THE PLATINUM STANDARD

May 2016

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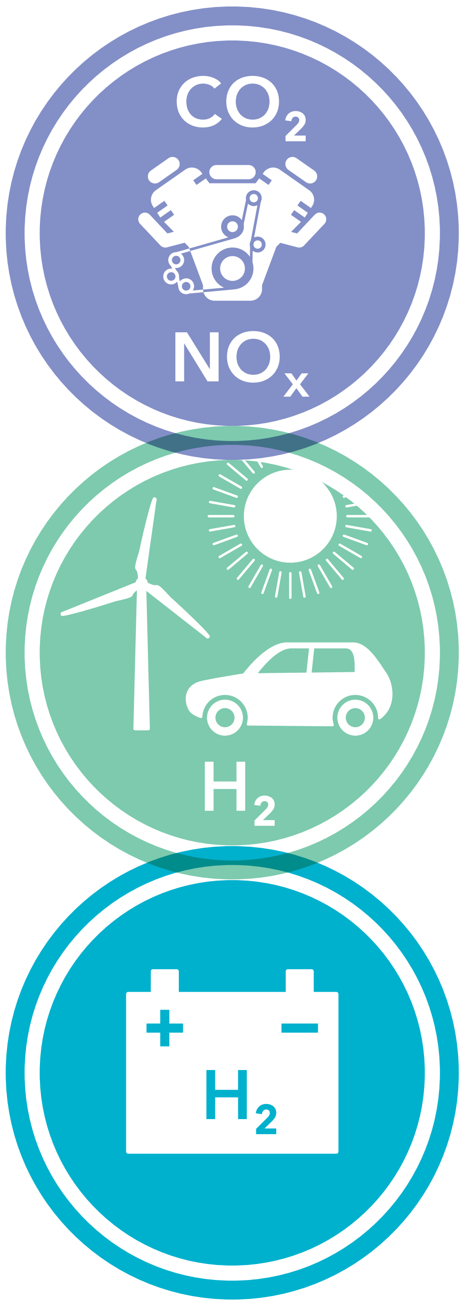


FOREWORD

Foreword

Desperately seeking sustainable demand

Who lost the car? Automotive platinum demand is still 1 million oz lower than in 2007, a 'performance' rivalled only by several peripheral Euro members.

Who lost the ETF? Since their peak in 2014, platinum and palladium ETFs have mislaid 460 koz and 810 koz respectively. This is the equivalent of losing a big PGM mine. Fortunately, in 2015 around 450 koz of platinum bars were purchased in Japan with consumers hedging against a weakening yen, but you wouldn't call this sustainable demand, more a temporary phenomenon.

So where, beyond the cycle (or even the 'Supercycle'), is PGM demand growth to be found? After all, investment in new mine capacity needs the assurance of long-term demand growth (especially when so much else is militating against it).

The reputation of platinum's mainstay, diesel powertrains, seems to be approaching that of politicians, bankers and some seedier 'stars' of the 1980s. Already with a target on its back for 'polluting our cities', diesel has been blown into an international incident and an economic catastrophe by the VW testing scandal. Are diesels now roadkill? Is it just a question of whether the divorce between platinum and cars will be amicable or messier still?

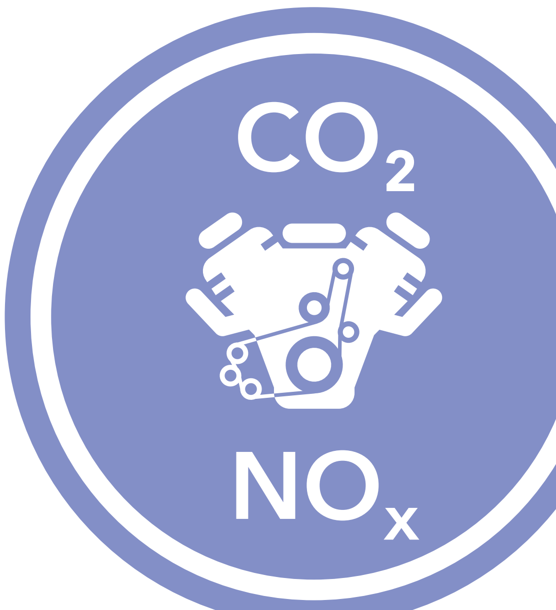
It's high time we took a deep breath from the blowhards. So it's timely that Dr Jenny Watts, SFA's technologies expert, reviews the issues of air quality, plus the political and legislative angles for PGMs, exhaustively. Achieving CO_2 and NO_x emissions standards targets is one of the greatest challenges for automakers over the next five years. Yet they are being asked to 'suck and blow' at the same time: cutting CO_2 usually leads to a rise in NO_x. We take issue with the Rolling Stones here: this is much more than just "a gas, gas, gas". It's a (high-wire, politically) balancing act: diesels are great at cutting CO_2, but so far keeping NO_x down (at least on the road) has proved 'testing'. Maybe this 'impasse' will be jolted by the electric car?

Further over the horizon, where rainbows end and pots of gold are said to be found, perhaps fuel cells could jump-start the car industry? Dr Katsuhiko Hirose, a long-time engineer at Toyota, leaders in fuel cell technology, looks over the cycle (and rainbow) to present his vision of 'sustainable mobility'. It's back to basics in the future. How will we choose to get from A to B? Where will the giant leaps in power come from to make these small steps? And will PGMs still get a ride?

But fuel cells are not just car parts. They have a multitude of applications potentially key to a liveable (let alone a sustainable) future. So we are pleased that Dr Kerry-Ann Adamson, our go-to fuel cell industry expert, contributes her assessment of global demand for multiple fuel cell uses and what it will take to steer round the roadblocks to higher platinum demand beyond autocatalysts.

Since Mao's revolution, but especially in the 1950s and 1960s, a debate raged over 'who lost China?' In due course it emerged that China hadn't gone anywhere, indeed it had re-invented itself in western-friendly ways no one could have imagined in those chilly-war days. And here we are, wondering where the foundations of PGM demand are? To paraphrase Mao: 'Let a hundred end-uses bloom'!

Air quality – political and legislative implications for PGM use



Air quality – political and legislative implications for PGM use

Dr Jenny Watts, SFA (Oxford) Ltd

Cars need platinum and platinum needs cars

In the current maelstrom over air quality, emissions legislation, vehicle testing (real-world vs. test bench), and current and future powertrains, SFA would like to look objectively at some of these issues and review the data supporting our view of the automotive industry and the part PGMs take in it.

An impossible task – which has actually been done very well

The processes going on in an internal combustion engine to turn the wheels of a car are extremely complex and produce a wide range of gaseous and fine particulate emissions; this is just an inescapable fact of basic physics and chemistry. Fortunately, vast industries have grown up to mitigate these emissions.

Juggling the apparently conflicting demands of breathing clean air and reducing global warming with unfettered personal mobility, in a cost-effective way, has kept powertrain and autocatalyst companies very busy over the past few decades. Reducing vehicle emissions to the atmosphere is a complex spectrum of technological activity – at one end, engine designers try to optimise the combustion process to minimise the 'engine-out' emissions, while at the other end, autocatalyst designers try to convert all the remaining harmful emissions into harmless materials with the help of PGM-based and other catalytic processes.

Today's real-world vehicles are a triumphant combination of reduced engine-out emissions and efficient catalytic aftertreatment. However, trying to optimise for all of the parameters is rather like herding cats – while doing well in controlling one parameter, it is difficult to avoid losing some control over another parameter.

The 'pick your pollutant' battle

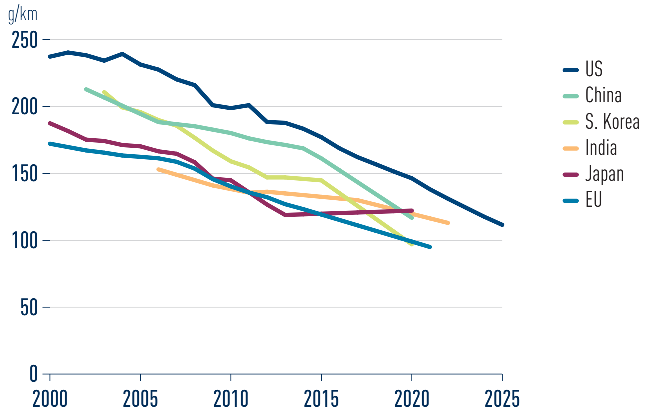
Recent months have perhaps seen a shift in the public eye from concern over reducing CO_2 emissions, to concern over reducing NO_x emissions. US regulations have tended to focus on criteria pollutant (NO_x, particulates, CO, HC) emissions control, while European legislation has focused more on fuel efficiency to control CO_2 emissions.

European authorities have prioritised the increasingly strongly perceived long-term global threat of CO_2 emissions. By contrast, US regulators have prioritised the proven and more immediate health implications of emissions such as NO_x. Following from this, in Europe, purchase and annual car taxation bands have been developed based on CO_2 emissions, which favours more fuel efficient diesel powertrains.

The public eye has shifted to concerns over reducing NO_x

Enormous strides have been made already in cutting CO_2 emissions from vehicles, with an eye on the tough targets and punitive fines ahead from 2020 and beyond. The chart below shows the progress made in the last decade and a half, and the unrelenting road ahead to lower CO_2 emissions further.

Grams CO_2 per km normalised to NEDC Test Cycle



Source: ICCT

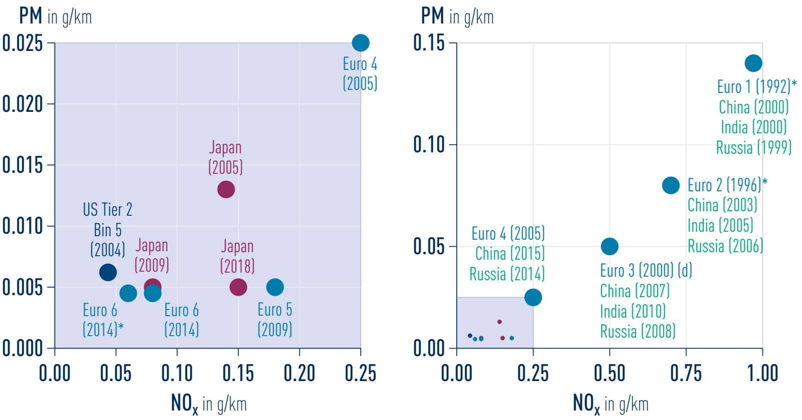
NEDC: New European Drive Cycle

There is also a regional difference in focus between particulate and NO_x emissions. The US has the more stringent NO_x limits, while Europe has more stringent particulate mass and number limits. Particulates are implicated in far more deaths than NO_x, so the European emission standards have been considered better from a public health point of view.

Similarly, legislated NO_x and particulate emissions levels have reduced by several orders of magnitude since emissions legislation was first introduced.

