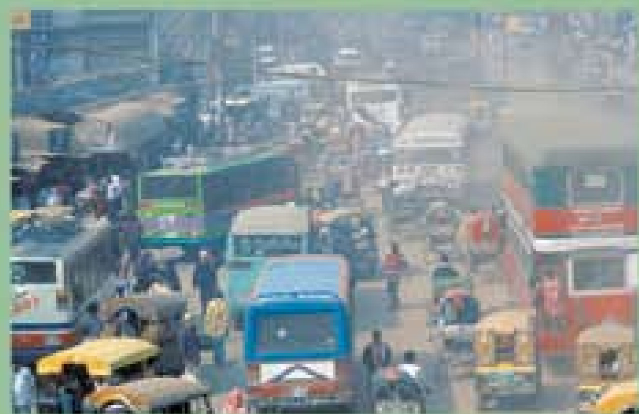
Opening the Door to

Cleaner Vehicles

in Developing and Transition Countries: The Role of

Lower Sulphur Fuels



Report of the Sulphur Working Group of the Partnership for Clean Fuels and Vehicles (PCFV)

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The mission of the Partnership for Clean Fuels and Vehicles (PCFV) is to:

- Help developing and transition countries to develop action plans to complete the global elimination of leaded petrol and start to phase down sulphur in diesel and petrol fuels, concurrent with adopting cleaner vehicle requirements;
- Support the development and adoption of cleaner fuel standards and cleaner vehicle requirements by providing a platform for exchange of experiences and successful practices in developed and developing and transition countries as well as technical assistance;
- Develop public outreach materials, educational programmes, and awareness campaigns; adapt economic and planning tools for clean fuels and vehicles analyses in local settings; and support the development of enforcement and compliance programmes, with an initial focus on fuel adulteration; and
- Foster key partnerships between government, industry, NGOs, and other interested parties within a country and between countries to facilitate the implementation of cleaner fuel and vehicle commitments.

For more information on the PCFV please visit the website: www.unep.org/pcfv or contact the PCFV Clearing House:

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1. Introduction

1.1 About This Publication

This publication provides information to help policymakers in developing and transition countries understand the effects of the presence of sulphur in transportation fuels and the options available to lower sulphur levels to reduce vehicular emissions. The publication provides a general, non-technical overview of the considerations, benefits, and options for the development of policies and actions to reduce the level of sulphur in transportation fuels.

1.2 The Partnership for Clean Fuels and Vehicles (PCFV)

The Partnership for Clean Fuels and Vehicles (PCFV) was launched at the World Summit on Sustainable Development (WSSD) in Johannesburg in September 2002 by a group of committed partners from governments, the private sector, non-governmental organisations, and international organisations. This global Partnership assists developing and transition countries in reducing urban air pollution through the promotion of clean fuels and vehicles. The initial focus is on the elimination of lead in petrol, the phase down of sulphur in diesel and petrol fuels, concurrent with the adoption of cleaner vehicles and vehicle technologies. As several developing and transition countries have made great progress in eliminating lead from petrol, the Partnership's attention is now shifting towards reducing the sulphur levels in transportation fuels.

At the fourth global PCFV meeting which took place on 14 and 15 December 2005 at UNEP Headquarters in Nairobi, Kenya, PCFV partners agreed to aim to reduce sulphur in vehicles fuels to 50 parts per million (ppm) or below world wide, concurrent with clean vehicles and clean vehicle technologies, with roadmaps and timelines developed regionally and nationally.

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1.3 The PCFV Sulphur Working Group

At the first Global Partnership meeting held in New York in November 2002, the Partners agreed on the need to advise developing and transition countries of the benefits of reducing sulphur levels in fuels, and issues that are related to this. For this purpose a Working Group was formed to develop a document to provide information about this topic.

PCFV Partners from government, industry, NGOs, and international organisations participated in this working group. This report, which is the product of the Working Group, describes the general benefits and associated costs of phasing down sulphur in fuels, the impacts on vehicles, and outlines the different options available to developing and transition countries for this purpose. It also provides references to more in-depth information on this topic.

2. How Fuel Sulphur Relates to Air Quality

This section addresses the contribution of the transport sector to urban air quality and the benefits obtained from reducing sulphur in fuels and introducing cleaner vehicles in developing and transition countries and countries with economies in transition.[1]

2.1 Urban Air Quality Issues in Developing and transition countries

The biggest air quality problem in developing and transition countries is air pollution in urban areas. The World Health Organization (WHO) estimates that almost 800,000 people die prematurely each year from urban air pollution.[2] Most of these premature deaths occur in developing and transition countries. In addition to cardiovascular and pulmonary impacts (detailed in section 2.4 below), air pollution can also have serious impacts on pregnancy outcomes and infant health.[3]

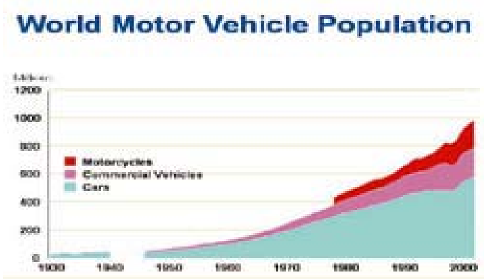
Vehicle emissions are one of a number of contributing factors to poor urban air quality.[4] Key emissions from vehicles include carbon monoxide (CO), unburned hydrocarbons or volatile organic compounds (HC or VOC), nitrogen oxides (NOx), and particulate matter (PM) (see paragraph 2.4 below and Annex 1 for an overview of these pollutants and their effects). These emissions depend very much on the fuels used and the design of the vehicles. It is expected that globally transport will grow rapidly through 2050, resulting in a doubling of worldwide demand for fuels from now to 2050. [5]

Estimates of motor vehicle contribution to urban air pollution worldwide vary anywhere between 25 and 75 percent, depending on pollutant and the location.[6] In many developing and transition countries, conventional vehicle emissions are expected to continue to increase over the next few decades. Given the present poor quality of fuels and vehicles often found in developing and transition countries urban air pollution problems that are now urgent are set to become even worse if no action is taken.

1 In the rest of this report we will use the term 'developing and transition countries' which should be understood to include countries with economies in transition
2 World Health Organisation (2002) Reducing Risks, Promoting Healthy Life
3 World Health Organisation (2005) Effects of Air Pollution on Children's Health and; World Health Organisation (2005) WHO Air Quality Guideline for Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide, Global Update. http://www.who.int/phe/air/aqg2006execsum.pdf
4 Other factors include industrial activity, haze from forest fires, smoke from cooking fires, and burning of wastes
5 World Business Council for Sustainable Development (WBCSD) (August 2004) Mobility 2030: Meeting the Challenge to Sustainability (www.wbcsd.org)
6 For example, a study in Kolkata, India, found that between 21 and 26 percent of the respirable particulate matter comes from mobile sources, while a study in Nepal estimates this is about half, and a study in Mexico City estimates 61% of PM10 emissions are from motor vehicles

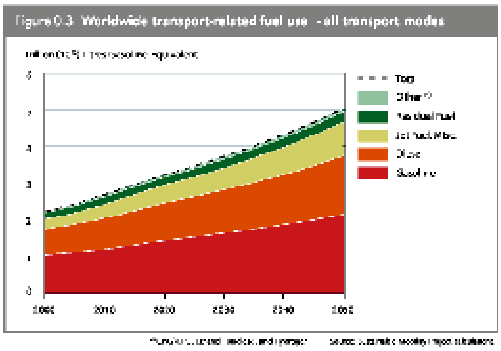
In developed countries emissions have gone down over the past decades. The main contributor to this has been the introduction of cleaner fuels concurrent with the introduction of improved engine technology and after-treatment devices. For petrol vehicles, the introduction of unleaded petrol in the developed countries has paved the way for after-treatment systems, especially catalytic converters. The introduction of very efficient petrol vehicles with additional emissions controls systems will further reduce emissions. For diesel vehicles, there has been significant progress in reducing the level of sulphur in diesel which has gone hand in hand with the introduction of cleaner diesel engines and after-treatment technologies. Further improvements, including advanced after-treatment devices such as particulate traps and catalyst-NOx controls and SCR systems, are being introduced, significantly reducing diesel vehicle emissions. The introduction of low-sulphur diesel fuels has made the introduction of after-treatment technologies possible.

Figure 1a: World Motor Vehicle Population (1930-2000)



source: MP Walsh

Figure 1b: Expected Growth of World-wide Transport-related Fuel Use (2000-2050)[5]



Studies show that developing and transition countries that introduce cleaner vehicles and cleaner fuels will be able to follow developed countries in reversing the trend of increasing vehicular emissions.[7] In this scenario some developing country emissions could be reduced quickly (e.g. lead) and others could begin to decline within a decade or two, even accounting for the growth in vehicles and vehicle use.

2.2 Reducing Vehicle Emissions

Reducing emissions from motor vehicles is an important component of an overall strategy for reducing air pollution, especially in developing country cities. One essential approach to reducing vehicle emissions is to eliminate lead from vehicle fuels and to require – through more stringent emission standards – the use of lower-emitting engine and vehicle technologies that can be enabled by lead removal (e.g. catalytic converters). A decade-long global effort has resulted in more than 90% of the world's petrol now being lead-free.[8]

7 See for example the WBCSD study mentioned in footnote 5

8 The Partnership for Clean Fuels and Vehicles is implementing a campaign to phase out leaded petrol world wide by end 2008. For more information about lead removal and updates on progress on lead elimination worldwide see the website of the Partnership for Clean Fuels and Vehicles (www.unep.org/PCFV)

Another important approach to reducing vehicle emissions – and the focus of this publication – is to lower sulphur levels in vehicle fuels. This will result in immediate reductions of emissions from current vehicles and is a necessary step for enabling the use of improved catalysts, filters, and other technologies that can remove most of the pollution from today's petrol and diesel-fueled vehicles.

In considering whether to adopt these approaches policymakers in each country should weigh several factors, including the importance of the vehicle emission contribution to urban air pollution as well as the comparative costs and benefits of cleaner fuels and vehicles relative to other available strategies.[9]

2.3 Reducing Sulphur-related Emissions

For the last 30 years, air pollution control programmes in developed countries have shown that cleaner fuels and vehicles are an effective pathway to cleaner air. Benefits from cleaner fuels and vehicles programmes in developing and transition countries include lower emissions from the existing fleet through improved fuel quality and enabling the introduction of cleaner vehicles and technology, which additionally reduce transport-related pollution.

Improved fuel quality contributes to lower emissions. In the case of lower sulphur levels, this is specifically in the form of decreased emissions of particulate matter (PM – see the next paragraph for a description of particulate matter and its impacts).

There are substantial emission reductions to be achieved when sulphur in diesel is reduced from very high levels that are common in many developing and transition countries (many developing and transition countries have more than 5,000 ppm in diesel fuels - see Annex 2). Reducing sulphur to very low levels (50 ppm and less) not only reduces PM emissions further but also enables the introduction of emission control technologies that provide even greater emission reductions. [10]

Car manufacturers are continuing to improve the design of engines to improve fuel efficiency and reduce emissions. For example, they are now introducing diesel engines with high pressure injection systems that are more efficient and less polluting. However, these recent diesel engine technologies do not function well with high levels of sulphur in diesel fuels.

