THE COSTS AND BENEFITS OF LOWERING THE SULPHUR CONTENT OF PETROL & DIESEL TO LESS THAN 10 PPM

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1. INTRODUCTION

The European Commission has recently adopted a proposal to amend Directive 98/70/EC on petrol and diesel quality[1]. The preparatory work for this proposal included a consultation on the need to reduce further the sulphur content of petrol and diesel to below 50 parts per million (ppm). The information received was summarised and subjected to peer-review by independent experts. The summary report prepared by AEA Technology and the original submissions can be found at the Commission's website[2].

To complement this work, DG Environment also undertook an economic analysis of the benefits and costs of introducing sulphur-free fuels[3]. This note reports the main findings.

The "Main" scenarios considered here correspond closely to the situation contained in the Commission's proposal. Sections 2 and 3 of the paper provide more detail on the scenarios and assumptions used in the modelling. Section 4 provides the results of the analysis in terms of costs and effects on total emissions. Section 5 provides a brief summary of results. Annex 1 provides more detail on the rationale for the assumptions made concerning the effects of sulphur-free fuel on vehicle emissions. Annex 2 provides more detailed results by Member State. Annex 3 gives the assumptions made in the benefit estimates for conventional (non-CO_2) pollutants.

The effects of sulphur-free fuels depend on the types of vehicle in which they are used. For example, they are expected to improve the fuel efficiency of EURO IV cars (all new cars coming onto the market from 1st January 2006) but not that of older cars. Other EURO IV vehicle types including light commercial diesel vehicles and heavy duty vehicles are also expected to improve their fuel economy. On the other hand, the production of sulphur-free fuels may require more energy and so the net effect on CO_2 emissions depends on the relative magnitude of these two effects.

The use of sulphur-free fuel is expected to reduce emissions of carbon monoxide (CO), nitrogen oxides (NOx) and volatile organic compounds (VOCs) from the existing fleet of petrol light duty vehicles. In addition, sulphur-free fuel reduces the emissions of particulate matter from existing (EURO I-III) diesel cars, diesel light-duty vehicles and heavy-duty vehicles. It is possible that use of sulphur-free fuel will reduce conventional emissions from EURO IV petrol vehicles as well, but for the purposes of this paper no reduction has been assumed.

The production of sulphur-free fuel may require additional refinery processing and may, therefore, be more expensive to manufacture due to additional investment and operating costs for refineries. This additional expense has to be weighed against the

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1 COM(2001) 241 final. Adopted on 11 May 2001.

2 http://www.europa.eu.int/comm/environment/sulphur/index.htm
Consultation on the need to reduce the sulphur content of petrol and diesel fuels below 50 ppm – A policy maker's summary. George Marsh, Nikolas Hill, Jessica Sully, AEA technology November 2000.

3 In this context "sulphur-free" refers to a sulphur content of less tan 10 mg/kg (ppm). These fuels are also referred to as "near-zero sulphur" or "ultra-low sulphur".

reduced fuel costs for operators of vehicles that run more efficiently with sulphur-free fuel.

2. SCENARIO DESCRIPTION

During the Auto-Oil II program (AOP II) a comprehensive transport "base-case" was constructed for nine EU Member States[4] using the TREMOVE model, with extensive data on vehicle stocks, vehicle-kilometres travelled, and aggregate emissions. The AOP II base case assumed that all fuel used from 2006 contains a maximum of 50ppm sulphur. The TREMOVE base case was used as the starting point[5] to analyse the following scenarios.

2.1. "Main Scenario 2005": Introduction of sulphur-free fuel in 2005

2005: Introduction of sulphur-free diesel & petrol to new vehicles
2011: 100% Sulphur-free petrol & diesel made compulsory

The analysis assumes that sulphur-free petrol and diesel fuels are introduced into the market at the beginning of 2005. Initially, it is assumed that only new vehicle types (EURO IV) which are able to derive an improvement in fuel efficiency will use sulphur-free fuels. This will include new passenger cars, light commercial vehicles and heavy duty trucks and buses. It is then assumed that in 2011 all of the petrol and diesel fuel sold in the EU will be required to be sulphur-free.

It has been also assumed that all new heavy duty vehicles sold post-2005 will experience a fuel economy improvement when using sulphur-free diesel fuel. However, only 20% of new passenger cars and light duty vehicles sold in 2005 will experience such an improvement. This is because while cars need to follow EURO IV norms, only 20% are assumed to reap the fuel efficiency benefit. This proportion is assumed to rise to 45% in 2006, 65% in 2007 and 90% in 2008 in line with estimates given by the European Car Manufacturers Association in the framework of their voluntary commitment to reduce the CO_2 emissions of new cars.

From 2011 existing petrol and diesel vehicles (EURO I, II, III) will also be required to use sulphur-free fuel. The use of sulphur-free fuels by older vehicles will produce an increase in emissions of CO_2 at refineries (and result in higher refinery costs) which will not be offset by improvements in new vehicle fuel economy. However, it will lead to benefits in terms of reduced emissions of conventional regulated pollutants from these older vehicle types.

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4 These were Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Spain and the UK. According to Eurostat Sirene database in 1998, transport fuel consumption in these Member States is 88% of total final energy demand of road transport sector in the EU. Thus, these Member States are considered representative for the purposes of this analysis.

5 The TREMOVE bases case includes the expected effects of the voluntary agreement with ACEA, JAMA and JAMA to improve the fuel efficiency of new vehicles. The base case files can be found at http://europa.eu.int/comm/environment/enveco/auto-oil/index.htm.

2.2. “Main Scenario 2007”: Introduction of sulphur-free fuel in 2007

2007: Introduction of sulphur-free diesel & petrol   ***2011: 100% Sulphur-free petrol & diesel made compulsory***

This is precisely the same as the scenario above except that the date of introduction of sulphur-free fuels is postponed by two years to 1 January 2007. The date for 100% sulphur-free fuels is 2011, the same as in the “Main Scenario 2005”.

As above, it has been assumed that 65% of new cars and vans sold will experience a fuel economy improvement when using sulphur-free fuels in 2007.) This share rises to 90% in 2008. All heavy-duty vehicles sold in 2007 and thereafter are assumed to experience a fuel economy benefit when using sulphur-free diesel.

2.3. “Phased-In” Scenario: Phased introduction for all vehicle types in 2007

2007: Sulphur-free fuels introduced at a rate required by new EURO IV vehicles

In this scenario it is assumed that both petrol and diesel fuels are introduced into the market in the quantities that are required by the fleet of new EURO IV vehicles. It is also assumed that the existing fleet of (pre-EURO IV) vehicles do not use sulphur-free fuel but continue to use fuel with a maximum sulphur content of 50 ppm. Therefore, there are no reductions in emissions of conventional pollutants in this scenario. Costs of producing the sulphur-free fuels at the refinery are calculated as a proportion of the cost that would be associated with producing sulphur-free fuels for the whole fleet.

2.4. “100% Switch for Passenger Cars in 2007” Scenario

2007: Sulphur-free fuels introduced for compulsory use by all passenger cars

In this scenario it is assumed that the sale of sulphur-free petrol and diesel fuel is mandatory from 2007 for all passenger cars. The refinery costs and additional refinery emissions of CO_2 are calculated as a proportion of the overall cost and emissions associated with 100% production of sulphur-free fuels for use by all vehicle types.

