# Sulphur-free fuels are on the way

## *Which advanced vehicle technologies are emerging?*

The final version of the revised EU Fuels Directive, 2003/17/EC, was published in March 2003. As expected, sulphur-free gasoline and diesel fuels (10 mg/kg maximum sulphur content), must be available on 'an appropriate balanced geographic basis' from 2005. Full market coverage of sulphur-free fuels is required from 2009, though the end date for diesel fuel remains subject to review. Other fuel properties are unchanged compared to the already agreed 2005 specifications. The Directive does not stipulate any change to the quality of diesel fuel for non-road vehicles for 2005, but requires that the Commission establish the future quality requirements for non-road diesel fuel in parallel with its work on the next stage of emissions standards for compression ignition engines used in non-road applications. The Directive also calls for a further review of the road fuels specifications to be completed by end 2005.

The specifications for the new generation of sulphur-free fuels were established following the Auto/Oil II programme and the EU Commission's subsequent sulphur review. Sulphur-free fuels should enable advanced engines and exhaust after-treatment systems to achieve the new Euro-4 and Euro-5 emissions standards with maximum fuel efficiency, also assisting the motor industry to meet their voluntary $CO_2$ commitments (European passenger car fleet average 140 g/km $CO_2$ by 2008).

At the time of the EU Commission's sulphur review in 2000, CONCAWE recognised that sulphur reduction helps the vehicle manufacturers to meet the new emissions standards, but identified that there were only a few vehicle technologies that potentially needed sulphur-free rather than 50 mg/kg maximum sulphur fuels. These highly sulphur-sensitive technologies included lean de-$NO_x$ catalysts (LNTs) and continuously regenerative particulate traps (CRTs). LNT systems also introduced a fuel efficiency and durability benefit from sulphur-free fuels since less frequent purging of sulphate from the catalyst would be required. The subsequent debate over the timing for introduction of sulphur-free fuels hinged largely on two elements:

- the overall well-to-wheels $CO_2$ balance in relation to the fuel efficiency of advanced vehicle technologies (in particular lean-burn direct injection gasoline engines with regenerative de-$NO_x$ catalysts) versus the increase in refinery $CO_2$ emissions for producing 10 mg/kg max rather than 50 mg/kg max sulphur fuels; and
- the ability of diesel engines to meet the new emissions standards.

The final adoption of the updated EU Fuels Directive provides a timely opportunity to review the emerging vehicle technologies and potential future fuel implications.

### Emerging vehicle technologies

With respect to meeting the future Euro-4 and Euro-5 exhaust emissions standards and $CO_2$ targets, the challenges lie in different directions for the different engine technologies.

Many gasoline engines today already surpass the Euro-4 emissions limits, well in advance of the 2005 deadline. The real challenge for gasoline engines is to reduce $CO_2$ emissions, while maintaining their low emissions of regulated pollutants. Lean-burn direct injection engines carry the promise of significant fuel efficiency gains, but require complex exhaust after-treatment systems for control of $NO_x$ emissions. The future predominance of lean-burn direct injection engines that was forecast only two years ago, is now considered less likely. A wide range of other gasoline engine technologies, including stoichiometric systems with conventional 3-way catalysts, will compete with the lean-burn approach. Direct injection, multi-point injection, variable valve actuation, turbo-charging and engine downsizing are all likely to play a role. A much lower market penetration of lean-burn direct injection engines with $NO_x$ storage catalysts is now expected. The

introduction of sulphur-free fuels will enable the widest range of vehicle technologies to be employed, though the change in the emerging technologies suggests that the $CO_2$ balance associated with the change from 50 to 10 mg/kg maximum sulphur fuels is likely to occur rather later than forecast in the EU Commission's sulphur review. The winning technologies are likely to be those that can deliver low $CO_2$ and pollutant emissions, while achieving good performance, reliability and durability at an acceptable cost to the consumer.

The challenge for diesel engines is to improve particulate and $NO_x$ emissions, while maintaining good fuel economy and $CO_2$ emissions. As engine measures to reduce particulate emissions generally increase $NO_x$ emissions and vice versa, some form of exhaust gas after-treatment is likely to be required. Application of LNTs to diesel engines is technically feasible but still requires considerable development and in the near term alternative approaches are more likely to be used.

For heavy-duty diesel engines, the major issue is to achieve the Euro-5 (2008) emissions limits for $NO_x$ and particulates (PM). Towards this objective, two fundamental development routes have been pursued:

- to optimise the engine for low particulate emissions, then to control $NO_x$ emissions with a Selective Catalytic Reduction (SCR) after-treatment system, using urea as the reducing agent; and
- to reduce engine-out $NO_x$ emissions via engine measures, including multiple high-pressure injections together with cooled Exhaust Gas Recirculation (EGR), and then to further control particulates with a particulate filter. The latest systems of this type appear capable of achieving Euro-4 limits without a particulate filter and may eventually even achieve Euro-5 limits without a particulate filter.

The SCR/urea route is currently the leading European option, strongly favoured by the European vehicle manufacturers as it is the most proven technology and provides the best fuel efficiency. A combination of SCR/urea with a particle filter is also feasible but this would negate a significant part of the fuel economy benefit. While SCR/urea systems will benefit from sulphur-free fuels, they are much less sensitive to sulphur content than CRT or LNT systems and their capability to meet the emissions targets with 50 mg/kg sulphur diesel fuels has been demonstrated. The SCR/urea approach does however raise a number of other issues, the main one for the oil industry being provision of urea for the vehicles.

