DIESEL CARS & PLATINUM DEMAND

Demand for diesel powered cars in Western Europe has grown remarkably over the last decade. Across the region as a whole, diesels now account for over one third of all new cars sold. Both gasoline and diesel cars are subject to strict limits on pollutant emissions, and both use autocatalysts containing pgm to reduce emissions. However, because diesel and gasoline engines operate under very different conditions, they utilise different pgm-based catalysts. Gasoline autocatalysts utilise platinum and/or palladium in combination with rhodium, whereas diesel autocatalysts currently only use platinum. The increased market penetration of diesels in Europe, therefore, has important implications for future pgm use in the region.

European Diesel Car Sales Have Been Rising Rapidly

The market for diesel cars in Western Europe has experienced phenomenal growth in recent years. In 1995 diesels accounted for 22.6 per cent of new car sales in the region, by 2001 this had risen to 35.9 per cent, equivalent to 5.33 million cars. In Austria, Belgium, France and Spain the penetration of diesel automobiles already exceeds 50 per cent.

The growth in popularity of diesels has been driven by several factors:

- **Performance.** Major technical developments in engine design and engine management systems have vastly improved the overall performance of modern diesel engines for light vehicles. They now compete effectively with gasoline engines in terms of noise and driveability, and offer a feeling of 'power' resulting from high torque at low speeds. As a result of increased demand, car manufacturers are offering a greater number of models with diesel engines.
- **Economy.** The fuel efficiency of diesel engines is significantly higher than comparable gasoline engines. The relatively high cost of both diesel and gasoline in the EU makes fuel efficiency an important consideration for European drivers. For example, in January 2002 the average price of a litre of unleaded gasoline in the region was equivalent to $3.07 per US gallon; in the USA it was around $1.15 per gallon – over 60 per cent cheaper. *

  **Source: The Automobile Association Ltd, UK, and the European Road Information Centre, Switzerland.*
- **Tax incentives.** Many European governments tax diesel fuel at a lower rate than gasoline, which reinforces the running cost advantage of diesel cars. In August 2001 diesel fuel was on average 23 per cent cheaper than gasoline in Western Europe, primarily due to taxation differentials.

Diesels also retain their traditional advantages of long life and low maintenance requirements. Although the purchase cost of new diesel cars can be higher than comparable gasoline models, they tend to retain their value better.

Why Do Diesel & Gasoline Autocatalysts Differ?

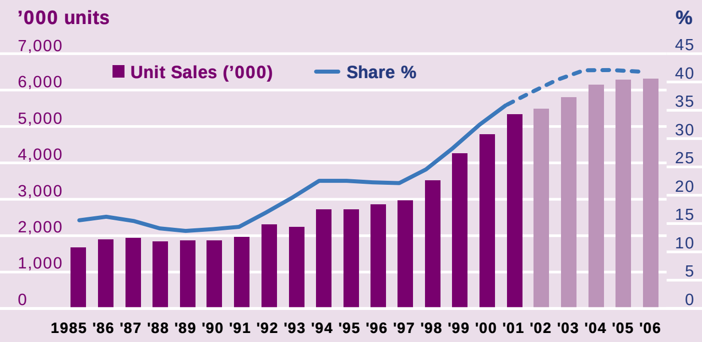
The amounts of air and fuel burnt in a gasoline engine are usually in chemical balance, there being no excess of either. This stoichiometric air:fuel ratio is typically 14.7 parts air to 1 part gasoline.

Under these conditions, and at the quite high temperatures (350-750°C) of the gasoline exhaust gas, platinum and/or palladium oxidise the pollutants carbon monoxide (CO) and hydrocarbons (HC), while rhodium catalyses the reduction of nitrogen oxides (nitric oxide and nitrogen dioxide, termed NOx) to nitrogen. Auto companies, therefore, use catalysts containing platinum and rhodium, palladium and rhodium, or a mixture of all three to meet current gasoline vehicle emissions regulations. These catalytic converters are known as three-way catalysts because they efficiently and simultaneously convert the three pollutants to harmless gases.

In marked contrast a diesel engine always operates with a large excess of air (the air:fuel ratio is typically ~30:1), often referred to as lean-burn operation; three-way catalysts cannot perform under these conditions. It has therefore been necessary to restrict NOx emissions by sophisticated diesel engine control measures and to use an oxidation catalyst to convert excess HC and CO to water and carbon dioxide.