2.5. "Phased Introduction for Passenger Cars from 2007" Scenario

2007: Sulphur-free fuels introduced at rate required by EURO IV passenger cars

This scenario is identical to the "phased-in" scenario at Section 2.3 above, except that the use of sulphur-free fuels is restricted to passenger cars. Vans, trucks and buses are assumed to continue to use fuel with a maximum sulphur content of 50 ppm. The difference between this scenario and that above is of interest because the proportion of cars which run on diesel is low compared to other vehicle types (vans, trucks and buses). This matters because the CO_2 savings from sulphur free fuel are assumed to be slightly higher from petrol than from diesel.

3. ASSUMPTIONS

Modelling the precise costs and effects of the availability of sulphur-free fuels is a potentially complicated exercise. First, sulphur-free fuel has different effects on different vehicle types, and these effects are not known with certainty. Secondly, the take up and use of sulphur-free fuels depends not only on market prices but also other determinants of consumer behaviour and this is difficult to predict with confidence. Thirdly, the additional costs of producing lower sulphur fuels may vary from place to place depending on the refinery configuration and crude oil used. A number of simplifying assumptions have therefore been made and these are set out in the rest of this section.

3.1. Emissions reductions

The relative reductions in emissions of CO_2 and conventional pollutants from vehicles using fuels with less than 10 ppm sulphur (compared to fuels with less than 50 ppm) are given in Table 1 below.

Table 1: Assumptions on vehicle emissions changes

Vehicle type		Emissions Reduction on 10 ppm sulphur fuels relative to fuels with 50 ppm			
		CO_2	NOx	HCs	PM
EURO IV cars	Petrol	3% (1-5%)	0%	0%	0%
	Diesel	2% (1-3%)	0%	0%	0%
EURO I,II,III cars	Petrol	0%	10%	10%	0%
	Diesel	0%	0%	0%	5%
EURO IV vans	Petrol	0%	0%	0%	0%
	diesel	2% (1-3%)	0%	0%	0%
EURO I,II,III vans	petrol	0%	10%	10%	0%
	diesel	0%	0%	0%	5%
EURO IV/+ HDVs	diesel	2% (1-3%)	0%	0%	0%
EURO I,II,III HDVs	diesel	0%	0%	0%	5%

A more detailed description of these figures can be found in Annex 1.

There is some uncertainty about the precise effects of sulphur-free fuel on fuel efficiency for EURO IV petrol vehicles. The figures submitted to the Commission's "Call for Evidence" lie in the range 1% to 5%. The mean of these two numbers (3%) has been used in this paper. For EURO IV diesel vehicles figures from the submissions to the "Call for Evidence" lie in the range 1% to 3% and so 2% has been used.

Concerning EURO I, II and III petrol vehicles using sulphur-free fuel, a flat reduction in emissions of 10% for conventional (non-CO_2) emissions (CO, NOx and VOCs) has been assumed. For existing diesel vehicles a reduction in emissions of particulate matter of 5% has been assumed. The rationale for choosing these numbers rather than others in set out in Annex 1 which provides more information on technical aspects of emissions control.

When estimating the reduction in conventional emissions from existing vehicles a simple percentage reduction factor was applied to estimate the reduction. For example, suppose emissions of NOx from a conventional EURO I-III petrol car are expected to fall by 10% when sulphur-free fuel is used. This is simulated by reducing the aggregate emissions of NOx for passenger vehicles entering the stock before 2007 by 10%, relative to the TREMOVE base case[6].

3.2. Additional Refinery Emissions of CO_2

The production of sulphur-free fuel may be more energy intensive. In such cases there will be additional CO_2 emissions at the refinery in line with the volume of sulphur-free fuel refined and produced. Volumes of fuel used can be derived from the TREMOVE base case. The size of the CO_2 emissions penalty per unit of fuel refined is open to question, but for the purposes of this analysis CONCAWE/EUROPIA figures taken from the Consultation report have been used. These are reproduced in Table 2 below.

CONCAWE estimate that there will be additional emissions of 25 kt of CO_2 for each additional Mt of sulphur-free petrol produced, and 27 kt of CO_2 for each additional Mt of diesel. If all fuel (both for passenger cars, as well as for heavy and light duty vehicles) were refined to 10 ppm quality, the emissions from refineries would increase by 4.6 Mt of CO_2. Sulphur-free petrol accounts for 3.1 Mt CO_2 and diesel 1.5 Mt CO_2 .

Table 2: Additional CO_2 emissions at refineries

	Petrol	Diesel
Additional CO_2 emissions associated with producing 100% sulphur-free petrol and diesel (per annum)	3.1 Mt	1.5 Mt

Figures taken from CONCAWE/EUROPIA Submission to "Call for Evidence"

For scenarios where the percentage of fuel refined to meet 10 ppm sulphur limits is less than 100%, the above figures have been adjusted on a *pro rata* basis. For example, if 30% of petrol is refined to 10ppm this would increase CO_2 emissions at refineries by 0.3 * 3.1 Mt.

3.3. Additional Refinery Costs

To assess the costs of using sulphur-free fuel we have to set the additional costs of refining sulphur-free fuel against the value of the potential fuel cost savings that arise from the greater fuel efficiency for EURO IV vehicles.

There are likely to be additional investment and refinery operating costs associated with lowering the sulphur content from a maximum of 50 ppm to a

[6] Note that this requires either a disaggregation of total emissions by type, or some assumption about the relative contribution of different types to overall pollution. In our modelling we have taken a conservative assumption that there would be no additional reduction of CO, NOx, PM and VOC from EURO IV cars. Thus, throughout this analysis, air quality benefits arise only from the pre-EURO IV cars.

maximum of 10 ppm. DG Environment commissioned a report from consultants Purvin & Gertz on the costs to refiners of producing sulphur-free fuels (less than 10 ppm)[7]. Table 3 indicates the range of costs that they identified. The main driver of cost difference between north and south EU is the quality of the crude oil (in particular the sulphur content) that the refineries are currently set up to handle. For the purposes of the scenarios in this paper average costs have been used as given in Table 3.

Table 3: Additional refining costs (€cents per litre) used in this analysis

	Petrol (min)	Petrol (max)	Petrol (ave)	Diesel (min)	Diesel (max)	Diesel (ave)
EU, North[8]	0.1	0.3	0.2	0.3	0.6	0.45
EU, South[8]	0.2	0.3	0.25	0.6	0.9	0.65

The analysis from Purvin & Gertz is based upon "yardstick" catalytic cracking refineries which represent approximately 75% of refining capacity in Europe. Costs are expected to be highest for these refineries rather than, for example, hydrocracking refinery configurations. In addition, the study assumed a complete switch to sulphur-free fuel production in 2008. If a phased introduction is implemented then investment costs are likely to be lower. This is because some new technologies under development are likely to make further progress towards market utilisation and because refiners can, at least initially, selectively desulphurise some fuel components for the 10 ppm sulphur pool whilst leaving others for the 50 ppm pool.

