**INTRODUCTION**

Three fundamental factors determine the amount of platinum group metals (pgm) used in the autocatalyst sector: vehicle production rates, fuel type, and emissions legislation. Use of pgm by the automotive industry has steadily increased as population growth and greater prosperity have raised demand for new vehicles while at the same time legislation has set ever-tighter limits on exhaust emissions. Generally, as emission controls become increasingly strict, more pgm are needed per vehicle to lower the pollutant content of the exhaust gas. Emissions standards are tightest in North America, Europe and Japan, which are the most developed markets with the highest ownership of vehicles per capita. These three regions, therefore, account for the majority of autocatalyst pgm demand today, with the major emerging markets of China, Brazil and India steadily increasing their global share. China is now the world’s largest vehicle producing nation and although Chinese demand for pgm in autocatalysts currently lags behind that of North America and Europe, it will rise in importance in coming years due to continuing growth in vehicle production in the country and increasingly tighter emissions limits proposed there.

Control of harmful emissions from vehicle exhaust using catalysts is the largest single application for pgm, in 2012 accounting for 56% of gross world demand for platinum, palladium and rhodium combined. In this special feature we have for the first time split platinum and palladium autocatalyst demand values into their main components of light duty gasoline, light duty diesel and heavy duty diesel vehicles. We have also included in our autocatalyst numbers demand for catalysts for diesel non-road mobile machinery – this was previously reported as part of Other demand. Here we examine the historical long-term drivers and the future opportunities for the use of pgm in each of these automotive applications.
In line with emissions standards, our light duty gasoline (LDG) and light duty diesel (LDD) categories include all on-road vehicles of gross vehicle weight (GVW) less than 3.5 tonnes (less than 4.54 tonnes in the USA and under 6.35 tonnes in California) and the heavy duty (HDV) category consists of vehicles of GVW above these weights.

**LIGHT DUTY GASOLINE**

The light duty gasoline sector comprises passenger cars and light commercial vehicles as well as two and three-wheeled vehicles. Light duty gasoline (LDG) vehicles make up the biggest share of the global vehicle fleet.

Since being introduced in the USA as a result of the 1970 Clean Air Act, emissions legislation for LDG vehicles has been progressively tightened and extended around the world. Initially, simple platinum-palladium oxidation catalysts were used to convert carbon monoxide (CO) and unburnt hydrocarbons (HC) from gasoline engines during lean (excess oxygen) conditions to form carbon dioxide (CO$_2$) and water. The three-way catalyst (TWC) was developed to meet the US–1983 emissions limits which now included oxides of nitrogen (NOx). TWCs allow the oxidation of CO and HC using platinum or palladium catalysts while a rhodium catalyst performs the reduction of NOx to nitrogen and oxygen under rich (oxygen depleted) conditions. This technology relies on the engine operating around the stoichiometric point (air to fuel ratio of 14.7:1) at which the optimal simultaneous reduction of NOx and oxidation of CO and HC take place.

Although platinum was originally used in TWCs for the oxidation reactions, during the 1990s the relatively high cost of platinum compared to palladium encouraged autocatalyst manufacturers to develop advanced washcoat technologies that allowed the substitution of platinum by palladium, leading to the development of Pt–Pd–Rh and Pd–Rh formulations. Most auto companies now use Pd–Rh TWCs in gasoline vehicles, though some continue to employ Pt–Pd–Rh systems.

Since palladium is the dominant component in gasoline exhaust aftertreatment, LDG vehicles are responsible for the majority of palladium demand in autocatalysts. Today, LDG catalysts account for just under 20% of autocatalyst demand for platinum but close to 90% of autocatalyst demand for palladium. As the global LDG fleet expands and more stringent emissions legislation is implemented, demand for pgm, and for palladium in particular, can be expected to grow.

**LIGHT DUTY DIESEL**

Our light duty diesel (LDD) category consists of passenger cars, pickup trucks and light commercial vehicles. LDD vehicles are today responsible for the majority of platinum demand in the autocatalyst sector and so the use of platinum is high in markets where LDDs make up a large proportion of the vehicle fleet, principally in Europe, India, Thailand and Korea.

Emissions legislation forcing the use of aftertreatment on LDDs was first implemented in 2000 with the introduction of Euro 3 standards in Europe. Platinum diesel oxidation catalysts (DOCs) were initially used to convert CO and HC in the exhaust stream, but as catalyst technology advanced and diesel fuel quality was improved manufacturers were able to thrift platinum from DOCs and substitute some of the platinum with palladium, producing a lower cost system.

The addition of particulate matter (PM) as a regulated pollutant in many of the developed markets provided a further opportunity for using pgm. PM, or soot, is trapped by a diesel particulate filter (DPF) downstream of the DOC. The DPF is then periodically regenerated with platinum and palladium catalysing the oxidation of soot into CO$_2$ and water. Adding palladium has improved the overall thermal durability of the system, allowing high-temperature regeneration events to take place without damaging the catalyst. However, platinum is more catalytically active in the oxidising environment of a diesel exhaust and for this reason palladium is unable to entirely replace platinum in diesel aftertreatment.
Stricter NOx emissions regulations to be introduced in the near future will provide an opportunity to increase the use of platinum and to introduce the use of rhodium in diesel catalysts. Diesel vehicles sold in North America and in Japan already require some additional form of NOx aftertreatment, and European diesels will face tighter NOx emissions limits at Euro 6, starting in 2014.

