Fifty years of fuel quality and vehicle emissions

Ensuring vehicle performance through high quality fuels

In the late 1970s, with growing emphasis on urban air quality in Europe, CONCAWE embarked on new research related to fuels and vehicles. After only a few years, it became clear that fuel properties and specifications would be increasingly important to the future of the European refining industry, and considerable research was completed in the 1970s to better understand the impact of fuel composition on vehicle performance and emissions.

This early work led to the formation of the first Fuels and Emissions Management Group (FEMG) in 1982, almost 20 years after the formation of the CONCAWE Association. Since these early days, FEMG has been responsible for ensuring CONCAWE's strategic outlook on future vehicle and fuel developments, monitoring regulatory and vehicle developments, and overseeing a diverse portfolio of fuel quality and vehicle emissions research.

Since the 1980s, tremendous progress has been made in improving European air quality, in part by reducing emissions from road transport and other sectors, and major improvements in European fuel qualities have contributed to these reductions. Nevertheless, many challenges are still ahead, especially further reductions in pollutant emissions from vehicles while also reducing greenhouse gas (GHG) emissions from transport. In the near-term, these GHG reductions will largely come from improvements in engine and vehicle fuel consumption and by blending of GHG-reducing bio-blending components. Dealing with these challenges to fuel quality and performance will require a continuing focus on CONCAWE's founding principles: sound science, cost-effectiveness and transparency.

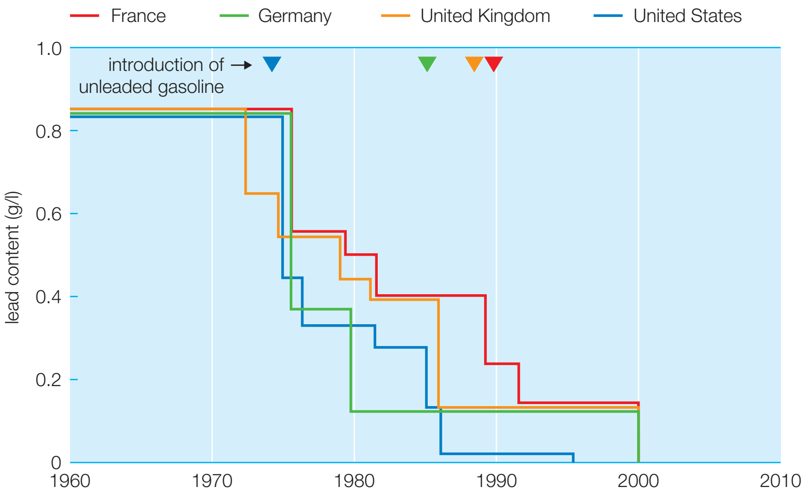
1960 to 1990: focus on gasoline

In CONCAWE's early years, much of the fuels and emissions work focused on the reduction and eventual elimination from gasoline of tetra-ethyl lead, a potent octane-enhancer and anti-valve recession additive that was widely used around the world. As concerns over the effects of lead in the environment grew, it was recognised that advances in refinery technologies would be required to reduce and then eliminate lead from gasoline while maintaining satisfactory octane quality for gasoline vehicles. Lead was finally eliminated from all European gasoline in 2000.

Eliminating lead as an octane improver required refineries to engineer new ways to increase the production of unleaded gasoline having a higher 'natural' octane. These improvements in new process units and catalysts resulted in investments and greater energy and hydrogen consumption. To find the best balance between refinery production of unleaded gasoline and vehicle performance, a major collaborative study was completed in the 1970–80s by the refining and auto industries to determine the optimum research and motor octane levels accounting for both vehicle performance and refinery operations. CONCAWE's 'Rational Use of Fuels In private Transport' (RUFIT) study provided the technical basis for this determination which established 95 RON (research octane number) as the new minimum for European market gasoline.

Because lead was also known to be a potent poison of catalytic metals, the move to unleaded gasoline that began in the 1980s also enabled the introduction of the first generation of cars equipped with rudimentary emissions aftertreatment systems, initially oxidation catalysts containing precious metals. These catalysts were able to reduce the concentrations of hydrocarbons and carbon monoxide in the engine's exhaust and initiated major advances in aftertreatment technologies that are still occurring today.