3.4. Reductions in operating costs of vehicles

As indicated above, it is estimated that the use of sulphur-free fuel would decrease the fuel consumption of EURO IV cars by an average of 3% for petrol cars and around 2% for diesel cars. Fuel consumption of older vehicles is assumed to be unaffected. It is likely that sulphur-free fuel would have positive effects on fuel consumption for diesel light duty vehicles and heavy goods vehicles of a similar order to those for diesel cars (see Table 1 above).

The TREMOVE base case contains figures for the average fuel consumption for small, medium and large passenger cars[9]. This information can be used to assess the value of the savings that arise due to improvements in fuel efficiency.

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[7] *ULS gasoline and diesel refining study*. C.H. Birch & R. Ulivieri, Purvin & Gertz, November 2000. http://www.europa.eu.int/comm/environment/sulphur/index.htm

[8] "EU, North" includes Austria*, Belgium*, Denmark*, Finland, Germany, Ireland, Luxembourg*, the Netherlands, Sweden* and the UK. "EU South" includes Greece, Italy, Portugal* and Spain. Note: For the purposes of this analysis, France was considered 50% North and 50% South. The Member States with an asterisk are not analysed as they are not included in the TREMOVE model. Note that in Finland and Sweden 10 ppm diesel fuel is already the norm.

[9] Both petrol and diesel. However, in TREMOVE small diesel cars are grouped together with medium sized diesel cars.

3.5. Other Assumptions

3.5.1. Treatment of fuel taxation

The current EU price before tax for petrol is around €0.24 per litre for petrol and €0.23 per litre for diesel. The cost increases at the refining stage from lowering the sulphur content to 10ppm therefore represent an increase of around 1-2%. At the petrol pump, however, the percentage increase seen by the consumer will be much smaller, as around three quarters of the price of fuel to the consumer is made up of excise duties and VAT.

It is important to note that consumers using EURO IV vehicles will benefit from the use of a fuel that improves fuel efficiency. For each unit of fuel they save not only do they not have to pay the production cost, but they also do not pay tax to the fiscal authority. The high rate of tax therefore provides an indirect stimulus for penetration into the market of sulphur-free fuel for those vehicles, which benefit from an improvement in fuel efficiency.

However, the benefit to the consumer of reduced tax payments is off-set by the losses of revenue to the tax authority, so there is no net saving for society as a whole in that regard. Therefore, in examining the costs of introducing sulphur-free fuel we focus only on the additional refining cost and the value of any fuel savings excluding taxes.

3.5.2. "Homologation effect"

As the EURO IV vehicle emission standards have already been fixed in legislation it can be argued that reducing the levels of sulphur in fuels to below 10 ppm (from 50 ppm) will have no further effect on emissions of regulated pollutants (NOx, CO, PM, Hydrocarbons). This is because there is no obligation on manufacturers to produce vehicles that perform better than the mandated standard. As there is no minimum sulphur content for type-approval reference fuels a vehicle can be certified on sulphur-free fuel although in practice it would actually use a higher sulphur fuel. Consequently, for the purposes of this analysis no conventional pollutant benefits have been assumed for EURO IV vehicles.

3.5.3. Representative years

For simplicity, figures for the EU as a whole are presented although the underlying analysis was performed on an individual Member State basis. Figures disaggregated by Member State can be found in Annex 2. Information for three representative years (2005 or 2007; 2012 and 2020) is given rather than a complete time series for the period 2005-20 or 2007-20 though this is available.

3.5.4. EU-9 vs whole Community

As the Member States in the TREMOVE model represent 88% of the final energy demand for the road transport sector, the results in this analysis are representative for the EU as a whole[10]. In this analysis, none of the accession countries have been included. It is unlikely that the results would change qualitatively if the accession countries were included. However, the rate of penetration of sulphur-free fuel might change slightly because of different vehicle stock turn-over times.

3.5.5. Fate of removed sulphur

It is also assumed that the extra amount of sulphur left in the refineries is disposed of without additional environmental harm. Implicitly, it is assumed that the extra cost of removing sulphur in the refineries includes the cost of its disposal.

3.5.6. Other greenhouse gases

It is possible that lowering the sulphur content of petrol would have other benefits that have not been covered in this analysis, e.g. reduced emissions of nitrous oxide (N_2O) from petrol cars fitted with three way catalytic converters. These have not been included in the analysis.

4. ANALYSIS OF A PHASED-IN INTRODUCTION OF ULTRA SULPHUR-FREE FUEL TO PASSENGER VEHICLES FROM 2005 OR 2007 ONWARDS

4.1. "Main Scenario 2005" : Introduction of sulphur-free fuel in 2005

The analysis in this section assumes that sulphur-free petrol and diesel fuels are introduced gradually into the market at the beginning of 2005 as described in section 2.1.

Initially, these fuels are likely to be used only by those vehicle types (EURO IV) which require sulphur-free fuel to operate optimally. This will include new passenger cars, light commercial vehicles and heavy-duty trucks and buses. It is then assumed that in 2011 all of the petrol and diesel sold in the EU will be required to be sulphur-free.

To model the introduction of sulphur-free fuels in a phased manner between 2005 and 2010 it has been assumed that only vehicles that derive an improvement in fuel efficiency will make use of sulphur-free fuel. Consequently, the value of fuel savings is higher than the additional refining costs during the phase-in period 2005 up to 2011 (see Figure 1).

10 Thus, no analysis has been carried out for Austria, Belgium, Denmark, Luxembourg, Portugal and Sweden. DG Environment has plans of increasing the coverage of the TREMOVE model to these (and Accession) countries in 2001-2002.

Table 4: "Main scenario 2005" - Costs, benefits and emissions reductions

Sulphur-free fuels introduced from 2005		2005	2012	2020
CO$_2$ emissions changes				
Change in CO_2 emissions in refineries, (kT)		215.7	5,348.3	5,404.3
CO_2 change from cars (3% petrol 2% diesel), (kT)		-562.8	-8,241.6	-14,960.5
Net change (- = decrease in CO2 emissions)		**-347.1**	**-2,893.2**	**-9,556.2**
Costs and Benefits, € million				
Increase in refining costs (average per year)		-39.0	-816.9	-831.4
Savings due to lower fuel consumption (average)		54.1	795.5	1,441.2
Benefits from better air quality		0.0	221.1	3.7
Net benefits (- depicts net costs)		**15.1**	**199.7**	**613.5**
Net Present Value (4%), €million	**2,673.5**			
Changes in air related emissions				
NOx, kilotonnes		0	-28.5	-0.5
VOC, kilotonnes		0	-10.6	-0.2
CO, kilotonnes		0	-135.9	-4.7
PM, tonnes		0	-280.8	-8.0

Note. All costs are without VAT or excise duties. For emissions negative signs indicate reductions, for benefits negatives signs indicate net costs. The above analysis has assumed a phased introduction of zero sulphur fuels in 2005.