For light-duty diesel vehicles, the Euro-4 standards for 2005 are expected to be achieved via a combination of engine measures, including high pressure injection, EGR, oxidation catalysts and particulate filters. Small vehicles are able to meet the 2005 standards with simple oxidation catalysts. Larger vehicles are likely to require particulate traps, with systems catalysed by fuel additives likely to be used in the near term. Active after-treatment for $NO_x$ reduction is unlikely to be required on light-duty diesel vehicles unless there is a significant further step in emissions standards beyond Euro-4. Application of SCR/urea is considered much less likely in the light-duty sector. Sulphur-free fuels will help the manufacturers to meet the emissions targets and provide flexibility to apply a range of advanced technologies but the timing for 100% market coverage of sulphur-free diesel fuels remains a relevant question.

Looking further ahead, hybrid vehicle concepts are showing potential to reduce $CO_2$ emissions without any need for further changes to fuels quality. Novel combustion concepts such as Homogeneous Charge Combustion Ignition (HCCI) engines continue to be investigated as a means to reduce engine-out $NO_x$ and PM emissions, thus minimising the need for exhaust gas after-treatment. Such new concepts may impact on fuel quality requirements and this will need to be assessed as these technologies develop.

## Fuels have made a substantial contribution

EU fuel specifications have been dramatically tightened over the past decade, culminating in the recent update to the EU Fuels Directive. Table 1 summarises the history of the key gasoline and diesel fuel property changes over the period from 1993–2009. The continuing challenge for

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**Table 1 Summary of European gasoline and diesel fuel specification developments**

| Year | | | 1993 | 1995 | 1996 | 2000 | 2005 | 2009 | WWFC[1] |
|---|---|---|---|---|---|---|---|---|---|
| **Gasoline Unleaded 95/85 – EN228** | | | | | | | | | |
| Sulphur | ppm m/m | max | 1000 | 500 | | 150 | 50/10 | 10 | 5–10 |
| Benzene | % v/v | max | 5 | | | 1 | | | |
| Aromatics | % v/v | max | | | | 42 | 35 | | |
| Olefins | % v/v | max | | | | 18 | | | 10 |
| Oxygen | % m/m | max | 2.5[2] | | | 2.7 | | | |
| RVP (summer) | kPa | max | up to 80 | | | 60 | | | |
| E100 | % v/v | min | 40(s)/43(w) | | | 46 | | | 50/55 |
| FBP | °C | max | 215 | | | 210 | | | 195 |
| **Year** | | | **1993** | **1995** | **1996** | **2000** | **2005** | **2009** | **WWFC[1]** |
| **Diesel (standard grade) – EN590** | | | | | | | | | |
| CI | | min | 46 | | | | | | 52 |
| CN | | min | 49 | | | 51 | | | 55 |
| Sulphur | ppm m/m | max | 2000 | | 500 | 350 | 50/10 | 10 | 5–10 |
| Density | kg/m$^3$ | min | 820 | | | | | | |
| | | max | 860 | | | 845 | | | 840 |
| T95 | °C | max | 370 | | | 360 | | | 340 |
| Aromatics | % v/v | max | | | | | | | 15 |
| PAH | % m/m | max | | | | 11 | | | 2 |
| Lubricity | µm @ 60 °C | max | | | 460 | | | | 400 |

[1] WWFC = Engine/vehicle manufacturers World-Wide Fuels Charter; Category 4 fuel requirements

[2] Up to 3.7% at Member State discretion. Individual limits apply to specific compounds

the oil industry is to supply the required market volumes at the specified quality. Apart from the new sulphur limits, diesel volumes are limited by constraints on density and back-end distillation points, while demand increases steadily. For gasoline the challenge is to satisfy the octane and distillation requirements with a decreasing choice of molecules available to the blending pool. Reducing gasoline sulphur to extremely low levels while minimising destruction of valuable high octane molecules, such as olefins, will be achieved through new refining processes.

Enabled by sulphur-free fuels, more advanced emission control technologies are expected to be introduced to meet the legislative requirements for 2005 and beyond, resulting in very low vehicle emissions being achieved. At such low emissions levels, additional changes to fuel quality are unlikely to contribute further to air quality improvement. More extreme fuel changes such as those proposed by Category 4 of the motor industry's World-Wide Fuels Charter (WWFC) would have limited environmental benefit but would increase refinery $CO_2$ emissions due to the increased processing needed and would potentially restrict the available fuel volumes.

### Outlook

A wide range of new low-emission vehicle technologies are expected to enter the market, assisted by major efforts from the oil industry to supply the new generation of sulphur-free fuels. The revised EU Fuels Directive already requires a further review, to be completed by 2005, both of fuel properties and of the end date for 100% market coverage of 10 mg/kg sulphur diesel. It is essential that this review be carried out in a scientifically sound manner, taking full account of the effects of the new vehicle technologies entering the market and of any proposed fuel changes on a well-to-wheels basis. It should also consider the impact of road transport emissions within the context of the overall emissions inventory under the umbrella of the Clean Air For Europe (CAFE) programme. Only such a rigorous and global approach can lead to the best choices for society as a whole.