Sulphur levels of 500 ppm and below open the door to an assortment of emission control technologies (reviewed in Chapter 4). For diesel vehicles, fuels with 500 ppm or less sulphur enable the introduction of newer vehicles that are equipped with diesel oxidation catalysts. This level of fuel sulphur also makes it possible for certain older diesel vehicles to be retrofitted with emission control technologies – a strategy that is increasingly used in many of the world's larger and more polluted cities. Even greater reductions can be

9 K. Gwilliams, M. Kojima, and T. Johnson (2004) Reducing Air Pollution from Urban Transport, World Bank Press, Washington DC

10 Ultra-fine particulate matter - PM2.5 - emissions are reduced on average by 33.4% when going from 500 ppm diesel to 50 ppm diesel. See: www.bp.com/products/fuels/bp_ecoultra/ulsd_faq.pdf

achieved by going to very low sulphur levels (below 50 ppm) after which diesel particulate filters can be introduced.

For petrol vehicles, reducing sulphur levels to 500 ppm and below improves the performance of catalytic converter systems that are standard in developed countries and are now being introduced in most developing and transition countries through new car sales and second hand car imports. Very low sulphur levels enable the use of the most advanced emission control technologies and may enable the use of fuel efficient lean-burn spark ignition engines

Recognising that fuels and vehicles work together as a system, the greatest benefits can be achieved by combining lower sulphur fuels with appropriate vehicle and emission control technologies .[11] This approach has proven to be more effective than treating fuels, engines, or emission controls separately.

2.4 Vehicle Emissions – Health, Welfare, and Environmental Considerations

Vehicle emissions pose a serious threat to human health and welfare, especially in urban areas; they are of particular concern because exposure to a mixture of air pollutants occurs at ground level where people walk, work, and play. There are significant social and economic benefits to be gained by avoiding the health impacts of disease and premature death caused by air pollution.[12,13] From a public health perspective, the main concern is the contribution of vehicle emissions to the atmospheric levels of six primary pollutants:[14]

• **Particulate matter (PM)** is the term for solid or liquid particles found in the air. Some particles are large or dark enough to be seen as soot or smoke, but fine particulate matter is tiny and is generally not visible to the naked eye. PM emissions from vehicles consist mainly of these tiny particles: coarse (PM10), fine (PM 2.5), and ultra-fine particles (PM of .1 microns or less).[15] PM is either emitted directly or formed in the atmosphere from precursors such as sulphur oxides (SOx) and nitrogen oxides (NOx).
• **Hydrocarbons (HC)** emissions result from incomplete fuel combustion and from fuel evaporation. Hydrocarbons combine with nitrogen oxides, in heat and sunshine, to form ground-level ozone.[16]

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11 Engine oil is part of the fuels-vehicle system. As fuel sulphur levels are reduced the relative sulphur contribution through combusted engine oil becomes more significant and the impact of this on emissions should be taken into account

12 Compared to other health intervention options – see Kseniya Lvovsky (2001) Health and Environment, Annex D, World Bank

13 In the United States, the most recent actions to reduce emissions from mobile sources through cleaner fuels and advanced control technologies have shown that the benefits have far outweighed the cost:
1999 - Cars and light duty vehicles benefits-to-cost ratio = 5:1
2000 - Heavy-duty diesel trucks benefits-to-cost ratio = 17:1
2004 - Non-road diesel equipment (construction, agricultural) benefits-to-cost = 40:1

14 See http://www.epa.gov/air/urbanair/6poll.html

15 PM2.5 is particulate matter finer than 2.5 microns in diameter, or less than 1/100th of the size of the period at the end of this sentence. For more information about particulate matter pollution see: http://www.epa.gov/air/particlepollution/basic.html

16 Ambient particulate matter, especially from diesel vehicles, is associated with two forms of particles: the diesel particulate matter directly emitted from vehicles and with particulate matter formed indirectly in the atmosphere by NOx and SOx emissions (and to a lesser extent HC emissions). In addition, both NOx and HC participate in the atmospheric chemical reactions that produce ozone

• **Nitrogen oxides (NOx)** are formed during the combustion process, i.e. when fuel burns at high temperatures, such as in motor vehicle engines.
• **Sulphur oxides (SOx)** are gaseous emissions formed by the oxidation of fuel sulphur during the combustion process and depend entirely on the level of sulphur in the fuel.
• **Ozone (O_3)** is formed when nitrogen oxides and hydrocarbons react in the presence of heat and sunlight. This is the major component of urban smog.
• **Carbon Monoxide (CO)** is a poisonous gas formed from incomplete (or partial) combustion.

To address the health effects of air pollution a number of countries and the World Health Organisation (WHO) have developed guidelines for determining ambient air quality standards for key pollutants.[17] These guidelines are used in the design of air pollution control programmes from all sources.

In terms of the health impacts of these various pollutants, four are of particular concern – PM, ozone, carbon monoxide, and sulphur oxides. Health effects associated with ambient PM – which can be inhaled deep into the lungs – include premature death, aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days), aggravated asthma, and acute respiratory symptoms. Additional studies have associated exposure to ambient PM with heart disease and changes in heart rate and/or heart rhythm. Diesel PM is of special concern because diesel exhaust has been associated with an increased risk of lung cancer.[18] Finally, scientists increasingly believe that PM can influence the local and global climate. The exact impacts of PM are still under debate; while it is believed that sulphate PM can have a cooling effect it is also believed that carbon PM contributes to the warming of the atmosphere.[19]

As noted above, ground-level ozone pollution (a key component of smog) is formed by the reaction of HC and NOx in the atmosphere in the presence of heat and sunlight. These two pollutants are often referred to as ozone precursors. Ozone can irritate the respiratory system, reduce lung function and make it more difficult to breathe deeply, and inflame and damage the lining of the lungs, which may lead to permanent changes in lung tissue. Recent studies have shown statistically significant links between short-term changes in ozone and mortality.[20] People who are particularly susceptible to the effects of ozone include children and adults who are active outdoors, the elderly, and people with respiratory disease such as asthma.

17 The following are some of the sources for understanding the setting of ambient air quality standards and the actual standards:
- US National Ambient Air Quality Standards: www.epa.gov/ttn/naaqs
- WHO Air Quality Guideline for Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide, Global Update, 2005: www.who.int/phe/air/aqg2006execsum.pdf
- UK Air Quality Standards and Banding: www.airquality.co.uk/archive/standards.php

18 USEPA (2004) Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines, Page 2-55. http://www.epa.gov/nonroad-diesel/2004fr/420r04007c.pdf

19 See e.g.: T. Bond and H. Sun (2005) Can reducing black carbon emissions counteract global warming?, Environmental Science and Technology, 2005, Vol. 39, No. 16, and: M. Jacobson (2002) Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming, 2002, Journal of Geophysical Research, Vol. 107, No. D19

20 Journal of the American Medical Association (17 November 2004) Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000

Carbon monoxide is a colourless, odourless gas produced through the incomplete combustion of carbon-based fuels. Carbon monoxide enters the bloodstream through the lungs and reduces the delivery of oxygen to the body's organs and tissues. The health threat from CO is most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Healthy individuals are also affected, but only at higher CO levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability, and performance of complex tasks. At sufficient concentrations CO poisoning can cause death.

Sulphur oxides (SOx), especially when present as particulate sulphates, have local health and environmental effects, such as impacts on respiratory health and asthma. In addition, SOx emissions result in the acidification of local environments, damaging buildings, and urban greenery (e.g. trees and shrubs). It should be noted, however, that the contribution of vehicle SOx emissions on non-local environmental issues (e.g. acid rain) is minimal compared with other sources, especially industry.[21]

Air pollutants emitted from vehicles are also associated with a number of so-called welfare effects. These effects include atmospheric visibility impairment, ecological and property damage caused by acid deposition, nutrient pollution of surface waters (including eutrophication and nitrification), and plant and crop damage from ozone.

21 For example, in the US, highway and non-road mobile sources contributed only 5% of the nationwide SOx emissions in 2003, while electric utilities contributed 69%. See: USEPA (2003) National Air Quality and Emissions Trends Report: 2003 Special Studies Edition. Chapter 2, page 36. http://www.epa.gov/air/airtrends/aqtrnd03/pdfs/cover.pdf

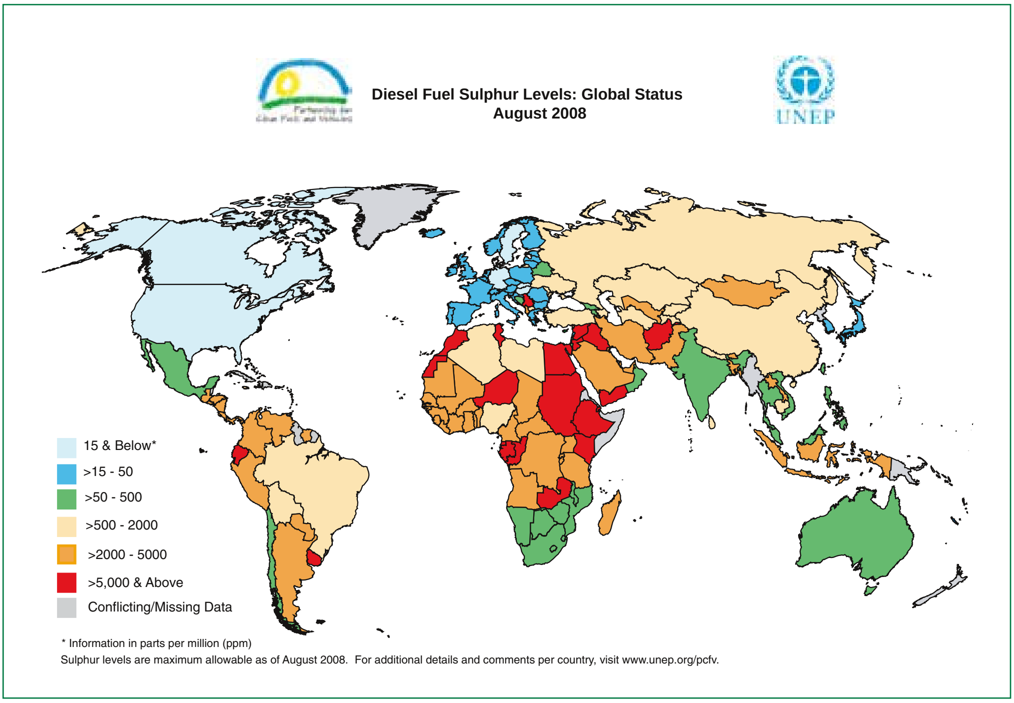
3. Global Snapshot

This section will give an overview of global sulphur levels in fuels and the progress that is being made to reduce them.

3.1 Global Sulphur Levels

Global levels of sulphur in fuels differ greatly, by country and by region. Depending on the crude oil used and the refinery configurations, sulphur levels in petrol range from below 10 ppm to as high as 1,000 ppm or more. In diesel fuel, levels range from below 10 ppm to more than 10,000 ppm. Europe, the US, and Japan have all put in place measures to reduce sulphur to lower levels (below 10-15 ppm), often along with emission standards that require advanced emission control technologies that cannot be used with higher sulphur fuels[22]. Some developing country regions have developed, or are now developing, harmonised standards that will allow them to use a regional approach to lowering sulphur levels and improving fuel qualities in general. Figure 2 gives an overview of diesel sulphur levels worldwide.