The US has the toughest NO_x limits

Diesel emission standards – Western world versus Emerging economies



Source: SFA (Oxford)

*Gasoline

*HC + NO_x

Of course, it is now well known that there are varying degrees of discrepancy for all types of vehicle emissions between those found under real-world driving conditions and those tabled in legislation or indeed measured under test bench driving conditions.

The automotive industry, through engine design and aftertreatment, has confirmed it has the technology available to meet real-world driving standards, so automakers must be forced to use it, and not find legal and not-so-legal ways to meet legislation under contrived conditions.

Technology is available to meet real-world driving standards

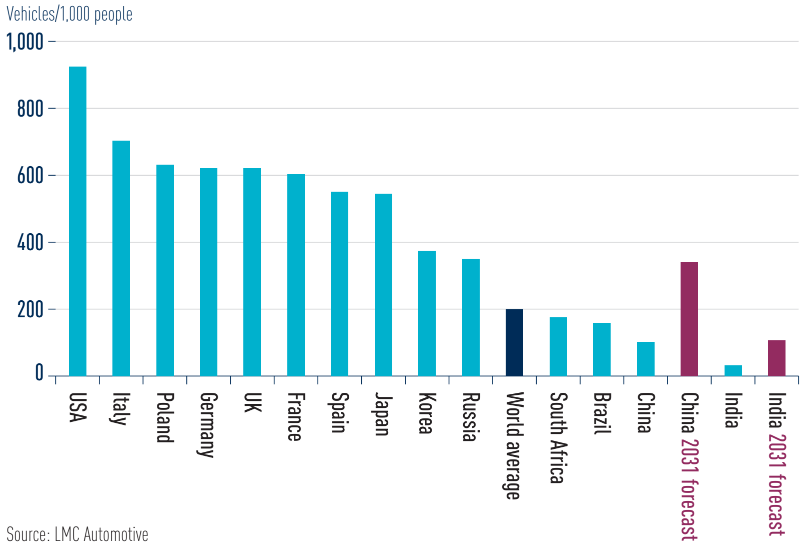
There will be more, not fewer, vehicles on the road ahead

Reducing emissions by limiting ownership and/or use of vehicles could be a simple and obvious solution to poor air quality. Several global cities including London, Paris and Beijing have experimented with outright bans, allowing only newer vehicles and restricting the sale of licence plates. These have had some limited, local and short-term success, but ultimately, people's desire for personal mobility is not going to go away.

Desire for personal mobility is not going away

While it is clear that no other country will ever approach the vehicle ownership levels of the US, the chart below highlights the growth expected from China, already the largest vehicle market, and India, a fast emerging market. Consumers in these countries, and many others, will expect to own a car when they can afford to do so, and will not see poor urban air quality as a reason for them to abstain.

Personal vehicles per 1,000 driving population, 2015



Source: LMC Automotive

Significant ownership growth potential in China and India

Internal combustion engines continue to dominate

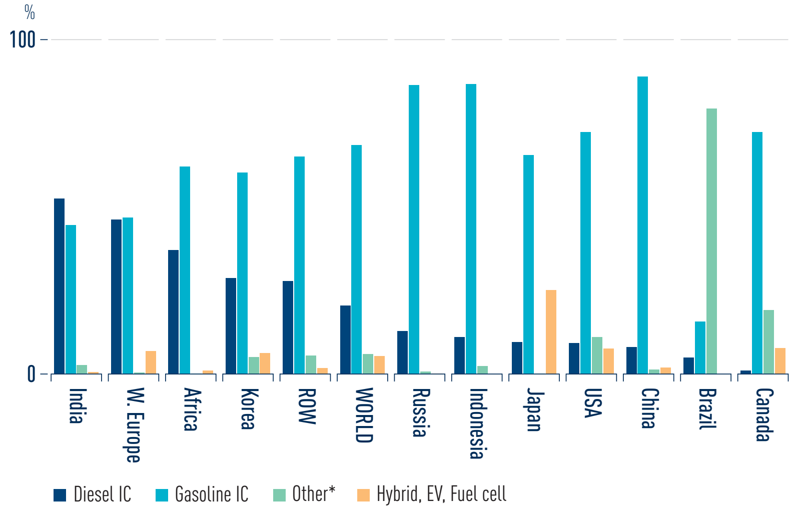
It is now abundantly clear that decarbonisation of automotive powertrains needs to take place to cut all types of emissions, but the ever-improving incumbent technology – gasoline and diesel engines – will be hard to displace.

Electrification is taking place throughout light-duty powertrains, but as an adjunct to internal combustion engine technology, rather than displacing it. A large fraction of the electrification expected over the next decade or more will be simply the addition of a small electrical system alongside mostly gasoline engines, in various shades of hybridisation. Mild and micro hybrids especially are expected to offer significant CO_2 savings at lower cost than a full hybrid system.

Electrification through hybridisation with limited replacement of internal combustion engines

For the medium term at least, shown in the chart below, the world is set to remain predominantly a gasoline internal combustion engine market, with diesel making up 20% of the market globally and making up half of production in substantial markets such as Western Europe, India and South Korea.

Light vehicle production by type, 2020 forecast, %



Source: LMC Automotive

*Other is mostly alternatively fuelled internal combustion engines

Over the medium term diesels hold 20% of the light vehicle market

Hybrid vehicles, however, are still a small part of the volume auto market according to LMC Automotive, with 1.4 million units expected to be added to production between 2015 and 2020, but still only taking the share from 2.2% to 3.2% of global production over this period.

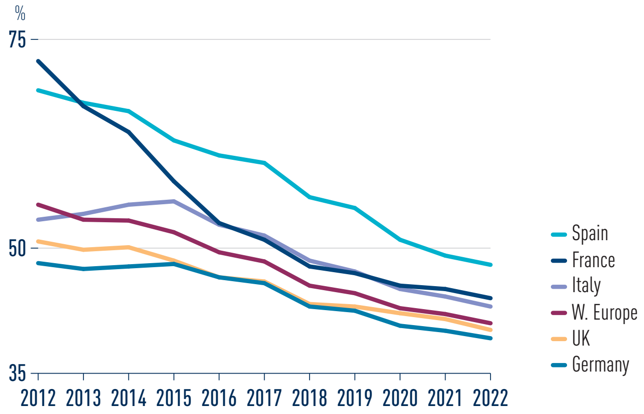
A bad year for diesel in the press, but the reality is not so bad

Diesel cars' share of their largest market, Western Europe, is in slow decline, but there appears to have been minimal damage from the 'dieselgate' events.

Forecasts over the last couple of years have consistently shown diesel market share falling gradually in Western Europe, and, despite the VW scandal last year, that forecast is little changed. Diesels are losing share as gasoline powertrains are becoming more competitive for some driving patterns where previously diesel was clearly more attractive.

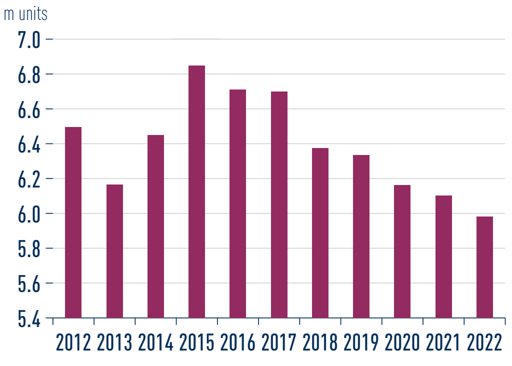
Diesel's share in Europe is in slow decline

Western European passenger car diesel share, %



Source: LMC Automotive

Western European passenger car diesel sales, m units



Source: LMC Automotive

The volume of diesel sales peaked in 2015

The additional cost and uncertainty over emissions legislation compliance may be deterring some potential buyers, but on nowhere near the scale feared when the VW scandal broke. While the rising fuel efficiency of gasoline engines erodes some of diesel's advantage, tightening emissions legislation affects gasoline powertrains too, so they must bear some of the same additional costs of aftertreatment as those that have hit diesels.

Looking ahead, we can expect a world where both diesel and gasoline powertrains continue to improve in emissions and efficiency terms. Diesel cars are expected to retain a distinct fuel economy advantage over most equivalent gasoline cars. Most importantly, their driveability and practicality for most consumers is expected to remain well ahead of that of pure electric vehicles, while battery capacity and charging issues are addressed.

Continued dominance of the internal combustion engine means continued demand for PGMs

On-road diesel vehicle autocatalysts, both light- and heavy-duty, accounted for 34% of total global platinum demand in 2015. The largest market by far is Western Europe, where platinum used in diesel vehicles accounts for some 70% of European platinum demand. It is clearly imperative that the case for diesel, with state-of-the-art catalytic aftertreatment, continues to be articulated here, in the face of sustained sniper attacks.

Diesel accounts for 70% of Western Europe platinum demand

The platinum used in heavy-duty diesels is largely captive, as diesel powertrains are expected to be the dominant choice for the foreseeable future. No other powertrain can serve the needs of the market in the way that today's highly developed diesels can. Gasoline powertrains cannot deliver the same towing power, fuel economy or durability. The risk then applies only to light-duty vehicles, where gasoline vehicles may be seen as a ready substitute.

Platinum use in heavy duty diesels is largely captive

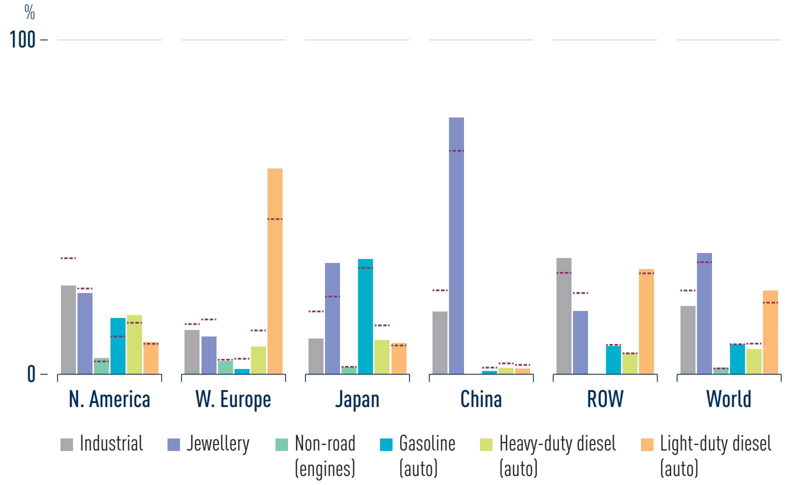
The RoW countries include India, where again strong growth has been forecast for diesel light vehicles; across the RoW countries, diesel vehicles account for 36% of regional platinum demand. The largest region overall for platinum demand, China, is the smallest by far for diesel autocatalyst demand.

