CLEANING UP THE GLOBAL ON-ROAD DIESEL FLEET

A GLOBAL STRATEGY TO INTRODUCE LOW-SULFUR FUELS AND CLEANER DIESEL VEHICLES

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CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

As prepared by the Heavy Duty Diesel Initiative of the Climate and Clean Air Coalition

August 2016

MEMBERSHIP OF THE HEAVY DUTY DIESEL INITIATIVE

The Government of the United States of America, the Government of Canada, the Government of Switzerland, the United Nations Environment Program, the International Council on Clean Transportation

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Preface

Diesel engines power the dominant share of goods movement, construction equipment, and public transport vehicles in the global economy. This strategy presents a roadmap to reduce small particulate and black carbon emissions from the global on-road diesel fleet through the introduction of low-sulfur fuels and cleaner diesel vehicle standards. This can prevent an estimated 500,000 premature deaths per year.

The *Global Strategy to Introduce Low-Sulfur Fuels and Cleaner Diesel Vehicles* has been developed by the five co-leads of the Climate and Clean Air Coalition's (CCAC) Heavy Duty Diesel Initiative (HDDI): the Government of the United States of America, the Government of Canada, the Government of Switzerland, the United Nations Environment Programme (UNEP) and the International Council on Clean Transportation (ICCT).[1] It constitutes a core output of the CCAC HDDI, supported and developed to inform the direction of our work to virtually eliminate fine particle and black carbon emissions from new and existing heavy-duty diesel vehicles and engines through the next decade (and beyond). This document builds the case for a strategic global approach by expanding on a set of preparatory studies, which include a market analysis, a refinery analysis, a health benefits analysis and several case studies to illustrate the benefits, identify opportunities and target countries and regions for action. This strategy is also an invitation to partner with the HDDI and CCAC in this global desulfurization effort and it is our hope that this strategy will guide the work of those institutions, governments and experts also concerned with the climate and clean air benefits from low sulfur fuels coupled with cleaner technology.

This strategy was developed on the basis of an oil and diesel fuel market strategy which analyzed oil and fuel flows in terms of quality and quantity worldwide, and a refinery study which analyzed opportunities for refineries to upgrade to allow for the production of low sulfur diesel fuels. Several case studies were analyzed in different regions and the health benefits of switching to low-sulfur fuels and cleaner diesel vehicles were modeled as part of this strategy. Combined, the markets and refineries studies, with the case studies and the health modeling, form the basis of this strategy.[2]

This strategy does not consider countries that have already adopted, at a minimum, 50 ppm fuel sulfur standards and associated Euro 4/IV equivalent vehicle emissions standards. These excluded countries include most of the OECD nations as well as China and Russia. While opportunities in these countries are not assessed in this strategy, it is important to note that considerable additional health and climate benefits are available from moving beyond 50 ppm fuels and associated vehicle emissions standards to ultra low-sulfur fuels and associated standards, and that additional benefits may also be delivered through improved measures for compliance and enforcement of adopted standards.

The first section (chapter 1) of the strategy looks at the current situation and state of low-sulfur fuel and vehicle emission standards worldwide, including the barriers and opportunities to introducing low-sulfur fuels. It also identifies the benefits of introducing low-sulfur fuels on a global scale in terms of both health and climate gains.

1 For more information about the CCAC see: http://www.ccacoalition.org/
For more information about the Heavy Duty Diesel initiative of the CCAC see: http://www.unep.org/ccac/Initiatives/ReducingEmissionsFromHeavyDutyDiesel/tabid/133573/Default.aspx
For more information about UNEP see: www.unep.org
For more information about the ICCT see: www.icct.org

2 Supporting refinery and market studies available from http://www.ccacoalition.org/en/initiatives/diesel

The second section (chapter 2) presents a roadmap to move to low-sulfur fuels, identifying the countries that are the highest priorities for action, and presenting a 'markets approach' based on the fuel trade relationships between countries and within sub-regions. We define four main categories of action based on whether a country primarily imports fuel, has refining capacity, has yet to match fuel quality with vehicle emission standards or has chosen to prioritize clean fuels in cities. It outlines 36 countries for immediate action based on the opportunities available in each.

Executive Summary

According to the World Health Organization (WHO), approximately one in eight global deaths in 2012 were a result of air pollution exposure, making this the world's single largest environmental health risk. The International Agency for Research on Cancer has classified diesel engine exhaust as carcinogenic to humans (Class 1). Nearly half of these early mortalities are associated with outdoor air pollution. Without additional actions, the contribution of outdoor air pollution to early deaths will continue to increase. The main cause is fine particles ($PM_{2.5}$). Vehicles are significant sources of $PM_{2.5}$ and in many cities the major source. To reduce $PM_{2.5}$ emissions from vehicles there is an **urgent need to introduce low-sulfur fuels** – fuels with no more than 50 parts per million (ppm) sulfur, and ideally ultra low 10 or 15 ppm sulfur. Low-sulfur fuels are also necessary for the **introduction and effective operation of cleaner vehicles and emission control technology. This combination of cleaner fuels and vehicles will have major health benefits and deliver substantial climate benefits through the reduction of short-lived climate pollutants** (i.e. black carbon).

This strategy considers desulfurization of on-road fuels globally. It excludes countries that have already adopted both on-road fuel sulfur standards of 50 ppm or below and vehicle emissions standards of Euro 4/IV equivalent or higher. 85% of road transportation is powered by diesel engines. A global transition to low sulfur on-road diesel and associated vehicle emissions standards by 2030 in the countries considered here would result in about 500,000 avoided deaths per year by 2050. The net present value of the health gains to 2050 is estimated at $18 trillion. The total costs of desulfurization and emission controls are estimated at around $1.1 trillion over the same period; therefore, **estimated benefits to 2050 outweigh costs by a factor of around 16.**

Many countries worldwide have already capitalized on these benefits by moving to low and ultra low-sulfur fuels through updated fuel quality standards and/or by upgrading their refineries to produce low-sulfur fuels. However, **more than half of the world's countries are still using high-sulfur fuels**. These are mainly low-and middle-income countries spread across Latin America, the Caribbean, Africa, the Middle East and Asia-Pacific. Global progress on desulfurization has been impressive over the past decade, but it needs to be accelerated and more widespread. Many of the benefits of desulfurization can be delivered with 50 ppm low-sulfur fuels, but the largest health improvements and climate benefits are associated with ultra low-sulfur fuels of 10 or 15 ppm.

This document presents a strategy for how the world can transition to low-sulfur fuels and cleaner diesel vehicles within the next decade. It also outlines why this is imperative for both health and climate goals. Achieving this change will require a focus on countries that are fuel importers, those struggling to secure financing for refinery upgrades, and those that have yet to match already-available low-sulfur fuels with the vehicle emission standards that secure the full air quality and climate benefits of desulfurization. In import-dependent countries, implementing new standards should not take more than two years. For countries with refining capacity additional time between rule promulgation and implementation will be needed but should not take more than five years.

The global fuels market is complex. Some countries are entirely self-sufficient in refinery capacity; in fact, some export considerable quantities of excess fuel. Others complement local fuel production with imports, while many have no refinery capacity at all and are entirely dependent on fuel imports. **This strategy focuses on the local markets in which countries are operating and proposes ways for these countries and markets to move to low-sulfur fuels within a feasible timeframe.**

Import-dependent countries are generally at an advantage in the adoption of low-sulfur fuel standards; low-sulfur fuels are readily available on the global market. Therefore, rapid adoption of low sulfur standards is attainable for these countries. The transition to low-sulfur fuel standards can be more challenging for **refining countries** since considerable investments must be mobilized to increase desulfurization capacity to produce low and-ultra-low sulfur fuels. Partnerships of private, public and development/donor finance have allowed desulfurization to proceed in many countries and we highlight case studies of where this has happened. By coupling desulfurization to investments in increased refinery capacity investors can improve the financial case for projects by allowing costs to be recouped through increased sales revenue.

Climate and Clean Air Coalition (CCAC) support and engagement should be targeted to countries and markets in which progress will likely lag or stagnate without additional support, where the potential health benefits are greatest and where action may catalyze additional improvements in related markets. While some of the largest refineries and fuel markets offer the largest health benefits from desulfurization and are well-placed to invest in desulfurization within regional and global markets, **a global transition and market for cleaner fuels and vehicles will require support in all developing markets**. The CCAC's engagement can be transformative in setting this transition in motion and partnering with initiatives and institutions beyond the CCAC will only strengthen this global effort and hasten desulfurization by 2030.

This document describes **four strategic categories of regional and national action**: 'importers', 'refiners', 'vehicle standards' and 'cities first'. The division of countries and regions into these categories guides our global approach to desulfurization. Based on the supporting research on markets and refinery operations several countries within each category stand out as key near-term opportunities for action.