Figure 2: Sulphur levels in diesel fuels in parts per million as of August 2008 (see Annex 1 and www.unep.org/PCFV)



22 In concert with these developments, new engine oils have been formulated with greatly reduced levels of sulphate ash, phosphorus and sulphur ("low SAPS") to protect emission control technologies from engine oil sulphur contamination while addressing the performance issues raised by low-sulphur fuels

Around the world, many countries are lowering the limit of allowable sulphur in fuels and adopting tailpipe emission standards to reduce vehicle pollution. However, the global picture is mixed. For example, the majority of African countries have more than 5,000 ppm sulphur diesel. In contrast, many Asian countries, including China and India, are following European standards and are presently at 500 ppm or have announced their intent to meet this target in the next few years.

As of December 2006, the PCFV has updated information regarding sulphur levels and limits for more than 130 developing and transition countries (see Annex 2 for a country-by-country overview). At present (August 2008) about 33% of the countries for which the PCFV has information available have regulatory diesel sulphur levels of 500 ppm or less. Most of these countries are in Central and Eastern Europe and in the Asia-Pacific region. About 14% of the countries are below 2,000 ppm, but above 500 ppm. Within these, there are some that are planning to establish lower sulphur limits. The majority of the countries, approximately 53%, have diesel sulphur levels of more than 2,000 ppm. In fact, most of these countries have diesel with sulphur levels of 5,000 ppm or higher, and about 8% of these countries have allowable levels of 10,000 ppm or more.

This means that 67% of the developing and transition countries for which the PCFV has information do not have fuel of a sufficient quality to allow for and enjoy the benefits of vehicle emission control technologies in widespread use in developed countries.

Table 1 below provides examples of sulphur level limits in selected developing and transition countries.

Country	Current Diesel	Current Petrol	Future Standards
Egypt	5,000 ppm	500 ppm	
Syria	6,500 ppm	1,500 ppm	50ppm planned for 2015
Yemen	10,000 ppm	1,500 ppm	
Mexico	300metro /500rural	500metro /1000 rural	Petrol sulphur levels to reduce to an average 30/80 ppm in January 2009 countrywide; diesel at 15 ppm in January 2009 for urban, September 2009 for rest of country.
Brazil	500metro /2000 rural	1000	Jan 2009 target of 50 ppm for both petrol and diesel (urban) and 500 ppm for rural diesel to coincide with Euro IV standards passenger vehicles. USD 5.5 billion refinery upgrade planned, 13 refineries
Venezuela	5000	1500	2000 ppm diesel, 400 ppm petrol planned for 2010, 5 refineries will be upgraded
South Africa	500 ppm	500 ppm	50 ppm (based on Lusaka-SADC agreement of March 2008)
Zambia	7,500 ppm	1,000 ppm	50 ppm (based on Lusaka-SADC agreement of March 2008)
Ivory Coast	5,000 ppm	1,500 ppm	

4. Fuel Sulphur: a Key to Reducing Vehicle Emissions

This section gives an overview of how sulphur in fuel affects vehicle emissions, and how the presence of sulphur influences the options for introducing emission control technologies. It also presents some options for next steps.

4.1 How Sulphur in Fuel Affects Vehicle Emissions: The Systems Approach

Fuel quality intimately affects vehicle emissions because the vehicle and its fuel (and oil) form an integrated system. The vehicle-fuel system determines the quality and amount of emissions and the extent to which emission control technologies will be able to reduce the emissions. It also determines how well the vehicle operates generally, which affects consumer satisfaction. Understanding this "systems approach" is key to understanding how fuel sulphur affects emissions.

Reducing sulphur levels in fuels is especially important in reducing the smallest particles and can reduce vehicle emissions in two ways:

First, reducing sulphur in fuels reduces direct emissions of both sulphur dioxide and sulphate PM from all vehicles, old and new.[23] Sulphur dioxide (SO2) emissions from diesel and petrol vehicles and particulate matter from diesel vehicles tend to increase in direct proportion to the amount of sulphur in the fuel. While sulphate particles may account for only a small fraction of particle volume or mass, they are fine and ultra-fine in particle size and account for a large fraction of particle numbers.[24]

Second, sulphur poisons or reduces the effectiveness of vehicle emission control technologies for petrol and diesel vehicles, resulting in increased vehicle emissions of carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NOx) and particulate matter (PM). It also poisons or reduces the effectiveness of new types of emission control devices such as advanced catalytic converters and diesel particle traps, which can further reduce NOx, HC, and PM emissions. For petrol vehicles, studies show that lowering sulphur enhances three-way catalyst operation and reduces HC, CO and NOx emissions.[25]

Vehicle emission standards and their associated fuel sulphur limits have evolved dramatically over the past 15 years. A detailed list of such standards for both diesel and petrol

23 Once fuel sulphur levels have been reduced, engine oil sulphur levels must also be taken into consideration. For example to ensure that no oil is leaking into certain engine parts compromising the performance of sulphur sensitive emissions control equipment

24 EPA (2005) Fact Sheet on Diesel Particulates. http://www.epa.gov/NE/eco/airtox/diesel.html and: Health Effects Institute (1995) Diesel Exhaust: Critical Analysis of Emissions, Exposure and Chronic Health Effects. http://www.healtheffects.org/Pubs/diesum.htm

25 See:

* A. M. Hochhauser, C.H. Schleyer and L.I.Yeh, ExxonMobil Research and Engineering Company, and D.J. Rickeard, ExxonMobil Petroleum and Chemical, Impact of Fuel Sulfur on Gasoline and Diesel Vehicle Emissions, SAE conference paper 2006-01-3370
* World Wide Fuel Charter 2006 (4th Edition), pp 16-19, http://www.autoalliance.org/archives/wwfcbrochure.pdf
* USEPA (1999), Regulatory Impact Analysis - Control of Air Pollution from Motor Vehicles: Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements, Appendix B-1. http://www.epa.gov/otaq/regs/ld-hwy/tier-2/frm/ria/r99023.pdf
* MECA (1998), The Impact of Gasoline Fuel Sulfur on Catalytic Emission Systems. http://www.meca.org/galleries/default-file/sulfur.pdf

fueled vehicles is available on the Diesel Net website. [26] Information about the emission impacts of sulphur on various emission control technologies can be found in the Worldwide Fuel Charter. [27]

4.2 Sulphur Impacts on Diesel Engines and Emission Control Technologies

Diesel vehicles are the engines of choice for heavy-duty applications. They provide important fuel economy and durability advantages for large heavy-duty trucks, buses, and non-road equipment used in, for example, construction and agriculture. Recent technological innovations have greatly improved the performance of diesel engines. This, along with their higher fuel economy compared to petrol vehicles, is making their use in passenger vehicles increasingly popular.

Diesel exhaust emissions are a complex mixture of gases, liquid aerosols, and particles. The emissions of concern for diesel vehicles are particulate matter (PM) and NOx, while emissions of HC and CO are low. PM comprises three basic fractions:
• solids (elemental carbon particles);
• soluble organics (heavy hydrocarbons which attach to the carbon particles); and
• sulphates, produced from oxidation of the sulphur burned.

The relative proportions of carbon, organics, and sulphates depend on both vehicle technology and fuel sulphur content. PM emissions from diesel vehicles are an order of magnitude higher than PM emissions from properly functioning petrol vehicles.

Vehicles without any controls will benefit from lower sulphur fuel by directly reducing SO2 and particulate emissions. Vehicles with diesel after-treatment emission control technologies treat engine exhaust to remove pollutants. As part of the exhaust system, the control devices convert or capture pollutants before they leave the tailpipe. All these technologies are sensitive to fuel sulphur to some degree.

4.2.1 New Diesel Vehicles

Europe, the United States, Canada, and Japan are currently in the process of implementing, or are about to implement, very stringent vehicle emission standards. In each case, these countries have also acted to reduce fuel sulphur to ensure that the required emission control technologies operate appropriately and with the greatest efficiency. These latest emission standards will require sulphur to be reduced to ultra low levels (e.g. 15 ppm and below).

Engine Developments

Over the last 15 years, engine manufacturers have introduced a variety of engine modifications to reduce emissions, improve performance and increase efficiency. These modifications include direct injection, high-pressure injection, computer controls, multiple injections, exhaust gas recirculation (EGR), and aftercooling. In the US these modifications

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26 Summary of worldwide emission standards and fuel regulations; http://www.dieselnet.com/standards/
27 See: http://www.autoalliance.org/archives/wwfcbrochure.pdf

have led to significant reductions in overall emissions, including PM and NOx, when compared to uncontrolled diesel engines. Although most of these technologies by themselves do not require specific fuel sulphur levels, most if not all, will be more durable with lower sulphur fuel, which reduces fuel injector corrosion, piston ring corrosion, oil acidification, and overall engine wear.

Exhaust Gas Recirculation (EGR) is a modified engine design where exhaust gas is recycled back to the engine inlet system, which reduces combustion temperature and hence NOx formation. This technique is widely used on many modern engines, but cannot be retrofitted. The EGR control valve can become corroded with high sulphur levels; hence sulphur levels should be restricted to maximum 500 ppm.

High pressure injection systems are used to improve the efficiency of the burning of the diesel/ air mixture in the cylinders, and thus increase fuel efficiency and reduce emissions. One such system that is now introduced, especially in Europe, is the so-called common rail diesel engine. As this systems works with very high pressure (up to 1,800 bar) it puts high demands on the diesel fuel quality, which should not contain any contamination (e.g. water and particulate matter). With the global move to near zero sulphur fuels such new technology is increasingly only tested – and approved – by international manufacturers for high quality/ low sulphur diesel fuel markets.

To meet stringent emission standards new vehicles can put in place some combination of the following emission control technologies.[28]

Particulate Matter Emissions Control

Diesel Oxidation Catalyst (DOC): After EGR, diesel oxidation catalysts (DOCs) are the most common emissions control technology found in current diesel vehicles. DOCs oxidize carbon monoxide (CO), gaseous and aerosol hydrocarbons (HCs) into carbon dioxide and water. They also help burn up the soluble organic part of carbon particles that comprise soot and smoke. A DOC can achieve a 20-50% reduction in total PM, and over 90% reduction in CO and HC. [29] DOCs are well-accepted technology and have been fitted to over 50 million diesel passenger vehicles and over 1.5 million trucks and buses worldwide. [30] DOCs can be installed in new vehicles or can be retrofitted on vehicles already in use. Higher sulphur levels can poison DOCs and cause them to become ineffective. When vehicles are fitted with DOC's diesel fuel sulphur levels should be limited to less than 500 ppm to avoid the occurrence of sulphate-related smoke.

