PANORAMA 2016

a look at ...

Diesel

Diesel vehicles have been the focus of recent national and world news coverage. This solution, with greater overall efficiency than spark emission engines (gasoline, LPG and natural gas), remains an essential aspect of road freight transport. Diesel has even gained a significant share of the light vehicle market in certain regions of the world. However, diesel is currently the focus of numerous controversies and has been condemned for its negative impact on air quality.

This note reviews the rise of diesel engines around the world, and attempts to shed light on the impact of diesel on local pollution emissions, the technical solutions to remedy the problem and changes likely to be triggered when these solutions are implemented.

Worldwide consumption of on-road diesel fuel: how has it changed?

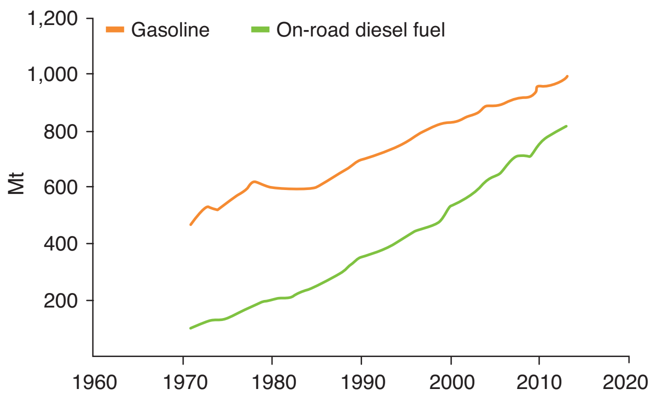
Diesel currently represents 45% of worldwide consumption of fossil-based road fuels. Its share was only 19% in the early 1970s. With the growth in transport of goods, passenger transport and the increasing reliance on diesel fuel by certain automobile fleets, demand for diesel has risen seven-fold over the past 40 years, while the use of gasoline has only doubled over the same period (Fig. 1).

The diesel/gasoline ratio rose constantly over this period in almost every region of the world (Fig. 2).

In Europe, where the adoption of diesel fuel in vehicles has been particularly strong, diesel currently represents two-thirds of road fuels. This makes Europe the leading importing region for middle distillates, despite refining capacity that allows it to meet its total domestic demand for oil products.

In the coming years, the rise in fuel consumption connected with growth in carriage of goods, the sharp decline in unit consumption by private vehicles and greater electrification of the automobile fleet are elements likely to contribute to the increase – or stability – of the share of diesel in worldwide demand for road fuels. IFPEN estimates that, by 2035, diesel could represent more than 50% of road fuels.

Fig. 1 – Trend in gasoline and on-road diesel fuel consumption worldwide between 1971 and 2013



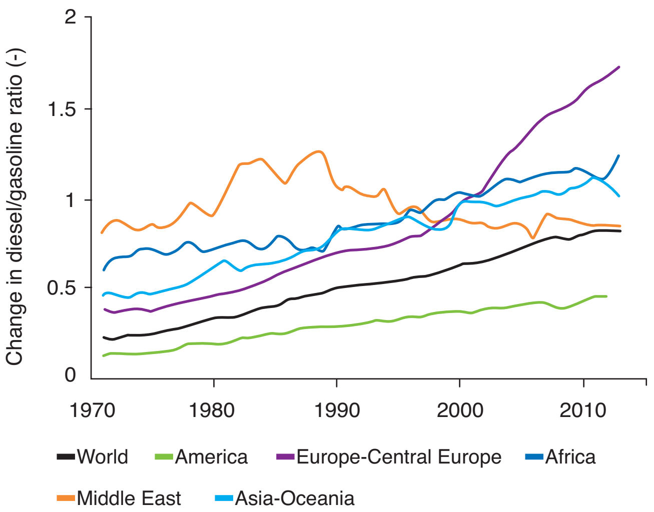
Source: IFPEN

Diesel vehicles: growth of diesel-powered light vehicles varies substantially by region and country

Around the world, regardless of region or country, diesel engines power a majority of heavy vehicles, trucks, buses and similar vehicles.