Figure 1 Eliminating lead from European gasoline

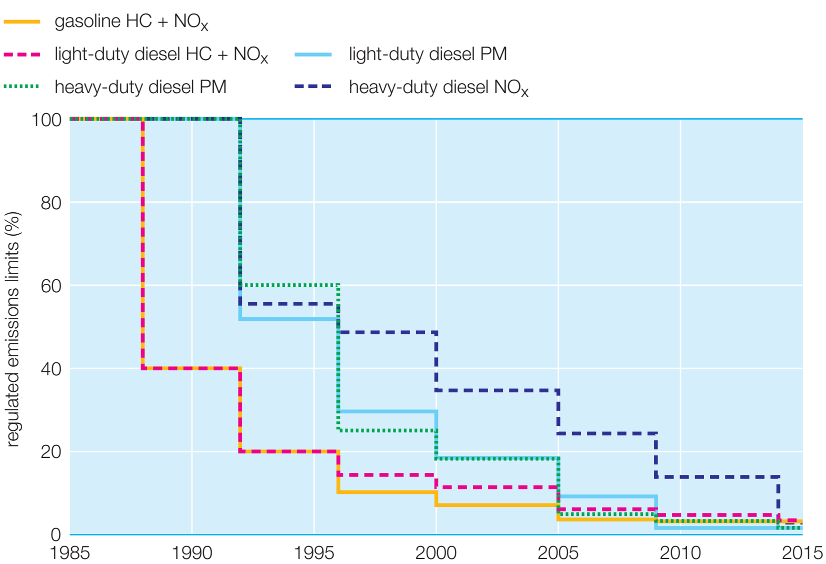


Evaporative emissions of volatile organic compounds (VOCs) from gasoline vehicles were also growing in importance due to urban air quality concerns. Several early CONCAWE studies also addressed this problem from the perspective of gasoline vapour pressure and evaporative emission control technologies, both at service stations and on board vehicles. This work demonstrated that 'closing up' the gasoline supply and distribution system using evaporative emissions controls at refineries, terminals and service stations and the use of activated carbon canisters on gasoline cars were effective at reducing fugitive VOC emissions. These measures were also found to be more cost-effective than dramatic reductions in the vapour pressure of gasoline.

While considerable attention was focused on gasoline vehicles, the relentless growth of the European diesel car and truck fleets brought forward new environmental questions related to diesel vehicle emissions and diesel fuel production. CONCAWE completed and reported its first studies on the relationships between diesel fuel composition and emissions from diesel engines and vehicles in the 1980s. A minimum 51 cetane number for European diesel fuel was later established as a satisfactory compromise between diesel vehicle performance and refinery production.

Below: impressive reductions in regulated vehicle emissions have been achieved since the late 1980s.

Figure 2 Reductions in regulated vehicle emissions, 1985–2015



As the regulatory requirements for vehicle emissions became more complex around the world, CONCAWE identified the need to compile information on the prevailing emissions regulations and fuel specifications in the world's major countries and markets. CONCAWE's first report on motor vehicle emissions legislation and fuel specifications was published in 1988 and has been periodically updated with the most recent version published in 2005.

1990 to 2000: Auto/Oil Programme

By the 1990s, it had become increasingly clear that a more 'integrated approach' between vehicle technologies and fuel composition would be needed in order to achieve the next big step in emissions performance. To provide the technical basis for future changes, the Auto/Oil I programme was completed between 1993 and 1995, including the European Programme on Emissions, Fuels and Engine technologies (EPEFE). CONCAWE's EPEFE task forces were actively involved with the European Commission and the vehicle industry in this Auto/Oil I research, contributing to the design, data collection and analysis of numerous emissions studies.

During this period, CONCAWE issued a series of reports on both gasoline and diesel fuel effects on vehicle emissions as well as on the economic impacts on EU refineries of changing fuel specifications. This work continued throughout the Auto/Oil II programme in the late 1990s followed in 2000 by a comprehensive evaluation of the effect of fuel sulphur content on advanced engines and exhaust aftertreatment systems.

Impressive reductions in regulated emissions limits have indeed been achieved for different vehicle types over several decades (Figure 2). Changes in fuel specifications have played a major role to enable these reductions, especially by removing sulphur from both gasoline and diesel fuels. The publication of the EU Fuels Directive (2003/17/EC) in March 2003 began the transition to 'sulphur-free' road fuels having less than 10 parts per million (ppm) sulphur which was completed in 2009. These fuels have enabled major advances in exhaust aftertreatment systems and engines that can achieve new vehicle emissions standards with ever-improving fuel efficiency.