Diesel Particulate Filter (DPF): DPFs are positioned in the exhaust system to collect a significant fraction of the small particulates in the exhaust while allowing other exhaust gases to pass through the system. Since the collected particulate builds up over time,

28 There are a number of emission control strategies anticipated to be on the cleanest vehicles. For a thorough discussion of the state-of-the–art technologies (as at 2001) see: http://www.epa.gov/otaq/regs/hd2007/frm/frdslpre.pdf and http://www.epa.gov/otaq/regs/hd2007/frm/ria-iii.pdf

29 MECA, Emissions Control Technologies for Heavy-Duty Trucks and Buses: http://www.meca.org/page.ww?name=Trucks+%26+Buses&section=Emission+Control+Technology and: MECA (2006) Retrofitting Emission Controls on Diesel-Powered Vehicles:http://www.meca.org/galleries/default-file/MECA%20Diesel%20Retrofit%20White%20Paper%200406%20(revised).pdf

30 MECA (2006) written statement of the Manufacturers of Emission Control Association on the California Air Resources Board's Draft Emission Reduction Plan for Ports and International Goods Movement in California

the DPF has been designed to automatically clean or "regenerate" the particle trap. This is accomplished by oxidizing or combusting the collected particulates using higher temperature exhaust. [31] This is called passive regeneration. Another method is to periodically replace the filter, which is called active regeneration. Some DPFs incorporate a catalyst into the DPF, which lowers the ignition temperature needed to oxidize the collected particles (catalyzed DPF or CDPF).

Over one million new passenger vehicles have been equipped with DPFs in Europe since mid-2000. Starting in 2007, every new diesel passenger vehicle and heavy-duty on-road diesel vehicle sold in the U.S. and Canada will be equipped with a high-efficiency DPF. [32] From 1 September 2009 all new diesel cars and vans in the European Union will have to be equipped with DPFs.[33] DPFs are currently being retrofitted on some older engines as well.

Over 200,000 on-road heavy-duty vehicles worldwide have been retrofitted with DPFs. [34] DPFs are quite effective and have reliably demonstrated over 95% reduction in particulate emissions, in addition to providing effective control of CO and HC emissions, reducing these emissions by 90 to 99% and 58 to 82% respectively.

However, sulphur greatly reduces their efficiency. When a DOC oxidizes sulphur, the resulting sulphate PM collects on the filter. This reduces its efficiency, which increases emissions, and increases the need for regeneration, which reduces the vehicle's fuel economy. High levels of sulphur can render the DPF ineffective or even stop the engine due to unacceptable backpressure. DPFs should not be used with fuel sulphur levels greater than 50 ppm. Also, low sulphur engine oils should be used. Studies show that DPFs achieved greater efficiency and required less frequent regeneration when combined with fuel sulphur levels of 15 ppm or below. The US, EU, and Japan have decided to limit sulphur in diesel to 15 ppm or less to ensure optimal functioning of DPFs.

Flow-Through Filter (FTF): Flow-through filters typically employ wire-mesh or "tortuous flow" designs to help oxidize most particles, and are more permeable than higher-efficiency DPFs. Flow-through filters may be suited for older heavy-duty diesel vehicles, especially those with mechanical controls. FTF technology may be retrofitted on some vehciles. The California Air Resources Board (CARB) has verified FTFs using market average California diesel (average fuel sulphur level of 150 ppm) and found they attain 50% or greater reduction in particulate matter. Verified FTF technologies that operate on 500 ppm sulphur fuel are combined with a fuel borne catalyst to achieve a similar level of emission reduction.

These are relatively new technologies and require availability of a fuel-borne catalyst or low-sulphur fuel. Flow-through filter effectiveness in reducing ultra-fine particulates is still under investigation.

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31 MECA Emissions Controls From Diesel Vehicles. http://www.meca.org/page.ww?name=Publications&section=Resources

32 http://www.aecc.be/content/pdf/AECC%20Position%20on%20emissions%20control%20technologies%20for%20Euro%205%20&%206%20240506.pdf

33 See: http://www.ec.europe.eu/enterprise/automotive/index_en.htm

34 MECA (2006) written statement of the Manufacturers of Emission Control Association on the California Air Resources Board's Draft Emission Reduction Plan for Ports and International Goods Movement in California

NOx Emission Controls

A variety of NOx control technologies are being developed to remove NOx emissions, and allow diesel engines to meet most stringent emission standards. Although NOx can also be reduced by engine modifications as listed above (especially EGR), these modifications will usually result in a trade-offs between controlling PM versus NOx. NOx control technologies include NOx Adsorbers and Selective Catalytic Reduction.[35]

NOx Adsorbers: In a NOx adsorber, NOx emissions are oxidized and stored as solid nitrate. When the adsorbent becomes fully saturated an increase in fuel-air ratio triggers the release of the NOx, which is then reduced to N2 as is passes over a precious metal catalyst site. NOx adsorber systems have demonstrated 95% efficiency in conversion of NOx with a nominal fuel penalty of 1.5% extra fuel use.[36] Unfortunately, the NOx traps also store sulphur very efficiently, following an almost identical reaction pathway as nitrogen. However the stored SOx is much more tightly bound and needs higher temperatures to be removed. Over a period of time fuel sulphur, even at low levels, fills the capacity of the trap, causing a decline in efficiency. Therefore the fuel sulphur levels for NOx adsorbers must be near zero (less than 15ppm). Although this technology shows promise, it is still in the demonstration phase and not yet commercially available.

Selective Catalytic Reduction: Selective Catalytic Reduction (SCR) systems require the addition of a reductant to help convert NOx to nitrogen and oxygen. The reductant most widely used is liquid urea, which is stored on-board the vehicle and must be periodically replenished. SCR has shown a 65 - 80% reduction in NOx. Importantly, it avoids the potential loss of fuel economy associated with some of the other technologies, with a difference of as high as 7%.[37] It is important to note that without the reductant the emissions can rise to the levels of uncontrolled engines; therefore urea must be made available in areas where SCR is utilized.

SCR systems are being utilized in Europe as NOx reduction technology to meet European heavy-duty diesel standards. SCR systems rely on an oxidation catalyst in order to provide the required NOx emission control. The use of an oxidation catalyst for emission control means that the SCR systems will produce significant amounts of sulphate particulates when operated with fuels containing high sulphur levels. Hence, to operate properly SCR systems require fuel sulphur levels of 50 ppm or less (depending on the emission standard).[38]

35 Many of the NOx control techniques require low sulphur engine oil

36 Faulkner (2002)

37 Johnson, T (2002) Diesel Emissions Control: Last 12 months in Review. Paper presented at the 8th Diesel Emissions Reduction Conference, San Diego, California, 25 to 29 August 2002 http://www.eere.energy.gov/vehiclesandfuels/resources/proceedings/2002_deer_presentations.shtml

38 EPA (2000) Regulatory Impact Analysis: Heavy-Duty Engine and Vehicles Standards and Highway Diesel Fuel Sulphur Control Requirements. Washington, D.C. U.S. Environmental Protection Agency and: Khair, M. (2002) Low Emissions Potential of EGR-SCR-DPF and Advanced Fuel Formulations - A Progress Report. Paper presented at the 8th Diesel Engine Emissions Reduction Conference, San Diego, California, 25-29 August 2002

Assessing the Potential to Retrofit

Key factors to be considered for undertaking a retrofit program:

Fleet Selection: It is important to do a detailed assessment to understand the current fleet to see what emission reduction strategies will be appropriate for that fleet.

Fuel Availability: It is important to ensure a steady supply of appropriate fuels with required sulphur levels.

Validated Technologies: When evaluating emission reductions options it is important to work with known and verified technologies to ensure that the proper engine configurations are matched to the appropriate control technologies and the anticipated reductions are obtained.

In a recent program in Mexico City, city buses were retrofitted with both DOCs and DPFs, and run with very low sulphur diesel fuel (less than 15 ppm) for 11 months. Intensive testing of the emissions before and after retrofit show a 20% reduction in PM from the DOCs on older buses and a greater than 90% reduction in PM from the installation of diesel particulate filters on newer buses. Other cities around the world have instituted successful retrofit programs, including Santiago, Chile, and Hong Kong, China. Both the U.S. EPA and the California Air Resources Board (CARB) have verification programs that provide key information on diesel emission control technologies and their expected benefits. For more information on these programs, see:

http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

http://www.arb.ca.gov/diesel/verdev/verdev.htm

4.2.2 Reducing Emissions from Existing Diesel Vehicles

Heavy-duty diesel vehicles last a long time. In the US, the life expectancy for heavy trucks is 29 years and 16 years for transit buses.[39] In other parts of the world, these vehicles may stay in the fleet even longer. Emissions tend to increase as vehicles age. This means that any action taken to reduce emissions by the introduction of new standards will not be realized for many years as the fleet takes 20 years or longer to turn over from the older models. Therefore, more and more countries are developing programs to reduce emissions from older vehicles, as well as more stringent standards, in their efforts to improve air quality.

Diesel vehicle upgrades and retrofits have been identified as among the most cost-effective measures for gaining near-term emissions reductions. Five different approaches, targeting primarily the existing vehicle fleet, are provided below.

REPAIR/REBUILD - Performing routine maintenance and rebuilding can bring many engines back into manufacturer's specification and achieve emission benefits that they were originally designed to meet.

REFUEL - Using cleaner diesel fuel (i.e., fuel with lower sulphur) can directly reduce emissions of small particulates, and it enables the introduction of advanced emission control technologies.

39 U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. National Transportation Statistics 2005. Washington, D.C. http://www.bts.gov/publications/national_transportation_statistics/

RETROFIT - The most common technologies used to retrofit heavy-duty diesel vehicles are diesel oxidation catalysts and diesel particulate filters. Flow-through filters are still rather new and are not commonly used yet. Diesel emission control devices can be installed in a wide variety of vehicles, including highway trucks and buses, off-road construction equipment, agricultural equipment, etc.

Diesel oxidation catalysts are the easiest, most flexible, and least expensive retrofit option and can be used with fuel sulphur of 500 ppm or less. A DOC can achieve a 20-50% reduction in total PM, and over 90% reduction in CO and HC. [40] Diesel particulate filters are also an easy, effective retrofit option, but require fuel with a sulphur content of 50 ppm, and preferably 15 ppm, and cannot be applied to older diesel vehicles. New technologies are being developed that have other requirements, such as fuel additives or different levels of fuel sulphur (e.g. flow-through-filter).

REPOWER - In some cases, a vehicle chassis or machine may have a substantial useful life. The emissions performance can be improved by removing the entire existing engine and repowering the vehicle with a new, or newer vintage, engine that emits fewer pollutants.

REPLACE - Diesel engines and equipment made before 1990 may not be technically suited for upgrading and the costs may be prohibitive. In these instances, replacement of the entire vehicle or machine might be the most cost-effective approach.

4.3 Petrol Vehicles and Sulphur

The primary pollutants of concern from petrol vehicles are carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOx). Compared to diesel vehicles, petrol-fuelled vehicles emit significantly less particulate matter. Sulphur levels in petrol tend not to be as high as those in diesel.

As noted above, lowering the sulphur content of fuel will immediately reduce particulate emissions, will allow current catalyst-equipped vehicles to operate more efficiently and cleaner, and will enable the use of new technologies that reduce emissions even further.