The chart opposite shows that globally, jewellery demand exceeded diesel autocatalyst demand for platinum in 2015, while total autocatalyst demand (diesel + gasoline + non-road) is ahead of jewellery. While light-duty diesel remains vulnerable, it becomes increasingly important to support platinum jewellery demand too.

Jewellery demand exceeded diesel platinum demand in 2015, important to support jewellery

Globally, light-duty diesel accounted for three-quarters of total diesel vehicle autocatalyst demand in 2015. For most buyers of light-duty vehicles, a gasoline or gasoline-hybrid would, in fact, meet their needs almost as well as a diesel; similarly low CO_2 emissions can be achieved with a hybrid and much of the running cost advantage of a diesel is bound up in fuel and vehicle taxation policy.

Platinum demand by end-use, 2015, %, with 2025 forecast



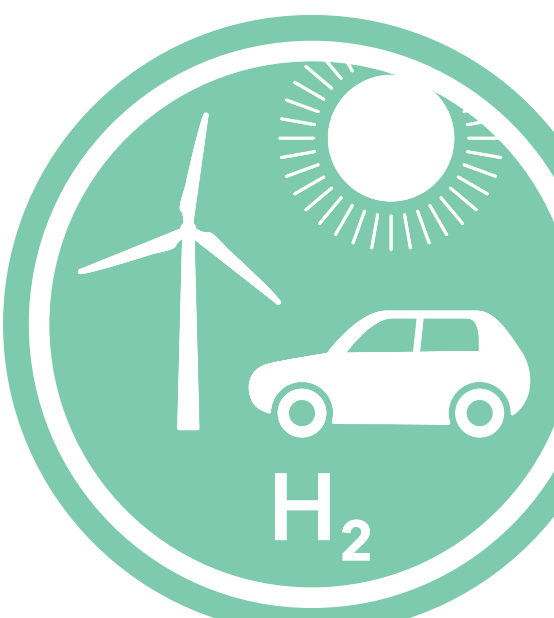
Source: SFA (Oxford)

The global and sectoral balance is expected to change over the next ten years, but overall platinum demand in diesel autocatalysts (light- and heavy-duty) is estimated to remain similar to 2015 at around 35% of total demand. Light-duty diesel is expected to decrease in importance in Western Europe, falling from 62% of demand in 2015 to 46% of demand in 2025, while in the RoW it increases in importance from 29% to 44%. Under current assumptions, by 2025, the RoW platinum market from light-duty diesel autocatalysts is forecast to be some 350 koz larger than that in Western Europe.

So, globally over the next decade, around 25% of platinum demand is potentially at risk from misunderstandings over the full package of emissions from diesel cars. It is important to stem the losses from Western Europe and simultaneously to ensure that currently forecast demand from the RoW (mainly India) does materialise. **Cars need platinum and platinum needs cars.**

RoW platinum market for light-duty diesel set to become 350 koz larger than Western Europe

Where do PGMs lie on the journey towards the future of sustainable mobility?



Where do PGMs lie on the journey towards the future of sustainable mobility?

Dr Katsuhiko Hirose, Professor of Kyushu University and Professional Partner Hydrogen & Fuel Cell Promotion Group, Toyota

Firstly, please read the following article

"My wife and I (already enjoying retired life) go to visit my son living near Lake Como in Italy. While approaching Malpensa airport, good weather makes both Venice and Milan clearly visible. Floods in the Piazza San Marco are a problem that hasn't occurred for a very long time. Since most vehicle powertrains have been replaced by fuel cells, finally, world carbon dioxide concentrations have stabilized and, indeed, started to go down. The façade of the Duomo in Milan shines brilliantly, since a few years ago it was totally cleaned up. I drive toward Como in the latest rental car, so I switch on the auto drive mode, and move to the back to watch our daughter's latest piano recital in New York.

The vehicle does not disturb her recital since the latest fuel cell does not make any noise because it generates electricity with air that is simply supplied by the vehicle running wind pressure. Thanks to this, the only noise I hear is a small amount of road noise from the high speed cruising. As the car approaches the hillside near Lake Como, I switch off the auto-drive mode and I take over the control of the car to enjoy the winding road. This much fun cannot be given to the car! The first feelings of strangeness disappear just after I install the characteristic data of my own car in Japan into this rental car. The car learns and memorizes the driver's characteristic then adapts to be like my own car in Japan. This has been realized by sharing the same protocol, and as a result many safety improvements have been achieved. I really enjoy the hillside driving except that the car stops once before the pass in order to avoid collision with a deer that suddenly jumps in front of the vehicle. Later, while my son and his wife are welcoming us to their house, the car leaves silently and returns to the airport. Before going, it refuels itself at the inner-court from the household waste hydrogen producer. Just before the car disappears, I sense it resembles my aged car left in Japan. It is not only from the body shape, but also in its manner. One scene I saw during my student life at London is still very clear in my mind because it impressed me greatly."

This article, written by me, was published ten years ago (1) and was derived from my experience in London during the 1970s. Horse-drawn vans delivered milk to the houses and the horse remembered the delivery stops. I saw the benefits of this collaboration and realised that the best vehicles would be as intelligent as a horse and integrate with the driver over time.

[1] Making the Fuel Cell Vehicle into a Modern Stromatolite, JSAE Paper Number 20064026, January 2006, Vol.27 No.1.

I am pleasantly surprised that these ideas are beginning to take shape for both current and future forms of mobility. They were all just a dream only ten years ago but most of them are becoming a reality now. However, the rationale behind these technologies differs slightly from my original thinking. The most important development in those ten years is the economic feasibility of these technologies, as autonomous driving then was just a technological target and there were doubts whether it could be implemented into normal cars. The same applied for fuel cell vehicles (FCVs); when I said FCVs would be on the road in ten years' time with a purchase price of around $50,000, I was heavily criticized. In the same vein, ten years ago the price of a house operating with 100% renewable energy was millions of dollars, but now the cost of photovoltaic (PV) power is falling it can be increasingly implemented in housing and the energy sustainability of a community is becoming feasible. Hydrogen produced from waste, as mentioned in my article, is now a commercial reality in both California and Fukuoka.

Hydrogen produced from waste is a commercial reality

A considerable change over this ten-year period is sustainability; it initially meant just the environmentalists' dreams of a cleaner world, but the current meaning of sustainability is much wider and has become real business. 'Sustainable society' is no longer just theoretical but is the real final goal of technologies, not just in energy terms but also to make society economically sustainable. Although PV or wind power can now provide enough energy for general or domestic use, it needs to integrate into the total management system with energy storage and power conversion systems, rather than just electricity. The greatest energy costs for society are fuel for mobility and energy for heating, so it is necessary for those to become sustainable. This is difficult to achieve because, whilst electricity may be sufficient for certain domestic situations, vehicle choice reflects individual lifestyle rather than just transportation needs. Society also scales sustainability, as the medium- to heavy-duty vehicles required to transport goods and people are more difficult to electrify. However, fuel cells and hydrogen can play a major role in solving these issues, both by storing energy from fluctuating renewable energy production and by converting hydrogen into electricity and propulsion.

Sustainable society has become a final goal of technologies

Fuel for mobility and energy for heating need to become sustainable

The future is, of course, not predictable but there will be uncertainties and certainties. Which technologies will become mainstream in future is uncertain but it is certain that sustainable mobility will be needed by society.

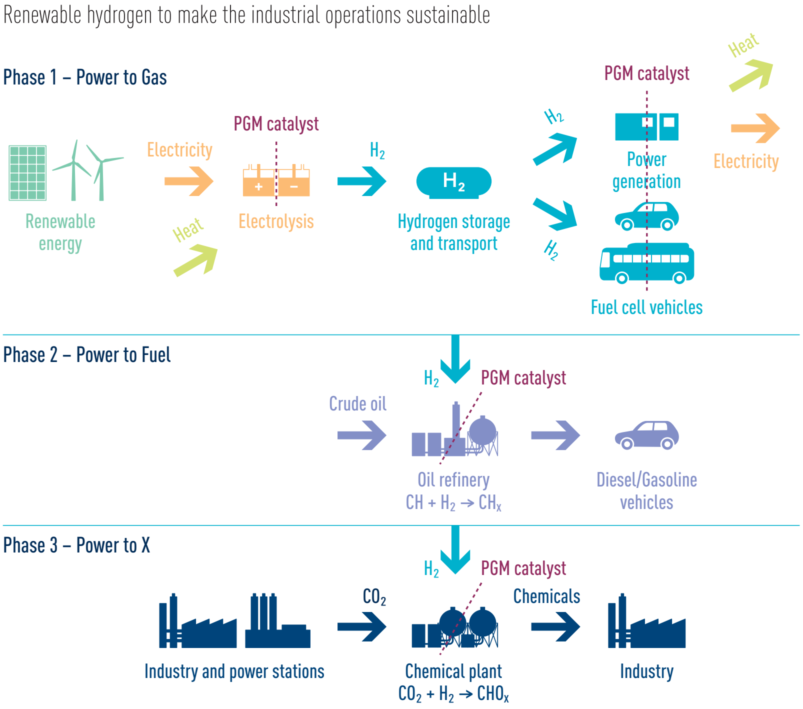
Throughout my career as an automobile engineer I had experience of working with platinum-group metals. I was involved in the development of a platinum-based, three-way catalyst just after I joined Toyota 30+ years ago and then spent years working to reduce the platinum content. However, with the development of ultra-low emissions vehicles, extra platinum was added to already highly loaded three-way catalysts. I also observed the substitution of platinum by palladium in the so-called 'non-platinum' catalyst. When working in Europe in the mid-1990s, I witnessed the rise in popularity of diesel vehicles and again observed the heavy increase in platinum use for diesel catalysts.

To progress towards a more sustainable society, recent more radical but interesting ideas are being raised and are close to being implemented; this is known as 'Power to X' and is shown in the diagram below. The cost of wind power has fallen and is approaching that of fossil fuel power generation. Wind and solar generators are now 'over-producing' electricity on a large scale in some places. The first step is to use excess electricity to electrolyze water to produce hydrogen which is stored to re-produce electricity when necessary. Next, this electricity can be used in the form of hydrogen to supply fuel for fuel cell cars or injected into the existing natural gas pipeline. This idea was welcomed since it reduces the use of high-cost oil and natural gas and is referred to as the 'Power to Gas' concept. The second phase further reduces oil consumption by injecting the hydrogen into the oil refinery where a large amount of hydrogen currently derived from hydrocarbons is used. The carbon dioxide footprint of all the cars can be reduced once the gasoline/diesel is low carbonised. This is called 'Power to Fuel'.

Use excess clean energy in certain locations to produce hydrogen fuel

PGM catalyst key to energy conversion to X

Renewable hydrogen to make the industrial operations sustainable



Source: Dr Katsuhiko Hirose, Professor of Kyushu University

PGM catalysts are key to energy conversion

The latest discussion among engineers (not scientists) is called 'Power to X', where the carbon dioxide from power stations or steel furnaces is combined with the hydrogen from renewables to produce valuable chemical intermediates such as methanol. The 'Power to X' concept could make all industrial activities sustainable.