We identify 13 countries in the "Importers" category. Because they are dependent on imported fuel, these countries can act relatively quickly to adopt new fuel standards, thereby reducing air pollution nationwide and driving forward regional and global demand for low-sulfur fuels. They make up the largest group of countries and have extensive influence on markets. Low-sulfur fuel could be provided through imports from the international market and the shift in regional demand from high-sulfur fuel to low-sulfur fuel will also spur investment in Refiner (category 2) countries.

The second category, called "Refiners," shortlists 13 countries. These countries have refining capacity that must be upgraded to support low-sulfur fuel standards domestically and regionally. While these countries face challenges in securing financing to upgrade their domestic refineries, they stand to gain from the investment by offering a higher-value fuel product that can be sold to an ever-growing market for low-sulfur fuels, especially when combined with increased capacity. Some refining countries still offer fuel subsidies that may undercut the ability of national and private refineries to recover refinery upgrade investments. This is a barrier that should be addressed through national policy.

The third category "Vehicle Standards" identifies 12 countries that have already achieved low-sulfur fuels but have not yet implemented commensurate cleaner vehicle standards that would maximize health and climate benefits from cleaner fuels and vehicles. These countries can gain from adopting stricter vehicle emission standards that align with the already-available fuel quality for both light- and heavy-duty vehicles; they can also take a leadership role within their regions, sharing their experience with implementing low-sulfur fuel in regional forums.

The first three categories prioritize countries in Africa, Asia, South America, Middle East and Eastern Europe for immediate action.

The fourth "City First" category includes three countries that have introduced more stringent fuel sulfur standards in cities, or in urban areas and along major transit corridors, **and require cleaner fleets to benefit from cleaner fuels available.** This adoption pattern is prevalent in South America, and has also been pursued in China and India. The "city first" model allows for rapid adoption of cleaner fuel and vehicle standards in high-impact urban areas during the period when refineries are transitioning to low-sulfur fuel production but do not have the capacity to meet national demands.

The strategy does pose logistical difficulties and risks of mis-fueling, but these risks can be reduced when accelerated fuel and vehicle standards are paired with a captive fleet with a centralized fueling location, such as a Bus Rapid Transit system. Countries should consider this a transition strategy, and plan a nationwide transition to low-sulfur fuels following urban implementation.

Our analysis identifies 36 countries in four categories for possible immediate action (Table A). Five countries (Nigeria, Pakistan, Malaysia, Indonesia, Tunisia) are identified in two categories, indicating options for multiple approaches. **Implementing the recommendations of this strategy would result in a near-elimination of on-road high-sulfur fuels and pave the way for reductions of 90% or more in small particulate emissions and black carbon of the global on-road vehicle fleet.**

Table A: Priority countries for action, by region and strategic category

Region	Category 1: Importers	Category 2: Refiners	Category 3: Vehicle Standards	Category 4: City First
Sub-Saharan Africa	Ethiopia	Cote d'Ivoire	East Africa region: Kenya, Uganda, Tanzania, Rwanda and Burundi	
	Mozambique	Ghana		
	Nigeria	Nigeria		
		South Africa		
Asia	Pakistan	Pakistan	Brunei	
	Bangladesh	Indonesia	Indonesia	
		Malaysia	Malaysia	
		India		
Latin America & the Caribbean	Central America region: El Salvador, Guatemala, Nicaragua and Honduras	Venezuela	Panama	Argentina
			Barbados	Brazil
				Peru
East Europe	Georgia	Ukraine		
	Moldova			
Middle East and North Africa	Lebanon	United Arab Emirates	Oman	
	Tunisia	Kuwait	Tunisia	
		Bahrain		

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1. Why does the world need low-sulfur fuels, and why doesn't it have them yet?

Over the past decade the world has seen a gradual move to low-sulfur fuels. Most developed countries have now moved to fuels with a sulfur content of 50 parts per million (ppm) or below. However, many countries, especially low-and middle-income countries, still have high fuel sulfur levels - often exceeding 500 ppm and even 5,000 ppm. Of the 900 billion liters of on-road diesel fuel consumed worldwide every year, thirty percent contains high levels of sulfur. As it stands, 4.1 billion people in over 120 countries have no access or limited access to low-sulfur fuel. And while some countries have access to low-sulfur fuels they have not implemented corresponding vehicle emissions standards to take advantage of these cleaner fuels. An estimated 80,000 premature deaths from transport-related air pollution occur each year in these countries. Mapping out a way to prevent these avoidable deaths is the focus of this global strategy.

What is low-sulfur fuel?

All crude oil contains certain impurities in addition to pure hydrocarbons. The most important of these, from an air pollution perspective, is sulfur. Sufficiently high sulfur levels in refinery streams can deactivate ("poison") catalysts used in certain refining processes, cause corrosion in refinery equipment, and lead to airborne emissions of sulfur compounds.

Low-sulfur fuels have been subjected to desulfurization processes, such as hydrotreating, at the refinery with the goal of restricting sulfur content below some maximum level. Sulfur levels below 50 parts per million (ppm) ('low-sulfur fuels') are needed in order to avoid damage to emission control systems in Euro 4/IV vehicles and above. Maximum sulfur levels of 10 to 15 ppm ('ultra low-sulfur fuels') are required for the most effective emissions control systems, such as diesel particulate filters, to achieve the emission reductions necessary to meet limits set by filter-forcing standards

This document explains how emissions of ultra-fine particles and black carbon from on-road diesel vehicles can be reduced by over 90 percent. International Energy Agency projections show that fossil fuels and internal combustion engines will continue to dominate road transport through 2030. However, cities and countries may opt to shift away from diesel technology altogether. Given the current turnover rates of existing fleets (upwards of 10-15 years), the vehicle technology adopted today will persist for years, if not decades, to come. An alternate path would be a shift away from diesel technology. While this strategy does not address alternative technologies in detail, it is important to note that non-diesel alternatives such as compressed natural gas, biofuels, hybrid-electric or fully electric vehicles may be appropriate in some markets.

Sulfur in fuel is problematic because it leads to increased air pollution. This occurs directly through emissions of harmful sulfur compounds such as sulfates, and indirectly by inhibiting the effectiveness of modern emission control devices. Sulfur in fuel is also a barrier to dealing with climate pollution from diesel engines. Black carbon associated with diesel combustion can be controlled using diesel particulate filters required by Euro 6/VI emissions standards, but these devices are only effective with low, or ideally ultra low, sulfur fuels.

Much has been achieved already. Over the past decade several low-and middle-income countries, including China, some South American, all East African countries, several East European countries, Thailand and several North African countries have completed a move to low-sulfur fuels of 50 ppm or below. Countries in which low-sulfur fuels are already matched by Euro 4/IV equivalent vehicle emission standards are not assessed in this strategy. More countries have moved from high fuel sulfur levels to intermediate levels (from red/ orange to green in the map in Figure 1.1), and more have adopted timetables to reach 50 or 10/15 ppm fuels. However, accelerated progress is needed over the next decade.