Three-way Catalysts (TWC) - the most commonly and widely used device for reducing emissions from petrol vehicles is the catalytic converter. Catalytic converters, which contain honeycombed ceramic structures coated with catalytic metals such as palladium, platinum, and rhodium convert exhaust pollutants into harmless gases before they are emitted from the tailpipe. Two-way catalysts (reducing HC and CO) were first introduced in the U.S., Canada, and Japan in the mid 1970s; technology advances led to the introduction of three way catalysts (which reduce CO, HC and NOx) in most developed countries in early 1980s through the 1990s. Three-way catalysts now dominate new vehicle production globally, and worldwide, as of 2000, about 85% of new petrol vehicles were equipped with a catalytic converter. [41]

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40 MECA, Emissions Control Technologies for Heavy-Duty Trucks and Buses http://www.meca.org/page.ww?name=Trucks+%26+Buses&section=Emission+Control+Technology and: MECA, Retrofitting Emission Controls on Diesel-Powered Vehicles, April 2006 http://www.meca.org/galleries/default-file/MECA%20Diesel%20Retrofit%20White%20Paper%200406%20(revised).pdf

41 MECA Clean Air Facts – Motor vehicle Emission Control: Past, Present, and Future. http://www.meca.org/galleries/default-file/advancedfact.pdf

To meet the most stringent emission control standards recently adopted in the U.S., Europe, and Japan, manufacturers have greatly improved TWC technology. The most advanced designs use tinier cells in the honeycomb structure to increase the reactive surface area (higher cell density), different coating formulas to improve precious group metals (PGM) dispersion (i.e. more PGM surface conversion area for the same amount of PGM mass), improved oxygen management, and improved thermal stability, to name a few of the advancements. These more advanced catalysts can reduce emissions to virtually insignificant levels, depending on the fuel quality. Sulphur greatly reduces the efficiency of these devices by blocking active catalyst sites. This effect is not completely reversible. Although conversion efficiency will improve with the use of low sulphur fuel, it does not always return to its original effectiveness after desulphurization. [42]

The impact of sulphur on these more advanced catalysts increases in severity as vehicles, and their emission control equipment, are designed to meet stricter emission standards

4.4 Support of the PCFV to Reducing Sulphur in Fuels

The PCFV has prioritised the phase out of leaded petrol and the reduction of sulphur in fuels, together with the introduction of cleaner vehicles.

While countries worldwide have adopted differing fuel sulphur levels at various stages of development, developed country fuel specifications have tended to converge numerically on at least the 50 ppm sulphur value for both diesel and petrol fuels. Recognising this, the fourth PCFV Global Partnership Meeting, held on 14 and 15 December 2005 at UNEP Headquarters in Nairobi, Kenya, agreed to adopt the following PCFV goal: "….to reduce sulphur in vehicle fuels to 50 ppm or below worldwide, concurrent with clean vehicles and clean vehicle technologies, with roadmaps and timelines developed regionally and nationally."

Through this objective the Partnership affirms that developing and transition countries deserve air quality equal to that of developed countries. At the same time, it was recognized that improving urban air quality is linked to other environmental and developmental goals, such as poverty alleviation and access to clean water, which all require scarce human and financial resources. It is therefore important to have the local situation determine the pace at which lower sulphur fuels should be introduced, depending, amongst others, on the severity of the urban air quality problems, the availability of vehicles that can make use of lower sulphur fuels and future opportunities for the reduction of vehicle emissions.

The Partnership recognizes that for the most part the decision to reduce sulphur from fuels is a local one, with involvement of all relevant parties such as refineries, automobile/ engine manufacturers, NGOs and national governments. Nonetheless, the adoption of the general sulphur objective of 50 ppm is to provide an 'aiming point' to indicate the

42 USEPA (1999) Regulatory Impact Analysis - Control of Air Pollution from Motor Vehicles: Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements. http://www.epa.gov/otaq/regs/ld-hwy/tier-2/frm/ria/r99023.pdf And: MECA (1998) The Impact of Gasoline Fuel Sulfur on Catalytic Emission Systems. http://www.meca.org/galleries/default-file/sulfur.pdf

Table 2: Optional Strategies for Reducing Vehicle Emissions

	For Diesel	For Petrol
If Sulphur > 500ppm		
	If the sulphur level of your diesel fuel is above 500 ppm, there are no diesel emissions control technologies that can be used with such high fuel sulphur levels. Your options include: • Start bringing fuel sulphur levels down to achieve immediate emissions benefits. • Develop vehicle emission standards, forcing the introduction of appropriate engine modifications, for all new vehicles, in line with the reduction in fuel sulphur levels. • Begin a program to replace the oldest vehicles in the fleet.	If the sulphur level of your petrol is above 500 ppm but below 1000 ppm, your options include: • Require catalytic converters in all new vehicles and simultaneously start bringing sulphur levels down. • Set age limits for imports of second-hand vehicles and require that they have catalytic converters.
If Sulphur < 500ppm		
	If the sulphur level of your diesel is 500 ppm or lower, some advanced emission control technologies can be introduced. Your options include: • Develop vehicle emission standards for all new vehicles, in line with the reduction in fuel sulphur levels, which will introduce additional engine modifications such as EGR. • Retrofit older, heavy-duty diesel vehicles with diesel oxidation catalysts to reduce HC, CO, and PM and explore the applicability of FTFs for further PM reductions.	If the sulphur level of your petrol is 500ppm or lower, introduction of advanced emission control technologies can take place. Your options include: • Develop vehicle emissions standards for all new vehicles. • Limit importation of second-hand vehicles to those that have catalytic converters.
If Sulphur < 50ppm		
	If the sulphur level of your diesel is 50 ppm or lower, more options become available. These options include: • Develop more strict emission standards for PM and NOx from new diesel vehicles to ensure the introduction of the most advanced control technologies. • Retrofit older, heavy-duty vehicles with particulate filters, matching the filter requirements, engine technology, and age of the vehicle.	If the sulphur level of your petrol is 50ppm or lower, introduction of more advanced emission control technologies can take place. Your options include: • Develop more stringent vehicle emissions standards for all new vehicles to ensure the greatest emissions control with the most advanced technologies. • Set import restrictions on second-hand vehicles to those that have catalytic converters and meet prescribed performance criteria.

ultimate target that will make an important contribution to reducing air pollution. It can be used for the development of national actions and regional harmonisation efforts, for the development of "roadmaps" to improved fuel and vehicle quality, and, ultimately,for better air quality.

The fundamental principle, as embedded in the Partnership mission statement, is to promote and support the introduction of cleaner fuels and vehicles, rather than to impose standards. Therefore the Partnership stands ready to support developing and transition countries in their efforts to reduce sulphur levels in fuels.

5. Reducing Sulphur in Fuels

This section discusses how decisions to reduce sulphur levels in fuels can impact on the fuel supply infrastructure. It also lists some additional issues that should be taken into consideration when reducing sulphur.

5.1 Sulphur: Where Does it Come From?

Both petrol and diesel fuels are produced from crude oil, which varies in density, gravity and composition from oilfield to oilfield. Sulphur is present in all crude oil, but to varying degrees. "Sweet" crudes such as Brent (North Sea) or Nigerian (Bonny Light) are low in sulphur, while crudes from the Middle East are relatively high in sulphur. The heaviest crudes, mainly from Mexico and Venezuela, have very high sulphur and are called "sour" crudes. Crude oils range in consistency from water to tar-like solids, and in colour from clear to black. An "average" crude oil contains about 84% carbon, 14% hydrogen, 1-3% sulphur, and less than 1% each of nitrogen, oxygen, metals, and salts. Table 2 lists average characteristics for a few selected crudes.

Table 3: Characteristics of Selected Crude Oils[43]

	Light ('Sweet') Crude		Medium Sulphur Crude		High Sulphur ("Sour") Crude	
	High Gravity (Bonny Light)	Low Gravity (Bonny Medium)	Light (Murban)	Heavy (North Slope)	Light (Arabic)	Heavy (Bachequero)
Gravity °API	37.6	26.9	39.4	26.8	33.4	16.8
Average Sulphur (ppm)	1,300 ppm	2,300 ppm	7,400 ppm	10,000 ppm	18,000 ppm	24,000 ppm
Sulphur Range (Wt.%)	0 - 0.5	0 - 0.5	0.51 - 1.0	0.51 - 1.0	1.0+	1.0+

Sulphur may be present in crude oil either as gaseous hydrogen sulphide (H2S) or chemically bound into heavier compounds. When crude oil is processed into petrol and diesel fuel in the refinery, these sulphur compounds find their way into the various fuel products, including petrol and diesel fuel. In general, the higher the density of the crude oil, the more difficult it is to remove the sulphur it contains.

5.2 Refineries: How Do They Work?

The function of a refinery is to process crude oil into a range of products with the right properties (including sulphur content) in the right proportions to meet local specifications and market demand. This requires a range of different processing units. Very briefly, the refining process is as follows:

43 Source: US Petroleum Refineries, National Petroleum Council (June 2000)

1. Crude oil is split into different fractions in the atmospheric distillation unit.
2. The lightest fraction is liquefied petroleum gas (LPG).
3. The next lightest fraction is naphtha, which is a building block for petrol. Sulphur is removed from the naphtha; heavy naphtha is sent to a reformer to increase octane, and lighter naphtha goes to an isomeration unit or directly into petrol.
4. The residue from the atmospheric distillation unit (long residue, which contains more sulphur than naphtha) is converted to lighter products (diesel). In 'semi-complex' refineries this is done by a thermal gasoil unit. In 'complex' refineries this is done by a vacuum distillation unit – which produces a heavy waxy distillate product, which must then be cracked in a catalytic cracker or a hydro-cracker.[44] In 'fully complex' refineries, the waxy distillate from the vacuum distillation unit is cracked by a number of different processes.[45]

Refineries also include a variety of treatment units such as hydrodesulphurisation, as described in more detail below. Additional information about refinery operations and a description of various processing units can be found in a recent IPIECA publication.[46]

5.3 Options for Reducing Fuel Sulphur

5.3.1 Countries Without Refineries

Countries without refineries – or those that require only low volumes of lower-sulphur fuel – can lower their sulphur levels by purchasing it on world markets. Importation of lower-sulphur fuels has also been a step taken by countries with refineries, who need to meet new and stricter fuel specifications, but whose refineries are still in the process of being upgraded. For example, India and the Philippines temporarily imported lower-sulphur fuels while their refineries were being upgraded to meet stricter specifications.

5.3.2 Countries With Refineries

Switch to lower sulphur crude

Countries that refine their fuels can significantly reduce sulphur in their produced fuels by switching to a lower-sulphur incoming crude oil, if their specific conditions permit. For example, moving from Arab Light (which has more than 1% sulphur) to Nigerian Bonny Light (less than 0.5% sulphur) can reduce the sulphur content of the distillate diesel component from 1.05% (10,500 ppm) to 0.13% (1300 ppm). Thus, by crude selection alone it is feasible to produce diesel fuel with 1,000 – 2,000 ppm sulphur, but not significantly lower than this. Sourcing crude from lower-sulphur sources is a strategy that China has adopted. Before switching crudes, refinery operators must assess factors such as gravity levels of the new crude to match design specifications of the refinery.

44 Catalytic cracked diesel components contain more sulphur than hydro-cracked diesel components
45 A fully complex refinery might have as many as 40 different interconnected process units that are designed to optimize manufacturing of a given slate of products
46 IPIECA (2006) Fuel sulphur: Strategies and options for Enabling Clean Fuels and Vehicles. http://ww.ipieca.org

Desulphurisation of blending components

To produce fuels with 1,000 ppm or less sulphur, it is important to look at options to remove the sulphur in high-sulphur distillation fractions before the final blending. Sulphur removal can be done either in conjunction with, or instead of, using lower sulphur crude oil. Complex refineries often find it more economical to invest in a sulphur removal plant (such as desulphurisation unit) and then operate it on higher sulphur crude oil. [47] Less complex refineries may have to choose among various combinations of capital investment in new desulphurisation units and crude oil selection.