What comes next is very difficult to predict but we can prepare for the future

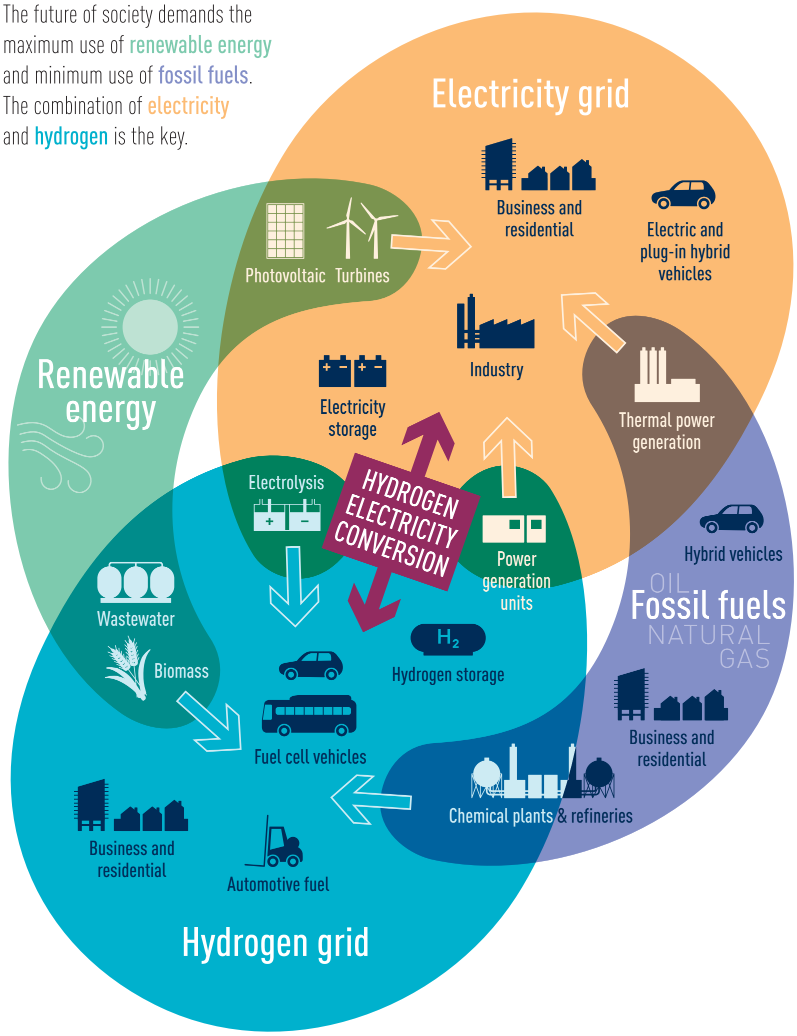
The future direction of both mobility and society is increasingly sustainable in my view. The success of FCVs is still uncertain but the need for low carbon and sustainable mobility cannot be ignored. Most importantly, a sustainable society needs hydrogen together with electricity. A hydrogen society needs a highly efficient way of using a fuel cell and electrolyzer, such as the HyGrid system, shown in the diagram below, and both technologies need platinum-group metals for splitting electrons and protons/ions or combining them to generate electricity. My view is that platinum-group metals are far superior to other technologies in catalyzing these electrochemical reactions.

The success of fuel cell vehicles is still uncertain

A sustainable society needs hydrogen together with electricity

HyGrid (Hybrid Grid)

The future of society demands the maximum use of renewable energy and minimum use of fossil fuels. The combination of electricity and hydrogen is the key.



Source: HyGrid Study Group

A sustainable society requires growing use of PGMs

In conclusion, I see a future sustainable society where the importance of platinum-group metals is not shrinking but rather is growing.

I will close this article with my new dream for the next generation.

On a clean day in the future, my grandchild and I visit my parents' home in Japan.

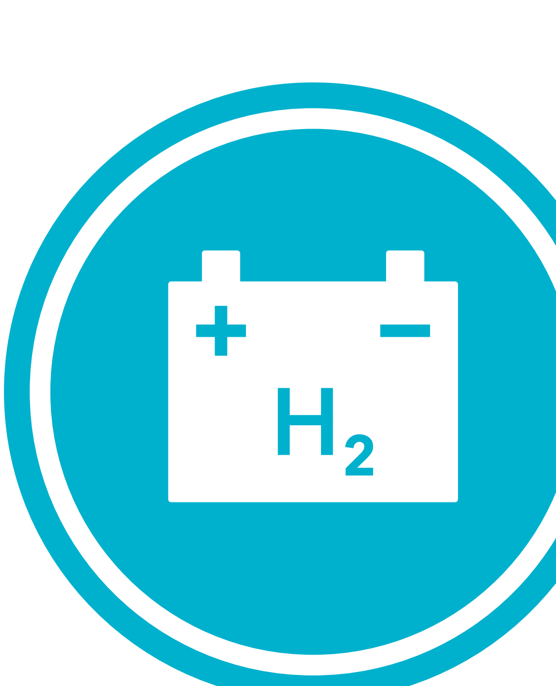
As the plane approaches Tokyo Haneda airport, the industrial complexes of Tokyo Bay are still visible below, but the bunches of chimneys are gone except in the preservation zone where students are taught how precious carbon resources such as carbon dioxide were once emitted into the atmosphere. Now, of course, carbon has become the precious resource of industrial activities. The sounds of engines are no longer heard since the electrochemical propulsion systems involve no burning of fuel; even the word 'fuel' means hydrogen now rather than hydrocarbons as it did in the last century.

After the plane has landed and connected to the terminal, as the passengers disembark from the plane, the baggage hold door opens and bags start to unload themselves.

Having greeted my parents, we exit to the car terminal. Vehicles are individually tailored for use by elderly people like my parents and travellers like us. When we sit in the car, a voice confirms that our luggage is already in the rear compartment, thanks to the luggage having its own power and mobility since the small battery of the installed hydrogen electric motor intelligently tracks our route. The car approaches my parents' house near Mount Fuji in less than an hour from the airport, as there is no longer any traffic congestion because all vehicles are connected virtually and traffic flow on the roads is optimised. Cars can travel only a few centimetres apart and roads can be flexibly used as two or three lanes, since there are no accidents or collisions between the cars. Drivers do not need to be concerned with the fuel as either battery electric mode or hydrogen electric mode is chosen automatically and optimally for the journey.

When we are in the pass travelling to view beautiful Mount Fuji, I move to the front seat and take over the steering wheel of the vehicle which is normally hidden. This is an antique from a 2015 Toyota Mirai fuel cell car and this car exactly follows its characteristics. Now cars are almost completely automated, but the fun of driving remains for people to enjoy when they want to.

Fuel cells applications beyond automotive – opportunities and challenges



Fuel cells applications beyond automotive – opportunities and challenges

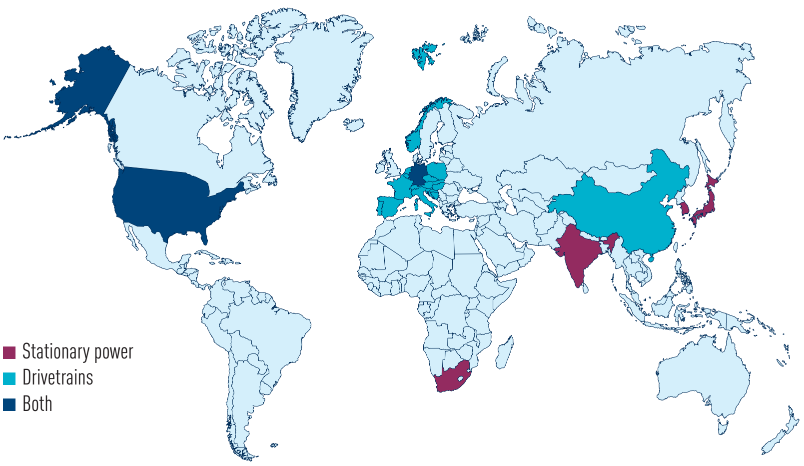
Dr Kerry-Ann Adamson, 4th Energy Wave

Whilst the world's press continues to focus on the photogenic and headline-grabbing aspects of fuel cell cars, the rest of the industry continues to expand, grow, reduce costs, improve the supply chain and move to profitability.

The map below shows the countries with active, government-level deployment plans specifically for fuel cell systems, other than automotive. On the map, burgundy represents areas developing fuel cells for stationary power, turquoise indicates where there is the adoption of fuel cell drivetrains into non-automotive applications, and dark blue is for both. These markets include: residential combined heat and power (resCHP), all-electric prime power, off-grid power, back-up power, combined heat and power, systems for remote monitoring, trucks, forklifts, boats, trains and trams. All of these have developers with platinum-based systems.

Multiple fuel cell applications with platinum-based systems

Plans for non-automotive fuel cell deployment



Source: 4th Energy Wave

Although it can be argued that the number of countries is low, it does include the key swing countries of Japan, South Korea, the US, China, the European Union and South Africa.

So why fuel cells? Why are fuel cells going into trains, trams, homes, data centres, off-grid power, etc? The table overleaf provides an overview of the key reasons why developers are deploying platinum-based PEM- and PAFC-based systems into these markets.

Application	Fuel cell under development	Why platinum-based fuel cells?	Notes
resCHP	PEM (Pt-based), SOFC (non-Pt-based)	PEM-based systems better suited for new builds, with lower heating requirements. Can potentially work in tandem with renewables. SOFC-based systems more suited to retrofit applications.	Japanese target of 5.3 million fuel cell resCHP systems installed by 2030. Not all PEM systems. In Europe, highly funded demonstration project, though long-term market model shaky.
Prime power	PEM, SOFC, MCFC (non-Pt-based)	No emissions, rapid start-up, can cycle up and down, low heat signature (important for data centres), low water consumption (important for data centres).	Limited availability of systems, but growing. Market demand increasing and forecast to jump over the next decade.
Off-grid power	PEM, SOFC	When coupled with renewables can run off hydrogen, or uses methanol which in Africa is more widely available than natural gas or hydrogen.	Demonstration projects only. Innovation in business models could really open up this market.
Back-up power	PEM	Rapid cycling, in terms of seconds, good durability, low maintenance required.	Increasingly widely available. Held back by market, not technology. Moving to supplying service, not technology, will open up this market to volume.
Combined heat and power	PAFC, MCFC	Good amounts of useful (waste) heat as a by-product. Economics can stack up.	Two companies (Doosan Fuel Cell America, Fuji Electric) with product, and order pipeline growing.
Remote monitoring	PEM, DMFC (Pt-based), SOFC	Long(er) maintenance intervals, quick start-up.	Growing market, driven by demand from oil and gas industry.
Trucks	PEM	Heavy-duty PEM units can provide the needed drive cycle.	Market being driven by the 'demonisation of diesel'. One to watch.
Forklifts	PEM	Zero emissions in indoor environment due to use of hydrogen, good drive cycle, lack of short run (12 hour) degradation of power as compared with batteries.	Growing market in the US but harder to make economics stack up in Europe. Japan will be next market to adopt them.
Boats	PEM	Heavy-duty PEM units can provide the needed drive cycle. Lack of vibration of the fuel cell could increase passenger comfort.	Longer term market but with massive potential due to need to reduce emissions.
Trains / trams	PEM	Heavy-duty PEM units can provide the needed drive cycle.	Market being driven by move away from diesel and economics. Along with trucks, one to watch.