IFP Energies nouvelles

Fig. 2 – Change in the diesel/gasoline ratio in various regions worldwide since 1971



Source: IFPEN

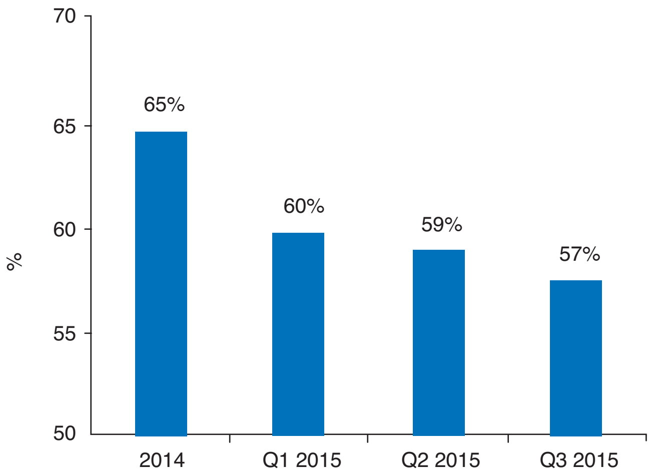
On the other hand, the use of diesel engines in private vehicles (PV) is far more variable. Gasoline-powered cars remain dominant on a worldwide scale. In many countries, diesel's share of the PV market is very low: less than 1% in China, slightly below 2% in the United States, and 3% in Brazil and Japan.

However, there are a number of exceptions to this rule. As a result of favorable industrial and tax policies, private diesel-powered cars are well-represented in some of the most significant regions. For example, in Europe (EU-27), diesel vehicles make up 35% of personal vehicles in circulation. This percentage has risen even higher in some countries such as Belgium (60%), France (57%), Austria (55%) and Spain (52%). In Europe, though diesel was merely a niche market until the early 1990s, sales have gradually increased over the past 20 years, exceeding 70% of new PV registrations in 2010 in France, Belgium and Spain, and 50% in most other European countries.

For PVs, recent trends in the use of diesel engines have been more subdued in many European countries. With lower-end vehicles (A and B segments) gaining market share, demand for diesel – a more costly solution for small vehicles – is declining. In France, market share of diesel among new registrations fell below 60% in 2015 (Fig. 3).

Elsewhere, India has recorded a significant increase in the number of diesel PVs since the early 2000s. Diesel engines represented 40% of private automobiles in 2010 and over 70% of sales.

Fig. 3 – Change in France of the share of diesel vehicles among new PV registrations



Source: CCFA

The growing number of diesel private vehicles is generally attributed to incentive policies, such as differentiated tax levels that result in significant differences between the prices of diesel and gasoline at the pump. This is the case in India, where taxes (taxes withheld by the central government and the State or territory) may be nearly double between diesel and gasoline. The tax differential partially explains the enthusiasm for diesel in European countries.

However, other mechanisms help to encourage the choice of this type of engine. In France, for example, in addition to different tax levels between gasoline and diesel, businesses can recover 80% to 100% of VAT on fuel expenses for passenger vehicles and utility vehicles. This measure applies to diesel (and also to E85 fuel and LPG), but excludes gasoline. Likewise, the tax on company vehicles, which is calculated based on fiscal horsepower, favors diesel engines. Finally, the ecological bonus-malus scheme, applied based on the vehicle's CO_2 emissions, has also worked in favor of diesel engines since its implementation. However, recent measures to change the TICPE (French energy consumption tax) on fuels and the environmental bonus has slowed interest in diesel.

Diesel and the environment: between global CO_2 emissions and NOx and particulate matter emissions

CO_2 and energy consumption

Customers' needs and aspirations, fuel economy and its corollary, carbon dioxide (CO_2) emissions and the reduction of pollutant emissions are the main challenges to be addressed by the transportation industry. It remains difficult to meet all of these demands simultaneously. Governments have established detailed regulations on pollutant and CO_2 emissions, but meeting these standards puts pressure on manufacturers which, above all, must offer products that customers want to buy, at a price they are willing to pay. In most cases, consumers want an economical vehicle to transport people and goods that is safe, comfortable and fun to drive.