Figure 1: Main Scenario 2005, € million

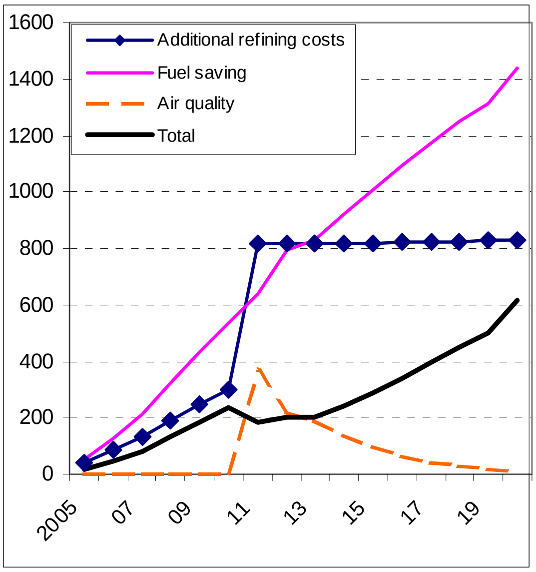
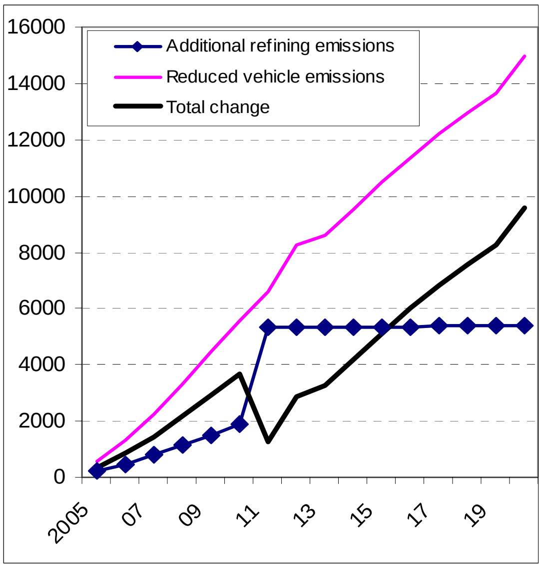


Figure 2: Main Scenario 2005, kilotonnes of CO_2



However, all vehicles will have to use sulphur-free fuel following its full introduction in 2011, including those older vehicles that do not derive any fuel economy benefits. There are therefore additional costs associated with refining larger quantities of sulphur-free fuel that are not balanced by fuel savings. In Figure 1 this appears as an upward spike in refining costs with no corresponding increase in fuel savings. The result is that the gap between fuel savings and refining costs narrows. From 2011 onwards however the fuel savings and additional refining costs lines diverge as more new vehicles enter the fleet, and so the number of vehicles that derive fuel efficiency savings from sulphur-free fuel increases.

In Figure 2 the line showing the net CO_2 balance dips for the same reason. In 2011 the introduction of sulphur-free fuel for older vehicles leads to a significant CO_2 penalty, but this falls over time with fleet turnover.

For the period 2005–2011 there are no reductions in emissions of conventional pollutants as only new EURO IV vehicles use sulphur-free fuel. Following the switch to full production of sulphur-free fuel from 2011 there are some reductions in the emissions of conventional air pollutants from older vehicles that yield improvements in air quality. However, as the number of older vehicles in the fleet falls these benefits decrease to zero. Values for the benefit per tonne of pollutant reduced for conventional pollutants are given in Annex 3.

The impact of this main scenario is a net present value of the benefits of €2.7 billion and reduction of the CO_2 emissions of 2.6 Mt of CO_2 per annum during the first commitment period of the Kyoto Protocol (2008-2012) (see Table 4). This is primarily due to a relatively long period where fuel costs savings can accrue and because of the fairly large number of vehicles in the fleet, which benefit from the use of sulphur free-fuels.

4.2. "Main Scenario 2007": Introduction of sulphur-free fuel in 2007

This scenario differs from the one above in that sulphur-free fuels are introduced two years later (1 January 2007). The results are set out in Table 5 and Figures 3 and 4.

The impact of this main scenario is a net present value of €1.1 billion and a smaller reduction of the CO_2 emissions of 1.8 Mt of CO_2 per annum during the first commitment period of the Kyoto Protocol (2008-2012). These numbers are smaller than in "Main Scenario 2005" primarily due to a short period where fuel costs savings can accrue and because of the decreased numbers of vehicles in the fleet which benefit from the use of sulphur free-fuels.

Table 5: "Main scenario 2007" - Costs, benefits and emissions reductions

Sulphur-free fuels introduced from 2007		2007	2012	2020
CO_2 emissions changes				
Change in CO_2 emissions in refineries, (kT)		407.0	5,348.3	5,404.3
CO_2 change from cars (3% petrol 2% diesel), (kT)		-1,245.9	-6,850.0	-13,574.9
Net change (- = decrease in CO2 emissions)		**-838.9**	**-1,501.7**	**-8,170.6**
Costs and Benefits, € million				
Increase in refining costs (average per year)		-75.4	-995.0	-1,019.0
Savings due to lower fuel consumption (average)		120.5	661.6	1,309.1
Benefits from better air quality		0.0	304.1	18.3
Net benefits (- depicts net costs)		**45.2**	**-29.3**	**308.4**
Net Present Value (4%), €million	**1,061.2**			
Changes in air related emissions				
NOx, kilotonnes		0	-39.0	-2.5
VOC, kilotonnes		0	-14.4	-0.9
CO, kilotonnes		0	-176.8	-9.9
PM, tonnes		0	-366.7	-11.8

Note. All costs are without VAT or excise duties. For emissions negative signs indicate reductions, for benefits negatives signs indicate net costs. The above analysis has assumed a phased introduction of zero sulphur fuels from 1 January 2007.

Figure 3: Main Scenario 2007, € million

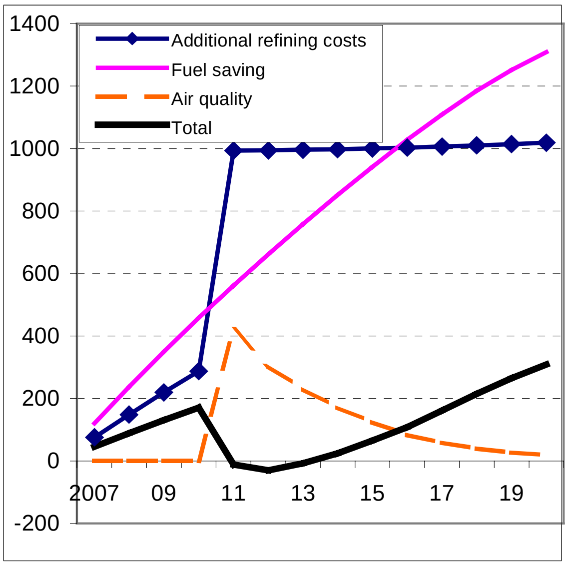
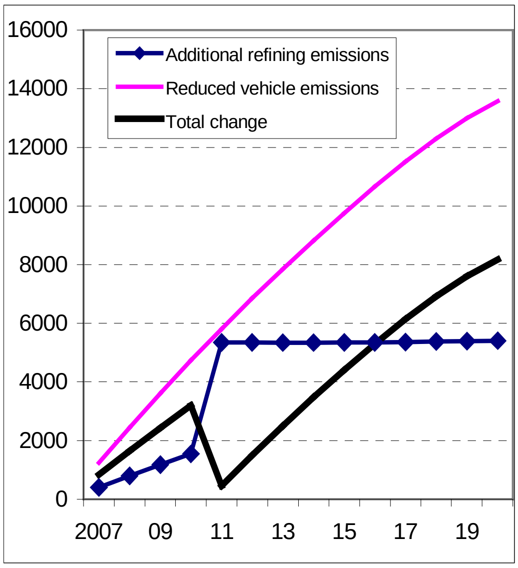


Figure 4: Main Scenario 2007, kilotonnes of CO_2



4.3. "Phased-In" Scenario: Phased introduction for all vehicle types in 2007

This scenario assumes that sulphur-free fuel is introduced in line with the number of vehicles that can benefit from a fuel efficiency improvement. The assumption is, therefore, that sulphur-free fuel is available for those who are able to take advantage of its improved fuel efficiency, but it is not compulsory. This scenario includes cars, light duty vehicles, buses and trucks. The results are set out in the Table 6 and Figures 5 and 6 below.

