WHAT IS NOx?
NOx is a generic term for oxides of nitrogen, a mixture of nitric oxide (NO) and nitrogen dioxide (NO2), which are by-products of combustion at high temperatures, such as those which occur in an engine cylinder. NOx is a leading cause of, or contributing factor to, a range of respiratory diseases such as asthma, emphysema and bronchitis, conditions which can lead to premature death. The formation of ozone, which can result in lung damage, is another major adverse effect of NOx emissions.

CONTROL OF NOx
Legislation requiring the control of NOx emissions from motor vehicle engines is now in force in many countries around the world. Technology to convert NOx to less harmful gases has made significant progress over the last few decades, and recent developments mean that NOx emissions from both gasoline and diesel engines can now be reduced to extremely low levels. In the European Union, the advent of Euro 5 emissions standards in 2009 introduced NOx limits of 0.06 g/km for gasoline vehicles and 0.18 g/km for diesels. Stringent NOx emissions limits are also in force in Japan. In the USA, considerably stricter emissions limits are in place for gasoline and diesel vehicles alike – on a fleet-averaged basis for each manufacturer, NOx emissions must not exceed 0.07 g/mile. The next step-change in European legislation comes in 2014 with the advent of Euro 6, which cuts the allowable NOx limits by over 55% for diesel engines, to 0.08 g/km, while keeping limits for gasoline engines at their current level. Countries which follow the European standards, such as India and China, will also see a tightening of NOx limits in the next decade as Euro 5 equivalent legislation is adopted.

PGM DEMAND
Gasoline
The control of NOx using palladium and rhodium in three-way catalysts (TWCs) is a well-established technology and gasoline emissions control accounts for the vast majority of rhodium demand. The new on-board diagnostic (OBD) limits that come into force at Euro 6 reduce by 70% the threshold amount of NOx emitted before the driver is notified of a problem with the catalyst. Manufacturers are therefore currently working on further improving the durability of catalysts. One of the potential ways this could be achieved is by increasing relative rhodium loadings. Due to the superior activity of rhodium in NOx reduction, it may be possible to thrift palladium from a TWC while adding a smaller amount of rhodium, to give a lower cost, higher performance system.

The drive towards more fuel-efficient engines has led to the development of gasoline engines which use a stratified charge, or lean burn, combustion. These engines generate more NOx in the cylinder than conventional gasoline engines and require some kind of NOx abatement, such as a lean NOx trap (LNT) catalyst in order to deal effectively with these emissions. As LNTs are rolled out by certain manufacturers, this will add to future demand principally for platinum, but also for palladium and rhodium.

Light Duty Diesel
Tighter NOx limits for light duty diesel vehicles around the world are driving the use of non-pgm Selective Catalytic Reduction (SCR) or pgm-containing LNT catalysts. In the US the emissions standards currently in force mean that light duty diesel vehicles already require some kind of NOx aftertreatment, the majority using SCR. In Europe, the introduction of Euro 6 emissions standards from 2014 will trigger the use of either SCR or LNT on most diesel vehicles. The choice of which technology is used will be a result of a number of different considerations including size and weight of the vehicle, level of
engine-out NOx and total costs of the aftertreatment system. Typically LNTs will be used on small to medium sized vehicles and SCR on larger vehicles. Adoption of LNTs in light duty diesels in anticipation of Euro 6 is expected to ramp up in the next few years, increasing pgm demand.

Heavy Duty Diesel
The use of SCR as a NOx reduction technique is well established in the heavy duty diesel market, where it allows operators to comply with emissions limits and maintain fuel efficiency. European manufacturers have used SCR for NOx control since Euro IV in 2005. In Japan, most manufacturers adopted SCR in the period leading up to the introduction of JP09 emissions limits in 2009. In the US, a diesel oxidation catalyst (DOC) and diesel particulate filter (DPF) were used by most manufacturers to meet US2007 limits. SCR was added to meet US2010 when NOx limits were tightened, and an ammonia slip catalyst is also used by most companies. European manufacturers will adopt a similar aftertreatment system in 2013/14 with the introduction of Euro VI emissions limits, adding to pgm demand.

Non-road
Emissions limits for non-road diesel engines were tightened sufficiently to require aftertreatment in January 2011 with the introduction of Interim Tier 4 limits in the US and Japan, and Stage III B limits in Europe. A wide variety of different aftertreatment strategies have been adopted by non-road engine producers based on the individual requirements of the engines in their diverse end-user applications. Tighter NOx emissions limits for these engines to be introduced from 2014 will require NOx aftertreatment.

**NOx EMISSIONS CONTROL STRATEGIES**

**EXHAUST GAS RECIRCULATION (EGR)** is an engine management strategy to control NOx which works by re-circulating a portion of an engine’s exhaust gas back to the engine cylinders. This acts to reduce the amount of excess oxygen in the gas stream and lower the temperature achieved during combustion. The technique is used on both gasoline and diesel engines but has the major disadvantage that it increases emissions of particulate matter (PM). EGR is not sufficient by itself to meet current NOx and PM limits in Europe, Japan and North America, and therefore some additional aftertreatment is typically required.

**THREE-WAY CATALYSTS (TWCs)** for gasoline vehicles were developed in the late 1970s to control hydrocarbons (HC), carbon monoxide (CO) and NOx. If a gasoline engine is operated around the stoichiometric point (air to fuel ratio of about 14.7:1), a single catalyst can remove the three pollutants simultaneously. Modern TWCs are typically palladium-rhodium or tri-metal formulations, where palladium is used to oxidise the HC and CO while rhodium performs the reduction of NOx to nitrogen.

**LEAN NOx TRAPS (LNTs)**, or NOx adsorber catalysts, remove NOx from a lean (high oxygen content) exhaust stream by oxidation to NO2 over a platinum catalyst, followed by adsorption onto a substrate to form a solid nitrate phase. The engine is then run rich (low oxygen content) and NOx is released from its adsorbed state and converted to nitrogen over a rhodium catalyst. Although this technique is effective at converting NOx, the need to periodically run the engine rich imposes a fuel penalty, which means LNTs have generally not seen the widest uptake in applications sensitive to fuel costs such as heavy duty diesel and agricultural machinery.

**SELECTIVE CATALYTIC REDUCTION (SCR)** uses urea solution (ammonia) as a reductant to convert NOx into nitrogen and water. The reaction typically takes places at temperatures that are high enough to enable a base metal catalyst to be used. Since this process requires an external urea tank and dosing system, it is typically restricted to heavy duty diesel vehicles and larger light duty vehicles. In some cases, particularly on heavy duty vehicles, a platinum-containing ammonia slip catalyst is also used to prevent the emission of excess ammonia from the tailpipe.