Table 1 in the article on 'The evolution of oil refining in Europe' shows the long history of gasoline and diesel fuel specification changes over the 1994–2009 period, associated with the development of European-wide fuel standards by the European Committee for Standardisation (CEN). As a liaison organisation to CEN, CONCAWE has been actively involved in these developments for many years.

The Clean Air for Europe (CAFE) programme in the early 2000s provided the next important step to take a more integrated approach to air pollution, human health and the environment, taking into account emissions from all sources including transport. CONCAWE supported the CAFE approach which provided a framework within which different ways to improve air quality could be evaluated for their potential and cost-effectiveness for meeting environmental and health targets.

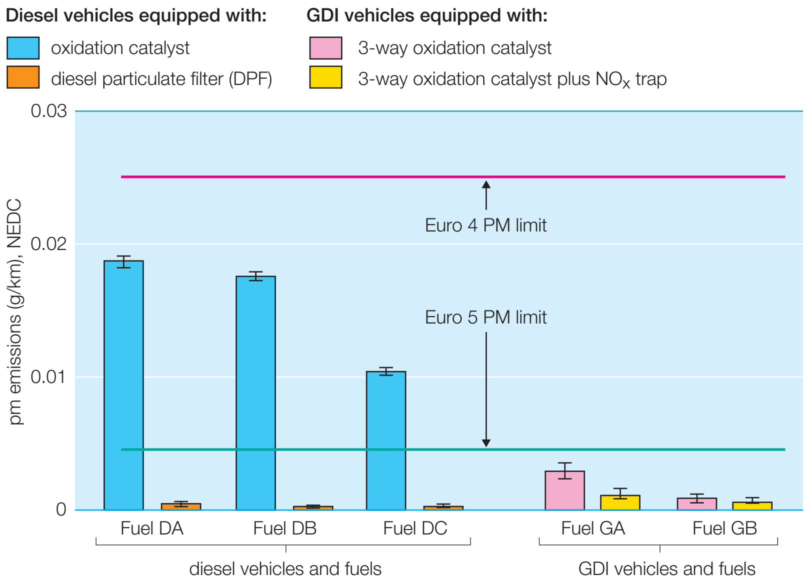
1993 to 2009: vehicle emissions limits

In addition to CAFE, other legislative and regulatory initiatives were under way to improve vehicle emissions performance. The 2003 EU Fuels Directive required that a thorough review of road fuel specifications would be completed by 2006. In parallel, the next stage of vehicle emissions standards, Euro 4/5 for passenger cars and Euro IV/V for heavy-duty engines, were implemented, with a primary focus on particulate matter (PM) and nitrogen oxide (NO_x) emissions from diesel engines.

In order to contribute to these technical evaluations, CONCAWE continued to test the effects of fuel composition on emissions from advanced engine and aftertreatment technologies as they entered or approached the market. Work completed on diesel vehicles and fuels in 2005 and 2010 showed that advanced engine technologies such as diesel particulate filters (DPFs) are much more effective for controlling PM emissions than further changes to diesel fuel properties (Figure 3).

While PM emissions are reduced using DPF technology, health-related questions are increasingly focused on much smaller particles generated during combustion, that can penetrate deeply into the human respiratory system. This new emphasis on ultrafine particles first required the development of robust measurement tools for particle number (PN) and size and CONCAWE has been an active contributor in this area. Through CONCAWE reports, SAE papers and research collaborations, the Particulates Consortium sponsored by the European Commission set the stage for the first new regulation on PN emissions, with the introduction of the Euro 5b PN emissions limit for diesel vehicles. Similar limits will be added for Gasoline Direct Injection (GDI) vehicles in 2014 (Figure 4).