Table 6: "Phased-In 2007 for all vehicles" - Costs, benefits and emissions reductions

Sulphur-free fuels introduced at a rate required by new EURO IV vehicles from 2007		**2007**	**2012**	**2020**
CO_2 emissions changes				
Change in CO2 emissions in refineries, kilotonnes		407.0	2,241.6	4,455.1
CO2 change from cars (3% petrol 2% diesel), kilotonnes		-1,245.9	-6,850.0	-13,574.9
Net change (- = decrease in CO2 emissions)		**-838.9**	**-4,608.4**	**-9,119.8**
Costs and Benefits, € million				
Increase in refining costs (average)		-75.4	-417.7	-841.2
Savings due to lower fuel consumption (average)		120.5	661.6	1,309.1
Net benefits (-=net costs)		**45.2**	**243.9**	**467.9**
Net Present Value (4%), €million	**2,755.3**			

Note: All costs are without VAT or excise duties.

Figure 5: Phased in Scenario (all vehicles) from 2007, € million

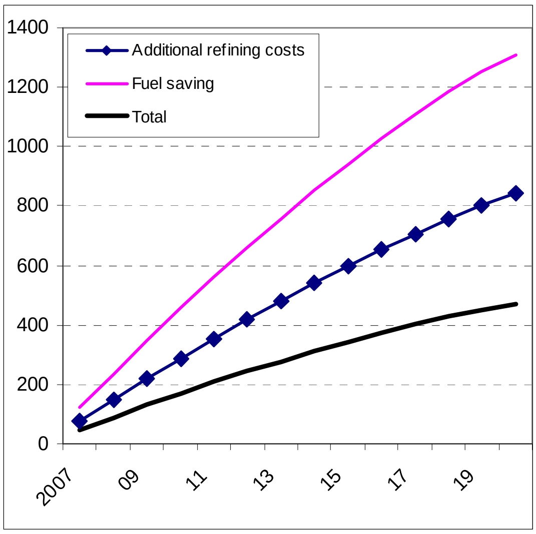
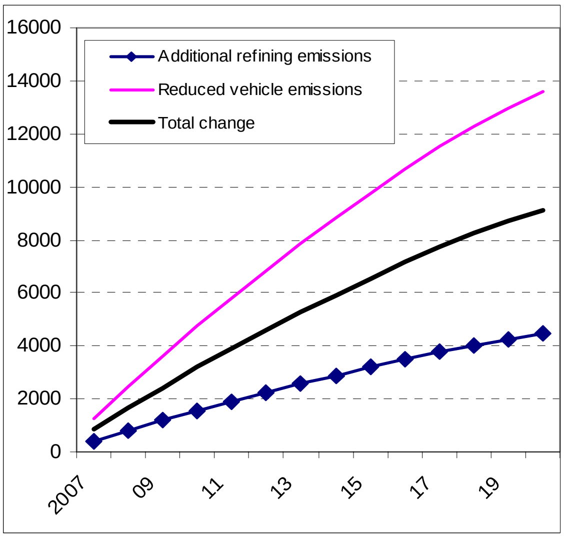


Figure 6: Phased in Scenario (all vehicles) from 2007, kilotonnes of CO_2



As the assumed percentage improvement in fuel efficiency outweighs the additional percentage increase in costs of refining, the value of fuel savings is consistently higher than the additional refining costs. This is because only vehicles that derive a benefit in fuel efficiency switch to sulphur-free fuel. The gap between the refining cost and fuel saving lines in Figure 5 widens as the number of vehicles in the fleet deriving a fuel efficiency saving grows over time with stock turnover. A similar story explains the CO_2 balance in Figure 6.

4.4. "100% Switch for Passenger Cars in 2007" Scenario

The compulsory use of sulphur-free fuels by all passenger cars from 2007 onwards has been analysed. Other vehicle types are assumed not to use sulphur-free fuels. Table 7 and the Figures 7 and 8 below show the costs and benefits and CO_2 balance if sulphur-free fuel is used by all passenger cars (but not by trucks and vans)[11].

Mandatory use of sulphur-free fuel would ensure full take up by EURO IV vehicles that derive an improvement in fuel efficiency. But it would also imply the use of sulphur-free fuel by older cars that derive no improvement in fuel efficiency. The effect is that the additional refining costs in 2007 are higher than the value of fuel savings. In addition, for older vehicles the net "well to wheel" effect of sulphur-free fuel on CO_2 is negative, due to the higher CO_2 emissions at the refining stage. Therefore, the mandatory introduction of sulphur-free fuels in 2007 leads to an immediate CO_2 penalty whose eventual scale would depend on developments in refining technology. This is evident in Figure 8, where the CO_2 balance is negative for the first few years.

The overall effect on CO_2 will clearly depend on the relative balance of EURO IV and later vehicles in the fleet. As the number of EURO IV vehicles in 2007 will be small the balance is negative to begin with, but this gradually changes over time as the number of EURO IV vehicles in the fleet grows. A cross over date occurs when the net effect of the introduction of sulphur-free fuels moves from negative to positive in terms of the balance between refining costs and fuel savings, and in terms of CO_2. This cross over point will vary by Member State depending on how quickly the vehicle fleet turns over, but for the EU as a whole the date is estimated to be around 2010.

On the other hand, it is expected that use of lower sulphur fuels would reduce conventional (non-CO_2) emissions in pre-EURO IV cars. The air quality improvements constitute a significant benefit in the first few years, but they fall away over time as older (EURO III and before) vehicles exit the fleet. The figures make the conservative assumption that there is no reduction in conventional pollutants from EURO IV cars using sulphur-free petrol.

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[11] Although the inclusion of trucks and vans would change the exact figures, we would not expect the results to change qualitatively.

Table 7: "Cars Only in 2007 for all vehicles" - Costs, benefits and emissions reductions

Mandated sulphur-free fuels for all cars in 2007		**2007**	**2012**	**2020**
CO_2 emissions changes				
Change in CO2 emissions in refineries, kilotonnes		3,196.6	3,090.1	3,022.0
CO_2 change from cars (3% petrol 2% diesel), kilotonnes		-1,245.9	-6,850.0	-13,574.9
Net change (- = decrease in CO2 emissions), kilotonnes		**1,950.6**	**-3,759.9**	**-10,552.9**
Costs and Benefits, € million				
Increase in refining costs (average)		-452.8	-436.7	-427.4
Savings due to lower fuel consumption (average)		86.4	472.1	927.2
Benefits from better air quality		578.4	118.4	6.5
Net benefits (-=net costs)		**212.0**	**153.8**	**506.3**
Net Present Value (4%), €million	**2,594.4**			
Changes in air related emissions (- depicts reduction)				
NO_x, kilotonnes		-78.3	-16.1	-0.9
VOC, kilotonnes		-53.8	-7.7	-0.4
CO, kilotonnes		-662.3	-163.1	-8.9
PM, tonnes		-439.5	-113.9	-7.4

Note: All costs are without VAT or excise duties.