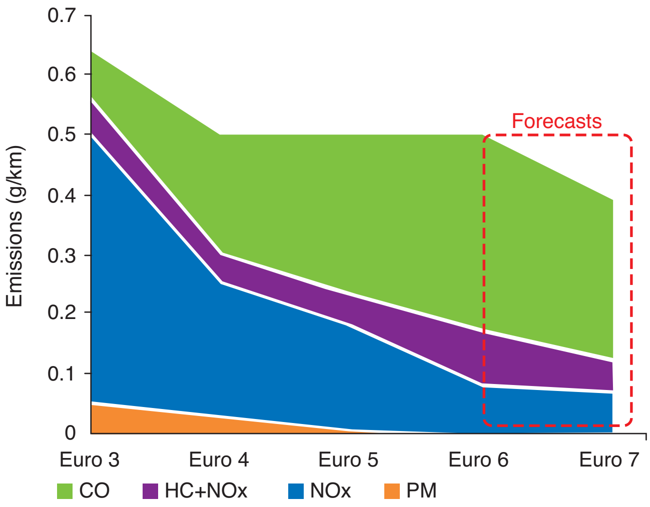
Initial governmental regulations concerned local pollution emissions. Limitations on the emission of carbon monoxide (CO), nitrogen oxides (NO_2 and NO, also known as NOx), particulate matter (PM) and unburned hydrocarbons (HC) were established, starting in 1975 in California, and during the 1990s in Europe for automobiles and trucks.

Regulation of CO_2 emissions came later, following a growing awareness of the effect of greenhouse gas (GHG) emissions on global warming. Measures have been adopted since 2007, particularly in Europe, and have focused the efforts of all manufacturers on reducing GHG emissions. The growing share of diesel engines among European automobiles, which was already significant due to political guidance on energy efficiency by the principal member states, quickly became an attractive way to quickly meet the targets established under CO_2 regulations. Due to their more efficient thermodynamic cycle, diesel engines offer 10% to 15% higher global efficiency compared with gasoline engines, leading to a near-monopoly of diesel fuel in the land and maritime transport of goods. Moreover, consumers, who purchase fuel by the liter, rather than per kWh of energy, achieve 10% lower fuel consumption in terms of liters per 100 kilometers, since diesel is denser than gasoline.

However, since the implementation of the Euro 5 emission standards in 2009 (Fig. 4), the compromise between CO_2 emissions and local pollutants – especially NOx for diesels – is harder to strike. In general, a diesel engine that emits less NOx emits more particulate matter. Likewise, combustion strategies used to reduce fuel consumption and CO_2 emissions typically emit more NOx.

To meet the established targets, complex combustion and pollution management strategies have been put in place by manufacturers, leading to positive results in the New European Driving Cycle (NEDC) certification cycle which has been in effect since 1973. However, these solutions often have limited effectiveness during actual driving, which is more dynamic and calls upon engine operating points not covered by the current cycle. Accordingly, under actual driving conditions, current diesel engines tend to

Fig. 4 – Change in European emissions standards for diesel vehicles



Source: Frost & Sullivan: Euro Emission Standards-Diesel Engines

emit more NOx than expected under the standards. These shortcomings will be corrected with the adoption of the new Worldwide harmonized Light vehicles Test Cycle (WLTC) to take effect in 2017, and of real driving emissions tests (RDE – Real Driving Emissions).

Particulate matter: a problem addressed

To treat particulate matter, the diesel particulate filter (DPF) was launched in 2000 and is now in widespread use. 98% of diesel engines will be equipped with DPF by 2020. This highly effective solution can systematically treat all engine exhaust gases regardless of usage, under any vehicle operating conditions.

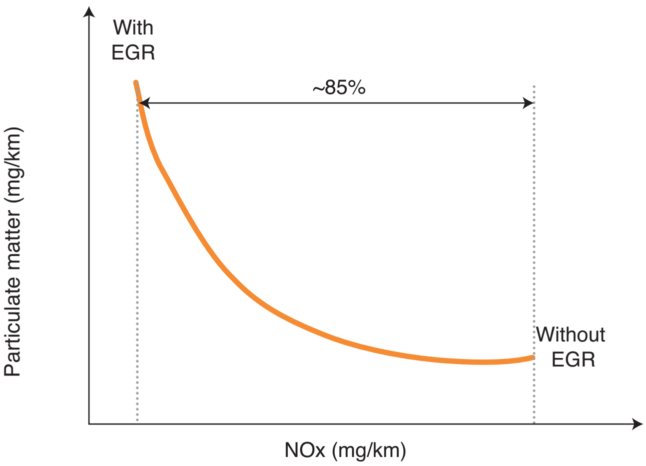
Its sticking point is the fact that the car must undergo regeneration every 350 to 1,000 km, depending on use. Soot that accumulates in the filter must be burned off on a regular basis to prevent clogging. Combustion occurs spontaneously only at temperatures above 450 °C, like an oven pyrolysis system. To reach this temperature, in some situations – especially city driving – the engine must be specifically adjusted to artificially increase exhaust temperature, triggering regeneration at the price of brief excess consumption.

