Consultation on the Need to Reduce the Sulphur Content of Petrol and Diesel Fuels Below 50 PPM: - A Policy Makers Summary

A report produced for the European Commission, DG Environment

George Marsh
Nikolas Hill
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1 Introduction

In May 2000 the Commissioner for Environment launched a "Call for Evidence" on whether petrol and diesel fuels with sulphur contents less than 50 parts per million (ppm) should be available on a Community wide basis. This report summarises the evidence received from the stakeholders consulted, identifying the potential benefits and disbenefits that were reported and highlighting key issues affecting the decision.

The report begins by setting out the background and context to the Call for Evidence, and by providing short descriptions of the vehicle and exhaust treatment technologies affected by sulphur in fuels. Subsequent sections (2 - 7) report the evidence presented concerning each of the six specific questions posed by the Commissioner. A final section (8) gives an overall summary of key conclusions and issues.

Independent experts were invited to review the report, and to present their own comments on the subjects covered by the submissions and the key issues that were raised. These comments are also included in the summary section of this report and short biographies of the reviewers can be found in Annex 2.

Finally the report's Annex 1 contains short summaries of the submissions received from the stakeholders responding to the Call. The references for the numbered superscripts are also listed at the start of this annex.

1.1 CONTEXT

1.1.1 The Auto Oil Programmes

The first Auto-Oil Programme was designed to provide the technical and economic basis for cost-effective vehicle and fuel standards for the year 2000. At the end of the programme the European Commission proposed new Community legislation for new vehicle and fuel standards that would come into force in January 2000. The Auto Oil Programme I (AOP I) studied sulphur effects in petrol (four fuels with sulphur levels 18, 95, 182 and 382 ppm) but did not study sulphur effects in diesel fuel.

The Auto-Oil II Programme (AOP II) was originally designed by the Commission Services to provide the analytical foundation for a full package of vehicle and fuel environmental standards to take effect from 2005. However, during the AOP II it became clear that the political agreement between Council and the European Parliament on the Auto-Oil I Directive proposals would also set some mandatory standards for 2005 as well. These included limit values for passenger cars, the maximum sulphur content for diesel and the maximum sulphur and aromatic content of gasoline.

The Commission is required to bring forward a proposal to define the remaining fuel parameters that have not already been established to take effect from 1 January 2005. The AOP II has therefore, in its analytical work, taken the legislative requirement for the sulphur content of diesel and petrol to be fixed at 50 parts per million for 2005 in accordance with the requirement of Directive 98/70/EC. While the results of the AOP I analysis will provide guidance on proposing numerical values for the remaining fuel parameters which are not yet fixed for 2005, further reductions in the sulphur content of petrol and diesel fuels have not been assessed within AOP II.

The Commission has recently published a Communication on the results of the AOP II, which indicates that emissions, of the regulated pollutants from road transport, are expected to fall to 20% of their 1995 levels by 2020, but that carbon dioxide emissions will continue to rise, at least until 2005. Atmospheric modelling has shown that this will result in large improvements in urban air quality by 2010, although some environmental objectives concerned with particulate matter, regional tropospheric ozone and localised nitrogen dioxide targets will not be achieved.

1.1.2 The Sulphur Question

Developments in the marketplace and particularly with respect to the evolution of diesel and petrol fuelled engines and their emission abatement technologies suggest that there may be additional benefits for fuel with a sulphur content that is lower than 50 parts per million to be available. There has been much discussion surrounding the appropriate sulphur content of petrol and diesel fuels and its potential contribution in meeting environmental emission targets for nitrogen oxides, particulate matter and carbon dioxide. The Commission decided, therefore, to conduct a consultation exercise to inform itself as to whether petrol and diesel with a sulphur content of less than 50 parts per million should be available on a Community wide basis.

1.1.3 Community's Strategy to Reduce CO_2 from New Cars Sold in the EU

The Community's strategy to reduce carbon dioxide emissions from passenger cars and improve fuel economy was endorsed by the Council in 1996 (COM(95) 689 final). The strategy aims to deliver an average CO_2 emission value for new passenger cars equal to 120 g CO_2/km by 2005 or 2010 at the latest. The strategy is based upon commitments made by the automobile industry, the fuel economy labelling of new cars offered for sale and the promotion of car fuel efficiency by fiscal measures.

The automobile industry, represented by the European Automobile Manufacturers Association (ACEA), the Japanese Automobile Manufacturers Association (JAMA) and the Korean Automobile Manufacturer Association (KAMA), has committed itself to improving the fuel economy of vehicles produced such that it aims to deliver an average CO_2 emission figure for new passenger cars of 140 g CO_2/km by 2008/2009. In addition, in 2003 ACEA will review the potential for additional CO_2 reduction, with a view to moving further towards the Community's objective of 120g CO_2 /km by 2012.

The automobile industry has attached great importance to the availability of low sulphur fuel to meet both the mandatory emissions limits for nitrogen oxides (NO_x) and the targets for improved CO_2 emissions. The automobile associations (ACEA, JAMA and KAMA) entered into their commitments on the basis of the fuel quality specifications contained in Directive 98/70/EC (maximum 50 ppm sulphur) although there was an expectation that better fuel quality might be available in the future. Specifically the agreement with ACEA states an expectation that fuels of the following better quality might be available:

- Some gasoline and some diesel with maximum sulphur contents of 30 ppm are provided in 2000 in the whole EU market.

- In 2005 full availability on the EU market of gasoline and diesel with a maximum sulphur content of 30 ppm. The gasoline having a maximum aromatic content of 30% and the diesel a minimum cetane number of 58.

1.1.4 Community Air Quality Legislation

The framework for the assessment and management of air quality is described in Directive 96/62/EC and the limit values for the air pollutants nitrogen dioxide, sulphur dioxide, lead and particulate matter are set out in the first daughter Directive 99/30/EC. The limit values for nitrogen dioxide are to be attained by 2010 and those for particulate matter by 2005. There are also indicative values for particles for the year 2010.

1.2 CONSULTATION

The Commissioner launched the "Call for Evidence" in May this year with a deadline of 31st July. The details of the questions she specifically posed, the organisations that were contacted directly and the responses that were received in electronic format can be found at http://www.europa.eu.int/comm/environment/policy_en.htm#b. For those responses that were not submitted in electronic form paper copies may be obtained from DG Environment by emailing ENV-SULPHUR-REVIEW@cec.eu.int

Every effort was made to cover all submissions in this review, but some were received well after the Commissioner's deadline. In this case the submissions were placed on the Internet site, but it was not possible to incorporate them in this review.

1.3 GLOSSARY OF TERMS & VEHICLE EMISSION STANDARDS

Sulphur in petrol and diesel has implications for both engine and exhaust after treatment technologies. The following gives brief descriptions of the main technologies that have featured in the responses to the Call for Evidence, and has drawn on the technical descriptions provided by some respondents.

1.3.1 Engine Technologies

Gasoline Direct Injection (GDI) - Lean Burn:
Also known as Spark Ignition Direct Injection (SIDI), this technology employs in-cylinder fuel injectors to combust petrol in an excess of air. The resultant improved thermal efficiency of the engine leads to fuel efficiency improvements commonly reported by automobile manufacturers to be 15-20% over conventional stoichiometric petrol engines. The disadvantage of this technology is the increase in NO_x production in the more air rich atmosphere, which cannot be dealt with using Three Way Catalyst (TWC) technology in the

lean exhaust stream. This necessitates the use of new NO_x emission reduction technologies to meet statutory emissions standards with GDI lean burn engines.

Diesel Direct Injection (DI) Engine:
Also known as the Compression Ignition Direct Injection (CIDI) engine, the direct injection diesel engine (DI), compared to the indirect swirl chamber diesel engine (IDI), is the most important option for reducing the fuel consumption of diesel engines. Compared to the IDI engine, it offers a fuel saving of around 15% and was introduced some time ago to the commercial vehicle sector where fuel consumption is considered of prime importance. The automobile industry expects the market to be mainly dominated by this technology in the future. The use of new NO_x and particulate reduction technologies will be needed for vehicles to meet future Euro emissions limits, which require substantial reductions in these emissions (see Tables 1.1 – 1.3 in section 1.3.3).

1.3.2 Exhaust Treatment Technologies

Autocatalyst:
The autocatalyst is a ceramic or metallic substrate with an active coating incorporating alumina, ceria and other oxides and combinations of the precious metals - platinum, palladium and rhodium. The substrate can be protected from vibration and shock by a resilient ceramic or metallic "mat". There are two types of autocatalysts:

(i) *Three Way Catalysts (TWC):*
Three Way Catalysts operate in a closed loop system including a lambda, or oxygen, sensor to regulate the air-fuel ratio. The catalyst can then simultaneously oxidise carbon monoxide (CO) and hydrocarbons (HC) to CO_2 and water while reducing NO_x to nitrogen. Three Way Catalysts are designed to work with petrol engines running under stoichiometric conditions.

(ii) *Oxidation Catalysts (OC):*
Oxidation catalysts convert carbon monoxide (CO) and hydrocarbons (HC) to CO_2 and water and decrease the mass of diesel particulate emissions, but have little effect on nitrogen oxides (NO_x).

Diesel Oxidation Catalyst (DOC):
The catalyst oxidises carbon monoxide, gaseous hydrocarbons**,** and liquid hydrocarbons (HCs), including those adsorbed on the carbon particles, to CO_2 and water. The liquid HCs are known as the soluble organic fraction (SOF) and make up part of the total particulate matter (PM); the carbon fraction of the PM remains unaffected.

Diesel Particulate Filter (DPF):
Also known as Diesel Particulate Traps (DPTs), DPF systems consist of a filter material positioned in the exhaust designed to collect solid and liquid particulate matter (PM) emissions while allowing the exhaust gases to pass through the system. DPF systems are currently used with heavy duty vehicles but could be used with some cars and light duty commercial vehicles in future. Modern filters are designed to achieve collection efficiencies of 90% or greater in terms of mass (over 99% when expressed as numbers of ultra fine particles).

DPTs become plugged with particulate material and it is necessary to "regenerate" their filtration properties by burning off the collected particulate matter on a regular basis. To achieve regeneration the collected particulate matter must attain a minimum temperature in the range of 600 to 650^{o}C in order to auto-ignite and sustain combustion. However, the engine-out exhaust temperature of a heavy-duty diesel engine does not typically achieve these levels. The most successful methods to achieve regeneration include:

- Electrical heating of the DPF either on or off the vehicle.
- Incorporating a catalytic coating on the DPF to lower the temperature at which particulate matter burns.
- Using very small quantities of fuel-borne catalyst, such as cerium oxide.
- Incorporating an oxidation catalyst upstream of the DPF that, as well as operating as a conventional oxidation catalyst, also increases the ratio of NO_2 to NO in the exhaust. Trapped particulate matter burns off at normal exhaust temperatures using the powerful oxidative properties of NO_2.

Continuously Regenerative Trap (CRT):
The CRT is also known as the Passive Self-Regenerating Diesel Particulate Filter, and works by continuously converting diesel soot particles (elemental carbon) to CO_2. The temperature of the carbon combustion is lowered by the use of NO_2 as the oxidising agent. Since the proportion of NO_2 in the raw exhaust gas is relatively low, an active oxidation catalyst (platinum) is used upstream of the trap to convert a significant proportion of the NO to NO_2. The high activity of the oxidation catalyst gives very low CO and HC emissions.

Exhaust Gas Recirculation (EGR):
EGR is a very cost effective means of reducing NO_x emissions. The engine-out NO_x levels for GDI lean burn and diesel DI engines with EGR are comparable to what can be achieved with conventional, stoichiometric petrol engines with EGR. However, more EGR means more HCs and CO in the exhaust gases and so more effective oxidation catalysts are required to meet the Euro IV limits for these gases, but these also more effectively oxidise sulphur to sulphate leading to an increase in PM emissions.

NO_x Storage Trap (NST):
(a) Petrol Engines:
These are also known as NO_x Absorbers, NO_x Storage Catalysts (NST), or Lean NO_x Traps and typically incorporate barium oxide into a conventional Three Way Catalyst (TWC) formulation. When the engine runs lean, the NO (nitric oxide) reacts over the catalyst to form barium nitrate. When the Engine Management System evaluates that the catalyst is close to saturation in barium nitrate, it triggers a gasoline-rich excursion that generates carbon monoxide and unburned hydrocarbon. The nitrates are decomposed to NO_2, which then react with the available reductant (such as CO) over the catalyst to form nitrogen and oxygen. Storage Traps are the most efficient existing lean burn NO_x treatment technology (more than 90% efficiency). In Europe this technology is considered the most promising for GDI lean burn engines.
(b) Diesel Engines:
Diesel NO_x storage catalysts operate similarly to those used in gasoline vehicles. Together with Selective Catalytic Reduction (SCR) systems, the diesel NO_x Storage Trap is the only technology that shows high NO_x conversion efficiency under lean burn conditions. Since the SCR is only suitable for trucks, the Diesel NO_x storage catalyst is considered by the automobile industry as a key technology that will enable diesel vehicles to meet the Euro 4 exhaust emission standards for passenger cars and light duty commercial vehicles.

Selective Catalytic Reduction (SCR):

Also known as De-NOx Selective Catalysts or NH_3-SCR systems, SCR technology is designed to permit the NO_x reduction reaction to take place in an oxidising atmosphere. It is called 'selective' because the catalytic reduction of the NO_x with ammonia (NH_3) as a reductant occurs preferentially to the oxidation of NH_3 with oxygen. The reducing agent reacts with NO_x to form N_2, H_2O and CO_2. The reductant source is usually urea ($CO(NH_2)_2$), which can be rapidly hydrolysed to produce ammonia in the exhaust stream. SCR technology can achieve NO_x reductions in excess of 90%, however, the injection rate must be carefully controlled to avoid low NO_x conversion or ammonia slip. Normally, the SCR system is coupled with an oxidation catalyst to avoid ammonia slip.

The drawback to the technology is the necessity of having a storage/supply tank for the reductant source. For this reason the technology is considered to be only really practically applicable to heavy duty vehicles by many in the EU automotive industry.

De-NOx Catalysts:

These are also known as Lean NO_x Catalysts (and sometimes HC-SCR systems) and diesel engine or GDI lean burn engine NO_x control is achieved using the exhaust hydrocarbons as a reducing agent. The De-NOx catalysts are characterised by low NO_x conversion efficiency (20-30%). Different chemical formulations result in a specific temperature range of activity. There are two basic types of De-NOx catalyst:

(i) Passive:

Passive De-NOx Catalysts use only the hydrocarbons already present in the exhaust stream to reduce NO_x.

(ii) Active:

Active De-NOx Catalysts use added hydrocarbons to reduce the NO_x instead of relying purely on the hydrocarbons already present in the exhaust stream.

The relatively low NO_x conversion efficiency gives limited prospects for its use in the long term. The De-NOx catalyst is considered by the EU automobile industry as a possible interim solution for some applications (passenger cars and light duty commercial vehicles).

1.3.3 Emission Limits for Passenger Cars (Directive 98/69/EC)

The following tables give current and future emission limits for passenger cars in **grams per km**.

Table 1.1a: Emission Limits for Petrol Cars [(a)]

PETROL	As from [(b)]:	CO	HC	NO_x
EURO I*	1/7/1992	4.05	0.66	0.49
EURO II*	1/1/1996	3.28	0.34	0.25
EURO III	1/1/2000	2.30	0.20	0.15
EURO IV	1/1/2005	1.00	0.10	0.08

* As measured on new test cycle for application in year 2000.

Table 1.1b: Emission Limits for Diesel Cars [(a)]

DIESEL	As from [(b)]:	CO	HC	NO_x	PM
EURO I*	1/7/1992	2.88	0.20	0.78	0.14
EURO II*	1/1/1996	1.06	0.19	0.73	0.10
EURO III	1/1/2000	0.64	0.06	0.50	0.05
EURO IV	1/1/2005	0.50	0.05	0.25	0.025

* As measured on new test cycle for application in year 2000.

Notes:

a) "Euro 3 and 4" (Directive 98/69/EC): Standards also apply to light commercial vehicles (<1305 kg).
b) The above dates refer to new vehicle types; dates for new vehicles are 1 year later.

1.3.4 Emission Limits for Light Commercial Vehicles (Classes N1, N2 and N3)

The following tables give current and future emission limits for light commercial vehicles in grams per kilometre. Light commercial vehicles are divided into three classes N1 (mass below 1350 kg), N2 (between 1305 and 1706 kg), N3 (above 1706 kg). Euro I and II limits are covered under Directive 93/59/EEC. Euro III and IV limits are covered under Directive 98/69/EEC.

Table 1.2a: N1 Class (<1350 kg) Emission Limits.

N1	As from:	Fuel Type:	CO	HC	NO_x	HC + NO_x	PM
EURO I*	1/10/1994	All	2.72	-	-	0.97	0.14
EURO II*	1/1/1998	Petrol	2.2	-	-	0.5	-
		Diesel	1.0	-	-	0.60	0.1
EURO III	1/1/2001	Petrol	2.3	0.2	0.15	-	-
		Diesel	0.64	-	0.5	0.56	0.05
EURO IV	1/1/2006	Petrol	1	0.1	0.08	-	-
		Diesel	0.5	-	0.25	0.3	0.025

* For Euro I and II the weight classes were N1 (<1250 kg), N2 (1250-1700 kg) and N3 (>1700 kg)

Table 1.2b: N2 Class (1305-1760 kg) Emission Limits.

N2	As from:	Fuel Type:	CO	HC	NO_x	HC + NO_x	PM
EURO I*	1/10/1994	All	5.17	-	-	1.4	0.19
EURO II*	1/1/1998	Petrol	4	-	-	0.65	-
		Diesel	1.2	-	-	1.1	0.15
EURO III	1/1/2002	Petrol	4.17	0.25	0.18	-	-
		Diesel	0.8	-	0.65	0.72	0.07
EURO IV	1/1/2006	Petrol	1.81	0.13	0.1	-	-
		Diesel	0.63	-	0.33	0.39	0.04

* For Euro I and II the weight classes were N1 (<1250 kg), N2 (1250-1700 kg) and N3 (>1700 kg)

Table 1.2c: N3 Class (>1760 kg) Emission Limits.

N3	As from:	Fuel Type:	CO	HC	NO_x	HC + NO_x	PM
EURO I*	1/10/1994	All	6.9	-	-	1.7	0.25
EURO II*	1/1/1998	Petrol	5	-	-	0.8	-
		Diesel	1.35	-	-	1.3	0.2
EURO III	1/1/2002	Petrol	5.22	0.29	0.21	-	-
		Diesel	0.95	-	0.78	0.86	0.1
EURO IV	1/1/2006	Petrol	2.27	0.16	0.11	-	-
		Diesel	0.74	-	0.39	0.46	0.06

* For Euro I and II the weight classes were N1 (<1250 kg), N2 (1250-1700 kg) and N3 (>1700 kg)

1.3.5 Emissions Limits for Heavy Duty Vehicles

The following table gives current and future emission limits for heavy duty vehicles are in **grams per kWh**.

Table 1.3: Emission Limits for Heavy Duty Vehicles.

	As from:	Test cycle	CO	Total HC	Non-Methane HC	NO_x	Particulate Matter
EURO I	1/10/1993	13-mode	4.5	1.10	-	8	0.612 <85 kW 0.36 >85 kW
EURO II	1/10/1996	13-mode	4.0	1.10	-	7	0.15 (a)
EURO III	1/1/2000	ESC (c)	2.1	0.66	-	5	0.10 0.13 (b)
		ETC (d)	5.5	0.78	1.6	5	0.16 0.21 (b)
EURO IV	1/10/2005	ESC (c)	1.5	0.46	-	3.5	0.02
		ETC (d)	4.0	0.55	1.1	3.5	0.03
EURO V	1/10/2008	ESC (c)	1.5	0.46	-	2	0.02
		ETC (d)	4.0	0.55	1.1	2	0.03

Notes:

(a) Until 30/11/1998 the particulate limit for engines <700 cc per cylinder and with a rated power speed of more than 3000 rpm was 0.25 g/kWh
(b) For engines <750 cc per cylinder and with a rated power speed greater than 3000 rpm
(c) Measured on the European Standard Cycle (ESC)
(d) Measured on the European Transient Cycle (ETC)

“Euro I and II”: Directive 91/542/EEC; “Euro III, IV and V”: Council position December 1998 and agreed with the European Parliament.

1.3.6 Relevant Fuel Specification Limits:

Table 1.4: Relevant Petrol and Diesel Fuel Specification Limits.

PETROL	2000	2005
RVP summer	60	-
Aromatics	42	35
Benzene	1	-
Olefins	18	-
Oxygen	2,7	-
Sulphur	150	50

DIESEL	2000	2005
Cetane # (min)	51	-
Density 15°C	845	-
Distillation 95°C	360	-
Polyaromatics	11	-
Sulphur	350	50

2 Question 1

The magnitude of the additional environmental benefit gained from using petrol and diesel with a sulphur content of less that 50 parts per million. More specifically what are the incremental benefits of using fuels with a sulphur content of (a) 5-10 ppm and (b) 30 ppm relative to fuels containing 50 ppm.

Contributor	Full Name
ACEA	European Automobile Manufacturers Association
AECC	Association for Emissions Control by Catalyst
AIT & FIA	The European Bureau of the Alliance International de Tourisme & Fédération Internationale de l'Automobile
CLEPA	European Association of Automotive Suppliers
CONCAWE	Oil Companies' European Organisation for Environment, Health and Safety
Czech Republic	
EMPA	The Swiss Federal Laboratories for Materials Testing and Research
EUROMOT	The European Association of Internal Combustion Engine Manufacturers
EUROPIA	European Petroleum Industry Association
Ford Motor Company	
FRG	The Federal Republic of Germany
IFP	Institut Français du Pétrole
Ireland	Department of Environment & Local Government
JAMA	Japanese Automobile Manufacturers Association
Netherlands	
SMMT, UK	The Society of Motor Manufacturers and Traders Limited
Sweden	Ministry of the Environment
T&E	European Federation for Transport and Environment
Toyota	
WGIII, Auto Oil II, Spain	Spain Representative of Working Group III, Auto Oil Programme
UK, DETR	Department of Environment, Transport and the Regions

Responses to this question showed that the sulphur level in petrol and diesel could have two effects:

- **Direct Effect** - involving the reduction of sulphur derived emissions.
- **Indirect Effect** - involving the improved performance of the engine and exhaust gas treatment technologies.

