**315.7**	**318.0**	**346.9**

Rhodium Supply & Demand

Troy ounces

RHODIUM '000 oz - Supply and Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Supply[1]	South Africa	470	611	615	611	618	652
	Russia[2]	80	80	85	78	69	73
	North America	24	22	24	23	22	23
	Zimbabwe[3]	36	36	44	42	43	39
	Others[3]	7	5	5	5	5	5
	Total Supply	**617**	**754**	**773**	**759**	**757**	**792**
Demand[4]	Autocatalyst[4]	771	760	811	844	869	957
	Chemical	90	73	64	71	62	63
	Electrical	3	3	4	5	5	5
	Glass	49	52	85	113	102	71
	Other	38	30	41	21	-12	23
	Total Gross Demand	**951**	**918**	**1,005**	**1,054**	**1,026**	**1,119**
Recycling[6]	Autocatalyst	-301	-260	-271	-310	-334	-371
	Total Recycling	**-301**	**-260**	**-271**	**-310**	**-334**	**-371**
Total Net Demand[7]		**650**	**658**	**734**	**744**	**692**	**748**
Movement in Stocks[8]		**-33**	**96**	**39**	**15**	**65**	**44**

Rhodium Supply & Demand

Tonnes

RHODIUM Tonnes - Supply and Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Supply[1]	South Africa	14.6	19.0	19.1	19.0	19.2	20.3
	Russia[2]	2.5	2.5	2.6	2.4	2.1	2.3
	North America	0.8	0.7	0.7	0.7	0.7	0.7
	Zimbabwe[3]	1.1	1.1	1.4	1.3	1.3	1.2
	Others[3]	0.2	0.2	0.2	0.2	0.2	0.2
	Total Supply	**19.2**	**23.5**	**24.0**	**23.6**	**23.5**	**24.7**
Demand[4]	Autocatalyst[4]	24.0	23.6	25.3	26.3	27.0	29.8
	Chemical	2.8	2.3	1.9	2.2	1.9	1.9
	Electrical	0.1	0.1	0.1	0.1	0.1	0.1
	Glass	1.5	1.7	2.6	3.4	3.2	2.3
	Other	1.2	0.9	1.3	0.7	-0.4	0.7
	Total Gross Demand	**29.6**	**28.6**	**31.2**	**32.7**	**31.8**	**34.8**
Recycling[6]	Autocatalyst	-9.4	-8.1	-8.4	-9.6	-10.4	-11.5
	Total Recycling	**-9.4**	**-8.1**	**-8.4**	**-9.6**	**-10.4**	**-11.5**
Total Net Demand[7]		**20.2**	**20.5**	**22.8**	**23.1**	**21.4**	**23.3**
Movement in Stocks[8]		**-1.0**	**3.0**	**1.2**	**0.5**	**2.1**	**1.4**

Ruthenium Demand

Troy ounces and tonnes

RUTHENIUM '000 oz - Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Demand	Chemical	357	470	365	428	267	315
	Electrical	351	454	436	416	429	419
	Electrochemical	145	149	176	191	198	221
	Other	108	150	155	173	182	188
	Total Demand	**961**	**1,223**	**1,132**	**1,208**	**1,076**	**1,142**

RUTHENIUM Tonnes - Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Demand	Chemical	11.1	14.6	11.4	13.3	8.3	9.8
	Electrical	10.9	14.1	13.6	12.9	13.4	13.0
	Electrochemical	4.5	4.6	5.5	5.9	6.1	6.9
	Other	3.4	4.7	4.8	5.4	5.7	5.8
	Total Demand	**29.9**	**38.0**	**35.2**	**37.6**	**33.5**	**35.5**

Iridium Demand

Troy ounces and tonnes

IRIDIUM '000 oz - Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Demand	Chemical	22	22	23	17	19	20
	Electrical	40	78	100	73	52	59
	Electrochemical	57	44	45	66	59	72
	Other	71	76	81	85	89	92
	Total Demand	**189**	**220**	**249**	**240**	**218**	**242**

IRIDIUM Tonnes - Demand							
							2019 numbers are a forecast
		2014	2015	2016	2017	2018	2019
Demand	Chemical	0.7	0.7	0.7	0.5	0.6	0.6
	Electrical	1.2	2.4	3.1	2.3	1.6	1.8
	Electrochemical	1.8	1.4	1.4	2.1	1.8	2.2
	Other	2.2	2.4	2.5	2.6	2.8	2.9
	Total Demand	**5.9**	**6.8**	**7.7**	**7.5**	**6.8**	**7.5**

Notes to Tables

[1]Supply figures represent estimates of sales by the mines of primary pgm and are allocated to where the initial mining took place rather than the location of refining.

[2]Our Russian supply figures represent the total pgm sold in all regions, including Russia and the CIS. Demand in Russia and the CIS is included in the Rest of the World region.