Hydrotreating is the most commonly used technology in desulphurisation. To reduce sulphur in petrol, it is usually necessary to hydrotreat only the cat-cracked stream.

For diesel, sulphur removal is harder, necessitating the use of more complex high-pressure units, which sometimes require two stages of treatment. Hydrotreating diesel fuel generally improves its properties and slightly increases its cetane number. However, there are other product quality issues to consider, as noted below in 5.4.

The other alternative for desulphurisation of diesel is to build a hydrocracker. This is the most expensive option (4-5 times cost of a high pressure hydrotreater) since it is a complex plant that requires a lot of hydrogen to operate. A new hydrocracker will yield high-quality, low-sulphur kerosene and diesel fuel components. Normally, a hydrocracker is only justified commercially if the refinery aims to increase the yield of kerosene and diesel and not merely to reduce sulphur. A proper sized hydrocracker can reduce diesel sulphur levels to about 50ppm; any further reduction requires both a hydrocracker and a hydrotreater.

As the demand for lower sulphur fuels increase, sulphur treatment technologies will continue to improve. Newer and alternative technologies that can reduce operating cost, capital cost or both are beginning to be used at some refineries and should be explored.[48]

5.4 Fuel Sulphur Reduction – Additional Considerations

There are a number of additional considerations related to reducing sulphur levels through improved refinery operations, including the following:

- Some refinery process upgrades may necessitate additional hydrogen (a crucial component of refinery operation). Assessing the source and cost of additional hydrogen must be part of the decision-making process.
- Some refining processes also have energy repercussions, both in terms of additional energy use and increase of CO2 emissions. [49] This must also be taken into account when exploring options to lower sulphur levels in fuels.
- Technical processes to reduce sulphur levels in fuels must take into account national fuel specifications, such as those for aromatics, cetane and lubricity in diesel fuel and octane in petrol.

47 Details on how desulphurisation processes work can be found in the 2006 IPIECA document Fuel sulphur: Strategies and options for Enabling Clean Fuels and Vehicles. http://www. Ipieca.org

48 See, e.g., U.S. Environmental Protection Agency (2003) Control of Emissions of Air Pollution from Non-Road Diesel Engines and Fuel, 68 Federal Register 28427 et seq. available at http://www.epa.gov/fedreg/EPA-AIR/2003/May/Day-23/a9737c.html

49 CO2 - carbondioxide- is a greenhouse gas that contributes to global climate change

- Desulphurizing diesel fuel may slightly increase cetane, which can improve engine performance and reduce smoke. At the same time, desulphurizing diesel also tends to reduce its lubricity, which is essential for performance of and minimizing wear in moving metal parts, such as in a rotary fuel pump or the engine. Inexpensive fruel additives and fuel conditioners are available to correct this.
- Some processes that reduce sulphur can also reduce the octane in the petrol, which may need to be recovered depending on national fuel specifications and vehicles requirements.
- Desulphurizing diesel fuel also tends to reduce the aromatics content; this change can affect some elastomeric seals in the fuel system and cause leaks.[50] Properly maintained vehicles with upgraded components are less likely to be affected. On the other hand, lower aromatics can help reduce emissions.[51]
- Although lower-sulphur fuels do not require special storage, care must be taken to avoid cross-contamination between lower and higher sulphur products (such as jet fuel and diesel for road transport). Cross-contamination can be prevented through strict quality control procedures, such as flushing of delivery tankers and ensuring adequate storage facilities for different products.
- Contamination of products that are transported through pipelines should be minimised. Some mixing occurs at the interface between batches, which can be addressed by properly ordering the sequence of high and low sulphur batches (which is called specific sequencing) or by separating the interface. The interface can then be blended into a higher-sulphur fuel product or reprocessed at a refinery.
- Caution should be taken during switch loading of petrol and diesel during filling of road and rail tankers, as low-sulphur fuels have poor internal conductivity and are more prone to discharge of static electricity which can spark and cause an explosion. This concern can be address through appropriate precautions.

50 See, e.g.: C.M. Cusano et al. (1994) Changes in Elastomer Swell with Diesel Fuel Composition. SAE 942017 And: S.D. Robertson et al. (1994) Effect of Automotive Gas oil Composition on Elastomer Behavior. SAE 942018

51 See e.g. U.S.EPA Staff Discussion Document (2001) Strategies and Issues in correlating Diesel fuel Properties with emissions, EPA420-P-01-001

6. Additional Considerations

This section provides additional considerations for reducing sulphur levels in fuels. These could either be additional benefits (like increased engine life and reduced maintenance costs) or additional issues to consider when developing a strategy (like distinguishing between metropolitan and non-metropolitan levels and adulteration issues).

6.1 Urban vs. Rural

Because the urban areas are most affected by air pollution, several countries have decided to introduce lower sulphur fuels in the cities first, before expanding to the rest of the country. For example, the revised standard for sulphur in fuels in Mexico which first focused on the US-Mexico border, followed by metropolitan areas (in 2009) and in the rest of the country by 2010. In Brazil the nationwide specification is 2,000 ppm, while the metropolitan specification is 500 ppm (see table 1 in chapter 3). In addition to stricter standards and lower emissions, these "urban levels" also allow for the implementation of retrofit projects (for example with urban bus fleets) - if the levels are low enough. However, introducing lower sulphur fuels in only parts of a country also comes with problems like unavailability of cleaner fuels for cars that need these fuels outside of the metropolitan areas and the potential of misfueling and contamination. Therefore in many cases, this approach is used for centrally fuelled urban fleets such as buses and taxis. Still, as increased fleet use will lead to increased demand for low sulphur fuel, the cost of providing the fuel is likely to decline. This will encourage additional production and facilitate the spread of lower sulphur fuel in the marketplace.

6.2 Corridors in Countries for Cross Country Transport

Many countries are starting to put in place corridors for transport across regions and across countries. In the US, for example, a variety of diesel corridor projects have been established along the West Coast (The West Coast Diesel Collaborative), in the Midwest (The Midwest Clean Diesel Initiative and the Blue Skyways project), and along the East Coast (The Mid-Atlantic Diesel Collaborative and the Northeast Diesel Collaborative) in advance of a national regulation to limit sulphur to less than 15 ppm.

The West Coast Diesel Collaborative is a partnership between leaders from federal, state, and local government, the private sector, and environmental groups committed to reducing diesel emissions along the West Coast. It is focused on creating, supporting, and implementing diesel emissions reduction projects. It also works to ensure clean fuels are available for traffic up and down the west coast of the US Highway system.[52]

52 For more information on these initiatives, see the following websites:
http://www.westcoastdiesel.org/
http://www.epa.gov/midwestcleandiesel/index.html
http://epa.gov/region6/6xa/blue_skies_collaborative.htm
http://www.dieselmidatlantic.org/diesel/index.htm
http://www.northeastdiesel.org/

As another example, Russia has established an ultra-low sulphur fuel corridor between itself and Europe to enable travel and commerce using newer vehicle technologies which cannot be operated on higher sulphur fuels.[53]

6.3 Vehicle and Engine Issues

6.3.1 Vehicle Maintenance

Lower sulphur in fuels helps reduce corrosion and acidification of engine oil, leading to longer maintenance intervals and thus reduced maintenance costs.

Table 4: Components Potentially Affected by Lower Sulpur Levels in Diesel Fuels[54]

Affected Components	Effect of lower sulphur	Potential Impact
Piston Rings	Reduced corrosion wear	Longer engine life, less frequent rebuilds
Cylinder Liners	Reduced corrosion wear	Longer engine life. Less frequent rebuilds
Oil	Reduced deposits, less need for alkaline additives	Reduced wear on piston ring/ cylinder liner, less frequent oil changes
Exhaust	Reduced corrosion wear	Less frequent part replacement

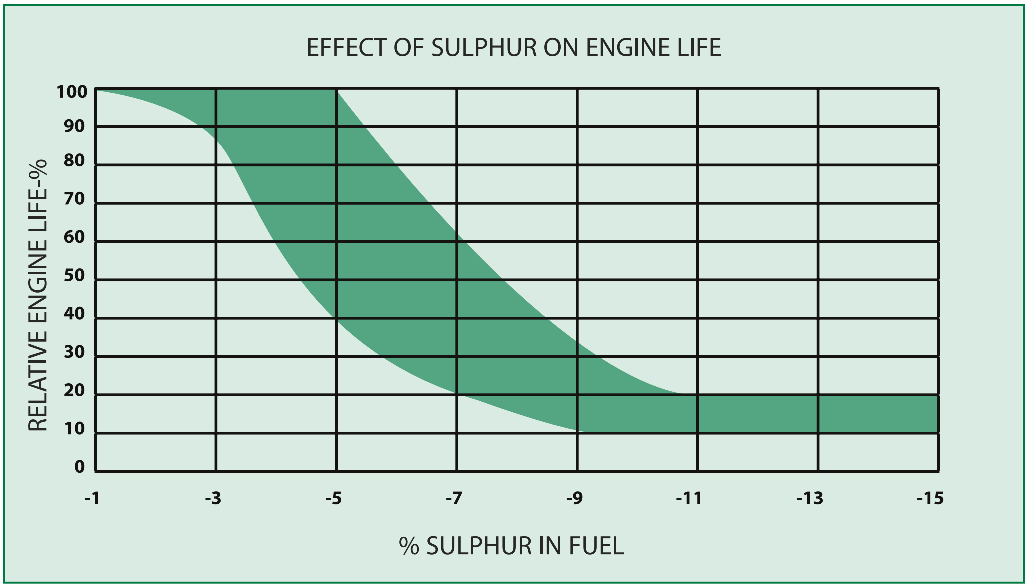
The actual value of the benefits depends on local circumstances and long term use of low sulphur fuels. The average savings were estimated by USEPA to be approximately 1.4 cents/USgallon for light heavy-duty diesel vehicles, 1 cent/ USgallon for medium heavy-duty diesels and 0.7 cent/USgallon for heavy heavy-duty diesels.[55] These benefits result in estimated savings from US$ 153 to US$ 610 for the life of the vehicle.

6.3.2 Engine Life

The presence of sulphur in fuel significantly reduces the life of vehicle engines. This is especially the case at higher sulphur levels (above 2,000 ppm). The graphic below shows an increase in engine life as a result of reducing sulphur levels in fuel. Going from 1.5 percent (15,000 ppm) sulphur in fuel to 0.1 percent (1,000 ppm) sulphur in fuel is estimated to increase engine life by 80 to 90 percent.