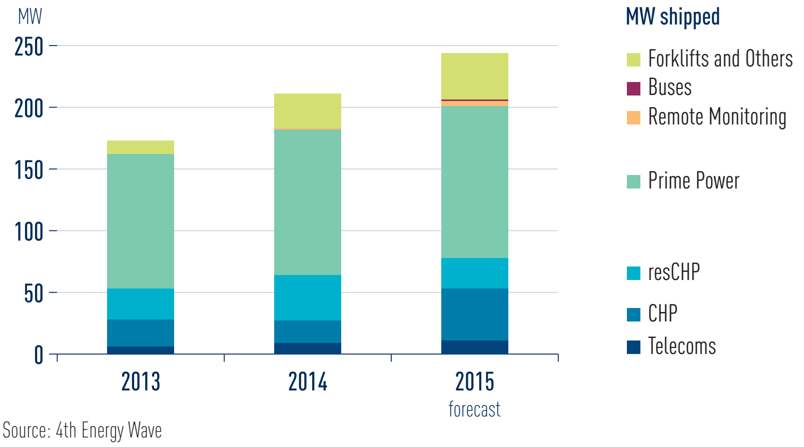
Source: 4th Energy Wave

Initialisms used in the table:

PEM – Polymer electrolyte membrane fuel cells – those used in cars
SOFC – Solid oxide fuel cells
MCFC – Molten carbonate fuel cells
PAFC – Phosphoric acid fuel cells
DMFC – Direct methanol fuel cells

The 2015 forecast for combined non-automotive fuel cell power is 245 MW (actual data to be released in May 2016).

Global shipments of non-automotive fuel cells



Source: 4th Energy Wave

This chart includes all types of fuel cells, not just PGM-based systems.

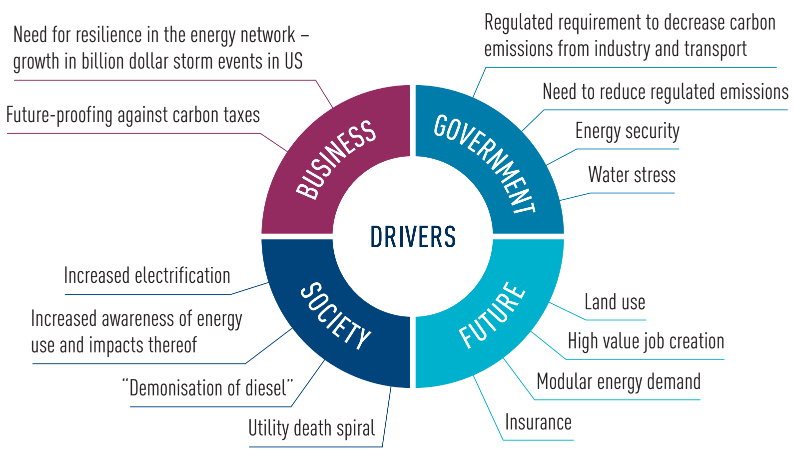
Cleantech economy is still a micro sector

Although the sector is posting growth, it should be noted that when compared with other industries in the Cleantech economy this is still a micro sector. It is expected that 245 MW of non-automotive fuel cell capacity was added in 2015, as compared with 57,000 MW of new solar power in the same period. To put this in context, there was more solar power added in Australia in 2015 than was forecast for fuel cell adoption globally during the same period.

Non-automotive fuel cell demand below 50 koz in 2015

In terms of platinum demand, the non-automotive platinum sector in 2015 was still below 50 koz. So the prime power market, which forms the largest segment of the non-automotive market in each of the three years shown, has only 1 MW, in 2015, of platinum-based systems. The rest are high temperature systems without a PGM catalyst.

When examining the reason behind this continued growth in deployment, a complex mix of societal, business-centric and government-focused drivers emerges. Different drivers dominate in different countries and regions, creating a patchwork of adoption around the world but also a much more complex story. After all, what works in one country might not in another. The silver bullet, answer to everything, approach that some propose for cars – fuel cells or batteries – is even more incorrect in these markets.



Source: 4th Energy Wave

The fundamental global shift in energy and transport networks should be an opportunity for fuel cells ...

... but there are many barriers to overcome

The abiding points of commonality, though, between these drivers are:

1. They are not going to go away. These are not short-term blips driven by swings in oil price but a fundamental global shift in the energy and transport networks.
2. The drivers are not unique to fuel cells. Although the global basket of drivers is strong and growing, in themselves they do not guarantee a future market for fuel cell technology.

In short, there is no USP in fuel cells that other technologies do not also exhibit which meets the drivers for change. This alone is one of the greatest challenges faced by the sector. In many ways the fuel cell industry remains balkanised and inward-looking, rather than working together to create a sustainable and profitable sector which works alongside and with the other technologies that the changes in society are demanding.

Some of the other barriers to adoption are shown in the diagram below.

Source: 4th Energy Wave

Heavily dependent on Japanese deployment to reduce costs

Needs a global standard stack design

Setting aside the technical challenges, the largest innovation seen in the non-automotive side of the industry is the move away from selling technology to selling services. It is well known that most customers do not want to buy the technology; they want electrons, the things that the fuel cell produces.

To date, the industry has focused on this being someone else's problem. Now, though, companies such as Bloom Energy, FuelCell Energy, Intelligent Energy and, to a certain extent, Plug Power have taken the leap forward and set up options to buy electrons. Often through a 20-year power purchase agreement (PPA), companies and adopters can now obtain long-term energy supply agreements, with the power coming from fuel cells. This is having a jump-start impact on the large stationary sector, and potentially telecoms, with the forecast being that 2016/2017 will be the years that for some companies there will be more orders for services than the actual sales of the systems.

However, the rub for the platinum industry is that three of the five fastest growing, non-automotive fuel cell companies produce non-PGM-based fuel cells. Whilst the market for PGM-based, non-automotive systems is growing, it is now very clearly being held back by a number of factors, none of which are based on the cost of the technology itself. The key challenges for the PGM-based fuel cell sector include:

1. Lack of multiple companies that can deploy at volume, on time and with acceptable quality. There is a reason that Ballard Power Systems, Hydrogenics and Intelligent Energy are winning big orders: they can supply at increasing volumes.

2. Lack of innovation and investment in alternative business models. This one needs flashing lights around it. Intelligent Energy is the only PGM-based fuel cell company that is trying to innovate into moving to a service-based company. At the time of writing it seems to have recovered from the brink of bankruptcy that was caused by the last minute withdrawal of an investor. The investment sector's traditional approach is to invest in technology, and whilst this is needed at stack and supply chain level, at the systems level the industry needs a rethink on business models. How these are going to be funded or invested in is a real challenge, but if this is addressed, the subsequent increase in product demand could see platinum demand from the fuel cell industry leap forward.

Although small companies are claiming that the lack of funds is preventing the transition, the reality is that the majority of the PGM-based industry is comfortable with the current status quo of small order volumes and the potential of a big pay-off at some point in the future. Innovation is challenging, so why undertake it when there are enough funds for more R&D and demonstration and to allow avoidance of the core issues?

Industry is shifting to selling services rather than technology

Long-term energy supply agreements with power from fuel cells

Three out of five fastest growing providers produce non-PGM-based fuel cells

3. Lack of access to fuel. Hydrogen and natural gas are the two main fuels that are being used in PEM-based fuel cells, while methanol is used in direct methanol fuel cells (DMFCs) and natural gas in phosphoric acid fuel cells (PAFCs). But these fuels are far from ubiquitous. Although technically a global supply of hydrogen is possible, the in-field reality is that this can lead to deployment complexity and such high cost that the project planning is unworkable. Electrolysis of renewable energy to produce hydrogen is seen by governments such as those in Germany and Japan and the Californian state government as one of the key planks in future energy storage. Whilst this could increase the amount of hydrogen available, the need for innovation here will be the matching of location of production with market need for the fuel.

Taking these challenges into account, there is a growing delta between the amount of platinum likely to be required by the non-automotive fuel cell sector under a business-as-usual outlook, and a realistic market demand for platinum, under known cost assumptions, if the barriers were to be addressed. In the stationary sector alone, this delta represents potential extra demand of over 15,000 oz platinum annually.

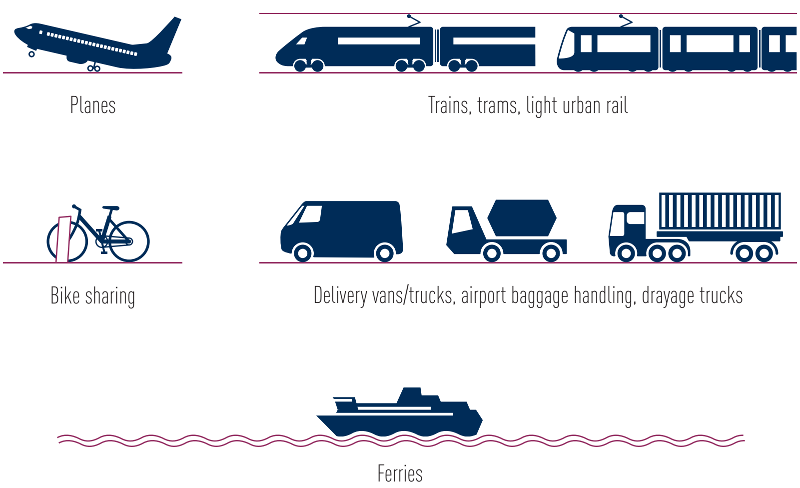
How to leverage this and create sustainable demand for platinum in the broader non-automotive fuel cell sector is not down to any one single stakeholder group or government. Although the Japanese government has clearly set out its stall for a hydrogen society, the reliance of the global industry on the success in Japan to drive global commercial viability, and cost out through volume, is a very high-risk strategy.

Industry is too heavily reliant on Japan for commercial success

Case Study: Back to Base Markets

Name two back to base markets that are not buses or forklifts…

Come on, think about it…



Source: 4th Energy Wave

And so on and so forth. In short, there are many of them.