An additional complication comes from the operating conditions of diesel engines that result in low exhaust gas temperatures (120-350°C). To date, only platinum based catalysts have been able to deliver the required

Diesel Passenger Car Sales in Western Europe



Source: DRI-WEFA Global Automotive Group performance under these operating conditions.

The low temperature of diesel engine exhaust gas also means diesel oxidation catalysts may have to contain higher loadings of platinum than their gasoline equivalents to achieve the necessary conversions of HC and CO.

Future Emissions Legislation May Benefit Platinum

As with gasoline-powered vehicles, diesel cars are subject to increasingly stringent exhaust gas emissions legislation, which drives development of improved combustion processes and increasingly efficient autocatalysts.

The Euro III legislation (effective from January 2000 for new models, and from January 2001 for all existing models) introduced stringent new limits for diesel vehicle emissions for HC, CO, and NOx, as well as for particulate matter (PM).

The permissible limits will be further reduced by the Euro IV regulations, due to enter legislation from January 2005 (see table), and by future Euro V regulations that are currently under discussion.

To meet the lower NOx and PM emissions limits set by Euro IV, and those likely to be introduced under future Euro V regulations, it may be necessary for some diesel cars to be equipped with additional pollution abatement technology. Several options that utilise the catalytic properties of platinum are being developed to meet the challenge.

Technology for Control of Particulate Matter

The nature of the diesel combustion process results in the formation of particulate matter (PM) or 'soot'. Improved engine control and combustion engineering have in recent years dramatically lowered the amount of PM formed by modern light duty diesel engines. Nevertheless, there are some concerns about the health effects of very small particles, and ways of completely eliminating them are being sought.

It is possible to remove virtually all of the PM from diesel exhaust by using a porous ceramic filter. However, the challenge is then to remove the trapped soot from the filter. One means of achieving this is to burn it but the direct reaction of diesel soot with oxygen (air) requires temperatures above 550°C, which do not normally occur in the exhaust gas of diesel cars. However, platinum catalysts can be used to oxidise additional fuel that is injected into the exhaust gas periodically, raising the temperature sufficiently to initiate combustion of the trapped soot.

A more elegant approach for the combustion of trapped soot involves the oxidation of nitric oxide (NO), which is already present in the exhaust gas, to nitrogen dioxide (NO_2) over a platinum based catalyst. The NO_2 produced is a much more powerful oxidant than oxygen, and it starts to burn PM at temperatures as low as 250°C. This concept has been commercialised as the continuously regenerating trap (CRT™) and has already been fitted to many thousands of heavy duty diesel trucks and buses in Europe. In North America and other industrialised regions, these devices are involved in several inner city trials, and sales are growing as their benefits become recognised more widely.

In future, both these approaches to PM reduction may become widely used on diesel cars, and both make use of platinum oxidation catalysts.

Technology for NOx Control

The oxygen rich environment of a diesel engine's exhaust gas favours the catalytic oxidation of CO and HC to water and CO_2 over the reduction of NOx to nitrogen, but all three emissions must be within the appropriate legislative limits. To date, NOx emissions from diesel cars have been reduced below these thresholds through

European Union Passenger Car Emissions Regulations

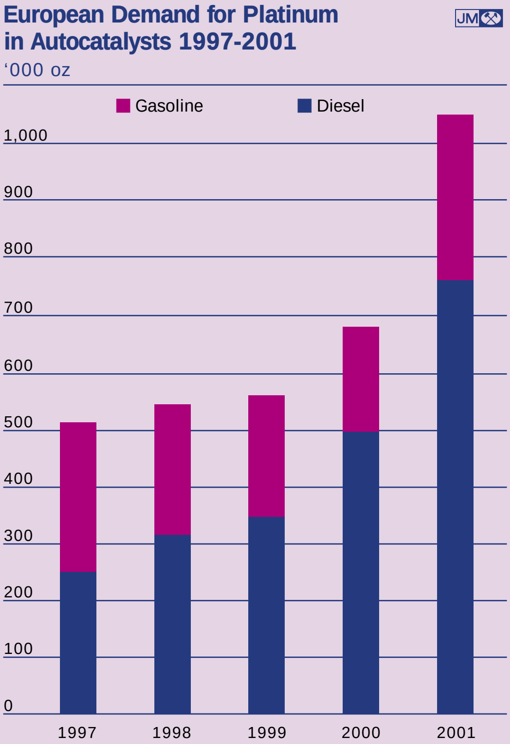
	1997 – Euro II		2000 – Euro III		2005 – Euro IV	
Pollutant (g/km)	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
HC	–	–	0.20	–	0.10	–
NOx	–	–	0.15	0.50	0.08	0.25
HC+NOx	0.50	0.70*	–	0.56	–	0.30
CO	2.20	1.00	2.30	0.64	1.00	0.50
PM	–	0.88†	–	0.05	–	0.025