[3]Supplies from Zimbabwe have been split from Others' supplies. Platinum group metals mined in Zimbabwe are currently refined in South Africa, and our supply figures represent shipments of pgm in concentrate or matte, adjusted for typical refining recoveries.

[4]Gross demand figures for any given application represent the sum of manufacturer demand for new metal in that application and any changes in unrefined metal stocks in that sector. Increases in unrefined stocks lead to additional demand, reductions in stock lead to a lower demand figure.

[5]Our Medical and Biomedical category represents combined metal demand in the medical, biomedical and dental sectors.

[6]Recycling figures represent estimates of the quantity of metal recovered from open-loop recycling (i.e. where the original purchaser does not retain control of the metal throughout). For instance, autocatalyst recycling represents the weight of metal recovered from end-of-life vehicles and aftermarket scrap in an individual region. These figures do not include warranty or production scrap. Where no recycling figures are given, open-loop recycling is negligible.

[7]Net demand figures are equivalent to the sum of gross demand in an application less any metal recovery from open-loop scrap in that application, whether the recycled metal is reused in that industry or sold into another application. Where no recycling figure is given for an application, gross and net demand are identical.

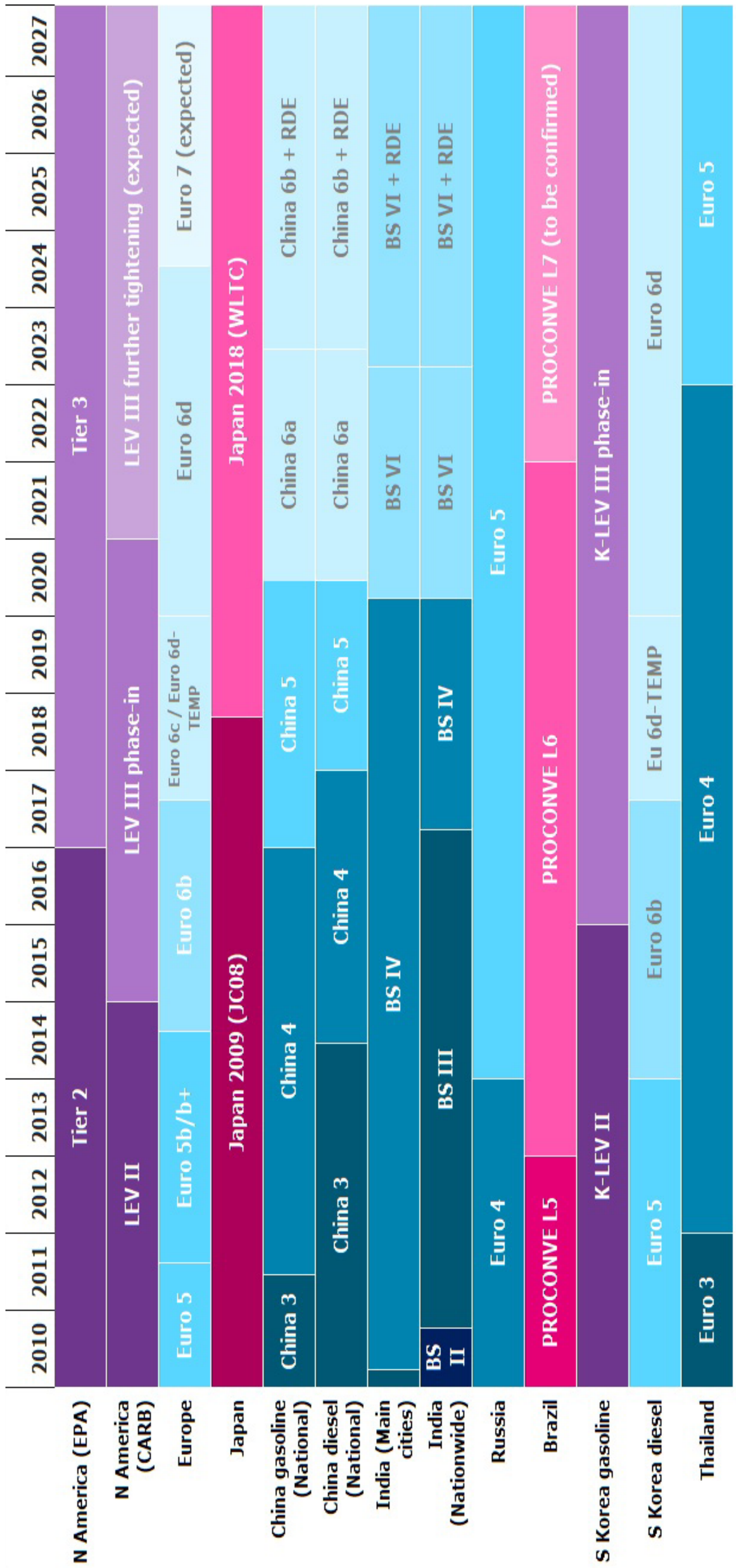
[8]Movements in stocks in any given year reflect changes in stocks held by fabricators, dealers, banks and depositories but excluding stocks held by primary refiners and final consumers. A positive figure (sometimes referred to as a 'surplus') reflects an increase in market stocks. A negative value (or 'deficit') indicates a decrease in market stocks.