Market potential in many other applications

Aside from forklifts and buses, fuel cell manufacturers tend to ignore all the other back to base markets. Although the power requirements of drayage trucks, ferries and trains can be hefty, so, too, is the market potential. There have been numerous (so-called) studies looking at the market potential at airports, but nothing has come of them. Part of the reason could be that the perception is that the volumes are too low to create a product to address these markets. So many companies are focusing on the potentially ultra-high volume markets of automotive and resCHP, and prime power, that the smaller markets, which run into hundreds and up to the low thousands per annum, are not worth addressing.

New fuel cell agreements for rail power recently signed

However, this may have started to change in 2015 with a couple of very significant orders. The first of these was between Hydrogenics and Alstom Transport. The deal, which is worth over €50 million, is for Hydrogenics to supply Alstom with over 200 PEM-based, heavy-duty propulsion systems. The engines are to be delivered and maintained for at least the next decade.

The second order involved Ballard Power Systems which signed a framework agreement with Tangshan Railway Vehicle Company Limited (TRC) for the development of a new fuel cell module that will be designed to meet the requirements of tram or ground transport vehicle (GTV) applications. The goal is to have a prototype vehicle on the tracks in 2016.

With each engine being over 300 kW and volumes running into the thousands per annum, this is not a market to be sniffed at. The world's railway rolling stock manufacturers should be prime targets for any fuel cell company with a PEM-based system powerful enough to meet the requirements, which currently means only Hydrogenics and Ballard.

Potential in truck logistics, ferries, bikes and delivery vehicles

This is an example of one market that is ripe for development once product availability and business models are established. The market for platinum in the sector will then start to jump forward as systems move into truck logistics, ferries, bikes and delivery vehicles.

30,000 fuel cell buses in South Korea by 2030 but deployment challenges

Overall the industry outside of cars is evolving fast, and in some pockets transforming. One example of this is during the period of drafting the first iteration of this article and the editing, South Korea announced that by 2030, 30,000 fuel cell buses would be in operation in South Korea. This now very much puts the lens of focus on the ability of companies to ramp up and deploy at scale.

However, there is still a job of work to be done. The question of advocacy is not a simple one either. An Elon Musk of fuel cells is needed, but not in terms of his being a champion of technology, in his case batteries, but in terms of his role as a market maker and a doer. He doesn't just talk, he does. Any advocacy that is done needs to be truly agnostic, not just for the platinum-based part of it, and independent of territorial issues, something of which all current associations fall foul.

Fuel cell potential for platinum is significant but a decade of hard work is required

So it is not a simple, straightforward equation, and although the potential for the platinum sector is significant, it will be at least a decade of hard graft before we reach a million ounce market from fuel cells, automotive or otherwise.

The PGM markets in 2015

The PGM markets in 2015

Platinum: a narrower deficit

Summary

The market deficit for platinum narrowed substantially in 2015, with primary supply growing by over 1.2 moz. Gross demand (excluding investment demand) increased by 125 koz, and recycled volumes decreased by 330 koz in response to lower scrap steel and PGM prices.

Mine supply recovered by over 1.2 moz

Mine supply

Following considerable disruption in 2014, it is no surprise that South Africa recorded a significant recovery in platinum production last year. The total came in slightly above expectation, at 4.47 moz (+1.3 moz y-o-y), with Anglo Platinum drawing down pipeline stocks and exceeding guidance by around 60 koz. Production at Mogalakwena increased by 60 koz y-o-y to over 400 koz for the first time, with operational improvements in the mine and toll treatment of ore by a third party.

Solid mine performance and pipeline destocking lifts South African supply

Glencore suspended the ramp-up of Eland mine in the second half of the year, but with development of Nyala shaft previously suspended in 2012, the impact on the supply total was very limited. The mine produced 30 koz in 2014 and 20 koz in 2015. Atlatsa also placed its UM2 and Vertical shafts on care and maintenance in December.

Production remained stable in Zimbabwe at 405 koz, but decreased by 4% y-o-y in North America to 385 koz and by 3% in Russia to 715 koz. Production from Vale's Sudbury Division was impacted by plant maintenance in Q3, while a major reconfiguration of processing facilities at Norilsk resulted in lost production. Global supply exceeded 6.1 moz for the year (4.8 moz in 2014).

The PGM basket price for South African producers has remained below $1,000/4E PGM oz since June 2015. The average dollar-based basket price for the year fell by 20% (-7% y-o-y in local currency). The rand weakened by 18% to 12.8:$1 in 2015, but with very little cost cutting in the post-strike ramp-up and higher-cost shaft closures mostly taking effect from 2016 and 2017, South Africa as a whole essentially broke even for the year.

South African producers raised over $1.1 billion in cash during 2015, including the listing of Northam's BEE partner Zambezi Platinum. The $1.1 billion will be used for the completion of Impala's 16 and 20 Shafts, to strengthen Lonmin's balance sheet and enable debt repayment, and to allow expansion of production by Northam. Net debt for South African producers (excluding diversified companies) reduced by more than $700 million y-o-y. However, lower prices resulted in PGM asset impairment charges exceeding $4.1 billion globally in 2015; this is more than 2.5x the total impairment value for any other year. Crucially, large write-downs impact on producers' borrowing capability in the near term. Cost savings, primarily relating to overheads and labour retrenchments, and further capital cutbacks will therefore be the focus of 2016.

Capital cutbacks, impairments, shaft closures and prudent balance sheet management to limit supply growth from 2016

Recycling

Total supply from recycling dropped by 330 koz (-16% y-o-y) to 1,710 koz in 2015. Lower PGM and steel prices negatively impacted scrap collection rates throughout the recycling sector. Jewellery recycling was most affected by the lower prices, with recycled volumes reducing by 260 koz to 515 koz (-34% y-o-y). Recycled platinum from autocatalysts declined by 65 koz to 1,190 koz (-5%). The already minor contribution from industrial recycling halved from 10 koz to 5 koz.

Recycling volumes hit by low steel and PGM prices

Demand

Gross demand, excluding investment, increased by just 2% to 7,955 koz in 2015. Automotive (including non-road) and industrial demand both rose by 5% y-o-y to 3,445 koz and 1,630 koz respectively. Jewellery use fell by 4% to 2,880 koz.

Healthy automotive and industrial demand offsets lower jewellery requirements

Automotive demand

Global automotive demand for platinum was up by 5% to 3,445 koz in 2015. A full year of sales of Euro 6-compliant vehicles in Europe lifted the amount of platinum used per car and aided demand growth by an estimated 135 koz. This is despite the VW diesel emissions scandal that broke at the end of the second quarter.

European demand growth was relatively well spread amongst Germany (+35 koz), Italy (+36 koz), Spain (+35 koz) and the UK (+22 koz), with the remainder not contributing much to continent-wide growth. Italy's vehicle production rose by more than 200,000 units. Perhaps unconnected but SFA tracked a rise in platinum sponge imports to Italy to levels not seen since before the financial crisis. Spain's vehicle output saw a sharp recovery too, while a stable diesel share in Germany helped it to reap the full impact of tighter emissions legislation.

More platinum used per car sold in Europe

Demand was relatively flat elsewhere, but vehicle production growth in the emerging markets also helped to boost usage. Owing to sluggish or contracting macroeconomic growth, metal requirements were down in Russia, Brazil and Argentina, but this was offset by higher vehicle production in India, Mexico and Turkey.

Jewellery

Global platinum jewellery demand fell by 4% to 2,880 koz in 2015. Demand in China, which accounts for the lion's share of jewellery consumption at 1,765 koz, decreased by an estimated 11% despite a 21% drop in the platinum price. Price dips have always been a buying opportunity for manufacturers, but not last year it appears. A slowdown in the economy hit retailer sales of jewellery, particularly in small independent outfits. Fewer marriages between Chinese couples (-6%) hit mainland jewellery sales, while tourists from China failed to prop up Hong Kong jewellery sales which fell by double digits.

Slowdown in China undermines jewellery demand growth, despite lower prices

Elsewhere, however, jewellery demand was relatively robust. India's requirements continue to grow from a low base, recording a 26% y-o-y rise to 220 koz spurred on by strong campaigns by Platinum Guild International including 'Platinum Day of Love' and 'Evara Blessings'. Men's adornment jewellery, which tends to be around 3-5 times heavier per piece than wedding bands, is helping the Indian market to establish itself. US and European sales were boosted by low platinum prices relative to gold.

Industrial

Industrial demand rose by a healthy 5% to 1,630 koz in 2015, led by the oil industry (+95 koz to 160 koz) and chemical sector (+25 koz to 595 koz). Electrical and glass consumption decreased by an estimated 40 koz and 15 koz respectively owing to weaker demand for hard disk drives and a net reduction in requirements due to glass plant closures in the US, Japan and Europe.

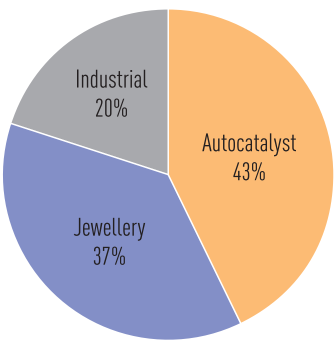
Expansion in oil refining capacity fuels industrial demand growth

There were some oil refinery closures during the year, but this was offset by capacity expansions, technology upgrades and an efficiency drive in Europe, which helped to lift margins for the industry. Chemical sector demand in China, the US and Europe stemmed mainly from higher silicone production and an increase in capacity of nitric acid and propane and butane dehydrogenation (PDH, BDH) plants, offsetting a drop in requirements in the RoW and Japan.

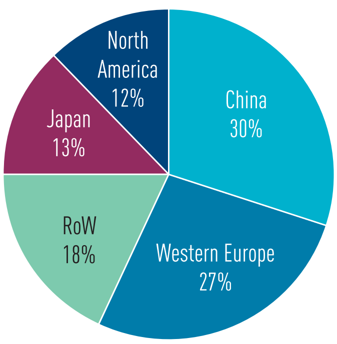
Investment and above-ground stocks

Global platinum ETF holdings decreased by 9% to 2.51 moz in 2015 owing to lower dollar prices. Holdings grew in Japan (from 18 koz to 87 koz), but declined elsewhere.

Pt gross demand by sector, 2015



Pt gross demand by region, 2015



Source: SFA (Oxford)

Global stock levels recovered to just over 11 moz in 2015. The increased flows of metal in Europe as well as a recovery in volume flow in China and Hong Kong are the major reasons for this growth. Stocks in Japan also appreciated considerably, but this is most likely related to the sharp increase in bar buying. Purchasing was up as platinum prices fell below the ¥4,000/gram threshold, incentivising consumer buying that has continuted into 2016.

Palladium: hit by China's slowdown

The fundamental deficit in the palladium market shrunk by 180 koz in 2015 as primary supply rebounded to its highest level since 2006 (+8% y-o-y). Gross demand growth slowed to 3% y-o-y (5% in 2014), but a 5% reduction in supply from recycling saw net demand increase to 7,945 koz overall (+5% y-o-y).