As in all lean burn engines, the chemical reduction of NOx is made difficult by the highly-oxidising conditions in the exhaust stream. Although vehicle manufacturers can, in some cases, calibrate a diesel engine to emit sufficiently low NOx to meet standards, most LDD vehicles will use either a pgm-containing lean NOx trap (LNT) or selective catalytic reduction (SCR), using a base metal catalyst. As a general rule, smaller diesels will employ LNTs, while larger vehicles which produce higher levels of engine-out NOx will use SCR.

LNTs contain relatively high amounts of platinum, along with palladium and rhodium. The SCR catalyst itself does not contain pgm. However, in systems being developed for the European market, the associated DOC and DPF components in the aftertreatment system benefit from a slightly higher ratio of platinum in their washcoat formulation in order to ensure optimum SCR activity at low temperature. These factors should together continue to boost pgm demand in the LDD sector in the medium term, and will later impact pgm demand in other regions as they gradually adopt tighter diesel emissions standards.

HEAVY DUTY VEHICLES

Heavy duty vehicles (HDVs) range from delivery vans to buses and large trucks. The majority of the 4.6 million HDVs produced in 2012 were powered by diesel engines. However, some larger gasoline or gaseous fuel vehicles are heavy enough to be classed as heavy duty and we include these vehicles in our pgm estimates.

The use of pgm-containing aftertreatment on diesel HDVs has a shorter history than light duty vehicles. Although emissions legislation for HDVs has been in place since 1987, the limits have not always necessitated the use of pgm catalysts.

The first national rules which forced the use of catalysts were the US 2007 standards, which were met by the addition of DOCs and DPFs to the engine to control PM emissions. The US limits were further tightened in 2010 leading to the use of SCR catalysts to reduce NOx emissions and a platinum-containing ammonia slip catalyst (ASC) downstream of the SCR to oxidise excess ammonia to nitrogen and water. The North American market, therefore, represents a major portion of current pgm demand in the heavy duty diesel (HDD) sector.

Japan, a major exporter of both light and heavy duty vehicles, produces more HDVs annually than North America, and accounts for the largest pgm demand in this sector. A range of aftertreatment configurations are used on Japanese-produced HDVs depending on the regulations in force in the end use market. For larger vehicles sold in the domestic market, aftertreatment systems with DOCs, DPFs, SCR catalysts and ASCs are used. Almost half of the HDV vehicles assembled in Japan are diesel mini vans. For domestic sales and certain export destinations these vehicles are fitted with NOx traps containing platinum, palladium and rhodium, in order to meet the local emissions limits.

The next area for growth in HDV pgm demand will be Europe. Euro VI legislation, introduced in January 2013, will apply to all vehicles sold in the region from January 2014. European vehicle manufacturers already employ SCR to meet Euro V standards, but only a small proportion of vehicles are fitted with pgm-containing catalysts. Euro VI will in almost all cases force the addition of DOCs, DPFs and ASCs to the SCR system. Platinum will benefit most from the transition to Euro VI as its use ensures good passive filter regeneration and promotes low temperature activity of the SCR.

HDV legislation in most of the emerging markets is not yet tight enough to require fitment of pgm-containing catalysts, though some ‘low emission’ vehicles in cities are fitted (or retro-fitted) with DOCs and/or DPFs. As in the light duty sector, most countries follow the European legislation, with China IV (equivalent to Euro IV) expected to be implemented in China later this year and Euro V in Indian cities in 2015.

NON-ROAD MOBILE MACHINERY

Non-Road Mobile Machinery (NRMM) is defined as any mobile equipment or vehicle in which an internal combustion engine is installed, but which is not intended for the transport of passengers or goods on the road.

The category encompasses a wide range of machinery including agricultural, construction and industrial vehicles, lawn and garden equipment, inland marine vessels, mobile generator sets and rail locomotives. Our NRMM category comprises diesel engines only. There are a number of small gasoline and gaseous fuel engines that are covered by NRMM legislation and the relatively small pgm demand from these sources is included in our Other demand category.
NRMM legislation is more coordinated globally than on-road emissions regulations. Due to the global nature of the NRMM industry, in which engines may be manufactured in one location, installed on vehicles or equipment in another country, and then sold around the world, emissions legislation for non-road engines is broadly harmonised across the three mature markets of Japan, North America and Europe. Other countries are expected to adopt these regulations over time; China, India and Brazil all have emissions legislation in place for NRMM but these are not yet tight enough to require catalysts.

Harmonised catalyst-forcing legislation was introduced for NRMM in Japan, the USA and Europe in 2011 and is being progressively phased in for engines of different power bands, starting with the largest engines. Manufacturers are able to make use of flexibility schemes to produce a certain number of engines meeting the previous stage of emissions limits in the first few years after the new legislation has been introduced. A tighter stage of legislation, Tier 4 final / Stage IV, will be implemented from 2014. In very general terms, current Tier 4 interim / Stage IIIIB emissions limits highlight reductions in particulate matter (PM), whereas Tier 4 final / Stage IV limits are focused on NOx emissions abatement.

Due to the diverse number of equipment types and end applications, a wide variety of aftertreatment and catalyst configurations are used, but they generally resemble those used in the on-road diesel sector. Platinum and palladium can both be used in NRMM aftertreatment, though platinum should retain the dominant role.

PGM demand from the non-road sector is currently small in comparison with that in on-road emissions control, representing just 3% of total autocatalyst platinum demand in 2012. However, NRMM is a promising future area of growth for pgm demand, as engine production in the mature markets increases from the currently depressed levels, and as catalyst-forcing legislation is progressively rolled out in other markets.