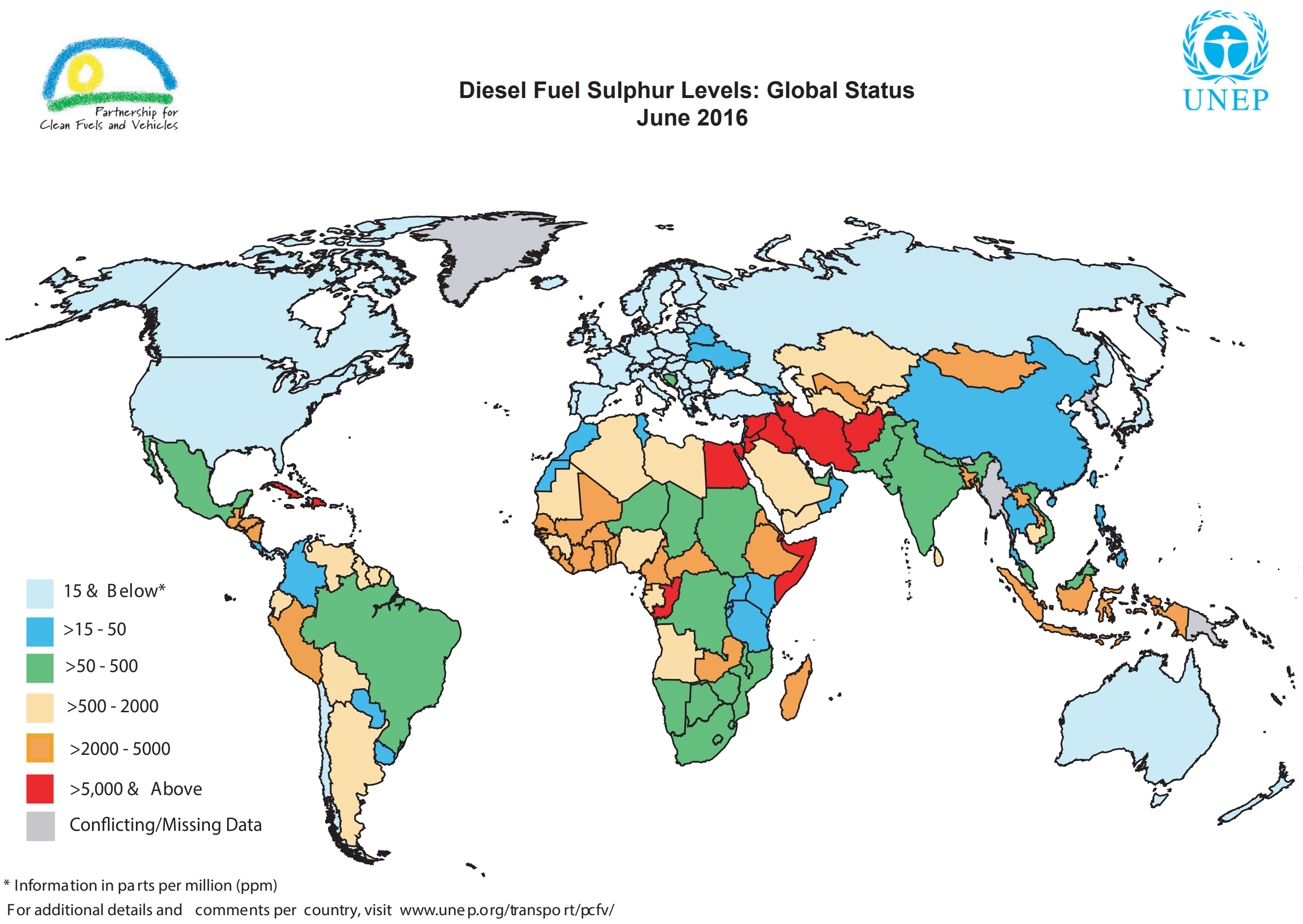


Figure 1.1. Global view of sulfur levels in diesel fuels
Source: UNEP, 2016

1.1. Health benefits of sulfur reduction

Outdoor air pollution ranks among the top ten global health risks. Air pollution exposure has been identified by the World Health Organization as contributing to one in eight deaths globally in 2012 (WHO, 2014a). Some 88% of premature deaths due to ambient (outdoor) air pollution occurred in low- and middle-income countries (WHO, 2014b). Without additional actions described in this strategy, the contribution of outdoor air pollution to early deaths could double by 2050 (Lelieveld et al., 2015). The main cause is fine particles ($PM_{2.5}$), to which global exposure has increased on average by more than 2 percent annually since 1998 (van Donkelaar et al., 2015). Motorized transport is a major contributor to outdoor air pollution, particularly near major roadways and in urban areas where vehicle and economic activity is concentrated (Health Effects Institute, 2010). Reducing fuel sulfur levels is a vital element of any global strategy to reduce the health impacts associated with transportation (Scovronick, 2015).

Removing sulfur from vehicle fuel is of two-fold importance in preventing harmful vehicle pollution. First, fuel sulfur directly increases production of fine particulate matter ($PM_{2.5}$) which is a dangerous pollutant associated with heart disease, lung cancer, and a range of other harmful health effects (Krewski et al., 2009). When diesel sulfur content is high, sulfate particles, formed from combustion of sulfur in diesel, make up a significant share of total fine particulate emissions. In countries without fuel sulfur limits, diesel sulfur content is typically 500 to 2,000 ppm, and sulfates make up 15% to 50% of diesel $PM_{2.5}$ emissions (using sulfate formation assumptions based on Glover and Cumberworth, 2003).

Second, low-sulfur fuels are necessary for cleaner engines (for example high compression diesel engines) and allow for the efficient performance of equipment designed to remove small particulates and other pollutants from the exhaust stream (including particulate filters and catalysts) (Corro et al., 2002). Diesel particulate filters, for example, perform best with a maximum diesel sulfur content of 10 or 15 ppm. These filters control not only $PM_{2.5}$ mass, but also can reduce the emission of ultrafine particles, which are thought to have a greater toxicity than larger particles due to their higher quantity, and ability to penetrate deep within lung tissue and cross into the blood stream (May et al., 2007; Health Effects Institute 2013). High-sulfur fuel can also damage some systems that control nitrogen oxides, a pollutant that leads to smog and additional $PM_{2.5}$ formation. While fuel sulfur reduction alone delivers significant health benefits, the full benefits of cleaner fuels are realized when low-sulfur fuel is combined with appropriate vehicle emissions standards.

Figure 1.2 shows that a combined approach of introducing low-sulfur fuels and cleaner vehicles standards will result in major particulate matter (PM) reductions. This figure shows the impact of Euro I-VI standards in heavy-duty diesel vehicles. While lowering sulfur in diesel fuel results in direct and proportional reductions in $PM_{2.5}$ emissions in all vehicles (even those without emission controls), cleaner fuel combined with emission controls at Euro IV and above results in drastic reductions in both $PM_{2.5}$ and black carbon emissions. Euro VI standard-level technology combined with 10/15 ppm diesel will result in an approximate 99% reduction in $PM_{2.5}$ as compared to combustion of 2,000 ppm fuel with no control requirement.

By convention, Arabic numerals used in the context of the Euro standards refer to light duty vehicles, Roman numerals to heavy-duty vehicles. The EU standards are the basis of the UNECE vehicle emission standards.[3] It should be noted that North America has a different, but similar, set of vehicle standards (e.g. U.S. Tier 1-3 standards for passenger vehicle emissions, and U.S. 2004 and 2010 standards for heavy duty vehicle emissions). The North American standards force adoption of similar emissions control technologies to the equivalent European standards.[4]

Vehicles and fuels must be treated as a system to achieve the optimum benefits from emissions control policy, which means matching vehicle emissions standards to fuel quality. The Euro 4/IV standards for light- and heavy-duty vehicles respectively require 50 ppm diesel fuel to be effective. Some more advanced emission control technologies associated with higher standards can also operate with 50 ppm fuels – for instance, diesel particulate filters will still deliver benefits with 50 ppm diesel – but the optimal system will pair a stronger vehicle emissions standard with ultra low-sulfur fuel (maximum 10 or 15 ppm). These stronger emissions standards, including Euro 5 and 6, and U.S. Tier 2 and 3, for passenger vehicles, and Euro VI and the U.S. 2010 standards for heavy-duty vehicles, require more advanced technologies to be employed in order for compliance to be achieved, including diesel particulate filters. In this strategy, we will refer to standards associated with ultra low-sulfur fuels as 'filter-forcing' standards, and refer to the standards associated with maximum 50 ppm fuels as Euro 4/IV (there are no North American equivalent standards based on a 50 ppm fuel sulfur limit).

3 http://www.unece.org/trans/main/welcwp29.html

4 https://www.dieselnet.com/standards/eu/ld.php

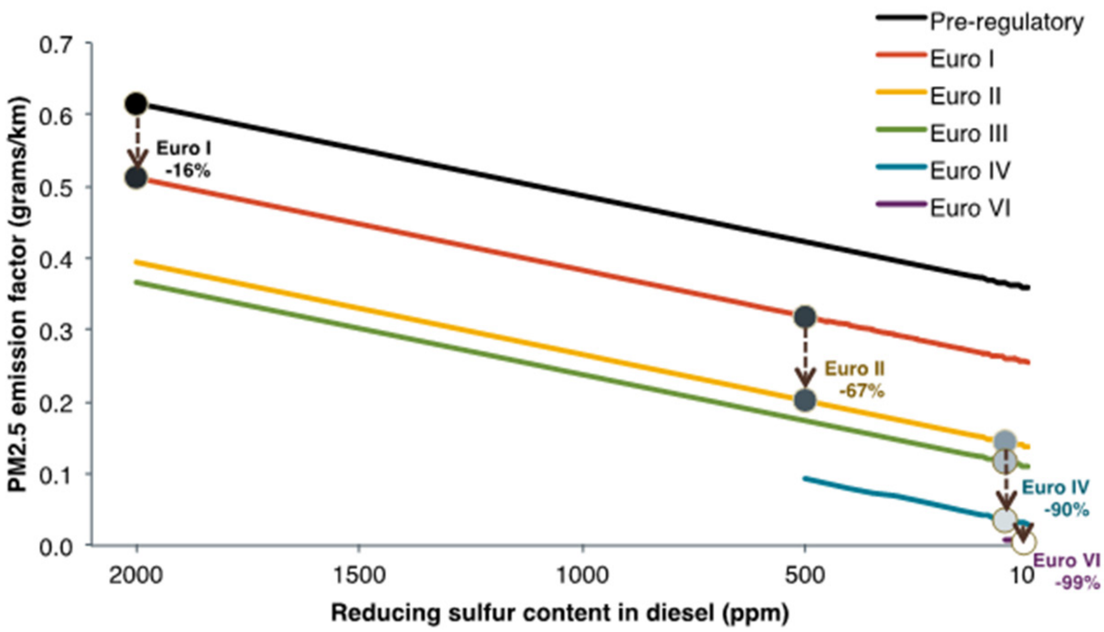


Figure 1.2. Impact of fuel sulfur levels and emissions control standards on $PM_{2.5}$ emissions from heavy-duty diesel vehicles (grams/km)