Figure 7: Sulphur-free fuel to all cars in 2007 ("Cars only Scenario"), € million

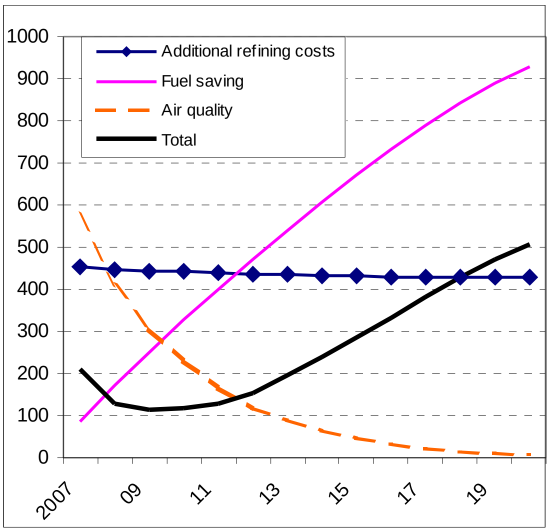
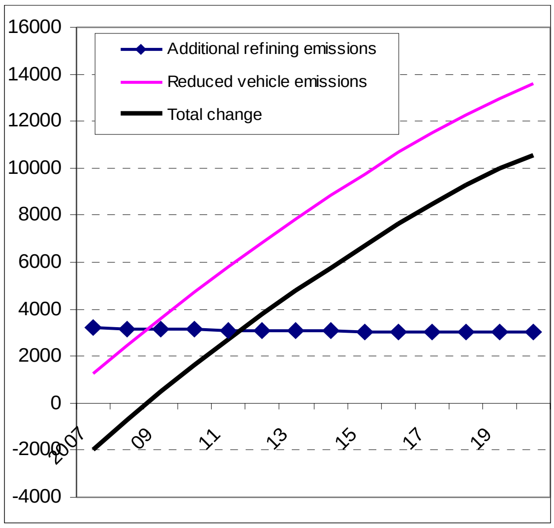


Figure 8: Sulphur-free fuel to all cars in 2007 ("Cars Only Scenario"), kilotonnes of CO_2



4.5. "Phased Introduction for Passenger Cars from 2007" Scenario

This scenario is identical to the "all vehicle phase-in" scenario, except that the take up of sulphur-free fuels is limited to passenger cars. As a much smaller proportion of cars run on diesel as compared to light duty vehicles or trucks, this scenario helps differentiate between the cost & benefits of sulphur-free petrol and diesel. Table 8 and Figures 9 and 10 below.

Table 8: "Phased introduction to Passenger Cars Only in 2007 for all vehicles" - Costs, benefits and emissions reductions

Sulphur-free fuels introduced at a rate required by new EURO IV passenger cars from 2007		**2007**	**2012**	**2020**
Changes in CO_2 emissions				
Change in CO_2 emissions in refineries, kilotonnes		239.2	1,299.6	2,527.1
CO_2 change from cars (3% petrol 2% diesel), kilotonnes		-846.8	-4,609.2	-8,984.6
Net change (- depicts decrease in CO_2 emissions)		**-607.6**	**-3,309.6**	**-6,457.5**
Costs and Benefits, € million				
Increase in refining costs (average)		-34.0	-184.4	-358.5
Savings due to lower fuel consumption (average)		82.3	447.3	871.6
Net benefits (-=net costs)		**48.3**	**262.9**	**513.2**
Net Present Value (4%), €million	**2,987.4**			

Note: All costs are without VAT or excise duties.

Figure 9: Phased in Scenario (cars only) from 2007, € million

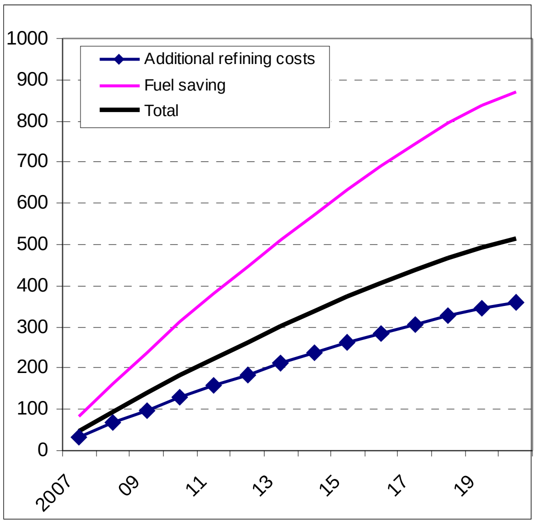
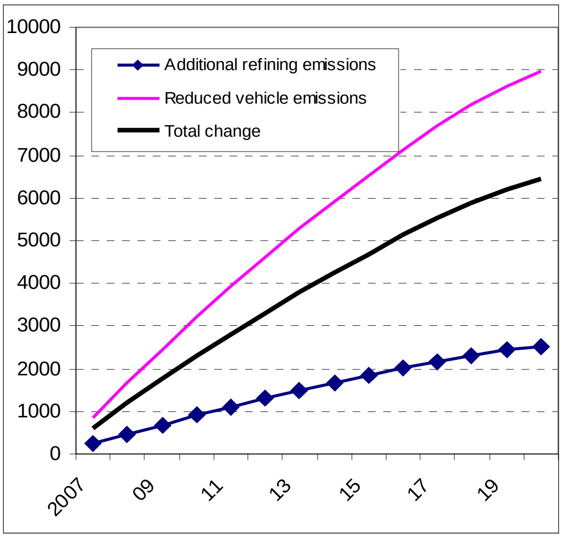


Figure 10: Phased in Scenario (cars only) from 2007, kilotonnes of CO_2



The shape of the curves is very similar to that for the "all vehicle phase-in" scenario above. As the assumed percentage improvement in fuel efficiency outweighs the additional percentage increase in costs of refining, the value of fuel savings is consistently higher than the additional refining costs. This is because only vehicles that derive a benefit in fuel efficiency switch to sulphur-free fuel.

The essential difference between the scenarios is that the total benefits are higher in the cars only scenario. This is because the additional costs of refining sulphur-free diesel are higher than for sulphur-free petrol, while the assumed fuel efficiency improvement for diesel vehicles is smaller. Therefore, there are net costs for diesel. Including trucks, buses and light duty vans therefore raises total costs more than it raises the value of fuel savings, and so the net benefits of the all vehicle phase-in are lower than for the car-only phase-in.

5. SUMMARY

This paper has examined the effects of shifting to sulphur-free petrol and diesel, comparing the effects on emissions of CO_2 and other pollutants and costs of five different scenarios, each of which is explained in detail in Section 2. The complete numerical results are explained in Section 4. Figures in this paper are for the EU as a whole, but it is possible that there are differences between Member States. The main results from the analysis are summarised in Table 9.