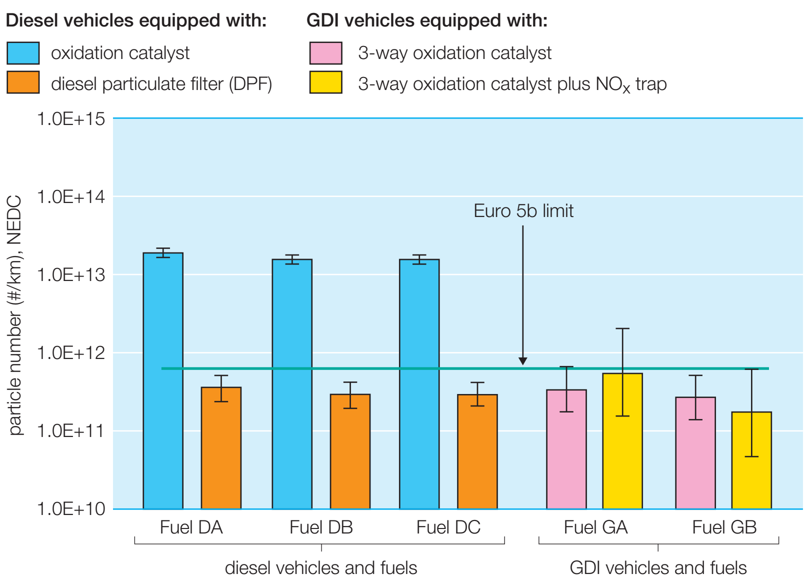
Figure 3 PM emissions from diesel and gasoline direct injection vehicles



Above: diesel cars with DPFs emit PM at well below the Euro 5 limit, whilst two GDI vehicles also produce very low PM emissions.

Below: while DPFs are also effective in reducing PN emissions, the effects of fuel composition on PN emissions are small.

Figure 4 PN emissions from diesel and gasoline direct injection vehicles



With higher than expected levels of transport-related nitrogen oxides in urban environments, new driving cycles will also be implemented in the coming decade to ensure that vehicles achieve low emissions performance over 'real world' driving compared to the regulatory cycles used for certifying performance in the vehicle testing laboratory.

From 2003 to 2020: GHG and biofuels

Although concerns about transport-related pollutant emissions have clearly not disappeared, vehicle fuel consumption and CO_2 emissions from transport have now become the focus for Europe's environmental agenda. With today's sulphur-free road fuels in the market, vehicle research has shown that more stringent fuel specifications offer only small environmental benefits while implementing them in the refinery would be likely to require new investments and lead to higher CO_2 emissions. CONCAWE has actively contributed to understanding this balance by pioneering work modelling the impact of changing fuel specifications on refinery operations. This work continues today at CONCAWE and is described in the article on 'The evolution of oil refining in Europe'.

Based on new regulations implemented in 2007, new passenger vehicles must meet fuel consumption targets in order to increasingly reduce GHG emissions from the vehicle fleet. For passenger cars, the 2014 limits require that each manufacturer's new vehicles must achieve 130 gCO_2/km, on a fleet-average basis, through engine and vehicle performance improvements, including hybridisation, alternative fuels, and other approaches. A fleet-average limit of 95 gCO_2/km is widely expected to be mandated for 2020 with potentially even lower fuel consumption targets beyond 2020. Mandatory targets are now in place for light-duty commercial vehicles and are being considered for trucks and buses.

In addition, the use of 'renewable' fuels to reduce the GHG footprint of transport fuels was required by European legislation, putting bio-blending components in sharp focus. While CONCAWE's first report on alternative fuels was published in 1995, a new literature review was published in 2002 on the overall energy and GHG potential for bio-derived components such as ethanol and fatty acid methyl esters (FAME). This review was completed in the context of the European Commission's (EC's) 2003 Biofuels Directive which encouraged the voluntary implementation of a variety of conventional and advanced fuel products derived from food crops and biomass.