1.1.1. Assessment of the health benefits of global low-sulfur fuel adoption

For this strategy, we have assessed the health benefits by 2050 of a gradual transition to lower sulfur levels in global on-road diesel fuel. In the analysis, low sulfur diesel (50 ppm) is phased in for most countries by 2020 and for all remaining countries by 2025, while ultra low-sulfur diesel (10 ppm) is phased in progressively, representing the majority of global on-road diesel supply by 2030 (see Figure 1.5). The health benefits analysis covers countries in Africa, the Middle East, Asia, Latin America, and Europe with a combined 2015 population of 4.6 billion, or about 64% of the global population. It excludes China, Russia, Japan, South Korea, Australia, the United States, Canada, and countries in the EU as these countries have already achieved low and ultra low-sulfur levels in fuels, accompanied by Euro 4/IV equivalent vehicle emissions standards (or better), but does include some countries in other regions that have already adopted low-sulfur fuels and accompanying standards. The full list of countries included in the modeling is provided in Annex C.

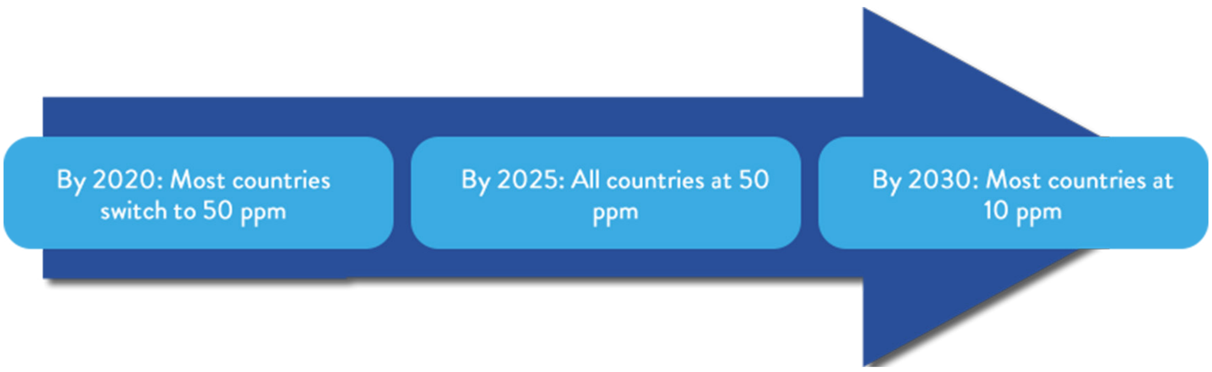


Figure 1.3. Summary of global low sulfur timeline

This analysis focuses on premature mortality from exposure to primary tailpipe $PM_{2.5}$ emissions in urban areas, which includes black carbon but excludes secondary particles such as sulfates and nitrates, reflecting an approach taken in similar studies (Chambliss et al., 2014b). Diesel engines produce a toxic mixture of pollutants that includes other gases such as nitrogen oxides, but for simplicity the health impacts of these were not modeled. Furthermore, exposure to diesel exhaust fine particles is associated with acute and chronic non-fatal health impacts such as exacerbation of asthma, but these also for simplicity were not modeled. By focusing on primary $PM_{2.5}$ exposures and their association with premature mortality this analysis is narrowly focused on the greatest health impacts of diesel engines but clearly provides an underestimate of the broad and diverse range of health impacts that are associated with exposure to diesel emissions. Modeling additional health impacts would increase the calculated benefits of sulfur control. This analysis adopts exposure response functions for selected major causes of death associated with prolonged exposure to $PM_{2.5}$ pollution for adults: cardiopulmonary disease and lung cancer (Krewski et al., 2009).[5] It also considers mortality in children from acute respiratory infection associated with long-term $PM_{2.5}$ exposure (Cohen et al., 2004). The methods for estimating premature mortality are detailed in Annex C.

Estimating a change in health outcomes from a change in fuel quality and emissions standards requires several stages of modeling. These stages are shown in Figure 1.2.1 below. Moving from left to right:

1. **Source -> Emissions:** The ICCT Roadmap model uses vehicle activity projections to create a global inventory of on-road vehicle emissions. The emission factors used in this calculation account for the level of emission control and diesel sulfur content. A different emissions inventory is generated for each of the two policy cases considered: the baseline, in which countries do not advance beyond the fuel and vehicle standards currently enforced, and the transition case, described below.
2. **Emissions -> Concentration:** The Roadmap produces a measure of annual $PM_{2.5}$ emissions for both policy cases. The urban portion of these emissions is determined and used with a set of metrics called "intake fractions" to predict the annual change in urban air quality caused by vehicle emissions.
3. **Concentration->Health Effects:** We estimate the health impacts associated with a change in average annual $PM_{2.5}$ concentration using exposure-response functions. These functions are based on long-term epidemiological studies, and are specific to the three health outcomes we focus on: cardiopulmonary disease and lung cancer in adults over age 30, and acute respiratory infection in children under age 5.
4. **Health Effects -> Economic Benefit:** Premature mortality associated with tailpipe $PM_{2.5}$ emissions is estimated for both the baseline and transition policy cases. The health benefits of the transition case are expressed as an economic value using a value called the value per statistical life (VSL), which expresses the aggregate willingness of society to pay to reduce the risk of premature death.

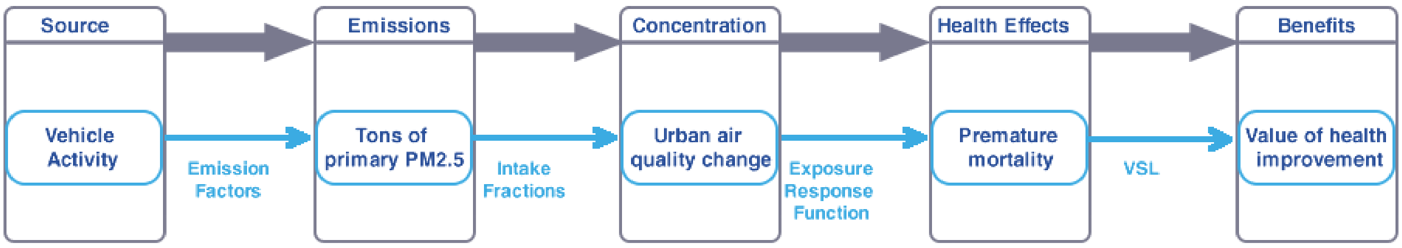


Figure 1.4. Modeling steps to estimate health impacts of vehicle emissions

This timetable for low-sulfur fuel deployment and the adoption of improved emissions standards for new vehicles is challenging but achievable (MathPro 2015b). A more rapid adoption of standards in some countries would increase the health benefits, while slower adoption in other countries would reduce them proportionately. The modeling does not include additional improvement in

5 The category of "cardiopulmonary disease includes upper and lower respiratory infection, hypertensive heart disease, ischemic heart disease, cerebrovascular disease, inflammatory heart disease, chronic obstructive pulmonary disease, and asthma.

fuel quality beyond 2030 – continued progress to global ultra low-sulfur fuels and commensurate vehicle and engine emissions standards would deliver considerable additional benefits. Note that the analysis assumes that in all cases improved vehicle emissions standards are introduced as appropriate fuels become available, so in the low sulfur case all new vehicles in countries with low-sulfur fuels (50 ppm) meet Euro 4/IV standards, while all new vehicles in countries with ultra low-sulfur fuel (10 ppm) meet Euro 6/IV standards. This matching of vehicles to fuels optimizes the available benefits.