The issues affecting petrol and diesel were somewhat different and therefore need to be presented separately. Furthermore, the sulphur concentration has potential implications for both existing technologies (an "enhancing effect") and new technologies (an "enabling effect"[i]). Therefore the following structure has been adopted for this section of the report.

- Petrol Vehicles
  - Existing Technology
    - Current Vehicle Fleet
    - Current Production
  - New Technology

- Light Duty Diesel
  - Existing Technology
    - Current Vehicle Fleet
    - Current Production
  - New Technology

- Heavy Duty Diesel
  - Existing Technology
  - New Technology

2.1 PETROL VEHICLES - EXISTING TECHNOLOGY

2.1.1 Current Vehicle Fleet

A large proportion of the current petrol fuelled car fleet consists of vehicles that are powered by engines working on stoichiometric fuel/air mixtures, and with Three Way Catalysts (TWC) to achieve emissions requirements for CO, HC and NO_x. The sulphur content of petrol can have both direct and indirect effects on the performance of this class of vehicles.

The **direct effects** of reducing sulphur from 50 ppm to <10 ppm are a reduction in sulphate based particulate matter (PM) and in total SO_2 emissions [2, 11]. However CONCAWE[6] have indicated that these emissions are already set to fall considerably due to the already mandated reduction in petrol sulphur level from the maximum of 3000 ppm in 1990 through 150 ppm in 2000 to 50 ppm in 2005. In comparison the impact of a further reduction in sulphur to less than 10 ppm will be negligible in comparison to this earlier fall, and even more so with regard to total sulphur emissions.

The **indirect effects** are that sulphur reduces the conversion efficiency of Three Way Catalysts (TWC) in existing vehicles, and therefore a reduction in the sulphur content of petrol has the potential to restore, at least partially, catalyst performance. The improvement depends upon the sensitivity of the catalyst to sulphur levels and the extent to which the catalyst's performance is reversible after exposure to higher levels of sulphur.

The submissions showed a divergence in opinion between respondents regarding the size of the impact of fuel sulphur on the above factors, which is linked to the effect of ageing on

[i] In this context "enabling" means attaining the full potential benefit of the new technology.

catalyst performance and recovery. Both fuel suppliers and vehicle manufacturers agree that the EPEFE equations, (developed as part of the European Programme on Emissions, Fuels and Engines Technologies) represent the response of non-aged and earlier generation TWCs to different fuel sulphur levels. These equations show a low level of sulphur sensitivity with NO_x emissions falling by only 1% in going from 50 ppm to 10 ppm sulphur petrol. Therefore, on the basis of these data, the restoring effect of going from 50 ppm to 10 ppm sulphur fuel would be expected to be small. However, the cars in the EPEFE Programme were only aged to the equivalent of 8000 km before tests were commenced. Results from US studies, which utilised cars artificially aged up to 100,000 miles, have been referred to by a number of respondents to show that such ageing is needed to show the real impact of sulphur (in the range 30-630 ppm) on emissions over a vehicle's life (e.g. SENCO in UK DETR response [25]).

The Federal Republic of Germany (FRG) [13] stresses the potential of the indirect benefits on air quality resulting from the use of sulphur-free fuels with the current vehicle parc. In particular they state that, in the USA, sulphur reduction is pursued for reasons of increased durability of the relatively sulphur-resistant TWC converters. Studies in California on the introduction of new reformulated petrol (CalRFG3) show that for designs with TWC converters using sulphur-free (i.e. < 10 ppm) rather than low-sulphur fuels, the NO_x emissions are reduced by 21% and the non-methane hydrocarbon emissions (NMHC) by 13%. Data from FEV are also quoted showing that emissions in cities from the existing car fleet are reduced by 15% in going from 50 to <10 ppm sulphur petrol.

There is also evidence for TWC equipped vehicles demonstrating that higher fuel sulphur levels increase the rate of deterioration of the lambda sensor (ACEA [1], AECC [2]). This causes fuel mixtures to drift rich, which in turn leads to an increase in vehicle CO emissions and a reduction in NO_x emissions. This change in emissions reduces TWC performance since these need stoichiometric mixtures to operate most effectively. A reduction in sulphur level would slow this general deterioration, improving the durability of systems in the field (FRG [13]).

AECC [2] have also referenced US results that are reported to show a reduction in emissions with TWCs as the sulphur content of petrol is reduced, with the greatest effect apparent between 100 and 30 ppm sulphur (the lowest level investigated). AECC [2] have concluded that "the bottom line is that higher sulphur fuels have an effect on durability if the criteria are the amount of untreated pollution emitted over the life of the vehicle".

It should be noted that discussions are underway on in-service compliance testing and the fuel to be used in these tests is yet to be decided. The AECC [2] submission has illustrated the importance of fuel selection by pointing out that deterioration in performance will "only be apparent if the test to check the catalyst/emission performance is conducted with the same fuel used during the durability test and not, for example, a standard reference fuel". In other words the deterioration of the TWC will not be fully apparent if its performance is measured with a lower sulphur fuel than that normally used by the vehicle.

The AECC [2] also mentions that the reduction in efficiency of TWCs using higher sulphur content fuels leads to an increase in N_2O and Methane emissions – both very potent greenhouse gases. This is attributed to the reduction in conversion efficiency of TWCs using higher sulphur fuel. Methane is a refractory molecule and relatively difficult to combust and conversion is consequently greatly reduced by increased sulphur content in petrol. The significance of this increase on the current vehicle fleet is not quantified though evidence is presented which shows that nitrous oxide emissions decrease as sulphur levels in petrol are lowered (AECC [2]). Conversely CONCAWE [6] have suggested the “possibility” that the emissions of N_2O might actually be increased by going from 50 ppm to <10 ppm fuel. The rationale is that this would occur during the TWC warm-up “as a consequence of the higher catalyst activity in a virtually sulphur-free environment”, though no substantiating evidence for this is given.

2.1.2 Current Production

The majority of new vehicles currently being sold in Europe are equipped with manifold/port fuel injection engines, working on stoichiometric fuel/air mixtures, and using TWCs to reduce emissions of CO, HC and NO_x. Advanced versions of this technology can meet the Euro III emissions standards, and probably the Euro IV, without difficulty. Therefore a substantial proportion of the European vehicle fleet in 2005 and beyond will be based on this technology.

Submissions, which consider this group of vehicles, have focused on the indirect benefits of reducing the sulphur in petrol. As discussed in the previous section sulphur reduces the conversion efficiency of TWCs, however the TWCs used in current vehicle production are reported by the automobile industry to be more sensitive to sulphur in petrol than earlier versions.

Responses show a marked divergence in opinion on the possible benefits to be gained by new Euro III and Euro IV vehicles, particularly in relation to NO_x emissions, from a reduction in the sulphur content of petrol. This divergence appears to be centred around the approach and assumptions made to assess the impacts of sulphur levels below 50 ppm. Representatives of the fuel refiners (EUROPIA [10]) have based their analysis on the vehicles and test programmes in the EPEFE study. These indicate small reductions of the order of 1% NO_x in going from 50 ppm to 10 ppm sulphur petrol, which has a negligible effect on both national and urban emission levels. This view has also been expressed by some of the government respondents [18, 25].

However, as noted earlier (section 2.1.1) some doubt has been cast by the motor industry over the applicability of the EPEFE equations to TWCs in current production. This is partly because the data they are based on include few results below 50 ppm sulphur (only down to 18 ppm), and also they do not take into account the full effects of ageing, having tested vehicles after only 8000 km [2]. Motor industry sources have presented data to show that advanced TWCs, while giving better absolute conversion efficiencies for NO_x, CO and HC, are more sensitive to sulphur levels in the 0 to 50 ppm range. The results quoted are listed in Table 2.

Table 2: Data Supplied by the Motor Industry on the Effect of Sulphur on Three Way Catalyst Systems

Change in Petrol Sulphur	Change in NO_x Emission[ii]	Source
50 ppm - 10 ppm	21%	CLEPA [5]
30 ppm - 8 ppm	20%	Toyota [24]
30 ppm - 1 ppm	13%	ACEA [1]

It should be stressed that there is no suggestion in the submissions that vehicles fitted with these advance catalysts will not meet Euro III or Euro IV standards, however, additional reductions might be achieved with sulphur levels below 50 ppm.

The data in Table 2 may not be directly comparable with each other, or with the EPEFE results, as no information was available in the submissions on the test methodologies used. These results have, however, led the motor industry to question the validity of the EPEFE equations at low sulphur levels with advanced and aged TWCs, and alternative relationships have been developed. An analysis for Ford, based on one such relationship, has estimated a 17% reduction in NO_x emissions can be gained with Euro III cars by reducing fuel sulphur from 50 ppm to 5 ppm (SENCO [11]). A more recent analysis for the UK Department of Environment, Transport and the Regions (DETR) [25] by the same consultant has estimated the emission reduction from Euro III and Euro IV cars gained by a reduction in sulphur from 50 ppm to both 30 ppm and 8 ppm. This suggested a 15% reduction in NO_x for 30 ppm sulphur rising to 79% with 8 ppm sulphur fuel. SENCO estimated that HC and CO emissions would also be reduced, but to a lesser extent than for NO_x. This study also assessed the impact of the fuel sulphur reductions on emissions from the EU vehicle fleet. This yielded values of 21%, 25% and 16% for NO_x, CO and HC in 2005, rising to 47%, 37% and 23% in 2010 for 8 ppm sulphur fuel, but only minor reductions for the 30 ppm sulphur fuel.

DETR, in their submission [25], considered the potential benefits of the above NO_x emissions reductions in relation to the requirements of the EU's Air Quality Directive. The 2010 reduction in NO_x would result in a 5% reduction in annual mean NO_2 concentrations in the UK. Although small in absolute terms it was estimated that this would lead to "significant" reductions at sites predicted to exceed the EU air quality limits.

The implication of the above on air quality is that some additional benefit will be gained by reducing fuel sulphur from 50 ppm to <10 ppm. However, some responses point out that the attainment of this additional benefit will depend on how sulphur free (i.e. < 10 ppm) petrol is introduced on to the European market, and how the motor manufacturers respond to sulphur free fuel. If sulphur free petrol is the only grade available, manufacturers will not have to calibrate their engines to run on 50 ppm sulphur fuel, but only on the lower sulphur grade. As the vehicle emission standards for petrol passenger cars are already fixed for the year 2005 the availability of zero sulphur fuel may not lead to any overall environmental benefit as there is no obligation on the manufacturers to do better than the exhaust emissions standards already mandated.

As noted earlier the AECC [2] mentions that the reduction in efficiency of TWCs using higher sulphur content fuels leads to an increase of N_2O and Methane emissions. Sulphur free fuels

[ii] No information was available in the responses on the test methodologies used in the derivation of data.

could therefore also provide greater scope for restricting emissions of N_2O and Methane [13]. Quantification of the magnitude and impacts in this area is still needed, however, especially to clarify the issue in relation to N_2O and the contradicting information from CONCAWE [6] mentioned earlier.

2.2 PETROL ENGINES - NEW TECHNOLOGY

The vehicle manufacture organisations responding to the consultation have all referred to their voluntary agreement with the European Commission to reduce the average CO_2 emissions from new cars by 25% to 140 gm/km by 2008/9. To achieve this with petrol engine vehicles a range of measures are being considered including improvements to transmissions and weight reductions. Also there is general agreement that the target will require a move to lean burn direct injection technology from the current stoichiometric engine systems. Conventional Three Way Catalysts (TWCs) are designed and operated under stoichiometric air/fuel ratios. Under lean burn conditions there is an excess of air and the reduction of nitrogen oxides cannot proceed effectively. The generally favoured approach is to retain a TWC for CO and HC control and to introduce an additional technology for NO_x control; the NO_x Storage Trap (NST).

NO_x Storage Traps (NST) function by first reacting NO_2 with basic oxides on the catalyst surface to produce basic nitrates. When the catalyst approaches saturation the engine management system triggers a petrol rich excursion to generate CO and hydrocarbons. The "stored" NO_2 is reduced by the CO and HC to produce nitrogen, CO_2 and H_2O. These short fuel rich excursions cause an increase in fuel consumption.

Current vehicle models with fresh NSTs can have a conversion efficiency of up to 90-95% [1], but are subject to degradation in service due to the poisoning effect of SO_2 present in the exhaust gas. This occurs through SO_2 competing with NO_2 to react with the basic oxides of the catalyst, and affects fuel consumption through two processes:

- By reducing the amount of basic oxide available to react with NO_2 the catalyst approaches saturation more frequently and consequently needs to be regenerated for nitrogen more frequently.
- Eventually the sulphur level on the catalyst becomes too great and sulphur regeneration is needed. Because the basic sulphate is more stable this requires a higher temperature and more prolonged regeneration than for nitrogen, which again is achieved by adjusting the engine to run rich for a limited period thus imposing a further fuel efficiency penalty.

Both of the above processes involve SO_2 originating from the combustion of sulphur in the engine, and therefore it would be expected that their severity would increase with the sulphur concentration in petrol. Motor manufacturers have submitted data to show the detrimental effect of the sulphur content of petrol on the conversion efficiency, regeneration frequency and time needed for regeneration of NO_x Storage Traps. These data show strong sulphur sensitivity across the 0 to 50 ppm range.

GDI-lean burn engine technology is estimated to offer a fuel efficiency gain of about 15 to 20% relative to a conventional petrol car fitted with a Three Way Catalytic converter (SENECO [25]). Data from a number of sources have been presented (Table 3) to show how much of this potential improvement would be lost by using 50 ppm rather than 10 ppm sulphur petrol.

Table 3: The Fuel Efficiency Improvement to be Gained by Using <10 ppm rather than 50 ppm Petrol

Change in Petrol Sulphur	Gain in Fuel Efficiency	Source
50 ppm - 10 ppm	3 to 5%	ACEA[iii] [1]
..	0.9 %	CLEPA [5]
Current - 10 ppm	5 %	FEV [11, 25]
50 ppm - 10 ppm	4%	Federal Republic of Germany [13]
50 ppm - 10 ppm	1 to 5%	NL (based on VW information) [18]
..	2.5 %	Ford [11]
..	2 to 4%	UK DETR [25]

The range of estimates reflects the development status of the NST system, with the potential for more sulphur tolerant catalysts to be developed. In general the higher fuel efficiency gains were measured with earlier catalyst systems. Nonetheless there appears to be general agreement that a move to 10 ppm sulphur petrol will yield fuel savings.

Responses from the fuel production industry (CONCAWE [6], EUROPIA [10]) stress that NSTs can "operate satisfactorily" with 50 ppm sulphur petrol, and that they are deployed in Japan for use with regular grade petrol containing 31 ± 20ppm sulphur. However, JAMA [17] have pointed out that ~20% of the petrol available in Japan is premium petrol, which has an average 5 ppm sulphur and maximum 10 ppm. In this regard it should be noted that the motor industry responses have not suggested that GDI-lean burn engines with NSTs will not meet Euro IV standards, nor the CO_2 emissions target, when operated with 50 ppm sulphur fuel. It must be assumed therefore that the main benefit of moving to petrol containing less than 10 ppm sulphur would be to deliver additional fuel economy benefits from the lean burn GDI technology relative to petrol containing 50 ppm sulphur. The submission from the FRG [13] goes further and states "that from the point of view of vehicle technology, reducing motor vehicle CO_2 emissions while at the same time meeting ambitious pollutant limit values with the proposed 50 ppm sulphur content of fuel cannot be achieved in an optimal and cost-effective manner".

The fuel industry also points out that NSTs are under further development to improve factors including thermal stability, NO_x conversion efficiency, sulphur tolerance and integration into the engine control system for regeneration cycles. It is suggested that with these on-going developments the question of how far sulphur free (<10 ppm) petrol will support lean burn plus NST vehicle fuel performance cannot yet be answered. Further analysis is needed to compare the cost effectiveness and environmental benefits of low sulphur fuel against other measures.

Finally the fuel manufacturers raise a concern over secondary particulate formation linked to ammonia production down stream of the engine in catalyst vehicles. It is claimed that the presence of sulphur dioxide limits ammonia production in the catalyst, and therefore

[iii] The ACEA document also contains information from BMW which shows a ~1% difference in fuel economy.

emissions will increase with 10 ppm sulphur fuel. EUROPIA [10] estimate that this could increase EU-15 ammonia releases by about 60kt/yr by 2010. Since EU-15 emissions of ammonia are expected to be some 3100 kt in 2010 (Analysis undertaken by IIASA after Council's Common Position on National Emission Ceilings proposal), this increase would be less than 2% of total ammonia emissions in that year. Of course, the further development which the fuel industry notes will occur with NSTs in coming years could reduce the potential ammonia emissions.

2.3 LIGHT DUTY DIESEL - EXISTING TECHNOLOGY

2.3.1 Current Vehicle Fleet

Current light duty diesel vehicles are fitted with Oxidation Catalysts to meet Euro II and Euro III standards for CO, HC and PM emissions. The **indirect effect** of sulphur in diesel is that the performance of the Oxidation Catalyst is affected by sulphur, which reduces conversion efficiency as well as requiring higher temperatures for "light off" that affects short journey performance. The **direct effect** of sulphur in diesel is that sulphur is oxidised to SO_3 by the catalyst. This gas is hydroscopic and attracts water to form H_2SO_4, and then basic sulphates, which are emitted as small particulate (PM) material. As a result manufacturers deliberately limit the size and efficiency of Oxidation Catalysts in order to avoid high sulphate particulate emissions.

ACEA [1] data shows a 20 to 25% increase in particulate emissions in going from 10 ppm to 30 ppm sulphur diesel. However, this effect seems to diminish at higher engine loads, and becomes negligible at loads above 75%. The Netherlands response [18] estimates a reduction of 5 to 10 mg/km (i.e. to be compared to the EURO II standard of 100 mg/km for N1 class vehicles - Table 1.2a), while the FRG [13] quotes data from FEV showing a 5% reduction in particulate emissions from deployed cars in going from 50 ppm to <10 ppm sulphur diesel. Respondents commenting on this aspect have acknowledged the uncertainty and lack of data to quantify the benefit of reduced sulphur.

Work by SENCO for the UK DETR [25] has used EPEFE data to assess the reduction in PM resulting from reducing diesel sulphur from 50 ppm to <10 ppm in 2005. This indicated a small reduction of < 1%, but it was noted that EPEFE relationships do not take account of the effects of sulphur on Oxidation Catalyst behaviour.

According to the World Wide Fuel Charter (WWFC, April 2000), presented in the ACEA response [1], the mass of sulphates emitted from the engine depends on the following parameters:

- The fuel consumption of the engine
- The fuel sulphur content
- The S to sulphate (SO_4^{2-}) conversion rate

It also states that the conversion rate can only be estimated, as it varies from engine to engine and is typically around 1%, however the use of an after-treatment containing an Oxidation Catalyst dramatically increases the conversion rate to up to 100% depending on the catalyst efficiency[1]. Therefore, with catalyst vehicles, there may be close to a one to one relationship between the mass of sulphur particulate emissions and the sulphur content of the fuel. Consequently the reduction of fuel sulphur from 50 to 10 ppm could reduce sulphur particulate by 80%. Clearly the impact on overall PM emission will be less, and will depend on the fraction of particulate emissions associated with sulphur.

2.3.2 Current Production

A possibility suggested for current production is that the benefit of low sulphur diesel could be taken by using more active catalysts to reduce CO, HC and PM (**indirect effect**), while accepting an increase in sulphur PM (**direct effect**), thereby keeping the particle emission constant. This would reduce PM from the soluble oil fraction (SOF), which raise particular health concerns. However, there is also some concern about the health effects of Ultra-Fine Particulate Matter (UFPM), this is discussed more in section 2.4.

2.4 LIGHT DUTY DIESEL - FUTURE TECHNOLOGY

Smaller cars fitted with advanced engines (i.e. Diesel Direct Injection/Common Rail) utilising Exhaust Gas Recirculation (EGR) and Oxidation Catalysts should be able to meet the more stringent Euro IV standard for CO, HC, PM and NO_x emissions (i.e. 50% decrease from Euro III to Euro IV). A reduction in diesel sulphur level may allow more cars to just use EGR and Oxidation Catalysts without additional PM after-treatment, however this leads to possible concern over possible increases in Ultra Fine Particulate Matter (UFPM). The current standard for measuring PM is by mass, though there is rising concern about the health effects of UFPM (in particular in relation to DI diesel and petrol engines). It has been suggested that PM measurement should move towards measuring the number of particles to reflect this.

Heavier cars and light commercial vehicles will need new exhaust treatment technologies, in addition to advanced engine technology, to meet the Euro IV standards (ACEA [1]; SENECO - UK DETR [25]). The implementation date for Euro IV standards is still some time away and it is still unclear which combination of technologies manufacturers will employ in order to comply with them. From the responses, the preferred technology of the vehicle manufacturers seems to be a combination of a NO_x Storage Trap (NST) with either a Diesel Particulate Filter (DPF) or Continuously Regenerative Trap (CRT). The alternative for NO_x control is the Selective Catalytic Reduction System (SCR), but this is only being considered for heavy duty diesel vehicles.

The final choice will be affected by the engine operating systems that are adopted. For example the Ford [11] submission discusses the impacts of using Exhaust Gas Recirculation to attain EURO IV NO_x limits for light duty diesels:

- More EGR means more HCs and CO in the exhaust gases and so more effective Oxidation Catalysts are required to meet the Euro IV limits for these gases.
- More effective Oxidation Catalysts will convert fuel sulphur into sulphate and so the PM limit may not be attainable without either lower sulphur diesel fuel or a particulate trap. The latter will be costly and give a fuel economy penalty.
- If sulphur in diesel limits the activity of the oxidation catalyst, some throttling of the engine may be needed to control CO and HC levels. This will reduce engine efficiency.

An alternative option could be to optimise the diesel engine for fuel economy, thus generating high engine emissions of NO_x but reduced levels of PM. The EURO IV levels could then be attained with a NO_x Trap (which also acts as an effective oxidation catalyst for CO, HC and PM), possibly without the need for a PM trap, which may entail additional cost and a fuel economy penalty.

Sulphur present in diesel adversely affects each of the components discussed above:

NO_x Storage Trap performance is degraded by the same mechanisms as when used in conjunction with lean burn petrol engines (Section 2.2), and has a similar impact on fuel efficiency. ACEA [1] have reported VW data indicating a 1% fuel penalty in going from 10 ppm to 50 ppm sulphur diesel. Regeneration of NSTs for sulphur is more difficult with diesel engines, which have lower exhaust temperatures and cannot operate with such fuel rich mixtures as with petrol engines. There may be a cut off above which NST systems will not be viable with diesel engines but it is not clear from the submissions if this is less than 50 ppm sulphur.