Soot combustion is exothermic in nature, and must be controlled to prevent damage to the DPF, generally made of silicon carbide, cordierite or aluminum titanate. This limitation means that combustion settings minimize particulate emissions at the source, to avoid excessively frequent regenerations that impact fuel consumption and DPF reliability. As mentioned above, a compromise must be found for NOx emissions, since they vary inversely to particulate emissions when setting the engine (Fig. 5).

NOx: a more complex issue

NOx form during combustion, with temperature as a key parameter. Any adjustment or device that limits combustion temperature would limit these emissions.

Fig. 5 – Illustration of correlation between change in particulate matter and change in NOx



Source: IFPEN

The main solutions to reduce NOx emissions have an effect on combustion through exhaust gas recirculation (EGR), post-treatment of exhaust gas through a lean NOx trap (LNT) and/or through selective catalytic reduction (SCR).

Exhaust gas recirculation (EGR) in intake gases allows the temperature – and therefore NOx – to be lowered by diluting the combustible mixture with inert gases and by reducing the oxygen partial pressure, hence increasing particulate matter. EGR, and specifically cooled EGR, is therefore the most widely used solution since the Euro standards were implemented, allowing compliance with the requirements of Euro 5 and even Euro 6 without adding an additional solution to treat NOx.

Insofar as integrating EGR required significant engine adaptations (exchanger, complex air loop, EGR valves, etc.) for the initial Euro standards, this technology, with its high pressure (HP) and low pressure (LP) variants, remains the basic solution favored by manufacturers. Its intensive use can nonetheless create reliability issues for the system and its components, such as the flow metering valves and exchangers, and also limit engine performances with regard to torque, power and transient speed response. This has led manufacturers to limit its use to certain engine operating conditions.

With increasing demanding standards, especially for trucks and automobiles, the level of NOx emissions achieved through combustion settings alone is no longer sufficient. Euro 6 requires use of a further LNT and/or SCR after-treatment catalytic system.

LNTs mainly apply to small to medium-sized light vehicles, depending on their weight/power ratio and their conditions of use. Manufacturers with a high proportion of compact vehicles are likely to adopt this solution as the main technology for lowering NOx emissions. LNTs function by storing NOx in the form of nitrates, followed by their periodic elimination and reduction, primarily into nitrogen, through use of a reducing agent. This can be achieved through combustion with a richer air-fuel mixture or injection of hydrocarbons into the exhaust. LNTs include materials for storing nitrogen oxides, composed of basic elements like barium oxide and precious metals like platinum, palladium and rhodium, catalyzing the oxidation reaction of NO into NO_2 needed to form and reduce the nitrates. This purge, which takes place more frequently than FAP regeneration, results in a short period of excess fuel consumption. To limit such excess consumption, the engine's baseline emissions must be minimized, requiring it to be combined with the EGR system. Finally, the trap only operates properly within a certain range of exhaust temperatures and remains vulnerable to poisoning, especially by sulphur, requiring additional desulphation phases.

SCR, whose key segments include sport utility vehicles (SUV), large sedans, minivans and utility vehicles, is also combined with high or low-pressure EGR systems. Automobile manufacturers like PSA Peugeot Citroën elected to widely introduce this technology to all of their applications. The same decision has also been made by heavy vehicle manufacturers. The system's high efficiency enables maintenance of engine settings which optimize fuel consumption. The high price remains a significant deterrent to the widespread adoption of this solution. However, rising volumes could substantially lower its price by 2020.

The SCR system is composed of a catalyst and systems for storage and for injection of a reduction agent, in this case ammonia contained in an aqueous solution containing 32.5% urea, known as Adblue. It converts nitrogen oxides into dinitrogen and water, thereby reducing NOx emissions in exhaust by approximately 90%. As with LNT, the catalyst's window is limited and may impact system performance, especially during cold operation. Finally, consumption of Adblue is directly proportional to the NOx flow to be treated, which remains a key issue for manufacturers with regard to maintenance and operating costs. Against this background, minimizing NOx engine emissions and extending the treatment of NOx to all phases of engine operation remain key issues to be addressed.

In conclusion, there is a range of solutions for treating emissions, specifically NOx and PM. However, as requirements on pollutant emissions, under both standards and actual conditions, are increasingly strict, these solutions become more difficult to implement while controlling the overall cost of diesel engines. This type of engine, with its significant potential to control CO_2 emissions, will likely have its application limited to higher-end automobiles, utility vehicles and the carriage of goods in the coming years.

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Final draft submitted in January 201