Table 9: Summary Results of the Scenarios

	Reduction of CO_2 during 2008-12		Reduction in CO_2 2013-20		Net present value (4%) € billion
	Total Mt CO_2	Per annum Mt CO_2	Total Mt CO_2	Per annum Mt CO_2	
Main Scenario: Introduction in 2005	12.9	2.6	50.8	6.3	2.7
Main Scenario: Introduction in 2007	9.2	1.8	44.5	5.6	1.1
Phased-in Scenario (all vehicles) from 2007	15.8	3.2	58.8	7.3	2.8
Cars only Scenario in 2007	7.8	1.6	63.1	7.9	2.6
Phased-in Scenario (cars only) from 2007	11.4	2.3	41.9	5.2	3.0

Note: Net Present Values (calculated using a 4% real discount rate) include net financial and air quality benefits

- The balance between pure financial benefits (fuel savings versus refinery costs), net CO_2 emission reductions and air quality benefits varies from scenario to scenario. The air quality benefits are not reported separately, but their impact is included in the net present value of benefits.

- For all scenarios considered, the accumulated benefits (financial and air quality) are higher than the costs and there is a positive effect on overall CO_2 emissions over the period considered. During the first commitment period of the Kyoto Protocol (2008-12) the CO_2 reductions are estimated to be between 1.6 and 3.2 Mt of CO_2 per annum depending on how sulphur free fuel is phased in to the market. After the first commitment period the CO_2 savings are between 5.2 and 7.9 Mt of CO_2 per annum on the average i.e. about 1% of CO_2 emissions of road transport.

- Air quality considerations would tend to favour an earlier date for the full introduction of sulphur-free fuels due to their positive effect on emissions from existing fleet of vehicles, whilst a consideration of CO_2 emissions would tend to favour a more progressive introduction of sulphur-free fuels. Obviously this balance is sensitive to technology development in the auto and refining industries and its impact on CO_2 emissions.

- The analysis seems to indicate that for petrol vehicles the benefits of a phased introduction in financial and CO_2 terms are very significant. For diesel the CO_2 balance is positive, but the economics are more sensitive to the initial assumptions about additional refining costs and fuel efficiency savings.

ANNEX 1 - ASSUMPTIONS REGARDING VEHICLE EMISSIONS

The quantification of vehicle emissions benefits resulting from the introduction of fuels containing a maximum 10 ppm sulphur are compared to similar vehicles using petrol and diesel containing a maximum of 50 ppm sulphur. This follows from the fact that vehicle emissions standards have already been fixed for new vehicles manufactured post-2005. In addition, the sulphur content of petrol and diesel sold after 1st January 2005 has also been fixed at 50 ppm.

The assumptions described briefly below are based upon the evidence submitted in response to the Commission's "Call for Evidence" which is summarised in the report prepared by AEA Technology.

Light duty diesel vehicles

Future technologies & fuel economy

From the responses to the Commission's "Call for Evidence" it appears that in order to attain the Euro IV emissions limits light duty diesel vehicles will have to employ one or more emission control technologies. These include NOx storage traps (NSTs), enhanced exhaust gas recirculation, selective catalytic reduction, more active oxidation catalysts, diesel particulate filters.

The use of NSTs in themselves would lead to a fuel economy disbenefit (about 3%) but the combustion optimisation which NSTs make possible (up to 15%) is likely to more than offset this[12]. There is a doubt about the viability of NSTs in the absence of 10 ppm sulphur diesel due to a possible inability to desulphate under certain operating conditions where the exhaust temperature is too low. In any event the NOx regeneration frequency will vary as function of sulphur content of the diesel fuel. Increased regeneration frequencies will lead to a fuel economy penalty.

Diesel particulate filters (DPFs) are affected in several ways by sulphur in the diesel fuel. Firstly, regeneration temperatures can be increased at higher sulphur levels which is of importance in some low-speed applications. Less efficient regeneration results in increased back pressure that in turns results in a fuel economy penalty. Reduced levels of fuel sulphur also results in less ash (calcium sulphate) being deposited on the filter that in turns reduces "clogging" and so improves fuel economy. In continuously regenerating DPFs the upstream oxidation catalysts- can increase the particulate matter emissions due to oxidation of the fuel borne sulphur to sulphate. This sulphate can also clog the DPF resulting in an increased back pressure and a fuel economy penalty. In summary, the use of DPFs with diesel containing 10 ppm sulphur can reduce fuel consumption by 3% relative to diesel containing 50 ppm sulphur[13].

Current diesel vehicles use exhaust gas re-circulation (EGR) and oxidation catalysts to meet the emissions limits for NOx, PM, carbon monoxide and hydrocarbons. Moving to lower sulphur diesel fuel will allow more active oxidation catalysts to be developed as

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12 Submission to the "Call for Evidence" from the Association for Emissions Control by Catalyst, 28th July, page 13.

13 FEV Report Nov 1999, *Influence of the Sulphur Content on fuel fuel consumlption and pollutant emissions of vehicles with gasoline and diesel engines.*

less particulate sulphate will be generated. In addition, this will permit the use of more EGR that means that the combustion can be better optimised for fuel economy.

The consensus from the “Call for Evidence” was that lowering the sulphur content of diesel to 10 ppm would lead to a better performance of these technologies leading to improved fuel economy. From the available reported data it would appear that a conservative estimate of the fuel economy improvement gained from using diesel fuel with 10 ppm sulphur (relative to fuel containing 50 ppm fuel) would be of the order 1-3%.

Existing vehicles and conventional pollutant emissions

No information was submitted in response to the “Call for Evidence” which addresses the emissions reductions in NOx, hydrocarbons and carbon monoxide following a switch to diesel fuel containing less than 10 ppm. In the benefits estimates presented here, no emissions reductions have been assumed for these pollutants from Euro III and earlier light duty diesel vehicles.

Information was however submitted regarding emissions of particulate matter. The FEV report[14] cites tests that show that a reduction of the sulphur content from 50 ppm to 10 ppm yields a reduction in emissions of particulate matter of 5%. In the absence of more detailed information this reduction has been applied to Euro I, Euro II and Euro III cars. Both Euro II and Euro III vehicles are fitted with oxidation catalysts and are expected to respond to lower sulphur levels in a similar fashion. If anything greater benefits are expected from Euro III vehicles as they are likely to have more active catalysts. The after treatment technologies on EURO IV vehicles are expected to be even more sensitive to sulphur though no emissions reductions have been assumed for these vehicles because of the “homologation” effect (see below).

Heavy Duty Diesel vehicles

It is expected that new heavy-duty diesel vehicles will need to employ after-treatment technologies to control emissions of particulate matter and nitrogen oxides. These include diesel particulate traps, catalytic DPFs and continuously regenerating traps etc. and Exhaust Gas Recirculation or Selective Catalytic Reduction for NOx control. SCR devices also contain oxidation catalysts to enhance the efficiency and also to ensure removal of the reductant. The performance of all these technologies is affected by sulphur as described above and a lowering off the sulphur content is expected to permit a similar improvement in fuel economy (i.e. 1-3%).

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[14] FEV Report Nov 1999, *Influence of the Sulphur Content on fuel fuel consumlption and pollutant emissions of vehicles with gasoline and diesel engines*. Page 16

Light duty petrol vehicles

Future petrol vehicles and fuel economy

The automobile manufacturers have indicated that lean-burn gasoline direct injection (GDI) will become the dominant technology for petrol passenger cars. Manufacturers have indicated that some 90% of new petrol car sales will be GDI by 2008[15].