Diesel Particulate Filters/Traps (DPF) become saturated more quickly with higher sulphur fuels due to the production of sulphate particulate. This increases the back-pressure, thus increasing fuel consumption, and also the frequency of regeneration. The FRG [13] also report that the regeneration temperature of particulate filters rises as the sulphur content increases (a rise of ~50 ^{o}C from 10 ppm to 50 ppm sulphur content). They go on to say that experiences in the field show that in the case of vehicles in city traffic this means that reliable regeneration can no longer be insured. They also report an anticipated reduction in fuel consumption of around 3% associated with a change from 50 ppm to 10 ppm diesel. Ford has reported a similar reduction in fuel economy of 2% associated with periodic regeneration, but this is not all attributable to sulphur since carbon based material forms a large fraction of the particulate load. Moreover, the introduction of Fuel-Borne Catalyst (FBC) additives in diesel, to enhance regeneration, is a potential option that Ford [11] consider to be insensitive to sulphur.

The insensitivity of FBCs mentioned by Ford [11] to sulphur is only partially agreed with by the AECC [2]. They state that: “A sulphur content of 10 ppm instead of 50 ppm will have a negligible impact on the catalytic activity of the FBC for the regeneration of the DPF [Diesel Particulate Filter], but it will have a positive impact on fuel consumption by decreasing the build-up of calcium sulphate ash.”

Continuously Regenerative Traps, operating in passive mode, oxidise soot particulate to carbon dioxide using NO_2 in the exhaust gas. The NO_2 is generated from the engine exhaust by having an oxidation catalyst up stream of the trap. Sulphur reduces the performance of the trap by reducing the conversion efficiency of the oxidation catalyst (Section 2.3). This reduces the quantity of NO_2 produced, which raises the temperature needed by the CRT to combust the soot particulate, and may be difficult to attain under normal operation. ACEA [1] report data showing that CRTs will not attain Euro IV standards with diesel sulphur levels above 30 ppm.

Overall it is difficult to quantify the benefit of lower sulphur levels on this group of technologies. The responses generally indicate that lower sulphur levels yield better performance from exhaust treatment technologies and better fuel economy, but there is little data presented to help quantify the benefit of going from 50 ppm to <10 ppm sulphur.

2.5 HEAVY DUTY DIESEL - EXISTING TECHNOLOGY

The current fleet of heavy duty vehicles do not use any exhaust gas treatment systems. Therefore the **indirect effect** of a reduction in diesel sulphur from 50 ppm to 10 ppm is small. However, as reported by a number of contributors [1, 2, 11], the engine-out emissions of SO_2 and sulphate particulates are **directly** related to the sulphur content in the fuel (see section 2.3.1).

2.6 HEAVY DUTY DIESEL - NEW TECHNOLOGY

Euro IV and Euro V standards for PM and NO_x emissions will introduce the need for exhaust treatment technologies on heavy duty vehicles. Respondents have identified a limited set of options:

Euro IV

Diesel Particulate Filter (DPF) plus Exhaust Gas Recirculation,
or
Selective Catalytic Reduction (SCR)

Euro V

Selective Catalytic Reduction plus Diesel Particulate Filter

For Euro IV the DPF option is reported to be the more sensitive to sulphur, and a 50 ppm sulphur in diesel level is expected to favour SCR.

It is not clear how sensitive SCR technology is to fuel sulphur. Technical evidence from The Netherlands [18] states that it is insensitive. However, ACEA [1] presented data showing an increase in PM emissions from 0.012 mg/kWh to 0.027 mg/kWh in going from 15 ppm to 50 ppm sulphur diesel. This should be compared to the Euro IV PM limits of 20-30 mg/kWh.

For Euro V SCR technology will probably need to operate with an oxidation catalyst up stream, to increase the de-NO_x effect of the SCR, and a particulate filter. The detrimental effect of sulphur on oxidation catalysts and DPFs has been discussed above (Section 2.4). In addition the Federal Republic of Germany (FRG) [13] also state that sulphur free fuels could also provide greater scope for restricting other emissions such as NH_3, N_2O and methane.

In common with the light duty diesel vehicles it is difficult to draw a firm quantitative conclusion on the benefit of lower sulphur levels on this group of technologies. The responses generally indicate that the exhaust treatments give better performance and durability at lower sulphur levels, and that it would be very difficult, and perhaps not possible, to meet Euro IV/V standards without 10 ppm fuel. The FRG [13] reports the results of a study by MAN indicating a reduction in fuel consumption of around 3% in going from 50 ppm to 10 ppm diesel. Otherwise, there is no data presented to help quantify the benefit on fuel efficiency of going from 50 ppm to <10 ppm sulphur. The attainability of Euro V standards for Euro V HGVs will be the subject of separate feasibility study as agreed between Council & Parliament.

2.7 SUMMARY

General:

1. Both existing and new vehicle technologies can function adequately on the existing and agreed fuel standards. The issue for low sulphur fuels is how to gain or maintain the full CO_2 benefit of the new technologies while respecting emission limit values
2. There was a general qualitative agreement amongst respondents that sulphur had a detrimental impact on exhaust gas emissions.
3. Respondents felt there was a need for further work to quantify the effects of low sulphur on the existing vehicle parc.
4. Respondents felt there was a need for further work to quantify the effects of low sulphur on the fuel efficiency with new engine technologies.

Petrol:

5. There is a divergence in opinion on the quantitative benefits (enhancing effect) of low sulphur fuels in reducing NO_x, CO and HC emissions from currently produced petrol cars fitted with Three Way Catalysts (TWCs). Fuel producers consider the reduction potential to be small, and the benefit to be negligible when compared to overall emissions. Other organisations, which included vehicle manufacturers and some government authorities, think the potential is greater and could make a significant contribution to meeting Air Quality standards.
6. A key issue related to the divergence of opinion is the EPEFE equations. Are these equations a good representation of the effect that sulphur in petrol has on the performance of advance TWC systems, or are new relationships needed to reflect the effect of sulphur concentrations between 0 and 50 ppm?
7. It should be questioned whether motor manufacturers would take the benefit of a reduction in sulphur in petrol to <10 ppm, by reducing production costs, or by producing vehicles that perform better than the Euro IV standard? However, since manufacturers can currently use low sulphur fuel for the Type Approval testing, they may be able to demonstrate compliance while in use emissions could be higher.
8. Most benefits of sulphur reduction with current production (stoichiometric) petrol vehicles come at the 10 ppm level, with only marginal benefits at the 30 ppm level.
9. There is evidence that lower sulphur levels result in reduced emissions of other greenhouse gases such as N_2O & Methane through improved TWC efficiency, though this needs quantification[iv].
10. The NO_x Storage Traps (NST) needed to attain Euro IV standards with lean burn direct injection engines will function with 50 ppm sulphur in petrol. However, there is a fuel efficiency penalty that current estimates suggest could range from 1 to 5%.

[iv] CONCAWE have also suggested the possibility of increased N_2O emissions from TWCs during the warm-up phase using lower sulphur petrol, but no substantiating evidence was provided.

11. A key issue is whether the sulphur sensitivity of NSTs will be reduced with further engine management/catalyst development?

Diesel:

12. With Oxidation Catalysts fitted to light duty diesel vehicles there is a trade-off between sulphur and carbon based PM. Reducing the sulphur content of diesel from 50 ppm to 10 ppm will enable more active oxidation catalysts to be used while maintaining or reducing sulphur based particulate emissions. This use of more active oxidation catalysts will reduce carbon based PM emissions. The extent of this benefit is unclear.
13. Future options for heavy cars and commercial vehicles will depend on the combination of engine operating systems and exhaust gas treatments chosen. One favoured option may be to fit both NST and particulate filter technologies to meet Euro IV standards. Both of these devices are sensitive to sulphur, but little information has been presented to quantify the potential benefits to be gained in going to 10 ppm sulphur diesel. Limited data suggests the fuel economy penalty for regenerating the NST system will be at least 1%.
14. Sulphur regeneration of NSTs is more difficult with diesel engines and some submissions suggest there is a cut off level of sulphur above which the NST will not be viable on a diesel vehicle. However, it is not clear from the submissions if this cut off is less than 50 ppm sulphur.
15. Heavy duty diesel vehicles will need to be fitted with both NO_x reduction and particulate filter technologies to meet Euro IV and Euro V standards. All of these devices are sensitive to sulphur, but no information was presented to quantify the potential benefits to be gained in going to 10 ppm sulphur diesel.

3 Question 2

Using the sulphur specification of 50 ppm as a reference, what incremental refining costs are incurred to produce petrol and diesel with a sulphur content of (a) 30 ppm and (b) 5-10 ppm.

Contributor	Full Name
ACEA	European Automobile Manufacturers Association
Akzo Nobel Catalysts	
CONCAWE	Oil Companies' European Organisation for Environment, Health and Safety
Czech Republic	
EMPA	The Swiss Federal Laboratories for Materials Testing and Research
EUROPIA	European Petroleum Industry Association
Ford Motor Company	
FRG	The Federal Republic of Germany
Haldor Topsøe A/S	
IFP	Institut Français du Pétrole
Ireland	Department of Environment & Local Government
JAMA	Japanese Automobile Manufacturers Association
Netherlands	
SMMT, UK	The Society of Motor Manufacturers and Traders Limited
Sweden	Ministry of the Environment
T&E	European Federation for Transport and Environment
WGIII, Auto Oil II, Spain	Spain Representative of Working Group III, Auto Oil Programme
UK, DETR	Department of Environment, Transport and the Regions

All respondents agreed that the production of petrol and diesel with sulphur contents below 10 ppm was technically feasible, and all the necessary processes were proven technology. It was also pointed out that such low sulphur fuels were already available in countries including Japan, Canada, Sweden and Finland and in California (and the UK for diesel).

Desulphurisation of petrol focuses on the components arising from fluid catalytic crackers and steam crackers that contribute 99% of the sulphur. In contrast all diesel components contain sulphur and need to be treated by hydrodesulphurisation. The latter may raise a supply problem if 10 ppm diesel was introduced in the short term, reducing output by the order of 10 to 20% (Netherlands response).

The costs of producing low sulphur fuels arise from the investment in new process plant and the additional fuel and other operating costs. Overall these costs will vary significantly between refineries, reflecting their different configurations and the mix of crude oils they operate with. Generally refineries operating with more sour crude oil will face higher costs. Refineries in the southern EU member states are reported to use more sour crudes than those in the north.

Responses from Akzo Nobel Catalysts [4] and Haldor Topsøe A/S [14] (refining catalyst suppliers) concur that there are currently technology options available (and already in use) to achieve the 10 ppm suggested limit for both petrol and diesel fuel.

Haldor Topsøe A/S also states that meaningful figures for the incremental costs associated with reducing the sulphur level in fuel from 50 ppm to lower levels can only be estimated if the other key specifications are defined. Even then, it is necessary to make a detailed analysis of the refineries in the EU. Extra refining CO_2 emissions as a result of changing the limit from 50 ppm to 10 ppm sulphur were estimated by Akzo Nobel Catalysts [4] to be in the order of 5-10% using current technology. However, they also state that history has shown that catalyst development has been fast and they expect that new catalysts will considerably reduce the impacts of fuel desulphurisation (on costs, CO_2 emissions and fuel specifications).

Incremental costs of producing low sulphur fuels have been reported by several respondents. In most cases these refer to national positions, and have been presented in different forms. These are summarised in Table 4 below. The range of cost reflects, at least in part, that oil refining is a dynamic operation with ongoing changes to plant and processes, and therefore the costs of producing <10ppm low sulphur fuel will vary between sites [v].

Table 4: Incremental Costs of Producing 30 ppm and 5-10 ppm Petrol and Diesel, as presented by the Respondents

Source	Petrol		Diesel	
	30 ppm	**5-10 ppm**	**30 ppm**	**5-10 ppm**
Irish Government for the Irish Republic [(a)]	Nil	Nil	13-16 Euro/tonne.	37-49 Euro/tonne
EUROPIA/CONCAWE for EU 15 (NPV)[(b)]	1.5 B Euro	4.8 B Euro	2.4 B Euro	6.7 B Euro
Ford for EU 15 [(c)]		0.0026 Euro/litre		0.0040 Euro/litre
Federal Republic of Germany [(d)]		1-2 Euro/tonne		2-3 Euro/tonne
Netherlands Government for NL (Capital) [(e)]		200 M Euro		650 M Euro
UKPIA for UK [(f)]		1.9 B Euro		
Czech Government for Czech Republic		84 - 112 M Euro (petrol + diesel)		

NOTES

a) Figures are for the Irish National Petroleum Corporation based on current product differentials and normal investment depreciation rates.
b) The UK DETR presented the same MathPro Inc. estimates as presented by Ford who commissioned this study
c) EUROPIA/CONCAWE presented costs in Net Present Value (NPV) terms based on a plant life of 15 years and a discount rate for annual operating costs of 7%.

[v] The EC, DG Environment have commissioned a study to specifically address the range of refinery costs associated with producing low sulphur fuels.

d) National refining costs calculated by the FRG where investment depreciation and operational costs are estimated at approximately the same level. The estimates do not take into account potential logistical/distribution costs.
e) Netherlands data are capital costs, in addition estimates of annual operating costs were given of 2M Euro/yr for petrol and 12 M Euro/yr for diesel.
f) The UKPIA data cover the capital and operating costs of producing <10 ppm sulphur petrol and diesel without a separate breakdown.

To facilitate caparison the data in Table 5 have been normalised to present the additional cost of low sulphur fuel in Euro Cents per litre. The results in Table 5 show a broad range of estimates with the FRG giving the lowest costs for both petrol and diesel and UKPIA and Ireland (for diesel) the highest estimates.

Table 5: Incremental Costs of Producing 30 ppm and 5-10 ppm Petrol and Diesel (Euro Cents per litre)

Source	Petrol		Diesel	
	30 ppm	5-10 ppm	30 ppm	5-10 ppm
Irish Government for the Irish Republic	Nil	Nil	1.0 - 1.2	2.8 - 3.8
EUROPIA/CONCAWE for EU 15 [a+b]	0.11	0.35	0.20	0.56
Ford for EU 15		0.26		0.40
Federal Republic of Germany [c]		0.08-0.15		0.18-0.26
Netherlands Government for NL		0.18		0.67
UKPIA [d]		4.3		4.3

NOTES
a) Calculations based on 15 year plant life and 7% discount rate.
b) Calculations used 1995 figures for EU 15 petrol and diesel consumption in order to calculate costs per litre.
c) As a result of national refining costs only. The FRG indicated that logistical/distribution costs could possibly increase these values substantially in some scenarios.
d) Calculation used UKPIA data for UK petrol and diesel production.

3.1 SUMMARY

1. All agree that the production of petrol and diesel with sulphur contents <10 ppm is technically feasible.
2. The production of 30 ppm and <10 ppm sulphur petrol and diesel is technically feasible, and such low sulphur fuels are currently produced in several countries.
3. A short term transition to low sulphur diesel could reduce production capacity by 10 to 20% but this problem would not arise over a longer time frame.
4. Incremental costs for the production of low sulphur petrol and diesel will vary between refineries reflecting their different configurations and the sulphur contents of the crude oil they operated with.
5. Generally southern European refineries are reported to operate on more sour crude than those in the north and therefore could face higher desulphurisation costs.
6. Estimates of incremental costs cover a wide range from about 0.1 to 4.3 Euro Cents per litre for a reduction to 5-10 ppm sulphur.
7. History has shown that catalyst development has been fast and refining catalyst suppliers expect that new catalysts may considerably reduce the impacts of fuel desulphurisation (on costs, CO_2 emissions and fuel specifications).

4 Question 3

Should the uptake of new emissions abatement technology or fuel-efficient technology be encouraged in the automotive fleet? If so what type of low sulphur marketing regime would be justified? For example, (i) a proportion of the market sold on a voluntary basis or (ii) a proportion of the market sold on a mandatory basis or (iii) the totality of the market that complies with a sulphur content fixed at a value less than 50 ppm? This should be considered in the context of the advancement of traditional petrol and diesel engine emission abatement technology and looking forward towards the introduction of new vehicle propulsion or power plant technology.

Contributor	Full Name
ACEA	European Automobile Manufacturers Association
AECC	Association for Emissions Control by Catalyst
AIT & FIA	The European Bureau of the Alliance International de Tourisme & Fédération Internationale de l'Automobile
CLEPA	European Association of Automotive Suppliers
CONCAWE	Oil Companies' European Organisation for Environment, Health and Safety
Czech Republic	
EUROMOT	The European Association of Internal Combustion Engine Manufacturers
EUROPIA	European Petroleum Industry Association
Ford Motor Company	
FRG	The Federal Republic of Germany
Ireland	Department of Environment & Local Government
JAMA	Japanese Automobile Manufacturers Association
Netherlands	
SMMT, UK	The Society of Motor Manufacturers and Traders Limited
Sweden	Ministry of the Environment
T&E	European Federation for Transport and Environment
Toyota	
WGIII, Auto Oil II, Spain	Spain Representative of Working Group III, Auto Oil Programme
UK, DETR	Department of Environment, Transport and the Regions

Responses to this question drew attention to a number of key factors, which affect the need for and timing for the supply of low sulphur fuels. These were:

- Encouraging technology development
- Merits of 30 ppm versus 10 ppm sulphur fuels
- Timing for the introduction of low sulphur fuel
- Scope and the type of marketing regime.

It is clear from the responses that the expectation is that ICE (Internal Combustion Engine) technology will be dominant to at least 2010, since there was little mention of other technologies (e.g. fuel cell, hybrids, etc).

4.1 ENCOURAGING TECHNOLOGY DEVELOPMENT

There was general support for encouraging the development and take up of new emissions abatement and fuel efficient technologies. However, there was no such consensus on whether low sulphur fuels (i.e. < 50 ppm) were part of the measures needed to support these technologies. Fuel suppliers felt that regulation should be limited to setting air quality standards and vehicle emission limits, and that the means of compliance should be left to vehicle manufacturers operating in a competitive market. If manufacturers develop cost effective technologies that require improved fuels, then the fuel industry is committed to providing those fuels.

In contrast the vehicle manufacturers pointed to a move to low sulphur fuels in other world regions, and suggested that this should be followed in the EU. There is also some concern that if the EC does not stay in line with other major national blocks, then there would be a negative effect. This is the case in both commercial trading and also in engine technical specifications. The possibility that USA or Japanese specifications might diverge significantly from European specifications was a real concern.

An important point made by technology developers was that a clear commitment to move to lower sulphur fuels would encourage the further development of technologies to take advantage of these fuels. It was also noted that one of the longer term technologies for improved air quality, fuel efficiency and greenhouse gas abatement, fuel cells, required zero sulphur fuel [2, 11].

4.2 MERITS OF 30 PPM VERSUS 10 PPM FUELS

There was little discussion on this subject, but when views were expressed there was no support for adopting a 30 ppm standard. In line with the observations reported under Question One, a move to 30 ppm sulphur fuels was considered to offer only margin benefits.

4.3 TIMING FOR THE INTRODUCTION OF LOW SULPHUR FUELS

Respondents described a series of drivers affecting the timing of any introduction of low sulphur fuels:

- 2008 Local Air Quality targets.
- 2008 Euro V emission limits for heavy duty vehicles.
- 2008/9 Fuel economy agreements with the automobile industry
  – EU new car fleet average of 140 gCO_2 /km.
- 2012 Fuel economy target (to be reviewed in 2003)
  – EU new car fleet average of 120 gCO_2 /km.

Views on the possible timing for the introduction of low or sulphur free fuels were divergent. The environmental group (T&E [23]) responding to the consultation supported early introduction (2002) with a mandatory requirement covering the full market by 2005. Vehicle manufacturers also supported an introduction timed for 2005, on the basis that this paralleled trends in other markets. However, it is not clear from their responses whether they wished for full or partial introduction by this date. The Federal Republic of Germany (FRG) [13] proposed that in order for the reduction potential for pollutant and CO_2 emissions to be fully exploited, the pending update of the Directive 98/70/EC beyond 2005 should provide for the introduction, as from 01.10.2007, of sulphur-free (<10 ppm sulphur content) petrol and diesel fuels. Again it was not clear if this referred to full or partial introduction. In contrast, as discussed in Section 4.1, the fuel manufacturers considered that the cost:benefit case for low sulphur fuels has not been made, and that their introduction should be left to the market.

A further point made by a number of respondents was that early "full" implementation might have a detrimental effect on the environment when assessed on a "well to wheel" basis. It was suggested that early full implementation needed to be justified by more detailed technical and economic analysis.

Some responses presented more detailed analyses of the timing for introducing sulphur free fuels, which was considered to be related to three factors:

- Introduction of lean burn Gasoline Direct Injection (GDI) engine technology
- Introduction of advanced diesel exhaust systems
- Air Quality benefits

With regard to GDI technology it was considered that <10 ppm sulphur petrol was not essential for operation, but that it was needed to capture the full CO_2 abatement benefit from such vehicles (see Section 2.2). However, it was estimated by the UK DETR [25] that only 10% of new vehicle sales would incorporate GDI technology by 2003, rising to 90% by 2010. Therefore there was no reason for full implementation of sulphur free petrol on these grounds before about 2008.

For current diesel vehicles it was suggested that the CO_2 benefit was uncertain, and did not merit an early move to sulphur free fuel due to greater and more definite CO_2 penalties at the refineries. Widespread use of NO_x catalysts/traps with diesels will not start before 2005, and then only for heavy cars and light commercial vehicles, therefore their share of the diesel vehicle fleet will not be sufficient to merit complete conversion to low sulphur fuel until about 2010. However, heavy duty trucks and buses are also expected to require NO_x/PM catalysts/traps across the board by 2005, thus increasing the benefits of low sulphur fuel in that time frame.

Air quality benefits related to NO_x and PM emissions, for which there are concerns that localised excedances of EU standards will occur, particularly in urban areas. The evidence presented in Section 2.1 and 2.3 above indicates that sulphur free fuel may help reduce such excedances by enhancing the performance of (a) current generation of 3 way catalyst petrol vehicles, thereby reducing NO_x emissions and (b) current generation oxidation catalyst diesel vehicles, thereby reducing particulate emissions. It was suggested that, in order to address these local/regional problems, there would be merit in having partial introduction of sulphur free fuels on an earlier timescale.