Deficit narrows to 1,005 koz

Automotive demand growth slowed to a 3% increase in 2015, totalling 7,760 koz (+5% for platinum). This slowdown relates mainly to China where automotive demand increased by 5% y-o-y in 2015 compared to 10% in 2014.

China autocatalyst demand growth slowed to 5% compared to 10% the year before

Industrial palladium usage edged up by 1% (20 koz) to 1,975 koz last year, lifted by a price-induced rebound in chemical demand (+33 koz) and benefitting from slower rates of decline in dental (-9 koz) and electrical (-10 koz) consumption. There was also a minor increase in other end-use demand. Despite lower prices, jewellery demand was up by only a meagre 5 koz to 300 koz.

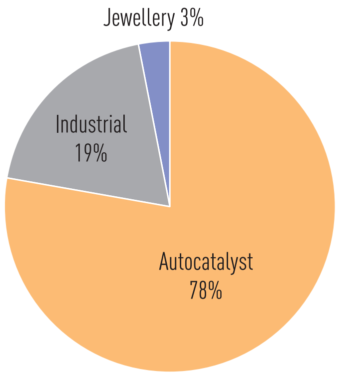
Primary supply increased by 8% to 6.9 moz in 2015. South African output recovered to 2.5 moz (1.8 moz in 2014), while production from North America and Russia decreased by 6% to 995 koz and 3% to 2.6 moz respectively.

Primary supply at highest level since 2006 owing to recovery in South Africa

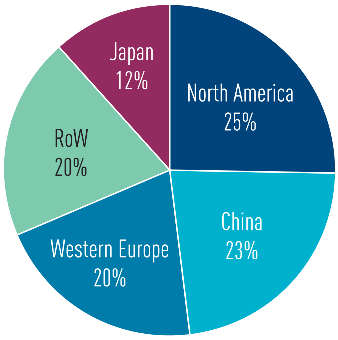
Secondary supply from recycling fell by 5% y-o-y to 2,090 koz in 2015. There was a slightly deeper cut for palladium autocatalyst recycling than for platinum, which was somewhat cushioned by the higher loadings of scrapped autocatalysts in Western Europe.

Palladium ETF holdings contracted by 23% to 2.27 moz, with selling in the UK, South Africa, the US and Switzerland.

Pd gross demand by sector, 2015



Pd gross demand by region, 2015



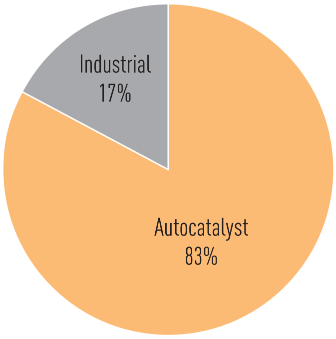
Source: SFA (Oxford)

Rhodium: balanced

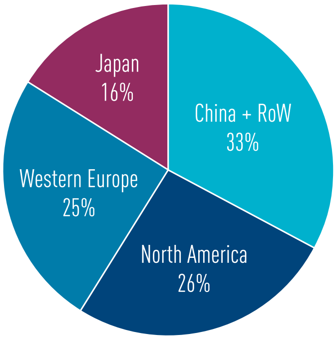
The rhodium market was just about balanced in 2015. After several years of reducing primary output, supply caught up to demand with a 175 koz (20%) rise in mined (entirely South Africa) and recycled production. Gross demand increased by 35 koz (entirely automotive), giving a deficit of 15 koz and little argument for a higher price.

Primary supply recovery swings rhodium almost back to balance

Rh gross demand by sector, 2015



Rh gross demand by region, 2015



Source: SFA (Oxford)

Price outlook for 2016

Platinum: $956/oz

Until recently, platinum prices averaged $934/oz and SFA forecasts an average of $956/oz for the year. Perhaps this is a touch conservative relative to prevailing prices at over $1,000/oz at the time of writing. However, there are still numerous headwinds to face as the year progresses.

Global economic growth forecasts continue to be ratcheted down, leading to lower industrial demand growth expectations, particularly from automotive production. Primary supply can still disappoint with wage negotiations ahead, but the appetite for a lengthy mine walkout is not what it was. Recycling may continue to struggle to recover, but this is down to low commodity prices. For now there is no panic to buy and it seems reasonable that prices trade close to the cost of production near current levels. Short positions on NYMEX have largely exited, so a short covering rally would not boost prices in the near term.

Demand pull not strong enough to lift platinum prices in 2016

Of course, the rand-dollar exchange rates influence our outlook. Our prices are based on a rate close to ZAR16:$1, so taking SFA's platinum prices in rand and converting using today's exchange rate yields a higher dollar platinum price of $1,040/oz for the year.

Palladium: $548/oz

Palladium prices could outperform other PGMs

SFA's price forecasts are conservative relative to the year-to-date average price of $537/oz and current prices, which are in the high $500s/low $600s/oz.

The bulls have largely exited the market, with long positions on NYMEX halving from over 3 moz. China, the engine of growth for the palladium market, continues to slow and this has removed some of the bull case for palladium. Nonetheless, the market remains in structural deficit and cars favour palladium use. Some disruptions to supply are predicted ahead, including the rejigging of Norilsk's processing capacity. Against this background, palladium appears relatively cheap. Assuming that China does not experience a hard landing and the US does not slip into recession, then palladium has the ability to outperform over the near term.

Rhodium: $733/oz

Rhodium price risks are downwards unless change is forthcoming

Unfortunately, rhodium remains over-supplied for the time being and this continues to cap meaningful price gains. Rhodium prices can recover only if significant mine closures are forthcoming in South Africa or if rhodium is readopted in catalytic converters.

Appendix

Platinum supply-demand balance, koz

	2008	2009	2010	2011	2012	2013	2014	2015	2016f
Primary supply									
Regional									
South Africa	4,555	4,550	4,725	4,595	4,200	4,355	3,115	4,465	4,210
Russia	805	775	790	800	780	740	740	715	675
Zimbabwe	180	230	280	340	365	405	405	405	430
North America	370	275	200	375	345	355	400	385	390
Other	0	0	120	145	180	215	220	180	190
Total	5,910	5,830	6,115	6,255	5,870	6,070	4,880	6,150	5,895
Demand & recycling									
Autocatalyst									
Gross demand	3,655	2,490	2,855	3,105	3,155	3,150	3,280	3,445	3,425
Recycling	1,055	835	955	1,210	1,175	1,120	1,255	1,190	1,305
Net demand	2,600	1,655	1,900	1,895	1,980	2,030	2,025	2,255	2,120
Jewellery									
Gross demand	1,935	2,680	2,170	2,450	2,760	2,945	3,000	2,880	2,895
Recycling	390	415	475	630	840	855	775	515	495
Net demand	1,545	2,265	1,695	1,820	1,920	2,090	2,225	2,365	2,400
Industrial demand	1,675	1,295	1,615	1,780	1,510	1,520	1,550	1,630	1,585
Other recycling	15	15	10	10	5	10	10	5	5
Gross demand	7,265	6,465	6,640	7,335	7,425	7,615	7,830	7,955	7,905
Recycling	1,465	1,260	1,440	1,855	2,030	1,985	2,040	1,710	1,805
Net demand	5,800	5,205	5,200	5,480	5,395	5,630	5,790	6,245	6,100
Market balance									
Balance (before ETFs)	110	625	915	775	475	440	-910	-95	-205
ETFs (stock allocation)	100	385	575	175	200	905	215	-240	
Balance after ETFs	10	240	340	600	275	-465	-1,125	145	

Source: SFA (Oxford)

Platinum demand & recycling by region, koz

	2008	2009	2010	2011	2012	2013	2014	2015	2016f
Gross demand									
Autocatalyst									
North America	570	335	390	385	425	425	460	480	440
Western Europe	1,850	1,265	1,280	1,495	1,340	1,350	1,445	1,595	1,585
Japan	540	315	480	500	600	580	585	570	570
China	150	95	135	120	115	130	125	115	125
India	90	100	145	180	200	160	160	170	180
RoW	455	380	425	425	475	505	505	515	525
	3,655	2,490	2,855	3,105	3,155	3,150	3,280	3,445	3,425
Jewellery									
North America	195	140	160	160	185	200	230	250	255
Western Europe	200	185	180	175	175	220	220	235	245
Japan	450	430	370	315	325	335	335	340	335
China	1,020	1,860	1,370	1,670	1,915	1,990	1,975	1,765	1,725
India	40	40	50	80	105	140	175	220	265
RoW	30	25	40	50	55	60	65	70	70
	1,935	2,680	2,170	2,450	2,760	2,945	3,000	2,880	2,895
Industrial									
North America	320	225	230	275	325	310	310	255	365
Western Europe	340	260	575	295	280	195	265	340	270
Japan	155	125	160	210	105	90	40	85	55
China	225	155	385	300	365	520	435	495	450
RoW	635	530	265	700	435	405	500	455	445
	1,675	1,295	1,615	1,780	1,510	1,520	1,550	1,630	1,585
Total gross demand									
North America	1,085	700	780	820	935	935	1,000	985	1,060
Western Europe	2,390	1,710	2,035	1,965	1,795	1,765	1,930	2,170	2,100
Japan	1,145	870	1,010	1,025	1,030	1,005	960	995	960
China	1,395	2,110	1,890	2,090	2,395	2,640	2,535	2,375	2,300
RoW	1,250	1,075	925	1,435	1,270	1,270	1,405	1,430	1,485
	7,265	6,465	6,640	7,335	7,425	7,615	7,830	7,955	7,905
Recycling									
Autocatalyst									
North America	580	550	580	600	575	560	560	505	545
Western Europe	310	135	195	420	405	365	470	450	535
Japan	115	110	145	115	115	95	105	95	95
China	0	0	0	5	10	20	30	55	40
RoW	50	40	35	70	70	80	90	85	90
	1,055	835	955	1,210	1,175	1,120	1,255	1,190	1,305
Jewellery									
North America	0	0	0	0	0	0	0	5	5
Western Europe	0	0	0	0	0	0	5	5	5
Japan	220	130	150	285	285	250	235	160	135
China	170	285	325	345	555	600	530	340	345
RoW	0	0	0	0	0	5	5	5	5
	390	415	475	630	840	855	775	515	495
WEEE	15	15	10	10	5	10	10	5	5
Total recycling									
North America	585	555	585	605	575	560	565	515	550
Western Europe	315	135	195	425	410	365	475	455	545
Japan	340	245	295	400	400	345	340	255	230
China	170	285	325	355	570	625	565	395	385
RoW	55	40	40	70	75	90	95	90	95
	1,465	1,260	1,440	1,855	2,030	1,985	2,040	1,710	1,805