53 Diesel Fuel News (9 June 2003) Russia Transport Ministry floats 2005 ULSD Plan – ultra-low sulphur diesel for international goods carriers. available at: http:// www.findarticles.com/p/articles/mi_m0CYH/is_10_7/ai_103382165
54 http://www.adb.org/Vehicle-Emissions/General/diesel.asp#2
55 USEPA (2000) Regulatory Impact Analysis: Heavy-Duty Engines and Vehicles Standards and Highway Diesel Fuel Sulfur Control Requirements. http://www.epa.gov/otaq/highway-diesel/regs/exec-sum.pdf

Figure 3: Decrease in engine life due to increasing sulphur levels in fuel [56]



6.3.3 Sulphur in Engine Oil

In addition to fuel, sulphur is also found in most lubricants used to protect engines from wear. To the extent that engine oil leaks into the combustion chamber, this sulphur can find its way into the exhaust stream, thereby helping to impair the operation of emission control systems. As fuel sulphur levels drop, the relative impact of sulphur from engine oils increases.[57] Many developed countries, notably the U.S., Japan and those in Europe, use voluntary industry self-regulation of engine oil quality, due to the complexity of ensuring proper lubricant quality for the engines in use. Countries with poor quality engine oil should discuss this issue with local industry (automotive, engine, oil and additive manufacturers) when adopting policies to reduce fuel sulphur.

6.4 Enforcement and Compliance

Enforcement is a vital part of encouraging governments, companies and others to meet their environmental obligations. Enforcement deters those who might otherwise profit from violating the law, and levels the playing field for those who do comply.

Enforcement is critical to ensure that the composition of the fuels actually meets the standards, and enables emission-control components of vehicles to work as designed. Vehicle fuel standards for petrol and diesel are usually required to be met by the refiners and importers and by other parties in the fuel distribution system.

56 http://www.fleetwatch.co.za/supplements/SADiesel/DieselFactsFictionS.htm , originally Detroit Diesel Corporation Fuel and Lubrication Service Bulletin

57 Engine oil also may include phosphorus and ash, which also can poison emission control systems. Some of these compounds, however, may be needed to protect engines from excessive wear, so lubricant formulation should be left to industry

6.5 Adulteration

Adulteration of fuel is a problem across the world that can have an adverse effect on emissions from motor vehicles. One common form of adulteration is the mixing of diesel fuel with cheaper, higher sulphur kerosene.

Enforcement of fuel standards at the refinery and at the pump are key means to ensure that fuel adulteration is minimized. The following links provide additional information about adulteration (with a case study of fuel adulteration in India and Nepal, where it is an ongoing problem):
http://www.cpcb.nic.in/fueladultration/ch60703.htm
http://www.cleanairnet.org/caiasia/1412/articles-58998_Fuel_Adulteration_Ale.pdf

Annex 1 – Overview of major pollutants from vehicle sources

Pollutant	Health Impacts	Additional Concerns
Particulate Matter (PM)	- aggravated asthma - decreased lung function - heart attacks - premature death - diesel PM is a likely human carcinogen	Fine particles (PM2.5) are directly emitted from combustion sources and are formed secondarily from gaseous precursors such as sulphur dioxide, nitrogen oxides, or organic compounds. PM2.5 is of the greatest concern because it can penetrate deep into the lungs. Fine particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometres.
Hydrocarbons (HC)	- includes many toxic compounds that cause cancer and other adverse health effects	Hydrocarbons also react with nitrogen oxides in the presence of sunlight to form ozone. In typical urban areas, a very significant fraction comes from mobile sources.
Nitrogen Oxides (NOx)	- reacts with hydrocarbons to form ozone, which can trigger serious respiratory problems; - reacts to form nitrate particles, acid aerosols, as well as NO2, which also cause respiratory problems.	NOx refers to various compounds and derivatives in the family of nitrogen oxides, including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide. NOx is one of the main ingredients involved in the formation of ground-level ozone. NOx reacts in the atmosphere to form nitrate particles, acid aerosols NOx and the pollutants formed from NOx can be transported over long distances
Sulphur Oxides (SOx)	- contributes to respiratory illness, particularly in children and the elderly - aggravates existing heart and lung diseases.	Contributes to the formation of atmospheric particles that cause visibility impairment; can be transported over long distances and deposited far from the point of origin.
Ozone (O3)	- triggers a variety of health problems even at very low levels; may cause permanent lung damage after long-term exposure; contributes to premature death	Ground-level ozone is not directly omitted from vehicle exhaust but is a product of reactions involving hydrocarbons and nitrogen oxides in the presence of sunlight.
Carbon Monoxide (CO)	- is poisonous even to healthy people at high levels in the air; low levels can affect people with heart disease; can affect the central nervous system; risk of premature mortality; lower birth weight	Motor vehicles are a major contributor to CO levels in cities; as much as 95% in U.S. cities.

Sources:
USEPA - www.epa.gov/air/urbanair/6poll.html
The American Medical Association (292: 19; 17 November 2004).

Annex 2 - Sulphur levels per country in developing and transition country regions (as of March 2008)

Latin America and the Caribbean - Sulphur Levels in Diesel and Petrol Fuel

Country	Diesel Sulphur Level (ppm)	Petrol Sulphur Level (ppm)	Comments	Reference
Anguilla				
Antigua and Barbuda				
Argentina	500/2500	300/500	Multiple grades available on market. 2009 target of 50 ppm city/1500 ppm national diesel and 50/300 ppm gasoline to coincide with Euro IV standards for diesel passenger vehicles. 10 refineries	Resolution 1283/2006, Secretary of Energy
Aruba				
Bahamas				
Barbados				
Belize				
Bermuda				
Bolivia	2000	500	2 refineries in country	ARPEL 2007; EIA
Brazil	500/2000	1000	Jan 2009 target of 50 ppm petrol and diesel and 500 ppm rural diesel to coincide with Euro IV standards passenger vehicles. USD 5.5 billion refinery upgrade planned, 13 refineries	CONAMA Resolution 315, of 2002
Cayman Islands (BVI)				

Chile	50/350	75	2010 plans for 50 ppm nationally diesel and petrol. USD 1 billion investment planned in upgrades; 3 refineries	CONAMA Chile, ARPEL 2007
Colombia	1200/4500	1000	Urban and rural grades. Legislation for Bogota mandates 500 ppm S level in diesel, 300 ppm petrol by 1 July 2008, 50 ppm from December 2009. The plan for the rest of the country is: 3000 ppm from July 2008, 2500 ppm from July 2009, 500 ppm from January 2010, 50 ppm from 2012. USD 1 billion investment planned; 5 refineries	National University of Colombia; ARPEL 2007
Costa Rica	4500		Plan for 50 ppm petrol and diesel by 2009.	
Cuba				
Dominica				
Dominican Republic				
Ecuador	500/7000	2000	USD 1 billion investment required to reach 50 ppm diesel and petrol. 3 refineries	ARPEL 2007
El Salvador	5000			Kukulkan Foundation Workshop Report, Guatemala 2004
French Guiana			No refineries	
Grenada				
Guatemala	5000			Kukulkan Foundation Workshop Report, Guatemala 2004
Guyana			No refineries	
Haiti				
Honduras	5000			Kukulkan Foundation Workshop Report, Guatemala 2004
Jamaica	5000			Jamaica aims to require 2% biodiesel additive.

Mexico	300/500	500/1000	City/Rural grades. Petrol levels to reduce to 30 ppm average/80 ppm in January 2009 for all country; diesel at 15 ppm in January 2009 for urban, September 2009 for rest of country.	SEMARNAT, PEMEX
Montserrat				
Nicaragua	5000			ARPEL 2005
Panama	5000			Kukulkan Foundation Workshop Report, Guatemala 2004
Paraguay	5000	1500	1 refinery in country	ARPEL 2007
Peru	3000/5000	2000	Government decree of July 2005 provides for reduction to 50 ppm metropolitan, 1500 nationwide diesel as of 2010. 6 refineries, USD 1 billion required for upgrades	USEPA Daily Environment Report 'Peru Cracks Down on 'Dirty' Diesel Fuel, Sets Deadline for Cutting Sulfur Content'
Puerto Rico				
St Kitts and Nevis				
Saint Lucia				
St Vincent and the Grenadines				
Suriname	5000			ARPEL 2005
Trinidad and Tobago	1500			ARPEL 2005
Turks and Caicos Islands				
Uruguay	8000	1000	50 ppm diesel, 300 ppm petrol planned for 2010 nationally, 1 refinery	ARPEL 2007
Venezuela	5000	1500	2000 ppm diesel, 400 ppm petrol planned for 2010, 5 refineries	ARPEL 2007
Virgin Islands				
Total: 42 countries				

References:
Alexander's Gas and Oil Connection. Five firms eyeing Costa Rica refinery revamp project. http://www.gasandoil.com/goc/news/ntl72640.htm
ARPEL February 2007 presentation by José Félix García, http://www.unep.org/pcfv/PDF/FundamentalsFuels-ING.pdf
ARPEL July 26, 2005 Personal Correspondence
Energy Information Administration (US), http://www.eia.doe.gov/emeu/cabs/contents.html,
Michael Walsh, International Consultant, Global Clean Fuels Overview, June 26, 2005
SEMARNAT, PEMEX Announcement of Low Sulphur Diesel, December 2005 http://portal.semarnat.gob.mx/comunicacionsocial/boletines_2005_275.shtml

West Asia, Middle East & North Africa - Sulphur Levels in Diesel Fuel

COUNTRY	CURRENT STATUS Diesel Sulphur Content (ppm)	COMMENT
Algeria	900	Very sweet crude. No plans to process crude further.
Bahrain	5,000 (500)	To be reduced to further by 2007, some low sulphur available
Egypt	5,000	No Plans to reduce levels, Standard 10,000 ppm
Iran	5,000	Standard 10,000 ppm
Iraq	10,000	Actual Standards 25,000 ppm. No plans
Israel	50	
Jordan	350	Actual Standards 12,000 ppm. Produced & imported 350ppm as a higher level – the international standard 14596. Planned to be reduced to 50 ppm after the refinery expansion is completed
Kuwait	3,500	Actual Standards 5,000 ppm. No plans
Lebanon		No information
Libyan Arab Jumhiriya	1,000	Standards are about 1,500 ppm
Morocco	350 / 50	Introduced 350ppm and 50ppm on limited bases (60KT) since 2007. Plans to go to full 50ppm by 2009 (once the project of modernisation is completed.
Oman	50-500	Oman oil refinery company has installed a diesel- hydro-sulphurisation unit and adopted the ISO-14001:2004 standard on environmental management that provides for the reduction of sulphur from the fuels
Palestine	10,000	Gets fuel from Jordan which is at 10,000 ppm
Qatar	5,000	
Saudi Arabia	5,000	Current Standards 10,000 ppm. Plans to go to 500 ppm and 50 ppm in future.
Syria	7000(6,500)	Actual Standards 7,000 ppm. Plans to go to 50 ppm 2015
Tunisia	10,000	Actual Standards 10,000 ppm. Change in 2011
United Arab Emirates	5,000	Plans to go to 2,500 ppm in late 2005 and 50 ppm by 2010.
Yemen	10,000	No current Standards. Domestic crude is somewhat sweet, but exported. Improvements by 2010
Total: 19 countries		

References:
http://www.hydrocarbons-technology.com/projects/sohar/
http://www.orc.co.om/business_process.shtml
MW = Mike Walsh Global Clean Fuels Overview, Memo sent via email on June 26, 2005.
IFQC = International Fuel Quality Centre, July 2005
Country Representative = Based on information obtained from various country representatives at the UNEP/PCFV workshop in Beirut in 2004.
The Marrakech Partnership Meeting, March 2005.
Gulf News Agency