4.4 SCOPE AND MARKETING REGIME

Views on the scope for introducing sulphur free fuels covered the full range from full mandatory introduction by 2005 to no regulatory action and leaving the decision to the market.

In line with the review of "timing" set out in the previous section, some respondents made the case for near term partial introduction, leaving full implementation to 2008 - 2010. In addition to matching the transition in the composition of the vehicle fleet and helping to tackle local environmental problems, this would also permit the refineries to be adapted in the most cost effective way. Moreover, it avoids concerns that full implementation in the near term may have negative environmental effects when considered "well to wheel".

Only a few respondents expressed a view on the market regime needed to implement a partial introduction of sulphur free fuel. One suggested that this should be left to the Member States, and that a key factor was that they should not be prohibited by the Commission from encouraging the early use of low sulphur fuels. No reference was made to mandatory action for partial availability, but the use of taxation to encourage take up was mentioned. Other issues raised were:

- How (and whether) to limit low sulphur petrol to lean burn GDI vehicles?
- Potential for restrictions on trade if Member States are left to set their own fuel quality standards.

Representatives of the users of off-road vehicles and stationary engines requested that they should have the same fuel standards as for road vehicles to avoid differences between Member States.

4.5 SUMMARY

1. Respondents were divided over whether low sulphur fuel is essential for encouraging the take up of new emissions abatement technologies and fuels.
2. Technology developers felt that a clear policy on low sulphur fuels would encourage the development of technologies to take advantage of them.
3. The reduction of sulphur levels to 30 ppm produces only marginal benefits and therefore respondents have focussed on <10 ppm sulphur free fuels.
4. Both existing and new light duty vehicle technologies can function adequately on the existing and agreed fuel standards. The issue for low sulphur fuels is how to gain the full CO_2 benefit of the new technologies while respecting emission limit values. The ability of heavy duty manufacturers to comply with the Euro V requirements is not yet assured and the likelihood increases with lower sulphur fuel.
5. Taking account of the rate of deployment of the new petrol and diesel technologies there is no need for a full transition to sulphur free fuels before 2008-2010 (given the lack of data quantifying any potential benefits on greenhouse gas reductions for current technologies).
6. A near term partial transition to low sulphur fuels would help with local/regional air quality problems by helping with the reduction of NO_x and PM from the current vehicle fleet.
7. Member States should be permitted to encourage an early partial transition to low sulphur fuels.
8. There are concerns to avoid fuel quality standards being set at Member State level since a multitude of standards would act as a barrier to trade.
9. Representatives of the users of off-road vehicles and stationary engines requested that they should have the same fuel standards as for road vehicles to avoid differences between Member States.

5 Question 4

What are the effects on other petrol and diesel fuel quality parameters of environmental relevance as the sulphur content is reduced from 50 ppm to less than 10 ppm?

Contributor	Full Name
ACEA	European Automobile Manufacturers Association
CLEPA	European Association of Automotive Suppliers
CONCAWE	Oil Companies' European Organisation for Environment, Health and Safety
Czech Republic	
EUROMOT	The European Association of Internal Combustion Engine Manufacturers
EUROPIA	European Petroleum Industry Association
FTA, UK	Freight Transport Association
Haldor Topsøe A/S	
IFP	Institut Français du Pétrole
Ireland	Department of Environment & Local Government
Netherlands	
SMMT, UK	The Society of Motor Manufacturers and Traders Limited
Sweden	Ministry of the Environment
UK, DETR	Department of Environment, Transport and the Regions

5.1 PETROL

The main issue raised with reducing the sulphur level of petrol is the potential for a small but significant reduction of octane level. Within refinery configurations the only other bulk component available to compensate for this is reformate, which would lead to an increase in the aromatics content. This goes against current fuel standards that include a reduction in aromatics from 42% in 2000 to 35% in 2005. It has been suggested that the aromatics content could be frozen at the 2000 level to overcome any such octane problem (UK DETR [25] and MathPro study for Ford [11]). This may be justifiable if account is taken of the introduction of improved vapour recovery systems, and the reduction of toxic exhaust emissions that will be delivered by the better performance of engine catalysts when operating with low sulphur petrol.

An alternative approach to the octane loss would be to add alternative oxygenates. However, this raises environmental concerns related to spillage and groundwater contamination.

If both the aromatics and oxygenate options are ruled out a large investment in alkylation processes will be needed. Respondents generally have not indicated if this is taken into account in the costs provided in Question 2, however the study by MathPro undertaken for Ford [11] includes a scenario where sulphur content is reduced to 10 ppm whilst restricting the use of MTBE. The scenario was also based on the simultaneous relaxing of restrictions on aromatics so that they remain at the current level of 42 % by volume instead of the drop to 35% by volume set to come into force in 2005. This resulted in an overall reduction in cost of about 1 US$cent per gallon (approximately 0.25 EUROcents/litre) compared to the scenario without an MTBE ban and relaxation of aromatic content limits.

As discussed in section 3 (Question 2), Akzo Nobel Catalysts [4] (suppliers of refinery desulphurisation catalysts) state that catalyst development in the past has been fast. The next generation of desulphurisation catalysts are expected to considerably reduce the impacts of fuel desulphurisation on costs, CO_2 emissions and fuel specifications (such as octane loss).

5.2 DIESEL

Reducing the sulphur in diesel could alter a range of fuel parameters including, T95, PAHs (polyaromatic hydrocarbons), cetane number, lubricity and density:

- Reduced density (and cetane number) would lead to a reduction in engine power output. In the longer term this could result in the use of larger engines, and consequently increased fuel consumption and the loss of the CO_2 benefits of low sulphur fuels.
- Reduced lubricity leading to more rapid wear of engine fuel systems.

Lubricity is currently poorly understood, but fuel suppliers in Sweden have been able to rectify initial lubricity associated problems with the use of appropriate additives.

Several respondents have indicated that it is important that other fuel parameters should be frozen when setting a standard for low sulphur diesel.

5.3 SUMMARY

1. Reducing the sulphur content of petrol may also result in a reduction in the octane level. Options for readjusting this include increasing the aromatics content or adding an oxygenates. Either option goes against the present targets for fuel standards.
2. If the use of aromatics or oxygenates are ruled out for restoring the octane level of low sulphur petrol significant investment in alkylation processes will be needed.
3. It has been proposed that all other properties of diesel must be frozen if a low or sulphur free grade is introduced.
4. In the longer term new refinery catalysts are expected to considerably reduce the impacts of fuel desulphurisation on costs, CO_2 emissions and fuel specifications (such as octane loss).

6 Question 5

What are the logistic impacts and investment implications for the distribution system for petroleum products of introducing petrol and/or diesel with a sulphur content of less than 50 ppm?

Contributor	Full Name
CONCAWE	Oil Companies' European Organisation for Environment, Health and Safety
Czech Republic	
EUROPIA	European Petroleum Industry Association
FRG	The Federal Republic of Germany
Ireland	Department of Environment & Local Government
Netherlands	
Sweden	Ministry of the Environment
T&E	European Federation for Transport and Environment
WGIII, Auto Oil II, Spain	Spain Representative of Working Group III, Auto Oil Programme
UK, DETR	Department of Environment, Transport and the Regions

Respondents to this question came from the fuel supply organisations and some governments. Their main concern was for the case involving partial introduction of sulphur free fuels to the market. The key issues that arose in these circumstances were:

- Cross contamination between fuels
- Availability of forecourt facilities

These are discussed separately in the following sub-sections. One general point was that contamination could not be totally avoided. Therefore to meet a 10 ppm sulphur standard fuels would need to produced at the refinery with 6-7 ppm sulphur. No comments were made concerning additional handling problems, which has been taken to imply that existing systems are capable of handling the low sulphur grades.

6.1 CROSS CONTAMINATION BETWEEN FUELS

Pipelines are a key element in the petroleum distribution systems of several Member States, as well as serving some trans-border movements (e.g. Rotterdam to Belgium and Germany). These are used for the sequential transport of different fuels and therefore there is the potential for cross contamination between low and higher sulphur fuels. The problem is greatest with interfaces between low sulphur petrol/diesel and domestic heating oil, agricultural diesel and aviation fuel. For example the specification for aviation fuel permits sulphur levels up to 3000 ppm.

The method for minimising such contamination is to separate the interface liquids and mix these with a product where some contamination is acceptable. Alternatively, if the volumes are too great the separated fuel is returned to the refinery. Clearly the introduction of sulphur free fuels could increase the amount of off-specification interface fuel that has to be returned. For example EUROPIA [10] and CONCAWE [6] quote UK experience from the introduction of 50 ppm diesel, that this resulted in about 200 more return trucks per month from one pipeline.

The UK DETR [25] respondent considered that the contamination problem would be manageable once the 50 ppm sulphur standard was introduced in 2005, thus reducing the interface contamination from alternate pumping of standard grades and sulphur free grades.. Estimates from UKPIA were quoted that gave additional trucking of interface fuel on introducing sulphur free fuel of about 400 trucks per year. This would entail an additional cost of 3 M Euro per year (equivalent to about 0.07 Euro Cents per litre assuming sulphur free grades have 10% of the market) and increase in CO_2 emissions.

In contrast The Netherlands [18] respondent suggested that the introduction of sulphur free fuel might require greater segregation. One possible option was to apply restrictions on the petroleum products that could be transported through existing pipelines, with some grades being moved by road or barge. Clearly the greatest benefit from such actions would come from separating the handling systems for low sulphur fuels from those handling high sulphur grades such as aviation fuel and domestic heating oils. Netherlands estimated that the cost of pipeline segregation would be about 10 M Euro (equivalent to about 0.05 Euro cents per litre) and would result in 260 kt/yr additional CO_2 emissions.

It is noteworthy that the Swedish respondent [21] reported that one factor in helping Swedish distributors maintain a low level of sulphur in their fuel was by having a separate system for home heating fuel.

Truck Movement of motor fuels is normally carried out by units that can handle up to 5 grades in separate compartments on the tanker. Switch loading between gasoline and diesel is also practised so the delivery of sulphur free fuels should not present a new problem. It was also pointed out that the quality difference between leaded and unleaded petrol had been maintained, and this covered a factor of 10 difference in lead level, whereas after 2005 the difference between sulphur grades would only be a factor of 5.

6.2 AVAILABILITY OF FORECOURT FACILITIES

The availability of fuel pumps on forecourts is only an issue if partial introduction of sulphur free fuel is adopted when there will be a need to offer two additional fuels (i.e. <10 ppm sulphur petrol and diesel). In the UK forecourts generally handle three grades of petrol - premium unleaded 95, super unleaded 97 and Lead Replacement Petrol. The UK respondent[25] suggested that low sulphur petrol could be accommodated if its introduction was timed to coincide with the withdrawal of the lead replacement grade. A similar approach to serving low sulphur petrol has also been suggested by France [15].

The problem is greater for diesel, which historically has only had one grade. If capacity to offer two grades of diesel was to be provided this will require new capital investment. The UK respondent has estimated this cost as about 16,000 Euro per site [25]. For the whole of the

UK with 13,000 service stations this would amount to an investment of about 208 M Euro. The options for responding to this are:

- Introduce a total market for low sulphur diesel on a mandatory basis.
- Leave it to the market, together with incentive measures adopted at Member State level, to determine how many/and or which grade of diesel is offered on forecourts.

6.3 SUMMARY

1. The main concerns are linked to the partial introduction of sulphur free fuels, which would mean that additional grades had to handled.
2. Contamination cannot be totally avoided, therefore to meet a 10 ppm sulphur standard fuels will need to produced at the refinery with 6-7 ppm sulphur.
3. A key issue is the potential for cross-contamination with high sulphur fuels, such as aviation fuel and domestic heating oil, which is greatest with pipeline distribution systems. Some respondents thought that this would require segregation of some grades to be transported by other modes. Others indicated that it could be handled by additional trucking of pipeline interface liquids back to the refinery for reprocessing.
4. The potential for cross-contamination would be reduced if the partial introduction of sulphur free fuels was scheduled to match with the general transition to the 50 ppm sulphur standard.
5. Estimates of the cost of returning pipeline interface fuel mixtures were equivalent to about 0.07 Euro Cents/litre from UK estimates [25] and 0.05 Euro-cents per litre from Netherlands figures [18].
6. Returning interface fuels will also result in some additional carbon dioxide emissions related to the fuel consumption for trucking. This has been estimated at 260 kt/yr for the Netherlands.
7. The partial market introduction of low sulphur fuels will increase the number of grades offered on forecourts. Low sulphur petrol could be accommodated if its introduction was timed to match the withdrawal of Lead Replacement Petrol.
8. The problem is greater with diesel, which historically has only been marketed as one grade. If additional pumps were introduced to offer two grades of diesel this would cost about 16,000 Euros per forecourt.
9. An alternative approach would be to leave fuel outlets to decide which of the two grades to offer based on demand.

7 Question 6

What will be the overall effect on greenhouse gas emissions of moving to petrol and diesel with a sulphur content less than 50 ppm? This should take account of changes in emissions in the refining and distribution systems and in the vehicle fleet through the pursuance of CO_2 efficiency technologies, the so called "well to wheel" life-cycle effect.

Contributor	Full Name
ACEA	European Automobile Manufacturers Association
AECC	Association for Emissions Control by Catalyst
Akzo Nobel Catalysts	
AIT & FIA	The European Bureau of the Alliance International de Tourisme & Fédération Internationale de l'Automobile
CONCAWE	Oil Companies' European Organisation for Environment, Health and Safety
Czech Republic	
EUROPIA	European Petroleum Industry Association
Ford Motor Company	
FRG	The Federal Republic of Germany
IFP	Institut Français du Pétrole
Ireland	Department of Environment & Local Government
Netherlands	
Sweden	Ministry of the Environment
T&E	European Federation for Transport and Environment
UK, DETR	Department of Environment, Transport and the Regions

7.1 BACKGROUND

Respondents to this question focused on the impact of going to the sulphur free (< 10 ppm) grades. The "well to wheel" impact of introducing these grades of fuel will depend on a range of factors:

- The fraction of the vehicle fleet that would benefit from low sulphur fuel in terms of increased fuel efficiency (taking into account the varying annual kms for different vehicle ages – new vehicles tend to be driven more).
- Size of the fuel efficiency improvement.
- Rate of introduction of 10 ppm sulphur fuel.
- CO_2 production associated with sulphur removal.
- CO_2 production associated with returning contaminated fuel (depending on phasing).
- CO_2 associated with the production or import of inputs to retain fuel properties (e.g. Oxygenates).

There are significant technical and market uncertainties affecting the assessment of each of these factors that are reflected in the submissions of the respondents. However, the question is essentially that of the relative size of two effects, and therefore where the cross-over point should come:

a) Gradual increase in CO_2 (and other greenhouse gases) benefits from cars.
b) Immediate CO_2 disbenefits from refineries.

7.2 ANALYSIS

7.2.1 Vehicle Benefits

Firstly the main vehicles to benefit from < 10 ppm sulphur fuels will be the lean burn petrol and diesel engines fitted with NO_x Storage Traps (NST). Petrol lean burn technology is only just becoming available in the EU market and it will take sometime for stock turnover to give it a large share of the vehicle fleet. One estimate from the UK DETR [25] suggested these vehicles would take about 10% of the new petrol car market in 2005, rising to 90% in 2010. In this case it would be well into the next decade before these vehicles had a majority share of the petrol vehicle fleet. In the case of diesel, it is only heavy cars and light commercial vehicles that will be fitted with NSTs, and therefore only a limited fraction of the light duty diesel fleet stands to benefit from sulphur free fuel. Conversely estimates from the Federal Republic of Germany [13] would indicate that much lower levels of fleet penetration by new technologies equipped vehicles would be necessary to balance increased refinery CO_2 emissions (see later).

With regard to the size of the fuel efficiency benefit to be gained from < 10 ppm sulphur fuels; the uncertainties on this have already been described under Question 1 (Section 2). Estimates vary from 1 to 5% and there is more doubt concerning diesel engines (Section 2.4) than petrol engines. Indeed the Netherlands respondent [18] has stated that "10 ppm diesel has no effect on the fuel consumption of diesel vehicles". However, with regard to future technologies their source documents indicate that this “does not include the effects of regenerations of most exhaust gas after treatment systems (except SCR). The magnitude of these effects is very much dependant of the practical usage pattern of a vehicle, although the fuel sulphur content will influence these effects in a negative way”. If low sulphur fuel is introduced ahead of the deployment of lean burn engine technologies, then much of it will be used in vehicles that may yield a zero fuel efficiency improvement.

Finally with heavy duty diesels there again is an indication from the submissions that there is some fuel efficiency benefit to be gained from sulphur free diesel, but no quantitative information has been provided.

7.2.2 Refinery Disbenefits

The additional CO_2 emissions at the refineries arising from the production of sulphur free fuels will vary depending on plant configuration. Estimations have been submitted by several respondents and these are summarised in Table 6.

Table 6: Summary of Information Submitted on the Additional Carbon Dioxide Emissions Arising at Refineries from the Production of Sulphur Free Fuels.

Source	Additional CO_2 emission (Mt/yr)	Additional CO_2 emission per Mt of fuel
Ford for all EU (petrol and diesel)	3.0	13 kt
EUROPIA/CONCAWE for all EU (petrol)	3.1	25 kt
EUROPIA/CONCAWE for all EU (diesel)	1.5	27 kt
Federal Republic of Germany for FRG (petrol)	0.01-0.02	0.4-0.8 kt
Federal Republic of Germany for FRG (diesel)	0.2	8 kt
Netherlands Government for NL (petrol)	0.25	28 kt
Netherlands Government for NL (diesel)	0.775	78 kt
UKPIA for UK (petrol and diesel)	1.13	31 kt

Generally these show reasonable agreement except that the Ford [11] estimate appears low by comparison with the rest, while the Netherlands [18] estimate for diesel seems high. However, the estimates from the FRG [13] (based only on additional desulphurisation and hydrogen production) are lower than all the other estimates, particularly for petrol. This appears to be linked to the number of petrol pool components assumed to need further desulphurisation, with the FRG having a low level of only 5-10%. This difference would have a large impact on the optimum timescale for introduction of legislation limiting fuel sulphur levels to 10 ppm.

CO_2 emissions from returning contaminated fuel to the refinery are particularly uncertain. This depends on the number of truck movements needed, which may be minimised by logistic measures (e.g. segregating high sulphur fuels). The Netherlands [18] have offered one estimate for the extra emissions of 13 kt CO_2 per million tonnes of fuel. Therefore this emission could be about 25 to 30 % of that linked to changed refinery operations.

No quantitative estimates have been offered for the additional emissions that could arise through the need to import blending compounds.

7.3 SCOPING

The Netherlands submission [18] has shown how the above estimates can be brought together to give a first order integrated assessment of the impact on CO_2 emissions of introducing sulphur free fuels. A slightly modified version of the Netherlands analysis is presented in Table 7, which indicates when there is a net reduction in CO_2 emissions (white boxes) or a net increase in CO_2 emissions (black boxes) for different combinations of:

- The share of Direct Injection engines in the car fleet (10, 20, 50 and 100%)
- The reduction of CO_2 emissions gained from a 1, 2.5 and 5% improvement in fuel economy of direct injection engines in the car fleet (i.e. 30, 75 and 150 kg CO_2/tonne of fuel consumed)
- The additional CO_2 emissions associated with reducing the sulphur in the fuel and in distributing sulphur free fuels.

Table 7: Estimates of the Net Reduction/Increase in Carbon Dioxide Emissions Resulting form the Introduction of Sulphur Free Fuels

Direct Injection Share of Car Fleet (%)	**Additional CO_2 Emissions kg/t of fuel [a]**	**Net Reduction in CO_2 Emissions (%)[b, c]**		
		For 1.0% Fuel Saving	**For 2.5% Fuel Saving**	**For 5.0% Fuel Saving**
100	45	- 0.5	+ 1.0	+ 3.5
50	45	- 1.0	- 0.25	+ 1.0
20	45	- 1.3	- 1.0	- 0.5
10	45	- 1.4	- 1.3	- 1.0

NOTES
a) Assumed to be 33 kt/tonne of fuel for refinery emissions and 12 kt/tonne of fuel for trucking returns to the refinery.
b) Emissions per tonne of fuel assumed to be 3000kg/tonne for both petrol and diesel. The emissions savings are 30, 75 and 150 kg CO_2/t of fuel for 1%, 2.5% and 5% fuel saving.
c) Redn (%) = (% Fuel Saving x CO_2 Emission from 1tonne of Fuel x Share of Car Fleet - Additional CO_2 Emissions from fuel production and distribution) x 100 / Emission from 1 tonne of Fuel.
Cells highlighted in **black** depict a net **increase** in CO_2 emission and cells left *white* depict a net **reduction** in CO_2 emission.

The analysis is only intended to be illustrative since the results could change with improved data on refinery carbon dioxide emissions and vehicle fuel efficiencies. Nonetheless there are several key conclusions to be drawn from this analysis:

- A net benefit from sulphur free fuel, in terms of the net reduction of carbon dioxide emissions, is critically depended on the amount of additional fuel efficiency gained by having the fuel, and on the proportion of the vehicle fleet made up of the lean burn engines with NSTs that are able to take maximum benefit from the fuel's availability.
- Taking the middle case 2.5% fuel efficiency improvement as an example, it is clear that in excess of 50% of the vehicle fleet needs to be composed of lean burn technology with NST to gain a positive benefit.
- Since only heavy diesel cars are to be fitted with NST, and direct inject petrol engines are just entering the market, the results in the table show that it is doubtful if a positive benefit can be gained from sulphur free diesel in light duty vehicles in the foreseeable future.

It is important to note that using the figures supplied by the Federal Republic of Germany [13] (50 Mt fuels, producing 157.1 Mt CO_2/a from current vehicle fleet) the extra emissions from refineries are balanced by fuel efficiency savings in the vehicle fleet at a much earlier stage.

Even for only 1% fuel efficiency improvement with new vehicles just 14% penetration of the vehicle fleet is needed to balance the additional refinery CO_2 emissions. This is reduced to less than 3% penetration if the fuel efficiency improvement is 5%. Whilst emissions arising from distribution of the fuel are not taken into account in the FRG calculations, it is clear this area warrants further investigation.