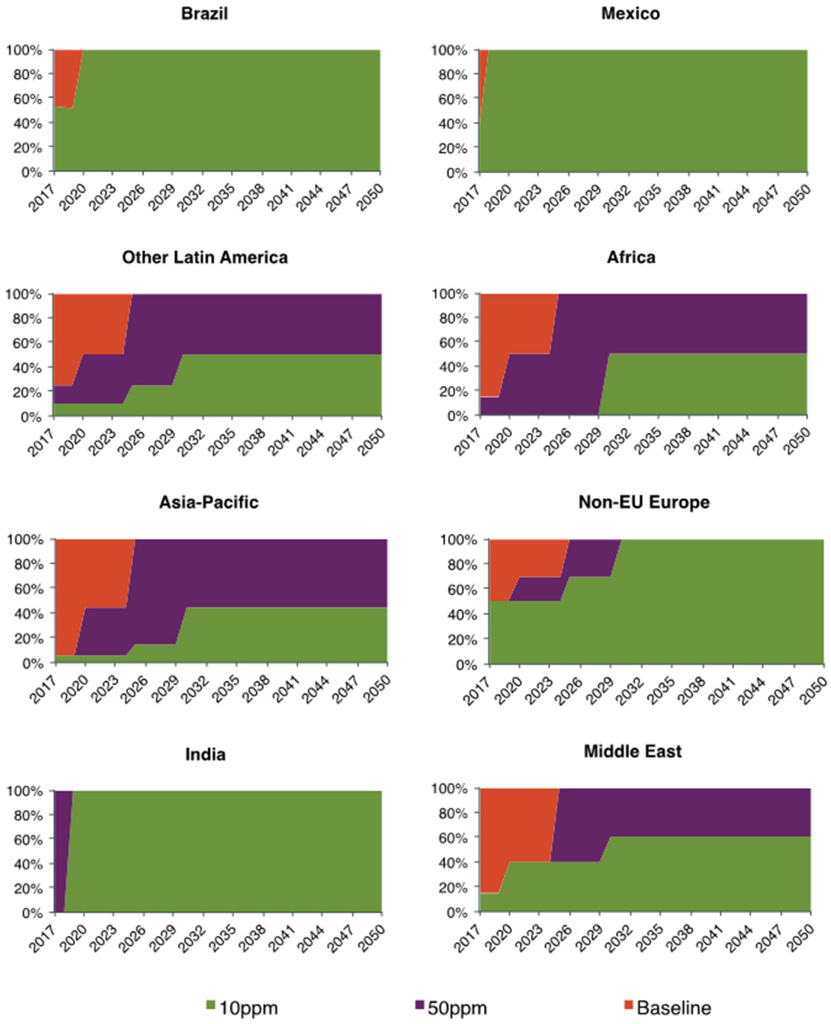


Figure 1.5. On-road diesel sulfur levels over time in the countries included in the health benefit assessment*

**New vehicle sales are assumed to meet the emissions standards made possible by the availability of lower-sulfur fuels. Percentage on left axis represents volume fraction of supplied road diesel fuel at each sulfur level.*

Estimates of emissions reductions are based on the ICCT Roadmap model, using the refinery and market studies prepared to support this strategy in order to inform the baseline diesel sulfur content. The baseline includes current low-sulfur fuel usage in each region, split between 50 ppm and 10 ppm fuel. The sulfur content of the remnant high-sulfur diesel fuel in 2015 is assumed to be 1,200 ppm across Africa, 1,000 ppm in Asia-Pacific (except 350 ppm in India), 2,000 ppm in Latin America (except 500 ppm in Brazil and 350 ppm in Mexico), 350 ppm in non-EU Europe and 2,500 ppm in the Middle East. These levels are held constant in the baseline case. The baseline vehicle emissions standards case assumes no advancement beyond policies that are currently enforced, described in more detail in Annex C. This health benefits assessment considers the overall benefits of a transition to improved fuel quality and vehicle emissions standards. Even without further intervention, it is expected that progress towards lower sulfur fuels and tighter vehicle emissions standards will continue in this timeframe. This strategy does not attempt to assess the marginal increase in the rate of desulfurization that can be delivered by interventions by the CCAC or other organizations, and similarly does not attempt to assess the health benefits that might be directly attributable to specific CCAC interventions.

Only the effects of diesel sulfur reductions were considered; reductions in gasoline sulfur content will deliver additional emissions benefits. The ICCT Roadmap model estimates, across the countries considered, that a move from current policies to low and ultra low-sulfur fuels (50 ppm, 10 ppm) and more stringent vehicle emissions standards could reduce vehicular $PM_{2.5}$ emissions by over 70%, cutting 14 million metric tons cumulatively through 2050.

As a consequence of emissions reductions, the introduction of low-sulfur fuel (for both petrol and diesel) could save thousands of lives annually. Early deaths from on-road diesel $PM_{2.5}$ exposure in urban areas in countries assessed will increase by over 50 percent by 2030 from 2015 levels in the absence of new policies. The mortality reduction assessed for this strategy represents a conservative estimate that considers only the health impacts of direct pollutant emissions in urban areas.[6] By this mortality reduction metric, the low sulfur transition described in Figure 1.5 would result in 7,000 avoided mortalities per year by 2020, 40,000 avoided mortalities per year by 2025, 100,000 reduced mortalities per year by 2030, and even without further improvement of fuel quality beyond 2030 would result in 500,000 avoided mortalities per year by 2050 (see Figure 1.6).[7] The very high number of annual avoided mortalities by 2050 (compared to current estimated mortalities at 80,000 per year in these countries) reflects the expected growth in fuel consumption over this period, and the associated increase in expected mortality rates over time if no action is taken.

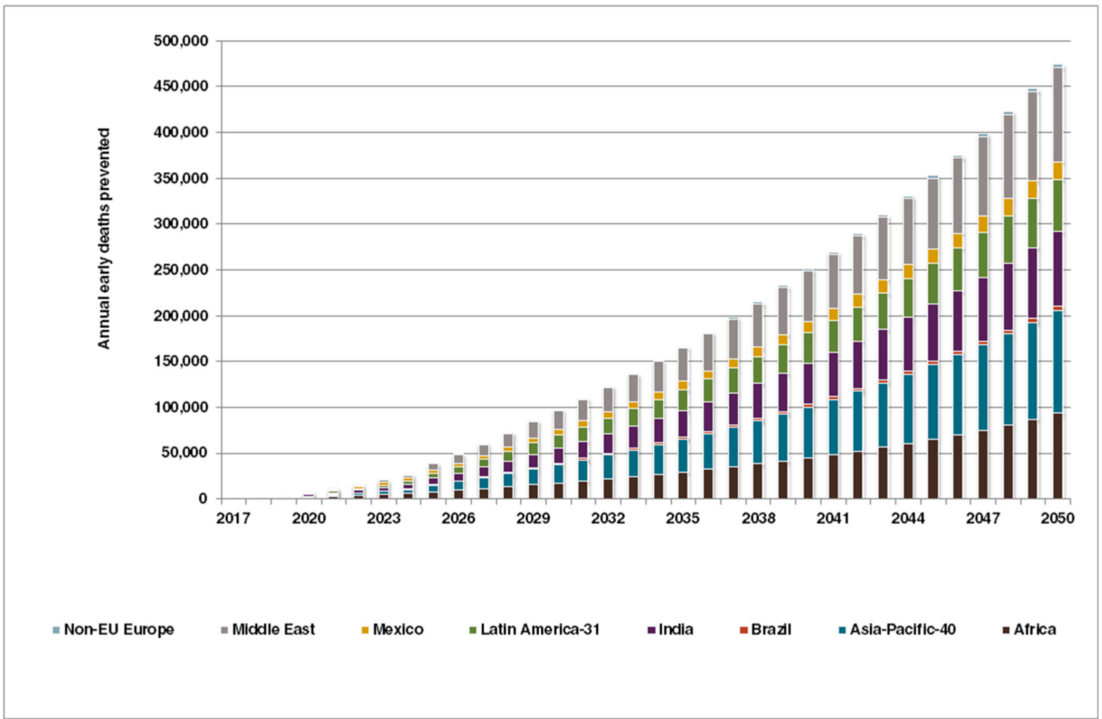


Figure 1.6. Urban health benefits of on-road fuel desulfurization in countries considered across Africa, Asia-Pacific, Latin America, and Middle East
Source: ICCT estimates

When a monetary value is assigned to these projected benefits, the present value of the cumulative health benefits of moving to low-sulfur fuel and corresponding vehicle emissions standards is

6 Using the same methodology developed in Chambliss, S., Miller, J., Facanha, C., Minjares, R., & Blumberg, K. (2013). The impact of stringent fuel and vehicle standards on premature mortality and emissions. The International Council on Clean Transportation.

7 Source: ICCT Roadmap modeling

approximately $18 trillion by 2050.[8] About a tenth of this ($1.6 trillion) is achieved in the first fifteen years by 2030. The increased rate of accrual of benefits in later years reflects the time it takes new vehicles to enter into the existing vehicle fleet, and the lag between adoption of standards and the prevention of mortalities. The monetization is based on the methodology described by Minjares et al. (2014), and adopted in Miller et al. (2014). In this methodology, a monetary value is assigned to an avoided mortality based on an assessment by the U.S. EPA of the 'value of a statistical life', adjusted to reflect the different average incomes in the countries considered.