Sub-Saharan Africa - Sulphur Levels in Diesel Fuel

COUNTRY	Sulphur Level (ppm)	COMMENTS	SOURCE
Angola	3000		Country contact
Benin	5000	Imports from Ivory Coast and Nigeria	PCFV meeting in Benin
Botswana	500	Supplied by South Africa	
Burkina Faso	5000		Country contact (Zéphirin Ouedraogo)
Burundi	5000	Imports from Tanzania and Kenya	
Cameroon	5000		Country Standards/Country contact (Molo Yenwo)
Cape Verde			No information
Central African Republic	5000-3000	Imports petrol from Cameroon	
Chad	5000	Imports petrol from Cameroon and Nigeria	
Comoros			No information
Congo (Brazzaville)	10000	Actual level from country contact is 1000ppm	Fred Sexsmith/Country contact (Séraphin Ele)
Democratic Republic of Congo	5000-500		Fred Sexsmith
Côte d’Ivoire	5000		Country standards
Djibouti	5000		Country contact
Equatorial Guinea	8000-5000	Supplied by Cameroon and Gabon	
Eritrea	7000		Fred Sexsmith
Ethiopia	5000	Standards may be higher - to be amended	PCFV workshop (EPE)
Gabon	8000	Intends to move to 5000ppm in 2010	World Bank meeting (Brussels)
Ghana	5000	Actual levels are lower	Country Standards
Guinea	5000	Supplied by Senegal	
Guinea-Bissau	5000	Supplied by Senegal	
Kenya	10,000 – domestic 5,000 – imported	2500ppm already being imported	Country standards
Lesotho	500	Supplied by South Africa	
Liberia	5000	Supplied by Senegal and Ivory Coast	

Madagascar	5000		Fred Sexsmith
Malawi	500		PCFV workshop, national standards to follow
Mali	5000	Imports from Senegal	
Mauritania	5000		Country contact
Mauritius	2500		Country Standards
Mozambique	500		Country Standards
Namibia	500	Imports from South Africa	
Niger	10000		Country contact
Nigeria	3000	Actual level 1330 ppm	Country contact (Aminu Jalal)
Réunion			No information
Rwanda	5000	Imports through Kenya and Tanzania	
Sao Tome and Principe	3000	Imports from Angola	
Sénégal	5000		Country standards
Seychelles			No information
Sierra Leone	5000	Imports from Senegal	
Somalia			No infomation
South Africa	500	National standards for 50ppm to be set but already available in major towns	Country Standards
Sudan	11000		From oil company contact
Swaziland	500	Imports from South Africa	
Tanzania	5000		Country Standards
The Gambia	5000	Imports from Cote d'Ivoire	PCFV meeting
Togo	5000	Imports from Cote d'Ivoire and Nigeria	
Uganda	5000	Imports through Kenya and Tanzania	
Zambia	7500		Country standards
Zimbabwe	500	Imports through Mozambique and South Africa	
Total: 49 countries			

References:
Fred Sexsmith: Consultant to the World Bank, May 2005
Various Country Standards and Contacts
UNEP/PCFV sponsored meetings
World Bank Clean Air Initiative in Sub-Saharan African Cities Meetings in Brussels, Belgium 2004 and Dakar, Senegal 2005

Central and Eastern Europe & Central Asia - Sulphur Levels in Diesel Fuel

Country	Diesel Sulphur Level (ppm)	Petrol Sulphur Level (ppm	Comments
Albania	2000	150	2000 ppm domestic refinery production (20 percent market share), 350 ppm diesel imported.
Armenia	350	150/500	Armenia imports; plans to transition to 50 ppm then 10 ppm petrol and diesel sulphur from 1 November 2008
Azerbaijan	2,000	1,000	Follows GOST standards.** Reduction of diesel sulphur content to 500 ppm by 2015.
Belarus	350	500	Adopted EN 228:1993 since 09/1993 but fuel does not yet fully comply. As its industry is gradually modernized, Belarus expects to be able to produce low sulphur fuel from 2008.
Bosnia and Herzegovina	350	150	Over 97 percent of fuel imported from neighboring countries, including Serbia.
Bulgaria	50	50	Follows EU Fuel and Vehicle Directives
Croatia	50	50	New regulation adopted May 2006 transposing 98/70/EC and 1999/32/EC. Rijeka and Sisak refinery upgrades have started, will continue to 2012 and will cost EUR 750 million.
Cyprus	50	50	Follows EU Fuel and Vehicle Directives
Czech Republic	50	50	Follows EU Fuel and Vehicle Directives
Estonia	50	50	Follows EU Fuel and Vehicle Directives
Georgia	350	500	Imports fuel. Gradual move to 50 ppm petrol by 1/1/2011; 50 ppm diesel 1/1/2010
Hungary	10	10	Follows EU Fuel and Vehicle Directives
Kazakhstan	2,000	150/500	Follows GOST standards.
Kyrgyzstan	2,000	1,000	Follows GOST standards.
Latvia	50	50	Follows EU Fuel and Vehicle Directives
Lithuania	50	50	Follows EU Fuel and Vehicle Directives
Montenegro	10,000	1,000	Imports from Serbia.
Poland	50	50	Follows EU Fuel and Vehicle Directives
Moldova	2,000	500	Follows GOST standards.
Romania	50	50	Petrom and Rompetrol already produce diesel as low as 10 ppm. National legislation harmonized with 98/70/EC (50 ppm). Follows EU Fuel and Vehicle Directives
Russia	10/50/350/2,000	150/500	Various grades on market. Lukoil has launched Euro 4 diesel production (50 ppm) in Moscow and St. Petersburg. Draft standards propose the Euro-3 standard for fuels from 1/1/2009, Euro-4 – from 1/1/2010, and Euro-5 from 1/1/2013.

Country	Diesel Sulphur Level (ppm)	Petrol Sulphur Level (ppm	Comments
Serbia	10,000	2,000	Domestic refineries produce 10,000 ppm diesel and a 350 ppm 'EKO' diesel grade, with very small quantities of 50 ppm diesel produced at Pancevo refinery. Lower sulphur diesel is imported in limited quantities.
Slovakia	10	10	Follows EU Fuel and Vehicle Directives
Slovenia	50	50	Follows EU Fuel and Vehicle Directives
Tajikistan	2,000	1,000	Follows GOST standards.
The former Yugoslav Republic of Macedonia	50	50	Plan for 10 ppm in fuels from 2009 in line with EU Directives. 5% bio diesel allowed in diesel - III grade.
Turkey	50/1000	150	Various grades available. National legislation limits diesel sulphur levels at 350 ppm (75 percent market share in 2005).
Turkmenistan	2,000	1,000	Follows GOST standards.
Ukraine	2,000	1,000	Follows GOST standards.
Uzbekistan	5,000	500/1000/5000	
Total 30 Countries			

*Please note that some of this information, especially for countries in the Former Soviet Union, are based on the most readily available information on existing conditions and are thus subject to correction or change. Email elisa.dumitrescu@unep.org with updates.
** Russian Gosudarstvennye Standarty State Standard

References:

Belarus Ministry of Economic Affairs
Clean Fuels and Vehicles Workshop for Central and Eastern Europe & Turkey, http://www.rec.org/REC/Programs/pcfv/countries.html
Croatian Ministry of Environmental Protection, Physical Planning and Construction
IFQC presentations and updates
Michael Walsh Global Clean Fuels Overview
Republic of Georgia Ministry of Environmental Protection
Various personal correspondence
Outcomes and reporting for the EECCA Cleaner Fuels and Vehicles Conference, 24-25 January 2008, http://www.unep.org/pcfv/meetings/tiblisimeeting.asp

Asia-Pacific - Sulphur Levels in Diesel Fuel

COUNTRY	Sulphur Level (max, ppm)	COMMENT	Source
Afghanistan	>10,000	No standards or ongoing plans	MW
Bangladesh	5,000	Euro 1(2,000 PPM) standards being discussed	ASCOPE, MW
Bhutan	500	No known plans	UNEP ROAP
Brunei Darussalam	1,000		ASCOPE
Cambodia	1,500	No Road map or formal emission standards	ASCOPE, MW
China (nationwide)	500	Plans to adopt Euro 3 and perhaps Euro 4 standards by 2010 Euro 3 emission standards (nationwide) Euro 4 standards by 2010 (passenger cars)	MW, Country Representative, CAI-Asia
China (Beijing)	50		CAI-Asia
China Hong Kong	50	Plans to adopt Euro 5 standards (10ppm) are under discussion	CAI-Asia
China, Macao Sar	50		MW, ASCOPE
China, Taiwan	50		ASCOPE, MW
Cook Islands			
Democratic People's Republic of Korea			
Fiji	500	Fuel standards approved by cabinet in March 2007 (Trade standards 2007)	Fiji (2008)
India (nationwide)	500	Plans to adopt Euro 3 standards (350 ppm) 1st April 2010	The gazete of India part ii-section 3-sub section (i) 5th July 2008
India (metros)	350	Plans to adopt Euro 4 standards (50 ppm) 1st April 2010	
Indonesia	4600	Currently at Euro 1 (2,000 ppm) plans to adopt Euro 3 standards (35ppm) after 2010. Two refineries at 500ppm(35%), two refineries at 1500ppm and one refinery at 3500ppm(39%) and imports at 5000ppm	
Kiribati			
Lao People's Democratic Republic	2500	Imports from Thailand, Vietnam & Malaysia. Currently developing an environmental sustainable transport strategy where Fuel Quality Standards are to be addressed	PCFV workshop August 2008
Malaysia	500	Plans to adopt Euro 4 standards (50 ppm) by 2009-2012	ADB, ASCOPE,CAI-Asia
Maldives			
Marshall Islands			
Micronesia, Fed. States of			
Mongolia	5000		PCFV workshop July 2008
Myanmar			
Nauru			

Nepal	2000		ADB
Niue			
Pakistan	5,000-7000		
Palau			
Papua New Guinea			
Philippines	500	Discussions ongoing on adopting Euro 4 standards (50 ppm) by 2010	CAI-Asia
Republic of Korea	50/10	Plans to adopt Euro 4 standards (10-15 ppm) by 2010	CAI-Asia
Samoa			
Singapore	50		ASCOPE,MW
Solomon Islands			
Sri Lanka	500	Standards in place, no decisions to lower sulphur levels	MW
Thailand	350	Plans to adopt Euro 4 standards (50 ppm) by 2010	ASCOPE
Timor-Leste			
Tokelau			
Tonga			
Tuvalu			
Vanuatu			
Vietnam	500	Plans to lower sulphur levels to 150 ppm by 2010	ASCOPE
Total: 41 countries			

References:
MW : Mike Walsh Global Clean Fuels Overview, Memo sent via email on June 26, 2005
UNEP ROAP : National State of the Environment publication by the UNEP Regional Office for Asia and the Pacific, 2001.
ASCOPE : Asian Council on Petroleum, Hart's WFC Nov, 2004
ADB : Asian Development Bank, 2007, " A Roadmap for Cleaner Fuels and Vehicles in Asia" – second consultative Draft, 19 December, 2007
CAI-Asia (2008): http://www.cleanairnet.org/caiasia/1412/articles-40711_SulfurDiesel.pdf
Fiji (2008): http://www.fiji.gov.fj/publish/page_8555.shtml

PSS/08-41396/1000/November08/