In addition, as mentioned in section 2.1, existing after-treatment technologies in the current vehicle parc and current production are reported to be affected detrimentally by sulphur and have reduced efficiency in dealing with emissions of other important greenhouse gasses, namely N_2O and Methane [2, 13]. However, conversely it has also been suggested that lowering sulphur levels further might possibly increase N_2O emissions in the warm-up phase of TWCs[6]. More detailed information needs to be gathered to quantify this effect in order to analyse its significance to the optimum timescale for implementation of <10 ppm fuels.

7.4 SUMMARY

1. Responses to this question have focused on sulphur free (<10 ppm) fuels.
2. The "well to wheel" impact on carbon dioxide emissions arising from a move to sulphur free fuels depends on a range of factors including:

- The fraction of the vehicle fleet that would benefit from low sulphur fuel in terms of increased fuel efficiency and distance travelled by each technology type.
- Size of the fuel efficiency improvement
- Rate of introduction of 10 ppm sulphur fuel
- CO_2 production associated with sulphur removal
- CO_2 production associated with returning contaminated fuel
- CO_2 associated with the production or import of inputs to retain fuel properties (e.g. Oxygenates).

3. Estimates of the fuel efficiency gain for lean burn petrol cars range from 1-5%, no firm data have been submitted for diesel vehicles fitted with NO_x Storage Traps (NST).
4. No quantitative data on fuel efficiency benefits of sulphur free fuels with existing engine technologies have been submitted, but it seems likely to be significantly less than for the new technologies.
5. Based on the information presented it appears that new lean burn technology with NST would have to penetrate over 50% of the car vehicle fleet in order to gain a net CO_2 benefit from sulphur free fuel.
6. From (5) above it seems unlikely that light duty diesel vehicles would deliver a net CO_2 benefit from sulphur free fuel because only the heavy cars and light commercial vehicles will be fitted with NST technology in the foreseeable future.
7. No quantitative data have been presented to enable an estimation of the benefit of sulphur free diesel with heavy duty diesel vehicles.
8. More data is needed in order to quantify the significance of improved efficiencies of existing technologies in dealing with other important greenhouse gases (N_2O and Methane) on the optimum timescale for <10 ppm fuel implementation.

8 General Summary

This section of the report is divided into two parts. The first part provides a summary for policy makers of the information and views presented in the responses to the Commissioner's consultation. The second part presents the comments and observations on the consultation made by the three independent reviewers of this report (a short biography of each of the reviewers is included in Appendix 2).

8.1 SUMMARY OF THE REVIEW

The review given in the preceding sections has aimed to give an objective and balanced synthesis of the information and opinions presented by respondents to the Commissioner's consultation. The approach taken has focused on presenting the information in a way that is easily accessible to both technical and non-technical readers. This summary follows the same structure as the report and presents the main points raised against each of the Commissioner's questions.

8.1.1 Question 1

The magnitude of the additional environmental benefit gained from using petrol and diesel with a sulphur content of less that 50 parts per million. More specifically what are the incremental benefits of using fuels with a sulphur content of (a) 5-10 ppm and (b) 30 ppm relative to fuels containing 50 ppm.

This question attracted the greatest response both in terms of number of respondents (21 of 25 respondents) and in the weight of information presented. It is clear that the question is complicated since it applies to two fuels and a range of different vehicle types, i.e.

- Current fleet of petrol vehicles
- Current production of petrol vehicles
- Future production of petrol vehicles
- Current fleet of light duty diesel vehicles
- Current production of light duty diesel vehicles
- Future production of light duty diesel vehicles
- Current fleet and production of heavy-duty diesel vehicles
- Future production of heavy-duty diesel vehicles.

All of these vehicles may be affected by a change in fuel sulphur level since much of the current fleet will still be in use in 2005 and beyond, while current production will account for a significant proportion of the fleet up to 2008-2010. Because the different vehicle groups have different engine and exhaust gas treatment technologies the environmental benefits of lower sulphur fuels also vary. With the current fleet and present day production vehicles the main benefit identified by respondents has been an improvement in the performance of the exhaust gas treatment systems that are fitted to reduce emissions of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and, for diesel vehicles, particulate material (PM). With future production the main benefit identified is a potential improvement in fuel efficiency, stemming from a reduction in the frequency with which the exhaust gas treatment catalysts (NO_x Storage Traps) need to be regenerated by periodically running engines on fuel rich mixtures. Additionally there is the direct benefit for all vehicles that lower sulphur fuels give lower SO_x levels in exhaust gases. This is most significant with vehicles fitted with catalysts that oxidise sulphur to sulphate, which is released as ultra fine particulate material (UFPM).

Table 8 gives a qualitative summary of the benefits of lower sulphur fuels for the numerous combinations of vehicle type, exhaust treatment technology and fuel discussed above. Respondents generally agreed that:

- Sulphur had a detrimental effect on exhaust gas treatment technologies and hence on emissions.
- Existing and new technologies, with the possible exception of heavy duty diesel vehicles, can function on agreed fuel standards, but that there may be additional benefits to be gained in going to lower sulphur levels.

However, there was no such agreement on the magnitude of these benefits.

For the present vehicle fleet and current vehicle production, lower sulphur fuel will slow the degradation of exhaust catalysts, and for the existing fleet, facilitate a partial restoration of catalyst efficiency. Submissions on the size of these benefits, based on experimental data and field measurements, have ranged from suggesting they are negligible to indicating that they could deliver worthwhile improvements to air quality in urban areas. This diversity of opinion appears to be linked to the sources of information available to the respondents, and to the test methods used to derive this information. For example, it was clear from the information presented that the restoration of exhaust catalysts, to be gained by running vehicles low sulphur fuel, was greater with high total use vehicles (i.e. higher mileage). Other respondents have pointed out that the magnitude of emissions reductions will also depend on the test cycle and the fuel specification used in the test.

With future vehicle production respondents identified improved fuel economy as the main benefit of adopting lower sulphur fuels. Quantitative data, mainly from vehicle manufacturers, estimated this benefit to be 1-5% relative to fuel with 50 ppm sulphur. However, it was not clear from the submissions whether this range reflected variations in the sulphur sensitivity of different technologies, the use of different test methods or an evolving position with the sulphur sensitivity falling as the catalyst technology undergoes further development.

Recognising the variability and uncertainties surrounding existing information several of the respondents felt there was a need for further collaborative work to:

- Quantify the effects of lower sulphur fuel on the existing vehicle parc.
- Quantify the effects of lower sulphur fuel on the fuel efficiency of new engine technologies.

Table 8: Additional Environmental Benefits of Lowering the Sulphur Content of Petrol and Diesel from 50 ppm to 10 ppm for certain Technology Options

Engine Type:	Petrol Conventional		GDI-Lean Burn	Diesel Cars & Light Duty Vehicles				Diesel Heavy Duty Vehicles			
Deployment Status:	Deployed	Current Production	Future	Deployed	Current Production	Future	Future	Deployed	Future (Euro IV)		Future (Euro V)
Catalyst Technology:	TWC	TWC	TWC + NO_x Storage Trap (NST) [a]	OC	OC	(OC +) NST [a]	(OC +) NST [a] + DPF [b]	-	DPF [b] + EGR	SCR	SCR + OC + DPF [b]
Fuel Cons./CO_2:	?	?	Yes	?	?	Yes	Yes	?	Yes	Yes	Yes
CO:	Yes	Yes	?	Yes	Yes	?	?	?	?	?	?
HC:	Yes	Yes	?	Yes	Yes	?	?	?	?	?	?
NO_x	Yes	Yes	Yes	No	No	Yes	Yes	?	Yes	Yes	Yes
SO_x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PM (Inc. Sulphate PM)	N/A	N/A	?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet Euro Limits with 50 ppm?	Yes	Yes	Yes	Yes	Yes	?	Yes	Yes	?	?	?

<u>Notes</u>

(a) De-NO_x catalysts are only likely to be used as interim NO_x abatement technologies and SCR is unlikely to be used with cars and light goods vehicles.

(b) CRTs (Continuously Regenerative Traps) are the alternative to DPFs (Diesel Particulate Filters) for PM reduction and are similarly affected by fuel sulphur.

(c) OC - Oxidation Catalyst.

(d) N/A - Not Applicable.

(e) ? - indicates that the position is unclear from the submissions.

8.1.2 Question 2

Using the sulphur specification of 50 ppm as a reference, what incremental refining costs are incurred to produce petrol and diesel with a sulphur content of (a) 30 ppm and (b) 5-10 ppm.

18 of 25 respondents addressed this question and generally agreed that the production of fuels with less than 10 ppm sulphur was technically feasible, with such grades already in production in some member states. The costs of doing this consists of capital investment in new plant and some increased running costs. These costs will vary between refineries, reflecting their present configurations and the sulphur content of the crude oils they operate with. It was suggested that southern European refineries generally operate on more sour crude oils and therefore could face higher desulphurisation costs.

Incremental costs of going from 50 ppm sulphur to 5-10 ppm sulphur fuels ranged from about 0.1 to 4.3 Euro cents per litre for petrol and 0.2 to 4.3 Euro-cents per litre for diesel, again reflecting refinery variations.

It was suggested that a short-term move to low sulphur diesel for the full market would reduce refinery capacity by 10 to 20%. However, a phased move would avoid this, while minimising costs since the capital investment could be incorporated in normal refinery up grades. Moreover, refinery catalyst suppliers expressed the view that new catalyst developments could reduce the impacts of desulphurisation on both costs and CO_2 emissions.

8.1.3 Question 3

Should the up take of new emissions abatement technology or fuel-efficient technology be encouraged in the automotive fleet? If so what type of low sulphur marketing regime would be justified? For example, (i) a proportion of the market sold on a voluntary basis or (ii) a proportion of the market sold on a mandatory basis or (iii) the totality of the market that complies with a sulphur content fixed at a value less than 50 ppm? This should be considered in the context of the advancement of traditional petrol and diesel engine emission abatement technology and looking forward towards the introduction of new vehicle propulsion or power plant technology.

19 of 25 respondents addressed this question. It was clear from the responses that Internal Combustion Engine technology was expected to be dominant, at least up to 2010, with few submissions considering alternatives such as fuel cells and hybrid systems. However, it was noted that fuel cell stacks were sulphur intolerant and vehicles with on-board production of H_2 from gasoline would need a maximum of 5-10 ppm sulphur in the fuel to avoid poisoning the reformer.

There was general support amongst respondents for encouraging the development and deployment of new emissions abatement and fuel efficient technologies. However, there was no such consensus on whether low sulphur fuels were part of the measures needed to support these technologies. Fuel suppliers felt that regulation should be limited to setting air quality standards and vehicle emission limits, and that the means of compliance should be left to vehicle manufacturers operating in a competitive market. In contrast the vehicle manufacturers felt that a clear policy on low sulphur fuels would encourage the development of technologies to take advantage of them. They pointed to a move to low sulphur fuels in other world regions, and were concerned that USA or Japanese specifications might diverge significantly from European specifications.

With regard to sulphur level, the submissions suggested that 30 ppm would produce only marginal benefits, and therefore most respondents concentrated on the < 10 ppm sulphur level.

Several respondents noted that the new engine technologies, that could potentially deliver additional fuel savings with low sulphur fuel, were only just entering the market, and therefore the benefits of a full transition to such fuels was not justified before 2008-2010. No information was presented to suggest that low sulphur fuels would yield a significant fuel saving with the current vehicle fleet. However, it was suggested that the effect of low sulphur fuel, in reducing exhaust emissions from the current vehicle fleet with the associated benefits to local air quality, could merit a partial market transition. Consequently some respondents proposed that Member States should be permitted to encourage a partial transition. However, there was concern that such action should be harmonised across the EU, and that Member States should not be left to set separate standards for low sulphur fuels.

8.1.4 Question 4

What are the effects on other petrol and diesel fuel quality parameters of environmental relevance as the sulphur content is reduced from 50 ppm to less than 10 ppm?

14 of the 25 respondents addressed this question. Reducing the sulphur content of petrol may cause a reduction in the octane level. Options for readjusting this include freezing or possibly increasing the aromatics content or adding oxygenates. Either option goes against present targets for fuel standards. However, it was suggested that amendments to the limit on the aromatics content may be justifiable if account is taken of the introduction of improved vapour recovery systems, and the reduction of toxic exhaust emissions that will be delivered by the better performance of engine catalysts when operating with low sulphur petrol. If aromatics or oxygenates are ruled out for restoring the octane level a significant investment in alkylation processes will be needed. It was not clear from the submissions if this investment was included in the cost estimates given under Question 2.

Reducing sulphur in diesel could alter a range of fuel parameters including cetane number, density and lubricity. Several respondents stressed the importance that other fuel parameters should be frozen when setting a standard for low sulphur. Experiences from countries that have already introduced low sulphur diesel indicate that the lubricity problem can be overcome with appropriate additives.

8.1.5 Question 5

What are the logistic impacts and investment implications for the distribution system for petroleum products of introducing petrol and/or diesel with a sulphur content of less than 50 ppm?

10 of the 25 respondents addressed this question. Two main issues were identified:

- Cross contamination between fuels
- Availability of forecourt facilities

Contamination cannot be totally avoided, and therefore to meet a 10 ppm sulphur standard fuels would need to be produced with 6-7 ppm. Clearly the potential for cross-contamination would be reduced if all fuels were required to meet a 10 ppm sulphur standard. However, if partial introduction was adopted, contamination could be minimised if the introduction was scheduled to match the general transition to 50 ppm sulphur fuels. Even so the potential for contamination with high sulphur aviation fuel and domestic heating oil would remain. Some respondents suggest that this would require segregation of some fuels for delivery by alternative modes, while others indicated that it would require additional trucking of pipeline interface liquids back to the refinery. Estimates of the cost of returning pipeline interface liquids were of the order of 0.05 - 0.07 Euro Cents per litre.

Partial market introduction of low sulphur fuels will increase the number of grades to be offered on forecourts. This should not be a problem for petrol, for which it has long been the practice to offer a range of grades. For example, low sulphur petrol could be accommodated by timing its introduction to match the withdrawal of Lead Replacement Petrol. The problem is greater with diesel, which has historically been offered at a single grade. One respondent estimated the cost of additional pumps to offer two grades of diesel to be 16,000 Euros per forecourt.

8.1.6 Question 6

What will be the overall effect on greenhouse gas emissions of moving to petrol and diesel with a sulphur content less than 50 ppm? This should take account of changes in emissions in the refining and distribution systems and in the vehicle fleet through the pursuance of CO 2 efficiency technologies, the so called "well to wheel" life-cycle effect.

15 of the 25 respondents addressed this question. Responses focused on sulphur free (<10 ppm) fuels.

The "well to wheel" impact on carbon dioxide emissions arising from a move to sulphur free fuels depends on a range of factors including:

- The fraction of the vehicle fleet that would benefit from low sulphur fuel in terms of increased fuel efficiency
- Size of the fuel efficiency improvement
- Rate of introduction of 10 ppm sulphur fuel
- CO_2 production associated with sulphur removal
- CO_2 production associated with returning contaminated fuel
- CO_2 associated with the production or import of inputs to retain fuel properties (e.g. Oxygenates).

Estimates of the fuel efficiency gain for lean burn petrol cars range from 1-5%, efficiency gains are also claimed for those diesel vehicles expected to benefit from low sulphur fuel (i.e. those fitted with NO_x Storage Traps and Diesel Particulate Filters), but no firm data have been submitted. No quantitative data on fuel efficiency benefits of sulphur free fuels with existing engine technologies have been submitted, but it seems likely to be less than for the new technologies.

Estimates of the additional CO_2 produced in refineries when reducing the sulphur level of fuels to 10 ppm ranged from about 0.5 to 78 kt per million tonnes of fuel produced. Again this illustrates the wide differences between refineries. One estimate was given for the extra CO_2 emissions caused by trucking contaminated fuel back to the refineries. This was equivalent to 13 kt per million tonnes of fuel produced.

Taking a mean level for the additional CO_2 of 45 kt per million tonnes of fuel produced (covering additional refinery and distribution related emissions), a scoping estimate has indicated that new lean burn technology with NST would have to penetrate over 50% of the petrol vehicle fleet in order to gain a net CO_2 benefit from sulphur free fuel. However, if the much lower refinery CO_2 emissions suggested by some respondents were used in this analysis a much lower penetration of lean burn GDI technology would be needed to yield a positive benefit. With regard to diesel vehicles the market penetration needed to give a positive benefit is more difficult to estimate because it is possible that only heavy cars and Light Goods Vehicles will need to be fitted with NO_x Storage Trap and Diesel Particulate Filter technology.

Insufficient quantitative data have been presented to enable an estimation of the benefit of sulphur free diesel with heavy duty diesel vehicles.

Some respondents also indicated that emissions of other greenhouse gases (N_2O and Methane) could potentially be reduced in the current and future fleets by taking advantage of sulphur free fuel, but the level of this benefit was not quantified.

8.2 INDEPENDENT REVIEWERS' COMMENTS

	Peer-Reviewers' Comments on the Sulphur Review Report
	GENERAL COMMENTS
1	The authors are to be congratulated on capturing the essence of the responses, many of which were long and complicated.
2	There is overall *qualitative* agreement that lowering the sulphur in petrol and diesel fuel in the 0 – 50 ppm range can improve the emission performance of engines and after-treatment devices. This includes existing, current and expected future vehicle technologies.
3	With regard to the six questions raised by the Commissioner in her call for evidence, questions (1) and (6) are the principal questions which determine whether near zero sulphur fuels (10 ppm max.) are necessary and beneficial whereas the other four questions relate primarily to details of implementation.
4	Other issues (Questions 2-5) associated with near zero sulphur fuels, such as manufacture, cost, segregation, distribution and effect on other fuel properties, present challenges but are not insurmountable barriers to the introduction of near zero sulphur fuels. (The one exception to this would be if near zero sulphur fuels were required to be introduced in the short term and over a short period of time).
5	The *quantitative* effect of sulphur on the emissions reduction (including CO_2 emissions) is much more difficult to assess on the basis of the information submitted. – A considerable amount of the data supplied refers to sulphur levels above 50 ppm and are not relevant to the questions posed by the Commission – There is insufficient information on the conditions of the relevant 0-50 ppm data (test conditions, test cycles, fuel composition, catalyst ageing etc) to make precise quantitative conclusions.
	SPECIFIC COMMENTS
6	***The Existing Fleet*** While existing vehicles can function adequately on the sulphur levels specified in the agreed fuel standards, the body of evidence indicates that in the short term the introduction of near zero sulphur fuel will reduce emissions of carbon monoxide (CO), hydrocarbons (HC including benzene), oxides of nitrogen (NO_x), particulate matter (PM) from the existing fleet of vehicles. (Sulphur dioxide will also be reduced but by an amount that is small compared to the total inventory of SO_2 emissions).
7	***Long Term Greenhouse Gases*** *In the longer term* (probably less than ten years after introduction), when a near steady state condition is reached where most vehicles in service are optimised for use with near zero sulphur fuel, the body of evidence indicates that there will be an annual net reduction in greenhouse gas emissions (including carbon dioxide, nitrous oxide and methane) from vehicles, well to wheel (i.e. including additional refinery emissions), with the use of near zero sulphur fuels compared to the use of fuels containing 50 ppm sulphur. Quantification of the effects on methane, nitrous oxide (N2O) and CO_2 is important for each of the technologies in order better to understand the impacts of the phase-in of near zero sulphur fuels. Taking the gasoline GDI+NST technology as an example, the CO_2 penalty associated with regeneration of the NST has been estimated at between 1-5% in going from petrol with 10 ppm to 50 ppm sulphur. Within this range there is a big difference in the overall CO_2 balance between additional emissions at refineries versus savings in the vehicle fleet. If the penalty is 1% then the extra refinery production of CO_2 to produce 10 ppm sulphur max would be more significant compared to the savings using GDI+NST. Conversely, if the penalty were 5% then the CO_2 saving in the engine technology would rapidly out-weigh the extra CO_2 produced in the refinery.
8	***Phase-In of Near Zero Sulphur Fuels*** The phase-in schedule for near zero sulphur fuels should carefully consider: (i) the short term emissions (including CO_2) and air pollution benefits of near zero sulphur fuels; (ii) the need for these fuels in order to achieve the 2008 Heavy Duty NO_x and PM standards (Euro 5); (iii) the further need for these fuels to simultaneously achieve the light duty vehicle Euro 4 emissions standards and the 140 grams CO_2 per kilometre fuel economy targets; (iv) the potential contamination and distribution problems associated with simultaneous distribution of both 50 ppm and near zero sulphur fuels; and

	Peer-Reviewers' Comments on the Sulphur Review Report
	(v) the carbon dioxide increases at the refineries due to the production of near zero sulphur fuel because the timescale associated with phasing in of **both** the near zero sulphur fuels **and** the vehicles fitted with the new technologies is important, it is imperative to evaluate in more detail the implications (especially the CO_2 balance) of the transition to near zero sulphur fuels.
9	***EU Air Quality*** More effort must be made to assess the actual changes in *EU Air Quality* that will be brought about by reducing sulphur content of petrol and diesel fuel. Little information was made available in the submissions on air quality although it is specifically requested in the Commission's questions. Methodologies have been developed in the Auto-Oil process that allows changes in vehicle emissions to be related to air quality in EU both at the local and regional level - these should be applied.
10	***Demonstration Testing*** Since very limited *public* data exist with near zero sulphur fuels, especially with regard to advanced vehicle technologies, additional test data would be helpful in quantifying the emissions and fuel economy (CO_2) consequences of the various fuels options with different vehicle technologies. Joint motor vehicle and oil industry demonstration projects with mutually agreed testing protocols would be helpful in this regard. The way to achieve this quantitative understanding is to **test** the new technologies using *standardised* test conditions and *standardised* fuels. Only three gasolines and diesel fuels (*ca 35 ppm, ca 25 ppm and ca 6 ppm sulphur in the standardised fuels*) need to be tested. (This is a much smaller requirement than was necessary for the EPEFE study). All tests would - of course - measure the CO_2 implications of the changes. However, Whilst it is recognised that the new vehicle and after-treatment technologies (Euro IV/V) are actively being developed and optimised and that meaningful testing of new vehicle systems requires appropriate ageing of components, it seems important to evaluate these new technologies in such a way that the results are acceptable to all.
11	***Euro 5 for HD Diesel*** The successful achievement of the so-called *Euro 5 standards* for heavy duty diesel vehicles is much more likely with the introduction of near zero sulphur fuels than it is with the use of 50 ppm sulphur diesel fuel.
12	***Euro 4 for LD Diesel*** The successful simultaneous achievement of both Euro 4 standards for light duty vehicles and the agreed 140 grams of CO_2 per kilometre is more likely with the use of near zero sulphur fuels than it is with the use of 50 ppm sulphur fuels.
13	***CO_2 Implications of New Diesel Technologies*** The implications of new diesel technologies with low sulphur fuels on CO_2 emissions - in addition to NO_x/PM - should be studied more extensively.
	OTHER COMMENTS
14	***Fuel Specifications for 2005*** There was agreement that there was no compelling evidence submitted, other than for sulphur, for modifying the gasoline and diesel specifications for 2005 beyond the current requirements (i.e. RVP, benzene, olefins and oxygen content for gasoline and cetane number, max density, 95% point and polyaromatics for diesel fuel should not change from the 2000 specs). It was also agreed that consideration should be made to including a *minimum* density specification for diesel fuel for 2005.