The GDI technology is reliant upon the NOx Storage Trap (NST) in order for such vehicles to comply with the EURO IV emissions standards for NOx. Much information was submitted in response to the Commission's "Call for Evidence" regarding the impact of sulphur on NSTs. The consensus reached by the review was that there is a fuel economy improvement of between 1-5% of the GDI technology (with NSTs) from using petrol containing less than 10 ppm sulphur instead of petrol with 50 ppm sulphur.

Existing petrol cars and conventional pollutants

There is a reasonable amount of information regarding the emissions reductions may be observed if existing petrol cars fitted with 3-way catalytic converters are switched to using petrol containing a maximum 10 ppm of sulphur (rather than 50ppm). There are estimates based upon the results of European Programme on Emissions, Fuels and Engine Technologies and other more recent studies from the USA. Using the EPEFE study emissions reductions of the order of 1% would be expected. However, some have criticised whether the EPEFE programme is appropriate as it did not study fuels with very sulphur-free contents, it only looked at EURO II vehicles and it used relatively un-aged catalysts.

Various responses to the Commission's Call for Evidence cited emissions reductions in the range 13-21%[16]. Indeed one response cited reductions 2 to 3 times greater than these. These figures include a mixture of different test methodologies with catalysts of different ages and different generations of catalysts. For example, it has been reported and that the performance of newer catalysts is more sensitive to the level of sulphur in petrol particularly at low levels.

A conservative estimate has therefore been used to quantify the overall benefits. It has been assumed that emissions from all 3-way catalysts (Euro I, II, III) are reduced by 10% when using petrol containing 10 ppm of sulphur (relative to 50ppm). This may underestimate the impact for newer catalysts but is in line with the conclusions of the FEV report[17] that states that reductions of between 10 to 15% can be expected.

New light duty petrol & diesel vehicles & conventional emissions

The emissions standards of new vehicles for 2005 and beyond (Euro IV) are already fixed in the directives resulting from the Auto Oil I programme.

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15 The Agreement by ACEA with the European Commission to reduce the CO_2 emissions of new passenger cars in the European Community.

16 AEA technology, November 2000. Consultation on the need to reduce the sulphur content of petrol and diesel fuels below 50 ppm. Page 14-15.

17 FEV Report Nov 1999, *Influence of the Sulphur Content on fuel fuel consumlption and pollutant emissions of vehicles with gasoline and diesel engines*. Page 4

It can be argued, therefore, that there should be no discernible reduction in the in-service pollutant emissions from these vehicles when using fuels containing 10 ppm sulphur relative to fuels containing 50 ppm sulphur (The so-called "*homologation effect*"). The rationale for this is that it is unlikely that manufacturers will construct vehicles to perform better than the mandated emissions standards.

This necessarily assumes that the in-service vehicle emissions are the same as those measured during the vehicle certification process. However, fuels used for type-approval do not have to meet any binding minimum sulphur content. In principle, therefore, it is possible that the vehicle certification process could use near zero sulphur fuels whilst the same vehicles would encounter fuels with a higher sulphur content whilst actually on the road. This would very likely result in increased emissions relative to those measured during certification. In such circumstances, the introduction of near zero sulphur fuels would return the levels of on-road emissions back to the certificated levels.

For the purposes of this analysis sensitivity cases have been investigated which exclude potential emissions reductions from new post-2005 cars.

ANNEX 2 – RESULTS PER MEMBER STATE ("MAIN 2005" SCENARIO)

The Net Present Values of the benefits and CO_2 emissions reductions are presented for the "Main 2005" Scenario and the corresponding CO_2 emission reductions are given in Table A.1 below for the Member States that are included in the TREMOVE model.

Table A.1 Results of Main Scenario 2005 by Member State (EU-9)

Member State	NPV (2005-2020) € million	Average annual CO_2 emissions reductions (kt)	
		2008-2012	2013-2020
Finland	31.1	28.0	81.5
France	283.3	463.1	1211.7
Germany	1.088.7	765.1	1.685.8
Greece	70.1	79.1	199.1
Ireland	28.5	19.7	48.4
Italy	545.6	371.9	955.9
Netherlands	170.9	108.5	273.9
Spain	302.4	273.5	689.9
United Kingdom	152.9	480.9	1199.8
EU-9	**2673.5**	**2589.7**	**6346.0**

ANNEX 3 – MONETARY VALUATION OF REDUCTIONS IN NON-CO_2 POLLUTANTS

The results in Tables 4-8 show reductions in tonnes per annum of emissions in nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC) and particulate matter (PM) from a mandatory introduction in sulphur-free fuel. These reductions have a direct benefit on human health and the environment. In order to provide some indication of the importance of these reductions in conventional pollutants we have converted them into monetary form. We have done this by attaching a simple cost per tonne to each tonne reduction, based on estimates produced under the DG RTD EXTERNE programme.

The national implementation reports for EXTERNE[18] provide figures for damage costs per tonne for NOx and particulate matter by Member State. Figures for the effects of VOCs were obtained from an EXTERNE collaborator[19]. The basic approach adopted in the EXTERNE programme to calculate monetary effects was "bottom up" – that is, starting by identifying changes in concentrations in pollution in air linked to emissions reductions, then used a dose-response functions to calculate impacts on the stock at risk. The number of cases is thus derived, and a total monetary damage costs is derived by multiplying impacts by the value attached to each case.

There is some debate about the appropriate methodologies for valuing small changes in risk. The approach taken in the latest EXTERNE work is to use an approach that attaches a monetary value to each year of life lost as a result of premature mortality. This "value of life year" or VOLY approach tends to put a relatively low weight on "acute" deaths – impacts on those who are already chronically ill, and where the main effect is to advance death by around 6 to 12 months. The VOLY approach therefore tends to provide lower estimates than the commonly used alternative method, the "value of a statistical life" or VOSL approach.

Although the DG ENV preferred position is to use a value of statistical life approach, we have used the EXTERNE approach here for simplicity. The figures used for each country (see Table A.2) are the bottom end of the ranges reported in the EXTERNE national implementation reports. The figures include both chronic (long term) and acute (short-term) effects, both valued using a VOLY approach. These figures could therefore be seen as providing a fairly conservative estimate of the monetary benefits from reducing conventional pollutants.

18 See http://externe.jrc.es

19 Correspondence with Mike Holland of AEA Technology.

Table A.2 Values for non-CO_2 pollutants by Member State used in this analysis, € per tonne of pollutant

Member State	Particulate Matter	NOx	VOCs
Finland	1300	900	200
France	6100	10800	1900
Germany	19500	10900	1900
Greece	2000	1200	200
Ireland	2800	2400	500
Italy	5700	4600	800
The Netherlands	15000	5500	1000
Portugal	5600	6000	1100
Spain	4400	4700	800
UK	8000	5700	1000

Sources: For NOx and PM the figures are from the EXTERNE phase III - national implementation reports. See http://externe.jrc.es. . For VOCs the figures for the UK comes from personal correspondence with Mike Holland of AEA who is closely associated with EXTERNE. Figures for other countries for VOC were derived by scaling the UK figure using the NOx figures.