**Limit was 0.90 for direct injection diesels until 30 Sept 1999 †Limit was 0.10 for direct injection diesels until 30 Sept 1999*

HC = Hydrocarbons; NOx = Oxides of Nitrogen; CO = Carbon Monoxide; PM = Particulate Matter

European Demand for Platinum in Autocatalysts 1997-2001

'000 oz



developments in diesel engine design and combustion technology. These include the use of very high-pressure fuel pumps in sophisticated direct injection systems, which precisely control the volume of fuel injected into the cylinder and produce a finely atomised spray. The delivery of fuel at very high pressure leads to a lower average combustion temperature that moderates the formation of NOx.

A second important way of reducing the amount of NOx formed is the use of exhaust gas recirculation (EGR), where partially oxygen-depleted exhaust gas is mixed with the fresh air that enters through the inlet manifold. This lowers the oxygen content of air in the cylinder, again lowering the peak combustion temperature and so reducing the amount of NOx formed.

There are practical limits, however, to what can be achieved by engine design and by improving the combustion process. In the future, measures such as these may not be able to reduce the formation of NOx to sufficiently low levels. To meet the lower NOx limits set by Euro IV, and those that may be introduced under future Euro V regulations, it might be necessary for some diesel cars to be equipped with additional pollution abatement technology.

One of the most likely catalytic ways of controlling NOx emissions is to chemically retain NOx as nitrate in what is sometimes called a 'NOx-trap'. During normal, lean operation of the diesel engine, NO is oxidised to NO_2 by platinum as the exhaust gas flows through the trap. The NO_2 is then retained in the trap in nitrate form. Periodically, the diesel engine is run richer than normal (with a higher proportion of fuel) for a short time. This produces exhaust conditions under which the nitrate is catalytically reduced to harmless nitrogen and released, regenerating the trap.

In NOx control, therefore, as in PM control, platinum is likely to have a key role. Already NOx-trap technology is used on some lean running gasoline engines. There are challenges for its practical implementation on diesel cars, but good progress is being made in this area.

US Market Yet to Follow European Growth

In the last quarter of 2001, diesels represented 39.8 per cent of Western European car sales. The impact of the growth in diesel car production on platinum demand is clear from the accompanying bar chart. With fuel costs unlikely to decrease significantly in the foreseeable future, the appeal of diesel cars to European consumers seems certain to increase further. Current estimations for the potential penetration of diesels across Western Europe range from 42 to 50 per cent by 2006, exceeding sales of 6 million vehicles annually.

In marked contrast, diesel cars accounted for less than 1 per cent of US light vehicle sales in 2001. US consumers were put off diesel cars in the early 1980s because the first models sold in the USA suffered from poor performance. This negative public perception persists today. However, advances in modern diesel engine performance are not yet recognised widely.

In addition, because gasoline in the USA is typically less than half the price of fuel in Western Europe, fuel economy is not an important consideration for most American consumers when purchasing a new car.

An increase in US national fuel efficiency standards could help to increase the appeal of diesel light vehicles but the Senate rejected the most recent proposals in March 2002.

The penetration of diesels into the US market is further hindered by current Federal vehicle emission regulations. These do not make a distinction between gasoline and diesel automobiles, and require significantly lower NOx levels than those applied under Euro III legislation.

Despite these hurdles, inroads are being made into the US market by the latest diesel cars, and the modern high speed diesel engine is well suited for use in the very popular sports utility vehicles. Nevertheless opinion is divided, even among the leading car manufacturers, about the level of market share that diesels could achieve.