Appendix 1

CONTENTS

ACEA RESPONSE

Executive summary

The main conclusions of the ACEA response are:

- The non-availability of sulphur-free fuels would hinder the development of lean burn gasoline engines to their full potential for enhancing fuel economy.
- To achieve further emission reduction together with lowered CO_2 emissions the fuel efficient lean burn technology will be combined with special exhaust gas after-treatment devices capable to reduce NO_x under lean burn conditions.
- The fuel efficiency improvement by using less than 10 ppm instead of 50 ppm sulphur content in gasoline direct injection engines can be as great as 3-5% as more efficient catalyst materials can be used.
- All of the after-treatment technologies that seem to be the most promising will benefit from sulphur-free fuels. Some of them can function properly only when operated with 'sulphur-free' fuel.
- Sulphur-free fuels also enhance the performance of existing after-treatment technologies. A vast literature exists on the enhancing effect of sulphur reduction on the conversion efficiency of TWCs (Three Way Catalysts).
- Although the poisoning effect of sulphur of TWCs is considered to be reversible, experimental tests show that the efficiency of the catalyst does not return always to its original state after regenerating for sulphur. Over time this means that the efficiency of the catalyst deteriorates. Similar poisoning effects have also been reported in the other prospective after-treatment technologies.
- For commercial vehicles, since there are no valid alternatives to diesel engines, sulphur-free fuel is imperative in order to meet the EURO 4 and the EURO 5 emission standards.
- A recent study, commissioned by Ford to the consultant MathPro, estimates the cost (before tax) to make available sulphur-free fuels in Europe by the year 2005 at 3.8 US$ cent/gal (around 1.0 Euro cent/litre).
- All manufacturers in the world are considering sulphur-free fuels as a major element for the future development of clean vehicles (see WWFC). European manufacturers should not be put at a disadvantage with respect to the others.
- The ultimate goal for ACEA is the full availability of sulphur-free fuels on the whole EU market. This objective has to be reached gradually, beginning in 2001 for gasoline and in 2002 for diesel cars.
- The optimum solution for how to promote the distribution of sulphur-free fuels in a cost-effective way would probably be a combination of different approaches, such as: harmonised fiscal incentives, phase-in scheme based on voluntary or mandatory distribution of sulphur-free fuels before 01/2005.
- ACEA experts believe that the removal of sulphur from fuels will not result in any penalisation of other environmental and performance parameters. Some aspects, such as fuel lubricity, need to be ensured. However, there are no side effects that could put into question the benefits resulting from sulphur-free fuels.

- One of the major environmental benefits of the sulphur-free fuels is the possibility to introduce on the market vehicle technologies characterised by high CO_2 efficiency.
- The resulting final increase of energy for the production of a litre of fuel has been calculated as about 1% using the figures from the results of the Ford commissioned MathPro study. This value has to be compared with the potential further fuel consumption reduction of 3-5% of a lean burn direct injection gasoline engine operating on sulphur-free fuels.

Documents supplied:

- Covering letter including a summary giving ACEA's answer to the questions posed.
- Six technical annexes which were referenced as sources for ACEA's comments:
    1. "ACEA Data of the sulphur effect on advanced emission control technologies", July 2000.
    2. "Effects of 10 ppm sulphur standard for gasoline and diesel fuel on CO_2 emissions of the refining sector", Prepared for Ford Motor Company by MathPro Inc, June 8 2000.
    3. Diesel Emission Control – Sulphur Effects (DECSE) Program: "Phase I Interim Data Report No. 1", August 1999, Sponsored by the U.S. Dept. of Energy, Engine Manufacturers Association and Manufacturers of Emission Controls Association.
    4. DECSE Program "Phase I Interim Data Report No. 2: NO_x Adsorber Catalysts", October 1999.
    5. DECSE Program "Phase I Interim Data Report No. 4: Diesel Particulate Filters – Final Report", January 2000
    6. "Influence of the sulphur content in fuel on the fuel consumption and pollutant emissions of vehicles with gasoline and diesel engines", FEV report commissioned by: Association of the German Automotive Industry (VDA), November 1999.
- Covering letter and Draft ACEA Paper on Sulphur in Fuels.

AECC (ASSOCIATION FOR EMISSIONS CONTROL BY CATALYST) RESPONSE

Executive summary

The main conclusions of the AECC response are:

- Sulphur creates sulphate particles, which are measured by current sampling & measurement techniques, with any emission control system that includes a precious metal catalyst with an oxidising function.
- Fuel sulphur levels of 30 ppm are enough to bring particulate levels up to the Euro 4/5 PM limit values even if the CR-DPF (continuously regenerating diesel particulate filter) removes all the carbon- and hydrocarbon-based particulate.
- The future European NO_x emission standards can be met with SCR (Selective Catalytic Reduction) technology with today's diesel fuel, and with the future 50 ppm sulphur diesel fuel further reduced PM emission will be achieved.
- New technologies to control ultra fine particulate matter perform better on diesel fuel below 10 ppm. However for technologies incorporating precious metal catalysts fuel sulphur levels significantly below 30 ppm will be necessary to avoid the mass of sulphate particulate matter (formed from the fuel sulphur) exceeding the 2005/08 heavy-duty particulate matter limit values.
- Sulphur:
  a) Inhibits catalyst performance by strong adsorption on surface and competes for space on the catalyst surface with pollutants.
  b) Limits the amount of NO_2 formed on an oxidising catalyst – a problem for some particulate DPFs (diesel particulate filters) and NO_x adsorbers that rely on NO_2 for their regeneration.
  c) Reacts with chemical NO_x traps more strongly than NO_x – this decreases NO_x storage capacity and requires more vigorous and frequent regeneration; increasing fuel consumption.
  d) Contributes to coating the catalyst surface.
- AECC conducted an extensive literature survey in 1997 of published information on the effects of fuel sulphur on the performance of three-way catalyst equipped vehicles. Most of the studies compare the tailpipe emissions using fuels with different sulphur levels and all conclude that the lower the sulphur level the lower the emissions on fresh or aged catalysts. There is however some evidence of a non-reversible interaction between the washcoat components and sulphur.
- For the existing fleet of vehicles lowering sulphur levels in petrol to below 10 ppm would give a reduction in emissions from all three-way catalyst equipped vehicles of up to 20%. US data indicates an enhanced effect on emissions at 30 ppm sulphur and it is known that sulphur affects catalyst performance all the way down to 0 ppm.
- Methane, NO_x and N_2O emissions have all been shown to increase with increasing fuel sulphur content when using three-way catalyst technology. Methane is a refractory molecule and difficult to combust and conversion is consequently greatly reduced by increased sulphur content in petrol.
- The promising NO_x adsorber technology that diesel and lean burn engines need requires sulphur levels significantly below 10 ppm. This will avoid compromising the lower fuel

consumption and CO_2 emissions by requiring frequent regeneration to remove the sulphur that is "clogging" the NO_x adsorption capacity.

- Regeneration temperatures are around 25 °C higher with 30 ppm than with 3 ppm sulphur fuel.
- Sulphur in fuel and lubricant adversely affects the performance for emissions control (regulated and unregulated) of all current and future emission control technologies. The degree to which they are affected varies from technology to technology.
- The best option to allow the unconstrained development and introduction of new emission control technologies is to set a specification for sulphur levels at below 10 ppm for introduction as soon as possible. This will allow Member States to introduce tax incentives and for market forces to bring the ultra low sulphur fuels to the market to allow the early introduction of the new technologies.
- Ultra low sulphur fuels are shown to reduce greenhouse gas emissions by:
  a) Reducing CO_2 emissions by allowing low fuel consumption vehicles, e.g. diesel and lean burn/petrol fuel injection, to flourish.
  b) Reducing emissions of greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) by allowing catalysts to more efficiently remove them.
- The bottom line is that higher sulphur levels in fuel have an effect on durability if the criteria are the amount of untreated pollution emitted over the life of the vehicle. This will only be apparent if the test to check the catalyst/emissions performance is conducted with the same fuel used during the durability test and not, for example, a standard reference fuel. Since the deterioration of catalyst emissions performance is gradual a vehicle aged and tested on a higher sulphur fuel will "fail" to achieve a given emission standard earlier than one on low sulphur fuel.

Documents supplied:

- Covering letter for the response to the questions.
- Response document containing a discussion of the effects of sulphur levels in fuels on current and future emissions control technologies.

THE EUROPEAN BUREAU OF THE AIT (ALLIANCE INTERNATIONALE DE TOURISME) & FIA (FÉDÉRATION INTERNATIONAL DE L'AUTOMOBILE) RESPONSE

Executive summary

The main conclusions of the AIT & FIA response are:

- Meeting the Kyoto requirements demands that CO_2 emissions are reduced. For the automobile sector, advanced diesel, lean-burn and GDI technology are an answer.
- It is known that advanced diesel, lean-burn and GDI engine technologies require low sulphur fuels. These technologies are creating a requirement for fuel sulphur levels lower than 50 ppm. The advanced catalysts needed for these technologies to meet emissions standards, such as the NO_x Storage Reduction (NSR) Catalysts are very vulnerable to sulphur.
- Advanced catalysts can work at levels of 50 ppm sulphur but work much better at 10 ppm (e.g. NSR) because they do not need to be purged of sulphur so frequently (due to poisoning), thus maintaining efficiency and fuel economy.
- Low sulphur diesel fuel will have a positive influence on the performance of PM traps.
- The AIT & FIA are supporting the current introduction of sulphur free (<10 ppm) and low sulphur (<50 ppm) fuels in Germany, UK and the Netherlands.
- The automobile technology that exists is held back by the current fuel environment, which in its unchanged state will remain a major obstacle to achieving ever lower emissions and fuel consumption as well as reaching the Kyoto agreement.
- At the moment the ADAC is performing emission tests comparing super petrol (50 ppm S) with sulphur free petrol (<10 ppm S) using cars in the current car fleet. The first results indicate that the sulphur free petrol can reduce (up to 15% in some cases) the emission components and the fuel consumption of the existing car fleet. A report will be available in a couple of months.
- The AIT & FIA are of the opinion that the advantages offered by the sulphur free and ultra low sulphur fuels will be bigger than the disadvantage caused by the extra energy (extra CO_2) needed for the production of low sulphur and sulphur free fuels.

Documents supplied:

- Covering letter and response to the questions posed.

AKZO NOBEL CATALYSTS RESPONSE

Executive summary

The main conclusions of the Akzo Nobel Catalysts response are:

- A further reduction of sulphur in gasoline and diesel is technically feasible. Catalyst and technology development have over the last few years considerably helped refiners to achieve lower sulphur specifications and thereby greatly reduced the required investments.
- Akzo Nobel has developed together with Exxon Mobil such process and catalyst. This technology can effectively remove sulphur to less than 10 ppm while minimising the octane loss. This technology is in commercial operation in 2 Exxon Mobil refineries, and has recently been licensed to companies outside Exxon Mobil as well.
- Important side issues concerning diesel are what will happen to the other specifications most notably: T 95% boiling point, density and (poly-nuclear) aromatics (PNAs). Setting of these specifications will have consequences for the chosen processing routes. A significant shift in T 95% e.g. to 345°C will require conversion from 345-370°C fraction back to the diesel pool.
- A severe specification on PNAs will require extra hydrogenation and hence high-pressure units. A significant reduction of total aromatics would require special hydrogenation units (on the basis of noble metal catalysts) to be installed in conjunction with the ultra deep hydrodesulphurisation (UD-HDS) unit.
- Summarising we can say for diesel specifications:
  a) The technology and catalysts to reach ultra low sulphur (<10 ppm) is there, it is already in use.
  b) History learns that catalyst development has been fast and enables us today to reach product specifications much more stringent than in the past at lower investment and environmental cost.
  c) Catalyst and technology development are continuing and now focusing on the last few ppm.
  d) For diesel the additional cost will primarily be in extra reactor capacity (compared to the 50 ppm case) but it is expected that new catalysts will considerably reduce the impact.
  e) In general lowering S from 50 to 0 has little effect on H_2 consumption. Substantial changes in the T95% and aromatics specs therefore will have the largest impact on CO_2.
- One parameter that can become critical in conjunction with very low sulphur gasoline is a lower specification on olefins. If it would be introduced at the same time as the very low sulphur, this will make achieving these specifications more difficult. It would lead to a significant octane loss and substantial higher requirements for hydrogen.
- The final solution required will certainly also be affected by the specifications set.
  a) 50 ppm will often still be possible with FCC (Fluid Catalytic Cracking) pre-treatment only.
  b) 30 ppm will be more critical and would often require post treatment as well.
  c) Sulphur free gasoline almost certainly always requires a combination of the two or in case of low sulphur crudes only post treatment.

- It should be noted that the option chosen would depend very much on the local situation of a refinery. The investment in a post treatment step is significantly less than in a large high-pressure hydrotreater for pre-treatment.
- Summarising we can say that for gasoline sulphur: the technology and catalysts are there to meet the new specifications. On one hand there are relatively low cost options in the post treat area, for which totally new catalysts and technology have been developed. On the other hand there is FCC pre-treatment, which is higher cost but already widely applied worldwide. For the latter process continuous catalyst innovations enables the refiners to meet stricter specifications. These improvements are certainly significant in their contributions to lower investment cost, and an aspect not discussed here, at the same time make these process more energy efficient and hence reducing CO_2 emissions.
- Extra CO_2 emissions, due to more severe processing and extra hydrogen requirements as a result of changing the spec from 50 ppm to less than 10 ppm will be in the order of 5 to 10%. Other specifications have a bigger impact in this respect. For gasoline the olefins spec, and for diesel the aromatics/density and T95% specs.

Documents supplied:

- Letter responding to the request for information giving a review of the refining state of technology and issues with regard to lowering fuel sulphur levels.
- Three supporting documents
  1. ‘Options to Meet Future European Diesel Demand and Specifications’, a presentation by L.A. Gerritsen, H. Sonnemans, S.L. Lee and N. Kimbara, Akzo Nobel Catalysts.
  2. ‘Production of Green Diesel in the BP Amoco Refineries’, WEFA Conference, June 2000, Berlin. L.A. Gerritsen, F. Stoop – Akzo Nobel Catalysts; P. Low, J. Townsend, D. Waterfield, K. Holder – BP Amoco.
  3. ‘The Development and Application of RT-225 for Selective Cat. Naphtha Desulfurisation’, K.L. Riley, J.L. Kaufman, S. Zaczepinski – Exxon USA; P.H. Desai, S.W. Mayo - Akzo Nobel Catalysts, USA.

CLEPA (EUROPEAN ASSOCIATION OF AUTOMOTIVE SUPPLIERS) RESPONSE

Executive summary

The main conclusions of the CLEPA response are:

Gasoline Fuels:

- Sulphur in gasoline lessens the performance of three-way catalysts (TWC).
- The German Federal Environmental Agency (UBA) verified a significant overall reduction of ozone forming emissions (NO_x: 21%, HC: 13%) in Germany gained by a reduction of the fuel sulphur content from 50 ppm to 10 ppm;
- The use of sulphur free gasoline (sulphur content less than 10 ppm) reduces the emissions of the unlimited, but toxic hydrogen sulphide (H_2S), which can be formed at high catalyst temperatures and slightly rich engine operation;
- Sulphur-free fuel reduces the emissions of sulphur oxides;
- The introduction of fuels with sulphur content below 10 ppm opens up new possibilities for reducing fuel consumption and emissions especially with respect to complex engine concepts like gasoline direct injection. The potential of gasoline direct-injection engines can be fully exploited through this new type of fuel only;
- Sulphur-free fuel leads to a reduction of nitrogen oxide, carbon monoxide, hydrocarbon, hydrogen sulfide and sulphur oxides emissions in all vehicles equipped with catalytic converters, independent from the type of injection;

Diesel Fuel:

- Lowering the level of sulphur in the fuel reduces the PM emissions with and without new technologies;
- The LDV Euro 4 standards (2005) can be fulfilled with vehicles of medium vehicle weight range without new after-treatment (except long ago implemented oxidation catalysts). Therefore a sulphur content of less than 50 ppm is sufficient. Euro 4 standards for heavy weight vehicles and Euro 5 standards for all vehicles will require a particular trap or a NO_x storage catalyst to be met. Therefore a sulphur content of 10 ppm is preferable;
- For HDV compliance of Euro 4 standards (2005) a catalytic particulate trap (CRT) is required. Sufficient regeneration and appropriate useful life is possible only with a sulphur content of less than 10 ppm;
- The urea-SCR-catalyst system introduced for Euro 5 is also sulphur sensitive. Hence the sulphur content in diesel fuel may not exceed 10 ppm for this option either;
- To comply with future emissions standards and to realise good fuel consumption a sulphur content as low as 10 ppm is required area-covering within the EU in 2005 at the latest.

General Comments:

- For vehicles using fuel cells for propulsion, with gasoline converter to produce hydrogen, a sulphur content between 5 and 10 ppm is required to avoid poisoning of the converter. If low sulphur fuel is not available, it will question this technology very promising not only in term of environment preservation but also in term of relatively easy implementation as it will use the existing fuel distribution network;
- In lowering the sulphur content of fuels, the other main characteristics should be preferably maintained or carefully look at when amending 98/70/EC. Any modification to Directive 98/70/EC should take into account all fuels characteristics.

Documents supplied:

- Letter of introduction;
- A separate document containing the formal response with a discussion the effect of sulphur content on realising future emissions limits.

CONCAWE RESPONSE

Executive summary

The main conclusions of the CONCAWE response are:

- A range of engine and after-treatment technologies is available to effectively contribute to meeting the CO_2 commitments and future exhaust emissions levels. Only some of the after-treatment technologies are reported to require fuels with a sulphur level below 50 ppm in 2005 and beyond. The NO_x storage technology is currently considered by many car manufacturers as the most promising route in the short term to optimise the use of high efficiency engines while meeting the 2005 emissions limits. The main effect of further sulphur reduction is seen in obtaining an additional fuel economy improvement by use of such catalyst technology. Both the NO_x storage catalyst and the catalysed trap technology are still under rapid development and co-operative investigations should be conducted when these systems become available.

- The reduction of the sulphur content of all gasoline and diesel to less than 10 ppm is technically feasible.

- It would require additional investments and increased operating costs in refineries compared to the AOI 2005 base case (50 ppm sulphur). For EU-15 the estimated NPV are 4.8 and 6.7 GEUR for gasoline and diesel fuel respectively (1.5 and 2.4 for sulphur reduction to 30 ppm).

- It would not cause significant and systematic changes to other fuel properties.

- It would entail an increase of refinery energy consumption and therefore CO_2 emissions.

- The reduction of SO_2 emissions, although undeniable, would be very small compared to global emissions from all sources.

- It would reduce the flexibility and, at least in the short term, the reliability of refineries and distribution systems and might result in supply disruptions.

- The effect on regulated vehicle exhaust pollutants would be insignificant.

- Exhaust emissions of other pollutants might actually increase. Specifically additional ammonia emissions would lead to an increase in secondary particulates while extra N_2O emissions would increase the greenhouse gases load.

- In terms of greenhouse gases emissions, the benefit of lower sulphur for the after-treatment devices is of the same order of magnitude as the debit incurred in the production process. The balance would depend on the rate of introduction and final market share of sulphur-sensitive technologies but might well remain negative for many years.

- Although ULS fuels might bring benefits to certain vehicle technologies, there are a number of identified negative effects. There is also some evidence of potentially negative consequences in terms of some air quality aspects and greenhouse gases that require further studies. For these reasons, it is CONCAWE's opinion that the desirability of ULS fuels should be studied in a comprehensive joint programme that would uphold the principles of cost-effectiveness, sound science and transparency as well as be consistent with the Precautionary Principle.

Documents supplied:

- A synthesis document specifically addressing all issues related to the production of gasoline and diesel with sulphur content of less than 10ppm.
- A separate document containing an analysis of the vehicle technologies available to the auto-industry to meet both its CO_2 emissions commitment and the mandated exhaust emission levels.
- Submitted together with EUROPIA response.

CZECH REPUBLIC RESPONSE

Executive summary

The main conclusions of the Czech Republic response are:

- A further reduction of sulphur content is more a political than ecological or technical issue and the aggregate profit is increasingly doubtful if compared with greenhouse gas emissions increases at the refinery;
- A preliminary estimation [for the modification of the two existing Czech refineries] is between 3 and 4 billion CZK (84 – 112 million EUR). Also the increase of production costs due to more intensive hydrotreating will be essential;
- The nature of the Czech market would probably mean that the full introduction of ultra-low sulphur fuel would be necessary;
- Effects of lowering fuel sulphur levels further on other fuel parameters such as aromatics and especially PAHs will have to be dealt with at the same time;
- In consideration of existing logistical system for the distribution of petroleum products in the Czech Republic, the investment implications related with introducing petrol and diesel with a sulphur content of less than 50 ppm will be secondary, supposing the conditions mentioned above;
- The Czech producers believe the increased CO_2 emissions from refineries will balance out or exceed any savings in emissions due to reduced fuel consumption in new technology vehicles.

Documents supplied:

- Single document with a summary of the Czech fuel market position and then answers to each of the questions based on the perspective of the fuel producers.