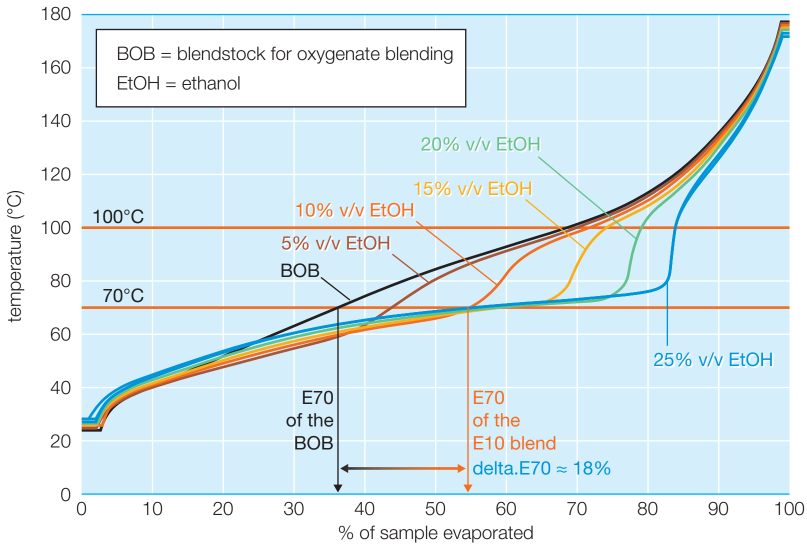
In 2009, two new regulations signalled the EC's intent to stimulate even greater use of renewable fuels in order to reduce GHG emissions from transport, improve energy security and support European agriculture. The Renewable Energy Directive (RED) mandated that 10% of transport fuels on an energy basis must be derived from sustainably produced, renewable sources by 2020. This percentage can include the use of bio-blending components, renewable electricity for vehicle recharging, biogas from waste materials, and other measures. Over the same time horizon, the Fuel Quality Directive (FQD) mandated that fuel suppliers must reduce the GHG emissions of transport fuels by at least 6% in 2020, compared to a 2010 baseline, primarily by blending certified bio-derived components.

To ensure the performance of these new fuel blends, CONCAWE has continued to represent the oil industry's efforts within CEN, drawing attention to the unusual effects that small amounts of some oxygenates, like ethanol, can have on gasoline properties (Figure 5). This work has resulted in changes to the CEN EN228 gasoline specification that are fully aligned with the FQD, allowing up to 3.7 wt% oxygen in gasoline using ethanol, ethers and other oxygenates. As shown by the 2012 market fuel survey results in Figure 6, different types and combinations of oxygenated blending components are increasingly used in European gasolines.

New specifications for FAME and for diesel fuel containing up to 7% v/v FAME have also been approved in the CEN EN590 diesel specification. To ensure that best practices to achieve 'fit for purpose' fuel products are also widely understood and implemented, CONCAWE has contributed several 'good housekeeping' guides to CEN covering fuel supply and distribution, and has actively supported the development of a new CEN standard for calculating the GHG footprint of bio-blending components.

Understanding the complexities from fuel production to consumption is also vitally important so that good regulatory decisions are made for future transport that achieve Europe's societal objectives. Beginning in 2001, CONCAWE began a long-term collaboration with the European Commission's Joint Research Centre (JRC) and the European Council for Automotive R&D (EUCAR). This 'JEC Consortium' successfully developed a comprehensive 'Well-to-Wheels' (WTW) methodology and comparative analysis of different combinations of fuels and powertrains that has become the European benchmark for contrasting different transport options. The first JEC WTW study in 2004 was updated in 2007 and 2011, and a fourth revision is expected in 2013 as more and better data become available. The JEC Consortium has also published work on vehicle performance and a detailed modelling study on biofuel implementation scenarios to achieve the 2020 RED and FQD mandates.

Figure 5 Effect of increasing ethanol content on the distillation curve of an ethanol/gasoline blend



Looking ahead

Over many decades, CONCAWE's fuels and emissions research has contributed understanding to the substantial progress in reducing pollutant emissions from the transport sector. And, from a refining and fuel supply perspective, substantial changes in fuel specifications, especially the elimination of lead and sulphur, have enabled these reductions. Although vehicle emissions levels have fallen dramatically, more progress will be needed to achieve future reductions in ultrafine particles, nitrogen oxides and emissions of all pollutants under 'real world' driving conditions. New driving cycles and vehicle durability requirements will be implemented to ensure that pollutant emissions measured in the vehicle laboratory also represent the performance of vehicles on the road.

At the same time, better fuel consumption will be required from both light- and heavy-duty vehicles, and fuels containing bio-blending components will be used to support regulatory drivers for GHG reductions and energy security. Benefits can be expected as new generations of low emission vehicles enter the market, enabled by high quality, sulphur-free fuels. Alternative fuels and vehicles will also find their market niche based on performance, cost and customer acceptance. Engines, aftertreatment systems and vehicles will continue to diversify over the coming decades to achieve these important targets and should be objectively assessed on a 'well-to-wheels' basis. More than ever before, sound technical results will be needed to support future vehicle and fuel decisions and CONCAWE's fuels and emissions research will contribute to this effort.

Figure 6 2012 survey of European gasolines from 100 service stations