This total benefit is many times greater than the cost associated with improved fuel quality and vehicle emissions controls. The largest cost is associated with fitting appropriate emission control technologies to new vehicles. In a conservative estimate that assumes no reduction in cost of vehicular emission control technology over the period, this would cost $790 billion. The second largest cost is that of refinery upgrades. Based on the refinery analysis by Ensys (described in more detail below), a total investment of $70 billion would be required to bring all refineries to 50 ppm.[9] Assuming an annual capital charge ratio of 0.25 (Hart Energy and MathPro, 2012) and applying capital charges for 15 years, the total cost of this investment would be up to $230 billion. Delivering ultra low-sulfur fuel[10] in most countries by 2030 would require an estimated additional $70 billion (authors' estimate based on MathPro, 2015a), for a total capital cost of $300 billion. Finally, the operational cost to produce lower sulfur diesel, assuming marginal increase of refinery operational costs of 20 ¢/barrel for 50 ppm diesel, and an additional cost of 10 ¢/barrel for 10 ppm diesel, would be $16.5 billion to 2050. Therefore, the total costs of desulfurization and vehicle emission controls could be up to and around $1.1 trillion.

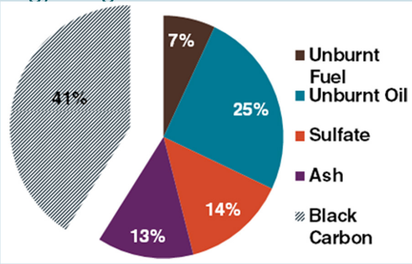
Estimated benefits to 2050 outweigh costs by a factor of around 16.

Components of $PM_{2.5}$

A number of components make up the total mass of $PM_{2.5}$ emitted by an engine, generally categorized into:

- Solid fraction, including black carbon and ash
- Soluble organic fraction, including unburnt fuel and oil
- Sulfate particles, including sulfuric acid and adsorbed water

The amount of any of these components varies greatly depending on engine technology, engine load, and—for sulfates—the sulfur content of the fuel. The chart below shows a composition typical of a heavy-duty diesel engine operated in the U.S. in 1998, when diesel sulfur limits were 500 ppm (Kittelson, 1998).



Higher fuel sulfur content increases the mass of sulfates produced, and as a consequence increases total $PM_{2.5}$, as illustrated in figure 1.3. Lowering sulfur levels decreases sulfate production, but does not directly lower production of other components (e.g. black carbon). However, it does enable the use of advanced emission control technologies and engine tuning that reduce the solid and soluble organic fractions of black carbon, and thus indirectly plays a role in reducing climate-forcing emissions.

8 This includes discounting at 3% per year. This discounting is also applied to the cost estimates given here.

9 It is likely, in practice, that some of the refineries that would be most expensive to upgrade will be closed, in which case costs could be lower.

10 Modeled as 10 ppm and below by MathPro (2015a).

1.2. Climate

The largest public benefits achievable through sulfur control are health-related, but many of the constituents of $PM_{2.5}$ also have an effect on climate change. One component in particular of $PM_{2.5}$, black carbon, is a potent climate forcer that absorbs sunlight and releases heat, causing warming. Because black carbon only has a life in the atmosphere of less than a week, it is a so-called short-lived climate pollutant. Reducing emissions of short-lived climate pollutants like black carbon has a direct and immediate impact on climate change, and can therefore be a valuable complement to reducing CO_2 emissions as a tool to limit climate change.

Pairing low sulfur diesel fuel with the right emission control technologies leads to reductions in black carbon as well as other climate pollutants (Bond et al., 2013). Euro VI-equivalent emissions standards that require particulate filters (i.e. filter-forcing standards) are the most effective option for controlling diesel black carbon, reducing $PM_{2.5}$ emissions by up to 99% and black carbon by over 99%. Euro 4/IV standards also lead to reductions in black carbon emissions of up to 90% by forcing improvements in combustion technology; but, in general, vehicles meeting Euro 4/IV equivalent standards are not equipped with particulate filters and so deliver lower emission reductions than engines meeting a filter-forcing standard. An additional benefit of the introduction of more modern vehicles through the application of filter-forcing standards, with cleaner and more efficient engine technologies, is that these modern vehicles are generally more fuel-efficient (because of the parallel implementation of fuel economy standards) and thus the CO2 emissions of these vehicles are often also reduced.

Therefore, there are substantial climate benefits to be gained by advancing vehicle emissions standards along with lowering fuel sulfur content globally. A move to more stringent standards for diesel fuel and vehicles as outlined in section 1.1.1 would reduce cumulative emissions of diesel black carbon by an estimated 7.1 million metric tons through the year 2050.[11] This would bring down annual black carbon emissions from on-road vehicles by over 85% throughout these regions by 2050. However, note that inspection and maintenance programs are necessary in order to maintain the gains made by cleaner fuels and vehicle emission standards. In addition, the benefits from black carbon emissions would be partially offset by increases in energy use at the refinery level.

Table 1.1. Annual (and cumulative) reductions in black carbon emissions (millions of metric tons) and net climate benefit (millions of metric tons CO2-equivalent, based on GWP-100) through low sulfur diesel and emission standards*

	2020		2030		2050	
	Black Carbon Reduction	Net climate benefit	Black Carbon Reduction	Net climate benefit	Black Carbon Reduction	Net climate benefit
Accelerated desulfurization scenario	.02 (.04)	16 (30)	.17 (1.0)	130 (780)	.41 (7.1)	320 (5,500)

**The net climate benefit includes the effects of methane (CH4), nitrous oxide (N2O), black carbon, organic carbon (OC) and sulfates. Sulfates emissions actually have a cooling effect in the atmosphere, and therefore*

11 When the climate impact is assessed over a 100-year time horizon, these black carbon reductions amount to the equivalent of 6.0 billion metric tons of CO2; over a 20-year time horizon, the CO2-equivalent is 23 billion metric tons. Accounting for concurrent reductions in other short-lived climate pollutants, the implementation of stringent standards would save the equivalent of 5.5 billion metric tons of CO2 over a 100-year time horizon, or 22 billion metric tons of CO2-equivalent over a 20-year time horizon. Desulfurization also requires additional energy expenditures at the refinery, increasing refinery emissions. In the absence of further decarbonization of refinery energy supply, we estimate that cumulative refinery emissions associated with this global desulfurization could be up to 1 billion metric tons of CO2. This leaves a net benefit on a 100-year time horizon of at least 4.5 billion metric tons of CO2 equivalent.

reducing sulfate production alone delivers no climate benefit. Black carbon reductions associated with better fuel quality and improved emissions standards offset this reduction in cooling and result in substantial climate benefits overall.

1.3. Opportunities for ultra low-sulfur fuels

The UNEP Integrated Assessment on Black Carbon and Tropospheric Ozone put forward 16 win-win strategies for the control of short-lived climate pollutants. In the transportation sector the key strategy is the introduction of diesel particulate filters as part of a filter-forcing vehicle standard and fuel policy package. Fuel standards in Europe set a limit of 10 ppm sulfur diesel to accompany the Euro 6/VI vehicle emissions standards, and no country that has adopted the Euro 6/VI vehicle emission standard has a maximum diesel sulfur content above 10 ppm. In the United States, where 2007 and 2010 heavy-duty vehicle emission standards and Tier 3 passenger vehicle standards have led to the deployment of diesel particulate filters, the maximum diesel sulfur level is 15 ppm. Canada and Chile are harmonized to the U.S. 15 ppm limit.

Diesel particulate filters are very effective at controlling not only black carbon but also ultrafine particles. Ultrafine particles are the smallest fraction of particulate matter, 100 nanometers in diameter or less, and regulated in the European Union via particle number standards (Health Effects Institute, 2010). Ultrafine particles, due to their small size, can be inhaled more deeply into the lungs than larger particles, and may therefore have enhanced toxicity. Motor vehicle exhaust is the primary source of ultrafine particles in urban areas, and diesel vehicles are the largest contributor. A diesel particulate filter can reduce particle mass from a model year 2004 engine by 90% and ultrafine particles by at least a factor of 100 (Health Effects Institute, 2013).[12]

In almost all cases, refineries will require additional investment to bring sulfur levels down from 50 ppm to ultra low-sulfur levels and will incur increased running costs. Countries with refineries can reduce the overall cost of sulfur control investments by choosing to leap to 10/15 ppm in the fewest steps possible (MathPro, 2015a) and to build to capacity to desulfurize all their diesel fuels, including on-road and non-road diesel fuels. Potential cost savings by going directly to ultra low-sulfur instead of in two steps include reduced overhead associated with managing and financing multiple projects and optimizing the choice of capacity additions. As discussed in the case studies in section 1.5.5 below, desulfurization investments often occur as part of larger refinery upgrade programs. In such cases, there is a very strong argument to go the full distance to ultra low-sulfur fuel. Going all the way in one step takes maximum advantage of the opportunity afforded to deliver environmental benefits on the back of capacity increases. In some cases improving the environmental performance of the package of upgrades may also assist in raising finance, for instance from development banks (as in the case of the Egyptian Refining Company, see section 1.5.5).