EMPA (THE SWISS FEDERAL LABORATORIES FOR MATERIALS TESTING AND RESEARCH) RESPONSE

Executive summary

The EMPA response provides evidence on the topics:

- Additional environmental benefit
  - Contribution of sulphur to gaseous emissions
  - Contribution of sulphur to particulate mass emissions
  - Gas to particle conversion
  - New particle formation

- Effects on other fuel quality parameters

Documents supplied:
- Response to questions 1 and 2 (part)

EUROMOT RESPONSE

Executive summary

The main conclusions of the EUROMOT response are:

- Lowering the sulphur content of fuel may necessitate the use of lubrifying additives to ensure the low sulphur fuel had the same lubricity properties.
- Low sulphur fuel would not only directly reduce SO_x emissions but also help to reduce particulate emissions from CI engines.
- Consideration should be given to the destination of the sulphur extracted from fuel for on-road or non-road vehicles. Adding it to heavy fuel oil (HFO) to propel seagoing ships is not an environmentally friendly solution. In fact the IMO has already identified SO_x emissions as a serious regional problem and has already defined special areas (Baltic Sea and North Sea) where only "low sulphur" HFO is allowed (1.5% instead of around 4% on average).
- It is strongly recommended to avoid two separate supply lines for on-road and off-road fuel, as this would unnecessarily increase fuel cost.
- Careful consideration should be made of the different taxation systems in the EU Member States and efforts made to harmonise them to avoid conflicts that might jeopardise the introduction of new abatement technologies in certain markets.

Documents supplied:

- Letter including a summary of the points that the non-road CI engine manufacturers associated within EUROMOT made in response to the call for evidence.

EUROPIA RESPONSE

Executive summary

The main conclusions of the EUROPIA response are:

- The requirement for ultra-low sulphur fuels to enable a range of engine technologies (especially aftertreatment systems) to be implemented or to work more effectively needs further co-operative study. While, from limited literature data, it is suggested that some technologies have enhanced environmental performance with ultra-low sulphur fuels, the extent and cost-effectiveness of the performance of these technologies is not clear. A range of other technologies can operate on existing or mandated fuel sulphur levels.

- The "well to wheels" balance for CO_2 associated with a move to 10ppm sulphur fuels, calculated using car industry data (introduction rates, catalyst regeneration etc.) and oil industry refining models, is either negative or would take a number of years to move into balance depending on the range of assumptions. The balance is potentially different for 30ppm fuels but catalyst regeneration rates are not known.

- The pan-European production of petrol and diesel fuel to a 10ppm sulphur specification is technically feasible (other specifications as now) given sufficient lead time and at a cost (NPV) of 11.5 GEuro (Petrol 4.8 GEuro, Diesel 6.7 GEuro) to the refining industry. For production to a 30ppm sulphur specification the costs would be 3.9 GEuro (Petrol 1.5 GEuro and Diesel 2.4 GEuro).

- If automotive technologies were to be shown to have a demonstrated cost effective need for enabling low sulphur fuels to meet environmental objectives, two scenarios could be envisaged in responding to this situation.

- A move to a mandated ultra-low sulphur European fuel specification:
  - This would need to be targeted for a time when there is sufficient new technology in the market place to give a positive CO_2 balance. The costs and effects of this approach are incorporated in this submission. As stated above, the "well to wheels" analysis under these circumstances is not favourable, at least for many years.
  - Lower sulphur fuels (petrol, diesel or both) could, in principle, be introduced in line with the rate of introduction of any new vehicle technology that is proven to need such enabling fuels. To ensure a positive CO_2 balance, the rate of manufacture of fuels would need to match the introduction of relevant new technology. This could lead to a wide and complex range of scenarios even with a neutral tax position and may provide some insurmountable logistics challenges with some products or markets (i.e. in some Member States). If the technology need was proven and this approach shown to be a cost effective route to meet environmental objectives, EUROPIA would be willing to co-operate with the Commission and the auto industry to further examine these issues.

- The effect on other specifications of manufacturing ultra-low sulphur fuels is negligible.

- There is no significant direct environmental benefit (NO_x, VOC, PM, SO_2) to be gained from introducing low sulphur fuels.

- The potential for a reduction in fuel sulphur levels to increase secondary particulates via ammonia emissions or to increase N_2O greenhouse gas emissions (more potent than CO_2) should be evaluated to avoid possible regretted actions.

- The logistics impacts, costs and lead times associated with any move to low sulphur fuels need more detailed evaluation to ensure pan-European security of supply. EUROPIA would be committed to playing its part in seeking solutions to any logistic problems should there be a proven need for ultra-low sulphur fuels.

Details of the technical evidence in support of these conclusions are given in this submission in answer to the Commission's specific questions and in the enclosed CONCAWE papers.

Documents supplied:

- Comments on all questions, supplemented by technical evidence
- Appendix on vehicle technology
- Submitted together with CONCAWE response.

FORD RESPONSE

Executive summary

The main conclusions of the Ford response are:

- Considerable research data has been developed by industry showing the essential need to remove sulphur from liquid transportation fuels in order to achieve significant reductions in emissions, and thus improvement in air quality. It is also essential to enable the industry to comply with its CO_2 voluntary reduction commitment.
- The most promising technologies for meeting future emissions limits and fuel economy targets are all detrimentally effected by sulphur in fuel. In general, most other options will either produce marginal results, are at too early a stage of development, or will require strategies that compromise vehicle performance, fuel economy, emissions performance or all three.
- Improvements in the levels of air quality (in particular NO_x) related emissions and fuel economy tend to compete. Thus the introduction of more thermally efficient engines (such as lean-burn GDI) leads to the production of greater amounts of NO_x, which would not be able to be removed by conventional Three-way Catalyst (TWC) technology. Therefore new aftertreatment technology such as deNOx catalyst systems have had to be developed. Likewise diesel engines also require deNOx technology to reduce their NO_x emissions.
- DeNOx system reduction efficiencies are even more sensitive to sulphur levels than stoichiometric systems, and respond very much better at sulphur levels much less than the currently legislated maxima.
- Sulphur impacts not only on future emissions reduction technologies but also on current ones including TWC for petrol vehicles and Diesel Particulate Filters & Oxidation Catalysts for diesel vehicles.
- Sulphur in petrol significantly deteriorates emissions of vehicles with a TWC system. The emissions tend to be more sensitive in lower sulphur concentration. The emission increase in a lower emission vehicle can be more sensitive to fuel sulphur levels.
- Sulphur effects on TWC performance appear to be reversible.
- New TWC technology is more sensitive to sulphur than predicted by the original EPEFE equations.
- The sulphur cost on current TWC technology for Euro IV emissions limits is $50 per vehicle (50 ppm relative to 10 ppm), with a reduction in fuel economy of 1-2%. Similarly, costs on diesel vehicles for the oxidation catalyst are an additional $40-$190 (depending on whether the vehicle needs a second catalyst) and a reduction in fuel economy of up to 2%.
- During the last 5 years there has been a rapid reduction in world sulphur levels in petrol and diesel as emission standards world-wide have become ever more stringent. In particular, levels in Japan, California, Sweden and Finland have been reduced to less than 50 ppm. Average sulphur levels in these markets are often less than 10 ppm as refiners' desulphurisation technology has performed better than expected.

- Refinery impact worst case is (MathPro report for Ford) 3 Mta for all refined diesel and gasoline in Europe; this assumes worst-case technology increasing refinery CO_2 by 3-4%. However new technology such as Phillips S-Zorb would reduce this increase to 1% or so.
- The Commission predict gasoline CO_2 emissions of 424 Mta in 2010, a prediction of 100% GDI (10% F.E.) in 2010 would reduce this by 42 Mta. Thus sulphur impact at 2.5% would give a reduction for GDI of 32 Mta; this is a loss of 10.3 Mta. This needs to be compared to predicted increase of 3 Mta for all fuels from the refinery of both gasoline, diesel HD/LD. In effect the refinery increase for sulphur free petrol would be in the order of less than 1 Mta.
- European cost implications of reduction of fuel sulphur from 50 to 10 ppm limit are less than 2p per gallon (<1 Euro cent/litre) petrol and 3p per gallon (<1.1 Euro cent/litre) diesel.
- There are secondary benefits associated with reduction in fuel sulphur to levels less than 10 ppm, such as decreasing the SO_2 transportation inventory. It is well documented that SO_2 plays a key role in secondary particulate formation, and this sulphur reduction could have substantial benefits in PM reduction.

Documents supplied:

- Letter of introduction briefly stating concluding position on the issue;
- Nine documents of supporting information on impacts of fuel sulphur level reductions:
  1. ‘Review of the Impact of Fuel Sulphur on Advanced Aftertreatment Systems.’
  2. ‘Effects of 10 ppm Sulphur Standard for Gasoline and Diesel on CO_2 Emissions of the EU Refining Sector. (This includes costs as well as CO_2 emissions estimates.)
  3. ‘Impact of 50 ppm sulphur versus Sulphur Free Gasoline and Diesel (one page), July 2000
  4. Diesel/Gasoline Direct Injection Technology – Implications of Fuel Sulphur. (Summary Document.) July 2000.
  5. Impact of Sulphur Control of Petrol on Regulated Emissions. A study for Ford Motor Company, SENCO January 2000.
  6. Diesel Emissions Technology – a presentation, D Ketcher.
  7. Emission Control Technology, Port Fuel Injection (PFI) and Direct Injection Spark Ignition (DISI) – a presentation, M J Hawkins.
  8. Fuel Economy Overview and Discussion – a presentation, M J Hawkins
  9. California phase 3 gasoline program Alliance sulphur data set by e-mail to P Wickes, European Commission.

FREIGHT TRANSPORT ASSOCIATION (FTA, UK) RESPONSE

Executive summary

The main conclusions of the FTA response are:

- The density and viscosity of low sulphur fuel must not be allowed to fall.
- Fuels with a density below 0.823 together with viscosities below 2.2 cSt have caused considerable starting and stalling problems in hot weather (above around 24 ^{o}C) especially with rotary injection pumps.
- To receive the tax rebate in the U.K. 50 ppm diesel must have a density below 0.835. This has resulted in the Oil companies using around 0.832 as the practical limit to allow for production variations. This is too close to the densities where problems occur. We are trying to get the limit raised to 0.845 as the Oil Companies advise that this will also have the effect of raising the viscosity of the fuel.

Documents supplied:

- Email response stating their support of the introduction of 50 ppm fuel in the UK and of the associated problems with fuel parameters they have encountered with it.

FEDERAL REPUBLIC OF GERMANY RESPONSE

Executive summary

The main conclusions of the Federal Republic of Germany response are:

Starting position:
- The reduction in CO_2 emissions from motor vehicles is a big challenge for the future.
- In its decision of March 2000 relating to the Commission's work programme on the review of the Fuels Directive 98/70/EC, the European Parliament also called for the introduction of sulphur-free fuels.
  Due to the tax incentives for the EURO III and EURO IV limit values for passenger cars and the promotion of the new strict limit values for commercial vehicles currently in preparation, as well as the introduction, earlier than planned, of the new fuel qualities, there are now new findings which demand the introduction of sulphur-free fuels.
- The prescribed target of 50 ppm has led to considerable progress in refinery technology, particularly with regards to selective desulphurisation.
- In order that the reduction potential for pollutant and CO_2 emissions can be fully exploited, the pending update of the Directive 98/70/EC beyond 2005 must provide for the introduction, as from 01.10.2007, of sulphur-free fuels (sulphur content less than 10 ppm for petrol and diesel fuels).
- Compared to low-sulphur fuels, sulphur-free fuels used with modern high-temperature De-NO_x catalytic converters permit an additional reduction in consumption of around 4%.

Conclusions:
- Sulphur-free fuels are necessary to permit the best possible framework conditions for placing vehicles with innovative drive technologies on the market (see also recital 6 of Directive 98/69/EC).
- To achieve low-pollutant, significantly consumption-reduced drive designs, sulphur must be removed from fuel.
- For reasons of durability alone, transferring desulphurisation to 200 million, in many cases badly maintained, motor vehicles makes no sense. It is considerably more convenient to carry out large-scale desulphurisation in the 94 European refineries.
- Assessment of data published up to now confirms that in all technologies in which the formation of sulphate can compete with the desired processes (NO_x reduction, HC, CO and particulate oxidation), minimising the sulphur content would allow the desired processes to be optimised.
- Sulphur-free fuels increase the efficiency factor and above all the durability of reduction systems in the field and facilitate the application of low-emission designs.

Emission Effects:
- According to the *FEV* study, emissions in cities from petrol passenger cars using sulphur-free rather than low-sulphur fuels were immediately reduced by around 15% in the fleet, the particulate emissions of diesel passenger cars by 5%.
- Studies in California on the introduction of new reformulated petrol (CalRFG3) show that for designs with three way catalytic converters using sulphur-free rather than low-sulphur

fuels, the NO_x emissions are reduced by 21% and the hydrocarbon emissions (NMHC) by 13%. Thus this is a rapidly effective step towards immediate ozone reduction.

- In the case of heavy commercial vehicles, sulphur-free diesel fuel is necessary to meet the Euro IV and Euro V limit values with new exhaust gas after-treatment systems while maintaining and undercutting the current level of consumption and the CO_2 emissions level.
- Sulphur-free fuels would give the designers considerably more freedom to develop efficient and above all durable reduction technologies for exhaust gas and consumption at relatively low cost. Sulphur free fuels would also provide greater scope for restricting other emissions such as NH_3, N_2O and methane.
- The regeneration temperature of particulate filters rises as the sulphur content increases. Furthermore, the activity of waste gas after treatment systems for NO_x reduction falls as the sulphur content in diesel fuel increases. The anticipated reduction in consumption if sulphur content is reduced from 50 ppm to 10 ppm stands, according to studies by *MAN*, at around 3% in both cases.
- In the use of oxidative catalytic converters for particulate reduction, the remaining particulate emissions would be reduced by around 70% if sulphur-free fuels were used instead of low-sulphur fuels. In particulate filter systems too, sulphur particulates are re-released during regeneration.
- Even if CO_2 emissions reductions in cars were to be compensated for in the refineries, the introduction of sulphur-free fuel would be clearly preferable on account of the emissions advantages and the drastically increased durability of vehicles. According to the estimates of the Federal Environmental Agency, the CO_2 emissions in the refineries are, however, visibly lower that the CO_2 savings quoted for cars.

Effects on Refineries:

- According to calculations on the additional costs and CO_2 emissions for German fuel production regarding the lowering of the maximum sulphur content from 50 ppm to 10 ppm (with fuel specifications remaining otherwise the same, in accordance with 98/70/EC), there will only be additional CO_2 emissions of around 220,000 t/a.
- The additional CO_2 emissions of around 220 000 t/a only account for about 1.63% of the refinery emissions, about 0.12% of road traffic emissions and about 0.11% of the total emissions for the sector refinery plus road traffic.
- The additional investment costs total about DM 335 million to DM 610 million. This would result in cost increases of about DM 4,-/t DM 6,-/t in the case of diesel fuel, and DM 2,-/t to DM 4,-/t for petrol fuels, leading to price increases of between 0.35 pfennigs/litre and 0.5 pfennigs/litre for diesel, and between 0.15 pfennigs/litre and 0.3 pfennigs/litre for petrol fuel.
- A prompt laying down of the target provisions for 2005 and 2007 for fuels leads to lower total costs, as many of the required measures can be undertaken at a much lower additional cost in the course of maintenance and modernisation work which is necessary in any event.

Documents supplied:

- Single response document discussing the technical and legislative issues and providing cost estimates in relation to the German refining industry for the implementation of 50 ppm and 10 ppm sulphur limits on petrol and diesel.

HALDOR TOPSØE A/S RESPONSE

Executive summary

The Haldor Topsøe A/S response provides comments in response to questions 2 and 4, and refers specifically to diesel.

Examples are provided that illustrate the factors governing the investments that will be necessary and these examples are used to comment on the effects on other diesel fuel quality parameters that might result as a result of tightening diesel fuel sulphur specifications.

Three cases illustrate the factors influencing investment and operating costs:

- **Case 1:** Hydrotreater producing 50 ppm sulphur operating at 30 bar hydrogen pressure on North Sea origin, straight-run feedstock.
- **Case 2:** Hydrotreater producing 50 ppm sulphur operating at 30 bar hydrogen pressure on Middle-East origin, blended feedstock containing 25% LCO and 75% straight-run.
- **Case 3:** Hydrotreater producing 50 ppm sulphur operating at 55 bar hydrogen pressure on Middle-East origin, blended feedstock containing 25% LCO and 75% straight-run.

For each case, calculations have been made to estimate the incremental reactor volume needed to reach a 30 ppm sulphur specification and a 10 ppm sulphur specification, and key product properties have been estimated. The basis for the calculations and estimates is extensive testing performed in the Haldor Topsøe A/S laboratories at ultra deep desulphurization conditions.

In conclusion, it is the respondents' opinion that meaningful figures for the incremental costs associated with reducing the sulphur level in diesel from 50 ppm to lower levels can only be estimated if the other key specifications for diesel are defined. Even then, it is necessary to make a detailed analysis of the refineries in the EU. An analysis based on an average EU refinery could lead to very misleading results. If the above two criteria are met, the figures developed by Bechtel in their report for Auto-Oil II can be used to estimate equipment and operating costs.

Documents supplied:

- Response to questions 2 and 4 for diesel

INSTITUT FRANÇAIS DU PÉTROLE RESPONSE

Executive summary

The IFP response provides evidence on the topics covered by questions 1, 2 and 4 as follows:

Concerning the critical pollutants due to the transportation activities such as nitrogen oxides (NO_x), ozone precursors and particulate matter (PM), several efficient after-treatment technologies have been recently commercialised or are under development by automotive equipment supplier or catalyst companies. Their efficiency seems to be linked closely to the sulphur content of gasoline and diesel fuel. The majority of the information available to the IFP engine department confirms this impact on these systems, particularly for de-NO_x catalytic converter, catalytic NO_x and PM traps. The essential reason is additional sulphate production, which is a competitor by saturating more or less rapidly the operating sites.

However in order to optimise the “acceptable” sulphur content in petrol and diesel fuel, the further following investigations should have to be achieved:

- An in depth review of sulphur impact on the post-treatment reliability and durability in the 5 to 50 ppm range.
- An evaluation of the potential of new better sulphur tolerance materials.
- R&D actions for implementing the best strategy in terms of desulphatation regeneration cycle.

A specific feature has also to be taken into account, which is the accuracy (repeatability and reproducibility) of the sulphur analysis methodology. Recent works have been carried out through the CEN/TC19/WG27, where IFP has been directly involved. Preliminary results show that very few methods could be used in the very low sulphur concentration range and would be consistent with an industrial laboratory control: the fluorescence UV seems to be one of them.

With regards to the refining issues, the production of very low sulphur gasoline could be addressed by selective hydrodesulphurisation of the unique fluid catalytic cracking (FCC) gasoline as the a priori less costly solution. The octane losses could be minimised depending on the process characteristics. The alternate solution that consist in the pre-treatment of the FCC feed should not be sufficient to go down 10 ppm level. There is another important issue, which is now well known: the so-called domino interaction for gasoline quality attainment including sulphur, octane, aromatic, olefin or ether problems. As an illustration a strong aromatic reduction could occur in a decrease of the reforming activity and thereby in lower hydrogen supply; a MTBE ban with aromatics limited to 35% will make necessary to increase dramatically the capacity of alkylation processes to provide substitutes (normal and isoparaffins).

About the hydrodesulphurisation of the diesel fuel, refining processes are again available to achieve 10 to 30 ppm goals by using improved catalysts and reactor technology with relative mild operating conditions. It is likely that some high H_2 partial pressure unit will be necessary to deal with high sulphur and resistant feeds such as middle distillates arising from conversion units.

But the diesel fuel quality for the future is still uncertain on other very important characteristics: cetane number, polyaromatics, density and distillation range (T95). These items could potentially have a deeper impact on the refining industry either in terms of capital expenditures or hydrogen balance and CO_2 emissions. New process schemes including high pressure reactor and specific noble metal catalysts could be required to maintain the diesel fuel production closed from its present level while the European demand is expected to grow significantly.

It is very difficult to give an actual estimation of the incremental refining cost for the oil industry. The ISBL investment for most of the considered processes for a standard configuration are relatively known but the real expenses in the refinery could vary a lot depending on many parameters: crude supply, existing capacities, inland demand etc. For the refinery operations to guarantee no contamination by higher sulphur content components will be considerably more difficult to achieve and is likely to be a very important challenge to meet. The issues are similar for CO_2 production directly related here to the hydrogen balance: additional supply from natural gas (via steam reforming) and residues (via partial oxidation) will result respectively in 10 and 14 tons of CO_2 emitted per ton of H_2 produced.

All these items are developed in the three technical annexes joined to this summary:

- The interaction of petrol and diesel fuel sulphur contents with after-treatment systems.
- The domino interaction of refinery processes for gasoline quality attainment.
- Distillate hydrotreating routes: from deep HDS to cetane number improvement.

At the end it appears to IFP that two supplementary features should be investigated as well so that the future specifications would be accurate:

- The fuel demand scenario particularly with regards to petrol/diesel ratio and heavy fuel oil should be reviewed at the horizon 2010.
- The consequences of the development of new type of engine or combustion mode on the fuel characteristics requirements should be also evaluated.

Documents supplied:

- Summary of essential remarks on the very low sulphur petrol and diesel fuel issues
- Technical annex: 'Interactions between sulphur in fuel and after-treatment systems'
- Technical annex: 'The domino interaction of refinery processes for gasoline quality attainment'
- Technical annex: 'Distillate hydrotreating routes: from deep HDS to cetane number improvement'

IRISH GOVERNMENT RESPONSE

Executive summary

The main conclusions of the Irish Government response are:

- Potential reductions of CO_2 achieved by the use of the lower sulphur fuels may be offset to some extent by the increased emissions of CO_2 at the refineries producing the fuel, particularly diesel fuel;
- The view of industry is that the benefits in terms of reducing other pollutants using lower sulphur fuels are minimal;
- There is some concern at the increased cost of refining diesel with lower sulphur limits;
- There is concern that the storage of a multiplicity of different sulphur content fuels may pose practical and operational difficulties.

Documents supplied:

- Letter of introduction briefly summarising opinions of relevant Irish bodies on the issue;
- Separate documents containing the formal responses from the Irish Petroleum Industry Association, the Irish National Petroleum Corporation and the Office of the Revenue Commissioners.