Glossary

ASC	Ammonia slip catalyst
BEV	Battery electric vehicle
CF	Conformity factor
CO	Carbon monoxide
CO_2	Carbon dioxide
DOC	Diesel oxidation catalyst
DPF	Diesel particulate filter
EC	European Commission
ELV	End-of-life vehicle
ETF	Exchange traded fund
FCEV	Fuel cell electric vehicle
GDI	Gasoline direct injection
GPF	Gasoline particulate filter
HC	Hydrocarbon
HDD	Heavy duty diesel
ISC	In-service conformity
LAB	Linear alkyl benzene
LDG	Light duty gasoline
LDD	Light duty diesel
LEV	Low emission vehicle
MLCC	Multi-layer ceramic capacitor
NEDC	New European Driving Cycle
NEV	New energy vehicle (BEV, PHEV or FCEV)
NOx	Oxides of nitrogen
NRMM	Non-road mobile machinery
NYMEX	New York Mercantile Exchange
PDH	Propane dehydrogenation
PHEV	Plug-in hybrid vehicle
PM	Particulate matter or soot
PN	Particle number
PNA	Passive NOx adsorber
PTA	Purified terephthalic acid
PX	Paraxylene
RDE	Real driving emissions
RoW	Rest of world region
SCR	Selective catalytic reduction
SCRF®	SCR integrated with a soot filter
SGE	Shanghai Gold Exchange
SUV	Sports utility vehicle
WLTP	Worldwide Harmonised Light Vehicle Test Procedure
4E grade	Combined content of four elements: platinum, palladium, rhodium and gold

Emissions Legislation

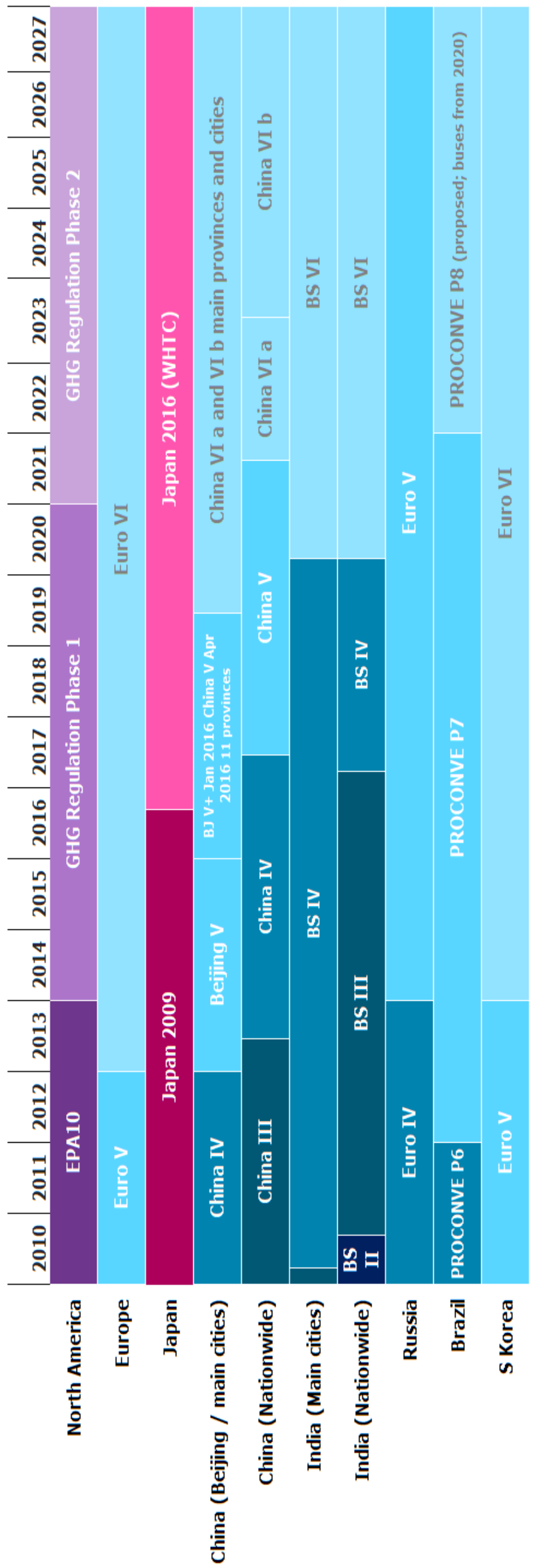
Light Duty



Dates shown are for New Vehicle Type Approvals for passenger cars

Emissions Legislation

Heavy Duty Diesel



Notes

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