Source: SFA (Oxford)

Palladium supply-demand balance, koz

	2008	2009	2010	2011	2012	2013	2014	2015	2016f
Primary supply									
Regional									
South Africa	2,345	2,425	2,590	2,550	2,355	2,360	1,855	2,560	2,385
Russia	2,700	2,675	2,720	2,705	2,630	2,580	2,690	2,605	2,390
Zimbabwe	140	180	225	265	280	315	330	325	350
North America	880	610	580	865	895	975	1,055	995	1,055
Other	0	0	300	390	445	450	460	455	460
Total	6,065	5,890	6,415	6,775	6,605	6,680	6,390	6,940	6,640
Demand & recycling									
Autocatalyst									
Gross demand	4,785	4,090	5,615	6,220	6,715	7,155	7,535	7,760	7,810
Recycling	1,215	1,155	1,395	1,525	1,485	1,645	1,720	1,630	1,730
Net demand	3,570	2,935	4,220	4,695	5,230	5,510	5,815	6,130	6,080
Jewellery									
Gross demand	855	705	595	470	420	350	295	300	290
Recycling	0	0	100	135	130	145	120	100	95
Net demand	855	705	495	335	290	205	175	200	195
Industrial demand	2,405	2,400	2,465	2,445	2,310	2,030	1,955	1,975	1,940
Other recycling	315	340	400	350	345	365	370	360	280
Gross demand	8,045	7,195	8,675	9,135	9,445	9,535	9,785	10,035	10,040
Recycling	1,530	1,495	1,895	2,010	1,960	2,155	2,210	2,090	2,105
Net demand	6,515	5,700	6,780	7,125	7,485	7,380	7,575	7,945	7,935
Market balance									
Balance (before ETFs)	-450	190	-365	-350	-880	-700	-1,185	-1,005	-1,295
ETFs (stock allocation)	380	505	1,085	-535	285	0	940	-670	
Balance after ETFs	-830	-315	-1,450	185	-1,165	-700	-2,125	-335	

Source: SFA (Oxford)

Palladium demand & recycling by region, koz

	2008	2009	2010	2011	2012	2013	2014	2015	2016f
Gross demand									
Autocatalyst									
North America	1,545	1,005	1,310	1,505	1,745	1,835	1,960	2,100	2,180
Western Europe	960	915	1,275	1,500	1,425	1,530	1,650	1,730	1,575
Japan	925	600	810	670	735	745	745	700	710
China	395	705	1,010	1,130	1,300	1,515	1,665	1,750	1,870
India	90	105	145	160	155	160	165	185	200
RoW	870	760	1,065	1,255	1,355	1,370	1,350	1,295	1,275
	4,785	4,090	5,615	6,220	6,715	7,155	7,535	7,760	7,810
Jewellery									
North America	60	60	65	45	45	40	35	35	35
Western Europe	45	50	65	65	80	75	60	55	55
Japan	90	65	65	70	75	65	55	60	60
China	635	505	370	260	190	145	120	120	110
RoW	25	25	30	30	30	25	25	30	30
	855	705	595	470	420	350	295	300	290
Industrial									
North America	515	495	495	485	440	430	415	415	405
Western Europe	375	360	405	365	365	280	265	270	260
Japan	605	590	580	550	555	430	410	405	390
China	325	425	435	425	405	405	395	405	405
RoW	585	530	550	620	545	485	470	480	480
	2,405	2,400	2,465	2,445	2,310	2,030	1,955	1,975	1,940
Total gross demand									
North America	2,120	1,560	1,870	2,035	2,230	2,305	2,410	2,550	2,620
Western Europe	1,380	1,325	1,745	1,930	1,870	1,885	1,975	2,055	1,890
Japan	1,620	1,255	1,455	1,290	1,365	1,240	1,210	1,165	1,160
China	1,355	1,635	1,815	1,815	1,895	2,065	2,180	2,275	2,385
RoW	1,570	1,420	1,790	2,065	2,085	2,040	2,010	1,990	1,985
	8,045	7,195	8,675	9,135	9,445	9,535	9,785	10,035	10,040
Recycling									
Autocatalyst									
North America	850	890	975	975	930	1,005	975	895	990
Western Europe	250	135	205	335	325	345	365	325	355
Japan	95	100	175	130	125	125	135	125	125
China	0	0	0	15	20	50	60	115	90
RoW	20	30	40	70	85	120	185	170	170
	1,215	1,155	1,395	1,525	1,485	1,645	1,720	1,630	1,730
Jewellery									
Japan	0	0	10	15	20	20	20	20	20
China	0	0	90	120	110	125	100	80	75
	0	0	100	135	130	145	120	100	95
WEEE									
North America	85	85	80	70	75	70	65	65	70
Western Europe	70	75	115	80	80	85	85	85	55
Japan	115	115	130	125	110	130	135	140	95
China	15	15	20	15	20	20	15	10	10
RoW	30	50	55	60	60	60	70	60	50
	315	340	400	350	345	365	370	360	280
Total recycling									
North America	935	975	1,055	1,045	1,005	1,075	1,040	960	1,060
Western Europe	320	210	320	415	405	430	450	410	410
Japan	210	215	315	270	255	275	290	285	240
China	15	15	110	150	150	195	175	205	175
RoW	50	80	95	130	145	180	255	230	220
	1,530	1,495	1,895	2,010	1,960	2,155	2,210	2,090	2,105

Source: SFA (Oxford

Rhodium supply-demand balance, koz

	2008	2009	2010	2011	2012	2013	2014	2015	2016f
Primary supply									
Regional									
South Africa	610	660	650	645	600	590	425	620	560
Russia	80	75	75	75	75	70	75	70	65
Zimbabwe	15	20	25	30	30	35	35	35	40
North America	30	20	15	30	30	35	30	30	30
Other	0	0	10	10	10	10	10	10	10
Total	735	775	775	790	745	740	575	765	705
Demand & recycling									
Autocatalys									
Gross demand	915	585	725	740	770	785	835	870	800
Recycling	190	170	220	235	235	260	275	270	295
Net demand	725	415	505	505	535	525	560	600	505
Industrial demand	140	110	170	170	150	160	170	170	165
Other recycling	3	2	1	1	1	1	2	2	2
Gross demand	1,055	695	895	910	920	945	1,005	1,040	965
Recycling	195	170	220	235	240	265	280	265	295
Net demand	860	525	675	675	680	680	725	775	670
Market balance									
Balance (before ETFs)	-125	250	100	115	65	60	-150	-10	35
ETFs (stock allocation)				15	35	50	5	-5	
Balance after ETFs				100	30	10	-155	-5	

Source: SFA (Oxford)

Rhodium demand & recycling by region, koz

	2008	2009	2010	2011	2012	2013	2014	2015	2016f
Gross demand									
Autocatalyst									
North America	275	150	180	180	200	220	235	260	255
Western Europe	265	190	195	215	190	195	220	240	170
Japan	240	115	165	135	150	140	140	125	125
China	30	45	70	75	90	95	105	110	120
India	10	10	15	20	20	15	15	15	20
RoW	95	75	100	115	120	120	120	120	110
	915	585	725	740	770	785	835	870	800
Industrial									
North America	15	10	15	20	15	15	15	15	15
Western Europe	15	15	25	20	20	15	20	20	15
Japan	45	35	45	45	45	40	40	40	40
China + RoW	65	50	85	85	70	90	95	95	95
	140	110	170	170	150	160	170	170	165
Total gross demand									
North America	290	160	195	200	215	235	250	275	270
Western Europe	280	205	220	235	210	210	240	260	185
Japan	285	150	210	180	195	180	180	165	165
China + RoW	200	180	270	295	300	320	335	340	345
	1,055	695	895	910	920	945	1,005	1,040	965
Recycling									
Autocatalyst									
North America	115	125	160	140	145	165	160	150	165
Western Europe	50	20	30	60	60	55	60	60	70
Japan	20	20	25	25	25	25	30	30	35
China	0	0	0	0	0	5	5	10	5
RoW	5	5	5	10	5	10	20	20	20
	190	170	220	235	235	260	275	270	295

Source: SFA (Oxford)

GLOSSARY OF TERMS

Aftertreatment
Systems after the tailpipe/exhaust to treat noxious emissions

Basket price
Collective revenue of metals divided by 4E oz

BEE
Black economic empowerment

By-products
Copper, nickel, iridium and ruthenium

CAPEX
Capital expenditure

CO_2
Carbon dioxide

Emissions legislation
Tailpipe regulations affecting particulate matter, hydrocarbons and oxides of nitrogen (NO_x)

ETF
Exchange traded fund

Euro 5/6 emission standards
Euro 5 legislation introduced in 2009, Euro 6 in 2014, will be widely adopted later in other regions

Evara Blessings
A Platinum Guild International jewellery campaign in India

Fuel cell
A device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidising agent

Gross demand
A measure of intensity of use

H_2
Hydrogen

HC
Hydrocarbon

HDV
Heavy-duty vehicle

koz
A thousand ounces

LCV
Light commercial vehicle

moz
A million ounces

Net demand
A measure of the theoretical requirement for new metal, i.e. net of recycling

Net supply
Proxy supply of metal surplus to requirements

NO_x
Mono-nitrogen oxides of NO and NO_2 (nitric oxide and nitrogen dioxide)

Non-road
Non-road mobile machinery installed with a combustion engine excluding aircraft and some military equipment

oz
Ounce

PDH
Propane dehydrogenation

PGMs
Platinum-group metals

Platinum Day of Love
A Platinum Guild International jewellery campaign in India

Powertain
The mechanism that transmits the drive from the engine of a vehicle to its axle

Primary supply
Mine production

Producer sales
Mine output plus inventory sold to market

Real-world driving emissions (RDE)
Real-world driving emissions from vehicles are often higher than those measured under laboratory conditions; it is proposed that Euro 6c legislation (expected around 2017) will begin to enforce these real-world limits

Secondary supply
Recycling output

Sponge
Metal in powder form

Supercycle
A premise that as emerging nations grew, the need to fuel that growth with all matter of natural resources would spur higher and higher long-term prices for such raw materials. Investors dived head first into steel, oil and other commodities in order to take advantage of the trend.

Tonnes milled
Concentrator throughput of ore

4E
Platinum, palladium, rhodium and gold

Currency symbols

ZAR	South African rand
$	US dollar
£	UK pound

METHODOLOGY NOTES

Primary supply is calculated from actual mine production and excludes the sale of stock in order to provide pure production data. Stock sales are treated separately in SFA's database as movement of stocks. Therefore, state stock sales from Russia are excluded in tabulations.

Gross demand is a measure of intensity of use.

Net demand is a measure of the theoretical requirement for new metal, i.e. net of recycling.

Automotive demand is based on vehicle production data not sales.

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Please note: Some tabulated data may not add up owing to rounding of individual numbers.

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