JAMA RESPONSE

Executive summary

The main conclusions of the JAMA response are:

- Even a small content of sulphur in gasoline is known to adversely affect catalysts. In particular, sulphur has been reported to have harmful effects on the NSR (NO_x Storage and Reduction) catalysts without which the future lean burn engines will not be able to realise their CO_2 emission reduction capabilities;
- JAMA has entered into a voluntary agreement with the EU on the achievement of 140 g/km of CO_2 by 2009. The improvement of fuel economy is vitally important for the reduction of CO_2 emissions from passenger cars;
- The sulphur contents of premium gasolines currently sold in the Japanese market average 5 ppm and maximum 10 ppm, and these premium gasolines already accounts for 20% of the total gasoline sold in Japan. Also gasolines of an equal sulphur content are sold in California. Consequently, it can be said that technologies for producing gasolines of less than 10 ppm sulphur content at a reasonable cost are already in service, and it is fully possible for the petroleum industry to acquire these technologies by 2005;
- As interim target JAMA proposes a reduction of sulphur in all gasolines to less than 10 ppm by 2005. While a new emission regulation has been decided to take effect in 2005, additional reductions in CO_2 and other exhaust emissions from cars will be necessary. JAMA therefore strongly requests a further reduction in gasoline sulphur content for the years following 2005.

Documents supplied:

- Letter of introduction briefly stating concluding opinion on the issue;
- A separate document containing the formal response with a brief discussion of exhaust emissions and catalysts.

NETHERLANDS GOVERNMENTAL RESPONSE

Executive summary

The main conclusions of the Netherlands response are:

Petroleum:

- Apart from the effects predicted by the EPEFE-equations ultra low sulphur petrol might have a technology enabling effect, as claimed by the car manufacturers;
- One of the promising technologies for future petrol engines is the direct injection - lean burn engine. A significant reduction of fuel consumption and CO_2 emission are possible with this concept. There is a small trade off, however. At higher sulphur levels of the fuel, the regeneration frequency of the exhaust treatment system will increase resulting in a higher fuel consumption. There is no evidence that other technologies are enabled with a 10 ppm petrol that cannot be applied with a 50 ppm petrol;
- In the refining process some components of feedstock contain higher levels of sulphur and desulphurisation will deteriorate the important octane qualities of these components. The requirement of an ultra low sulphur petrol will thus put constraints on using higher sulphur components as blendstock. More MTBE may need to be used to up the octane quality;
- The share of the car fleet with direct injection - lean burn engines will have to increase considerably before an overall reduction of the CO_2 emission will result due to the increase in refinery emissions of CO_2 caused by lowering the fuel sulphur content;
- Further research is needed to establish:
  - the effect on fuel consumption;
  - the pace of market introduction of DI-LB engines and the EU wide effect on the refinery sector, with focus on the possible increase of transport of intermediate products.

Diesel:

- The only significant effect of ultra low sulphur diesel would be a reduction of the emission of particulates due to the effect of sulphate formation in the oxidation catalyst. As catalyst calibration may be adjusted to the lower sulphur level, a more active catalyst may be installed, resulting in the same emission of total particulates, but in lower emissions of CO, HC and carbon bound particulates;
- PM emission reductions using low sulphur fuel appear to be limited to diesel fuel, either facilitating the achievement of Euro 4 and 5 standards without using particulate traps, or by enhancing their effects;
- Using current technology, the heavier components of diesel fuel are extremely difficult to desulphurise, these components may no longer be used as blend stock for diesel. This will result in a decrease of T95 and of the content of PAH. The cetane number and the density will deteriorate. Also a production loss of diesel will take place of 10 to up to 20 %. With future technology, desulphurisation of these components will be feasible and then the only side effect is a reduction of the content of PAH;
- As 10 ppm diesel has no effect on the fuel consumption of diesel vehicles, the overall effect on CO_2 emissions will always be negative due to increases in CO_2 emissions from refineries;

- Further research is needed to establish:
  - the effect on oxidation catalysts and particulate filters; and
  - the EU wide effect on the refinery sector, with focus on the possible increase of transport of intermediate products.

General:

- The effects and costs related to a 30 ppm fuel can be estimated to be 50% of those related to 10 ppm;
- The encouragement of the voluntary marketing of ultra low sulphur fuels by authorities (e.g. by means of tax incentives) can only be employed as a forerunner of a mandatory introduction. A strictly voluntary marketing (without any action from authorities) can be successful if there is an incentive to buy the more expensive fuel, e.g. a lower fuel consumption;
- There may be a rationale to limit the use of 10 ppm sulphur petrol to direct injection - lean burn engines. A general introduction may lead to negative effects on both environment and economy;
- It is uncertain in what pace the market introduction will take place. As history demonstrates, it may take over 15 years before cars are commonly supplied with these fuel efficient engine types;
- The demand for ultra low sulphur products may add to the trend towards a EU wide refinery specialisation. This trend will lead to an increase of volumes of half and end products to be shipped between refineries.

Documents supplied:

- Letter of introduction.
- A separate document containing the formal response with a discussion of the questions posed.
- Excel spreadsheet with refining NPV cost calculations.

SMMT (THE SOCIETY OF MOTOR MANUFACTURERS AND TRADERS LIMITED, UK) RESPONSE

Executive summary

The main conclusions of the SMMT response are:

- In order for the automotive industry to satisfy Euro III and Euro IV emissions standards and to honour the voluntary carbon dioxide commitment of 140g/km by 2008, new technologies will need to be introduced whose effectiveness is inversely proportional to fuel sulphur levels.
- The introduction of sophisticated PM and NO_x after treatment devices, which do not tolerate sulphur, is predicated upon the availability of fuels containing no, or extremely low levels of sulphur.
- Studies by Professor David Kittelson (Minnesota University) show that removing sulphur from fuel almost eliminates the formation of nano-particulate. It is widely recognised that such technologies offer the potential for significant improvement in air quality in terms of NO_x reduction.
- Research work by AECC (ref 1) describes how the presence of sulphur in TWCs and new catalyst technologies competes strongly with pollutants for contact with the active catalyst surface and can cause irreversible changes to the washcoat and some base metals. It should be noted that the significant reductions in emissions with GDI technology depend on the use of TWCs. Sulphur presence at any concentration limits the efficiency of catalysts to convert pollutants, and this reduced efficiency becomes more critical at very low emissions levels. In the case of DeNOx catalysts, performance is compromised by the presence of sulphur.
- Sulphur levels also have an effect on durability and accelerate the deterioration in catalyst performance. A number of papers by SAE have been published on the impact of sulphur (ref 2).
- The World-Wide Fuel Charter, a joint initiative sponsored by ACEA, Alliance, EMA and JAMA representing automobile manufacturers around the world, was established two years ago to define automotive fuel quality needs and to harmonise these worldwide. The Charter as issued in April 2000 defines the maximum fuel sulphur level required for new technologies as 5-10ppm.
- In the case of off-road diesel engines, a key technology for compliance with stage 3 off-road emissions standards will be Exhaust Gas Recirculation (EGR). This technology unfortunately increases engine component wear that is significantly accelerated when using high sulphur fuel. The view in the UK off-road industry is that technology needed to enable off-road engines to meet stage 3 standards will require the same fuel as on road engines i.e. 10ppm max sulphur content.
- The cost of reducing the amount of sulphur in fuels from the present level of 50ppm (maximum) to below 10ppm, has been assessed at less than 2p a gallon for petrol (0.007 Euro/litre), and 3p a gallon for diesel (0.01 Euro/litre).
- The need to reduce fuel sulphur levels is being recognised in major market areas. In the USA it is reported that the maximum permissible sulphur content of automotive fuel is

being substantially reduced from 2006. In Japan, it has recently been announced that diesel automotive standards scheduled for introduction from 2007 are to be brought forward two years, to enter into force from 2005. Very low sulphur levels are already the norm for gasoline fuel in Japan.

- Although diesel fuel with a sulphur level not exceeding 50ppm will become mandatory in the EU from 2005, fuels containing substantially lower levels of sulphur are already available in many Member States. In the UK, for example, current market road vehicle diesel fuel typically contains no more than 30ppm sulphur.
- One of the consequences of the current method of desulphurisation of diesel fuel is that some components with lubricant properties are also removed. Therefore it is essential in order to maintain durability and performance of key components such as fuel injection equipment, that the fuel complies with the lubricity requirements specified in EN 590 (corrected wear scar diameter of 460µm at 60ºC measured according to ISO 12156 part 1).
- For temperate climates, fuel viscosity (at 40ºC) must not be less than 2 mm^2/sec (the lower limit specified in EN 590).
- Any reduction in aromaticity must be compatible with older in-service equipment, e.g. no leakage from fuel injection pump seals.
- Any deviation from the density specified in EN590 (and which will affect heat content) could invalidate the fuel injection equipment calibration, and, therefore, the engine certification. Coking propensity must be reduced as far as possible to maintain combustion efficiency and should on no account be allowed to deteriorate.

Documents supplied:

- Document giving general background comments on the automotive industry followed by comments based on replies received following circulation of the original letter from Commissioner Wallström within the UK Motor Industry.
- References are made to two documents:
    1. AECC paper (Automobile Emissions Control by Catalyst) dated 18 June 1997 and entitled The Effect of Sulphur on the Durability and Performance of Catalyst based Emissions Controls
    2. SAE papers on the effect of sulphur, SAE 910814, 912321, 912323, 920329, 920557, 920558, 922245, 930137, 930385, 940783, 940928, 942001, 950255, 952421, 952561.

REPRESENTATION OF SPAIN AT WORKING GROUP III AUTO-OIL II PROGRAMME RESPONSE

Executive summary

The main conclusions of the response from the Representation of Spain are:

- The issue of environmental performance of motor fuels with less than 50 ppm is relatively new. No specific programme on their evaluation has been carried out in Spain, therefore no original technical evidence is presented. It is possible, however, to provide a fair assessment of the situation as of today by analysis of the available technical information (main source being the car and the oil industries) and identification of knowledge gaps.

- It is preferred that the issue of lower sulphur fuels be studied within the context of wider programmes aimed at setting the technical basis for regulatory policy, reviewing and revising, as required, European Union fuel specifications. Auto-Oil 1 and 2 programmes to set fuel quality for 2000 and 2005 are this type of process:
  - A stable horizon is set for planning and implementation of the required productive infrastructure modifications. In this context a five-year period for successive regulation revisions is considered adequate.
  - Decisions are based on the best available scientific knowledge.
  - It is pursued that the best environmental value is obtained from the incurred costs.
  - Pan-European fuel specifications, when introduced in the same time horizon, help prevent “balkanization” of fuel qualities, thus favouring trading and competitiveness and therefore ensuring wider supply and lower consumer prices.

- As a conclusion, further work is needed before setting fuel sulphur specifications beyond 2005. Such work can be properly planned and executed in the context of wider air quality studies to allow for an integrated assessment of the most cost-effective measures that can be taken.

Documents supplied:
- Comments on all questions

MINISTRY OF ENVIRONMENT, SWEDEN RESPONSE

Executive summary

The response from the Ministry of Environment, Sweden, provides evidence on the topics covered by questions 1-6 summarised below.

- Sweden introduced low sulphur diesel in 1991 (10 ppm) - class 1 diesel; this was originally intended as city fuel but in 1999 it reached a market share of approximately 95%. This was achieved through introducing it more widely and using tax incentives (for the low sulphur fuel) and disincentives (for the higher sulphur fuel).

- Since 1st January 2000, Sweden has used petrol with 50 ppm sulphur content, through a voluntary agreement with the oil industry.

In summary, Sweden's comments in response to the specific issues were:

1) For both diesel and petrol, 10 ppm is preferable to 5-10 ppm. A reduction below 50 ppm represents a significant environmental benefit in reduced emissions and corresponds to the demands of the motor industry, i.e. 10ppm. It is recommended that the current standard for 2005 be followed by a reduction to 10ppm.

2) It is technically feasible to produce low sulphur fuels. It is not possible to give an accurate cost estimate as several factors have first to be analysed to allow costs to be estimated such as:
   - future supply and demand balances (e.g. super unleaded vs unleaded vs regular; petrol vs diesel)
   - quality and price of crude oil
   - different investment cases
   - other fuel parameters.

3) There are strong environmental reasons to allow for the introduction of new technologies. Sweden has had a positive experience of using tax incentives to promote fuel qualities with enhanced environmental properties and to allow for these technologies to be introduced. Tax incentives and disincentives are used to initiate a new market and to decrease the market for poor fuel qualities.

4) The effect on other fuel quality parameters depends on the refining technology chosen. For diesel, the lowering of sulphur content will only slightly affect other parameters (e.g. total aromatics/ PAH content). Some processes may increase aromatics saturation (improving diesel quality further), but this involves additional cost (primarily the consumption of additional hydrogen). For petrol it is not anticipated that desulphurisation will have an overall positive effect on other important fuel parameters.

5) In terms of logistics, in Sweden the fuel distributors have been able to maintain the low sulphur levels to end user at pump (checked through a test program run 2 years ago).

6) To assess the overall effect on CO_2 emissions, further study is needed. Roughly, it must be considered that emissions of CO_2 from vehicles cf. refineries for a given amount of fuel produced is 9:1. So any reduction from vehicles will have a much higher impact than a change in refinery emissions. Although the stricter fuel standards will require more energy, it is Sweden's opinion that this will not outweigh the 25% reductions from vehicles required by 2008.

Documents supplied:
- Views on the issues
- Case Study - The Introduction of Improved Transport Fuel Qualities in Finland and Sweden': Presentation report to the Governments of Finland, Norway and Sweden Final Report July 27, 1998, Arthur D Little.

SYNTROLEUM CORPORATION RESPONSE

Executive summary

The Syntroleum Corporation response provides information on the "Syntroleum Process". This is a simplification of traditional Fischer Tropsch fuels technology (Gas-to-Liquids or GTL technologies) for converting natural gas into ultra clean synthetic liquid fuels and speciality products. This process is aimed at substantially reducing both the capital cost and the minimum economical size of a GTL plant. Syntroleum believes that the Syntroleum process can be a cost-effective tool to produce cleaner fuels or clean blending components for fuel (diesel).

Syntroleum encourages the Commission to carefully consider not only the impact on the conventional industries, including the fuel product refining and distribution sectors, the vehicle, engine and related product sectors, but also the other, currently less conventional industries. Consideration of alternative processes, production and technologies must be assessed and factored into how these products can play a role and what opportunities exist to achieve the air quality and public health goals. Consideration of how the EC can align conventional and less conventional products and markets are vital.

Documents supplied:

- Comments from Mr Mark Agee, Syntroleum President and Chief Operating Officer
- Prepared Remarks by Nick Economides, Director, Refining and Reformulated Fuels, Hart Fuels Information Services on the U.S. Environmental Protection Agency’s Proposed Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.
- Prepared Remarks by Larry Weick, Vice President Business Development and Licensing, Syntroleum Corporation on the U.S. Environmental Protection Agency’ Proposed Heavy Duty Engine and Vehicle Standard and Highway Diesel Fuel Sulfur Control Requirements

EUROPEAN FEDERATION FOR TRANSPORT AND ENVIRONMENT (T & E) RESPONSE

Executive summary

The main conclusions of the T & E response are:

- Auto Oil II has demonstrated that low sulphur fuel is necessary for AQ daughter Directive compliance in locations across the EU, and remains useful in improving air quality in many others;
- There is a need to protect the integrity of the single market and have low sulphur fuels available across the EU15;
- A distinction needs to be drawn between the marketing of fuel in any one member state, and the assistance granted to its refining industry;
- The variability of the estimated costs and impacts on the refining industry of low sulphur fuels, including from the industry itself, need to be taken into account;
- It is important to stimulate breakthrough technologies;
- There is credible evidence on the impact of low sulphur levels (30-50 ppm) on emissions and that the more advanced control equipment becomes as emission limits are lowered, the greater this effect appears to become. For this reason they advocate a standard of 10ppm in both petrol and diesel;
- Action to reduce sulphur in fuels below 50ppm is necessary, and that continued air pollution problems in urban areas across the EU is the main reason for this. The advantage of low sulphur fuels is that they have an immediate effect on the emission levels from traffic;
- The significance of cost confidentiality to the industry seriously undermines any process that is only to be decided upon solely by comparative costs effectiveness;
- Costs have come down over time as process innovations have continued alongside competition amongst those who supply refinery equipment. It is also clear that there is a large difference between average costs for the industry as a whole, and costs for individual refiners;
- New emissions technology should be encouraged rather than discouraged by the fuel quality Directive. This would mean that 10 ppm sulphur fuels must be not just allowed onto the market by the Directive, but should be mandatorally available. This should occur across the EU as soon as practicable, from the start of 2002. The entire fuel specification should then become 10ppm sulphur from the start of 2005;
- The only logistical problem of significance that will occur with a low sulphur fuel being marketed relates to the sales point. Pump availability for the different qualities of fuels will be problematic until after the complete ban on leaded petrol has come into force;
- In their view – all things equal – a net increase in CO_2 emissions of around 1% "well to wheel" is expected. However they say this will be massively outweighed by the benefits of more efficient vehicle technology as "the entire point of 10ppm fuel is that all things do not remain equal".

Documents supplied:

- Letter of introduction to response briefly stating opinion;
- A separate document containing the formal response and discussion of the questions posed.

TOYOTA RESPONSE

Executive summary

The main conclusions of the Toyota response are:

- It is well known that fuel with high levels of sulphur has a significant impact on the performance of the 3-way catalyst;

- As required emissions levels become more stringent, the sensitivity to high sulphur fuel on exhaust emissions is of increasing importance;

- In the case of 3-way catalysts – necessary to reduce emissions using current engine technology, the regeneration frequency is more frequent the higher the sulphur content of the fuels. With higher emissions standards coming in the catalyst needs to be maintain its optimum range and regenerate more frequently (which also degrades the catalyst) to maintain compliance. Regeneration increases the vehicles fuel consumption and therefore increases CO_2 emissions;

- Lean-burn direct injection engine technology can potentially reduce both carbon dioxide (CO_2), and other emission gases such as HC, CO and NO_x. NO_x Storage Reduction catalysts are needed to reduce nitrogen oxide (NO_x) emissions from lean-burn direct injection engines, however their effectiveness is also affected by sulphur content of the fuel;

- In order to achieve the successful reduction of emissions the early and widespread introduction, throughout Europe, of low sulphur (50 ppm) fuel over a transitional period, and of sulphur-free fuels (max. 10 ppm) is vital;

Documents supplied:

- Letter of introduction briefly stating concluding opinion on the issue;
- A separate document containing the formal response with a discussion of exhaust emissions and catalysts.

UK DETR (DEPARTMENT OF ENVIRONMENT, TRANSPORT AND THE REGIONS) RESPONSE

Executive summary

The main conclusions of the DETR response were summarised by them as follows:

- The improvement in vehicle catalyst efficiency resulting from a 10ppm-sulphur limit may be significantly greater than a 30ppm limit.

- A 10ppm-sulphur limit for both petrol and diesel could result in significant long-term air quality benefits and may play an important role in helping the UK to meet the EU limit value for NO_2 for 2010.

- The available information would suggest that the overall impact on CO_2 emissions by 2010 from the introduction of petrol and diesel fuel with <10ppm sulphur could range from being broadly neutral to a small net increase. This depends on the assumptions made on future vehicle fuel economy trends and the projected refinery impact. Optimisation of other fuel properties could minimise this effect.

- A pre-tax cost to the consumer of a <10ppm-sulphur limit is likely to be in the range from 0.1 to 0.25 pence per litre, with the most likely outcome of 0.2 pence per litre (€0.0032 per litre) taken over a 15 year time period. For a typical car user, this is equivalent to roughly **£2.50** per year **(€4 pa**). For a heavy vehicle covering some 70,000 miles per year (112,000km pa) this is equivalent to **£80 p**.a. **(€128 p.a.)** or about 0.1% increase in annual running costs for a 38 tonne vehicle.

- Freezing petrol and diesel fuel specifications for all parameters, other than sulphur, at the 2000 level (Directive 1998/70/EC, Annexes I & II) could maximise cost effectiveness.

- Dates for the mandatory introduction of <10ppm sulphur fuels should reflect the availability of the relevant vehicle technology and also take account of the pace that refineries can adapt. This would seem to indicate an implementation towards the end of the decade (possibly 2008 for petrol and 2010 for diesel).

- Member States should not be prohibited from encouraging the early availability of <10ppm-sulphur fuels in advance of any mandatory application dates where they consider it to be cost-effective to do so.

- The UK would, nevertheless, like to make it clear that these summary views are preliminary and are subject to change on the basis of further evidence.

Documents supplied:

- Letter of introduction advising that the attached documents are merely a technical assessment of the information that they have available to date and are not to be taken as official UK government policy;
- Summary document bringing together the information from the responses by UKPIA, The Ford Motor Company and SENCO (independent consultants commissioned by the DTI).
- Four annexes:
  1. Annex A - "Emissions Effects and Costs of Sulphur Free Petrol and Diesel", a report by SENCO for the UK DTI.
  2. Annex B - "Effects of 10 ppm sulphur standard for gasoline and diesel fuel on CO2 emissions of the EU refining sector", a study by MathPro Inc. for The Ford Motor Company.
  3. Annex C - Response from UKPIA (UK Petroleum Industry Association).
  4. Annex D - Cost summary for oil producers.

Appendix 2

CONTENTS

Ref. No.	Peer Reviewers' Biographies
A	Professor Bernard J Challen
B	Dr Robert MacKinven
C	Michael P Walsh

PROFESSOR BERNARD J CHALLEN

Professor Challen is an independent Engineering consultant with Shoreham Services based in the United Kingdom and has over thirty years' professional experience. He is a fellow of SAE and serves on the Council of the Institute of Mechanical Engineers. He provides technical advice to clients mainly in the automotive industry. His particular areas of expertise include: internal engine combustion design, instrumentation, measurement and control (including On Board Diagnostics) and noise and vibration. Before establishing Shoreham Service, Professor Challen was the Technical Director at Ricardo Consulting Engineers and was responsible for the creation and development of Ricardo North America.

DR ROBERT MACKINVEN

Dr MacKinven now manages his own Consultancy firm, MacKinven Consulting, offering expertise in the areas of fuels quality and the environmental effects of transportation systems. He has spent some twenty-seven years in the oil industry in the UK, Europe and North America involved mainly in research and product development. Prior to setting up his own independent consultancy he worked for Shell where he was involved in various capacities on global fuel development and marketing. He represented the Shell in EUROPIA for several years and was also involved in the Auto Oil I programme in the Technical Task Force and acted as a report writer.

MICHAEL P WALSH

Michael Walsh has over thirty years' experience dealing with aspects of motor vehicle pollution. He is a member of several Advisory groups including the External Review Committee of the South Coast Air Quality Management District (US) Technology Advancement Office, Chairman of the Inspection & Maintenance Peer-review Panel of the California Air Resources Board and the American Lung Association Technical Advisory Committee. Before becoming an independent consultant Mr Walsh was the Deputy Assistant Administrator for Mobile Source Air Pollution at the US Environmental Protection Agency.