The costs of going all the way to ultra low-sulfur fuel instead of stopping at 50 ppm will tend to be moderate compared to overall project costs. An estimate by MathPro (2015a) finds that for 226 global refineries the additional weighted-average investment cost to transition from 50 ppm diesel and gasoline to 10 ppm diesel and gasoline is between 0.4 and 0.7 USD per barrel of capacity. This represents an additional 15 to 32 percent investment cost increase compared to the cost of upgrading only to produce 50 ppm fuel. Two thirds of this is the cost to desulfurize diesel, and the balance is for desulfurizing gasoline. As noted above, the operational cost of additional diesel desulfurization from 50 ppm to 10 ppm is estimated to be around 0.1 USD per barrel of on-road diesel produced.

In summary, diesel particulate filters as part of a filter-forcing package of fuel and engine standards are one of the 16 win-win strategies for control of short-lived climate pollutants, including black carbon (UNEP, 2011). All countries that systematically force the use of diesel particulate filters have

12 During regeneration events, whose duration and frequency will vary by engine design and duty cycle, ultrafine particulate emissions can temporarily increase but still remain lower overall.

ultra low-sulfur fuel standards, and the additional cost to deliver ultra low-sulfur fuel at 10/15 ppm instead of 50 ppm fuel is modest compared to the potential environmental benefits. All refining countries should aspire to 10/15 ppm diesel production in order to achieve the widespread adoption of diesel particulate filters in the vehicle fleet.

1.4. Barriers to low-sulfur fuel adoption

There are many reasons why countries thus far have not introduced low sulfur fuels. They include the cost of investment in increasing refinery capacity; the increased cost to consumers of low-sulfur fuels; difficulties in recouping investments in markets where fuel prices are regulated; and a lack of the political prioritization of fuel desulfurization. Often, there is a set of interlinked reasons that have prevented the introduction of low sulfur fuels.

1.4.1. Cost of refinery capacity

All crude oil contains some fraction of sulfur as an impurity – this fraction could be higher ("sour crudes", > 0.5% sulfur) or lower ("sweet crudes", < 0.5% sulfur). Reducing the sulfur content of refined fuels requires oil refineries to install specialized refinery units. Some units that reduce sulfur levels may also deliver improvements in refinery yield, and therefore may pay for themselves. However, to reach 50 or 10/15 ppm sulfur standards will normally require additional units to be installed specifically for the purpose of sulfur control, and this is associated with capital expenditures and increased operational costs. The primary process for delivering sulfur reductions for diesel fuel is distillate hydrotreating. Reducing the sulfur content of diesel output at a given refinery involves either replacing, expanding or retrofitting existing or adding distillate hydrotreating capacity and arranging an increased hydrogen supply (either by adding hydrogen capacity, adjustments from other processes which create hydrogen, reducing sales or increasing imports).

Refiners will not make investments in hydrodesulfurization unless there is a clear market for lower-sulfur fuels and a price premium that offsets the costs incurred to produce them. The costs of upgrading a refinery to produce low-sulfur fuels are generally substantial. Refinery upgrades typically require hundreds of millions of dollars of investment. Analysis by the consultancy Ensys for this strategy (referred to here as 'the refinery study', see Section 1.5.4 below) estimates that the average investment required to upgrade a refinery to produce 50 ppm fuel is about $4,000 per barrel per day of additional low-sulfur fuel capacity,[13] with per-barrel costs typically lower for large refineries than for smaller ones. For a 'typical' developing economy refinery needing to upgrade 30,000 barrels per day of diesel production capacity,[14] the required investment would be of the order of $200 million. Section 1.5.4 below contains additional details on costs for each region. In some cases, the overall investment picture for a refining project may be improved by coupling investment in desulfurization to larger investments in capacity increases or upgrades designed to improve refinery margins. The case of the Egyptian Refining Company (1.5.5 below) is an example in which desulfurization was made financially appealing when combined with increased capacity to produce higher value products. In such a case, while the desulfurization project on its own may not be economically attractive without stringent standards being imposed, desulfurization as part of a refinery upgrade package could make a compelling financial case.

Often, governments in low-and middle-income countries own, or partially own, refineries and exercise control over the national fuel market. In these cases governments may be reluctant or unable to fund refinery upgrade projects through direct public expenditure (and borrowing). In

13 A barrel per day of desulfurization capacity refers to adding enough capacity to a refinery to desulfurize one additional barrel of oil every day.

14 This typical refinery would have about 90,000 barrels per day of nameplate capacity and be able to increase low-sulfur fuel production capacity at an average cost of about $6,000 per barrel. This cost is higher than the average cost for an addition barrel of low sulfur capacity because the 'typical' (median) refinery is smaller than the average refinery.

countries such as China and Mexico, where the government has been willing and able to invest, rapid progress on desulfurization is being made. In other countries, access to finance remains a major barrier. In Section 1.5.5 below we discuss examples where projects have gone ahead in recent years in which the financing arrangements are often complex, and which have required a great deal of effort to bring together financing agents.

Long-term investment in domestic refining can be further complicated by a challenging global refining outlook. Market conditions including variable oil prices, worldwide excess refinery capacity, the efficiency of the domestic refineries and their competitive position, and the relatively low cost of shipping refined product are all outside of a country's control and can affect refinery margins in the short term and refinery viability in the long term. For energy security reasons, governments may be unwilling to allow the closure of ailing refineries with a questionable long-term future, but are also unwilling to encourage further investment. Mixed ownership structures of refineries can further complicate the investment process.

1.4.2. Cost to consumers

The market for lower-sulfur fuel is driven by the adoption of fuel quality standards, either domestically where national refineries sell into local markets or abroad where refineries are oriented for export. Without tighter national standards as a driving force and guarantee, refiners may not invest. However, governments are often reluctant to impose higher standards because of the costs that would be imposed on the local refining sector or, in the case of import-dependent markets, passed through directly to taxpayers or fuel consumers.

In general, the price difference between high and low-sulfur fuel has decreased in recent years. According to one study, depending on the market the cost of a liter of diesel could increase by 0.6 to 2.1 U.S. cents when going to 50 ppm (depending on the baseline fuel quality), up to 3.2 cents going down to 10 ppm (ICCT, 2012b). In some local markets, with local production, the price differential may be higher. For example, South Africa markets both 50 ppm and 500 ppm diesel and the price difference has dropped from more than 5 per cent several years ago to between one-half to one percent today. In other markets the pump price may actually drop with the introduction of low sulfur diesel. In 2015 East Africa introduced low-sulfur fuels following the closure of the Mombasa refinery (see section 1.5.5 below). The refinery had produced high-sulfur fuels at high costs; due to sub-regional trade arrangements, demand for this fuel was high and Kenyan national regulations created a captive market for the national refinery's high-sulfur product. After the refinery's closure, the surrounding countries and Kenya switched to imported low-sulfur fuels that were actually cheaper on the global market. The Mombasa oil refinery was inefficient, leading to a 5% fuel loss. Around 30% of the crude oil produced was also fuel oil (low end of production) which meant a high overall production cost. Following the closure of the refinery, the country could benefit from prevailing market prices. In addition, the Kenya government introduced an open tender system that ensured that the oil trader with the lowest premium imported fuel for the other traders. This system ensured that the country continued to procure low sulfur diesel fuel (50 ppm) at the price of Mean of Platts Arabian Gulf (MOPAG) 500 ppm. Since refineries around the world have shifted to 10 ppm, Kenya also has an advantage of getting 10 ppm fuel at MOPAG 500 ppm prices. Therefore, the price differential between high and low sulfur diesel fuel is below normal fuel market price fluctuations.

The price increase associated with desulfurization is always smaller than the normal fluctuation of market fuel prices. Fuel prices fluctuate significantly so introducing a few cents' premium for low-sulfur fuels is significantly less than normal market price fluctuations unless the price is completely fixed by government intervention. Several countries have made use of this by introducing low-sulfur fuels while fuel prices were decreasing.

1.4.3. Cost recovery can be made difficult by regulated fuel prices

Many low-and middle-income countries, especially oil producing ones, control the retail price of fuels by imposing controls or limits on fuel prices, effectively subsidizing fuel consumption. This interference with the market price of fuels means that refiners may be unable to pass through the capital and operational costs of desulfurization to consumers. Similarly, in these price-controlled markets importers have no option to pass through higher costs of low-sulfur fuel purchased on the market. This can make investment financially non-viable from the point of view of the refiner.

Direct and indirect fuel subsidies are often regressive policies that impose substantial fiscal and economic pressures on developing countries. The IMF (2013) estimates that subsidies for petroleum products account for around $211.2 billion annually on a pre-tax basis and on a post-tax basis (in which the IMF includes negative externalities from fuel consumption and implied assumed loss of tax revenue due to low energy taxes), cost up to $836 billion (IMF, 2013). Despite the documented high costs of these subsidies, removing them is almost always a difficult political process. In some cases removal of subsidies has resulted in social upheaval and the loss of political capital for the ruling government – for instance, in 2012 the Nigerian government was forced to reverse course on subsidy removal following nationwide strikes and protests after fuel prices reportedly as much as doubled, while in 2013 the Sudanese government was similarly faced with protests after announcing subsidy removal (Associated Press, 2015; El Wardany, 2013). However, with good timing and management it is possible to remove subsidies relatively smoothly. Indonesia drastically reduced fuel subsidies at the start of 2015 without experiencing the same type of opposition, aided by the concurrent reduction in world oil prices (Wulandari et al., 2014).

1.4.4. Lack of political prioritization of low-sulfur fuels

Cleaner fuels and vehicles are rarely prioritized in developing countries, competing for resources and attention with other national developmental issues. By convening specialized national working groups and bringing high-level attention to the policy and technology options available for promoting low-sulfur fuels and complementary vehicle standards, these solutions could be given priority on the political agenda at the regional, sub-regional and national levels as feasible solutions to both climate and health challenges from the transport sector.

In addition, developing countries have traditionally been 'takers' of vehicle technology in that they are mainly importing markets and hubs for second-hand vehicle sales. In fact, in some cases developing markets have effectively become dumping grounds for obsolete vehicle technology from more developed markets as these markets advance in terms of emissions and air quality standards. However, used vehicles imported from markets with advanced emissions control requirements may have relatively advanced emissions technologies already installed, requiring low-sulfur fuels in order to continue functioning properly. These developing countries rarely control technology entry by setting minimum technology standards at import. However, this is changing as the demand for more advanced, more efficient vehicles grows in developing markets. In countries like Kenya policymakers are instituting import standards including requirements for age restrictions that complement or act in place of emissions standards. Rather than acting as passive consumers, developing markets are becoming market movers of cleaner technology by improving fuel standards and controlling the types of technologies that they import.

This changing environment and the increased importance of importing and developing markets is due in large part to the advocacy efforts of cleaner fuel and vehicles programs worldwide. These efforts include increasing the awareness and knowledge base of policymakers and consumers – both in terms of what is possible but also what is already available on the market. 'Awareness' refers specifically to the understanding and actions that result in the political support for cleaner fuels and vehicles as a way of improving public health and a means of mitigating emissions. While developing countries struggle with the consequences of rapid motorization, cleaner fuels and vehicles are often overlooked as a basic building block for low emission transportation systems.

Better outcomes can be delivered by a systems approach that encompasses both the fuel used to power vehicles and the technology enabled by the quality of fuel used, all contributing to lower emissions and the utilization of more advanced vehicle technologies.

One of the most effective examples of how working toward an increased awareness and knowledge of the benefits if cleaner fuels could dramatically alter standards and emissions is the global phase-out of leaded gasoline. The initiative to phase-out leaded gasoline in Sub-Saharan Africa began in 2001 with a regional conference in Dakar, Senegal and the agreement of the "Dakar Declaration" in which delegates from 28 countries committed to phase out leaded gasoline in the Sub-Saharan Africa by December 2005. The intervening years between the declaration and the phase-out date saw concerted efforts by the Partnership for Clean Fuels and Vehicles that included technical training, national, sub-regional and regional meetings of policymakers and practitioners specifically on leaded fuel, and national campaigns that publicized blood lead level testing in children. By January 2006 all Sub-Saharan countries were declared unleaded. The measured benefits were immense: over 1.2 million premature deaths avoided per year, of which 125,000 are children (Hatfield and Tsai, 2011).

1.5. Progress on low-sulfur fuel adoption

While many countries have moved to low-sulfur fuels (50 ppm or below), or to intermediate levels, the majority of middle-and low-income countries still lack plans to move to low-sulfur fuels. To support the development of this global strategy, studies were conducted to identify obstacles, and opportunities, for a global transition to low-sulfur fuels.

1.5.1. Global low-sulfur fuel availability

In 2012 the world consumed 88.9 million barrels of oil per day. While OECD consumption declined by 1.3% that year, consumption grew by 3.3% outside the OECD. This trend looks likely to continue. In 2009, for example, Asia overtook North America as the world's largest petroleum-consuming region, with consumption increasing by 4.4 million barrels/day between 2008 and 2012.

Most OECD countries are now at ultra low-sulfur fuels. These countries consume about 8 million barrels of road diesel fuel per day, over 50% of the road diesel consumed worldwide. Non-OECD countries, however, have varying standards in place, with many at 500 ppm or above for automotive diesel fuel. Many rapidly developing countries – China, India, Mexico, Brazil, and South Africa – have taken significant steps to transition in whole or in part to low or ultra low-sulfur fuels. This is a major shift in the non-OECD market and is driving significant new refinery investments. Still, given that these and many other countries are experiencing increased fuel consumption and rapidly growing vehicle fleets, it is important that all non-OECD countries move to cleaner fuel standards to reverse the trend of growing health and climate impacts from their fleets.

1.5.2. Learning from existing standards

Much can be learned from the experience of desulfurization in OECD countries that can be utilized to assist the process in low- and middle-income countries. Various regulatory levers have been used in the implementation of low-sulfur fuel standards in order to support a gradual implementation in the refining sector – these tools are particularly relevant to countries with their own domestic refining capacity in need of upgrade (see section 2.4). In several past implementations, interim standards and derogation periods have been used to allow a degree of staggering in the process of refinery upgrading. Interim standards could include the interim adoption of an intermediate sulfur grade, the temporary use of national average sulfur standards rather than an absolute sulfur cap[15] or the introduction of regional sulfur standards before national rollout (see Section 2.6). Derogations refers to specific relaxations allowed to standards after they come into general force – for instance, there may be a case to provide derogation for a small refinery supplying a specific region where the cost per barrel of additional desulfurization capacity could be much higher than for larger facilities. Measures of this sort can and have been used to manage a staggered process of refinery upgrade where it is unrealistic to expect all facilities to upgrade simultaneously (for instance due to limited technical capacity for upgrading and to avoid concurrent refinery shutdowns).

There has been considerable variation in the time between program announcement and full implementation, from 2.5 years in California to 6 years in total for the U.S. ULSD on-road diesel standard. It is important to understand that the context for introduction of the U.S. and European standards was different than the context for countries considering adopting standards now. When the U.S. ULSD standard was introduced in 2001 (followed shortly by the EU standard in 2003), it was driving the development and adoption of high severity desulfurization technology that had not been widely applied before (although the basic processes used for desulfurization were already well established). The portfolio of tools available to refiners to meet new, more challenging, standards has now been widely demonstrated, with 15 years of opportunity to improve efficiency and reduce costs. Therefore, it is feasible for low-and middle-income countries considering desulfurization to effectively leapfrog both in terms of technology and timeframe.

Previous programs have also been preceded by planning and preparation periods to allow refiners to select strategies for compliance and raise the necessary capital. MathPro (2015b) conclude that the average effective planning period available for the set of standards considered (given that in most cases standards are already expected by industry well before formal promulgation, and including some of the interim standards periods) was about 5 years. Again, for low-and middle-income economies adopting low sulfur standards now, these historical planning periods may be longer than is necessary, as the refining industry now has a good understanding of the technologies required to deliver low-sulfur fuel down to limits as low as 10/15 ppm.[16] For example, China announced standards in 2013 requiring full nationwide availability of 10 ppm sulfur fuels by the start of 2018 (5 years lead time), and then in 2015 accelerated the deadline to 2017 (3 years lead time). In general, 5 years should be sufficient between announcement of a new low sulfur standard and full implementation in a country with refining capacity. Depending on the specific refinery complex in a given country, a briefer implementation may be viable (for instance, for countries reliant on a single refinery there may be non need for staggered implementation). For fuel importing countries, the ability to source low-sulfur fuels from the international market while regional desulfurization capacity is upgraded means that standards could be adopted much more quickly (see East Africa example, Section 1.5.5 below).

In addition to fuel and vehicle standards, the importance of the global second-hand vehicle trade must not be overlooked. In some regions, particularly in Africa, most vehicle sales are second-hand vehicles from Europe and Japan. However, as long as age limits or emission standards and good compliance and enforcement mechanisms are in place this should not prevent countries from realizing the benefits of desulfurization. In Kenya, for example, there is an age limit on used imports (maximum allowable 8 years) and most imported used vehicles come from Japan, which has strict emissions standards. Now that East Africa has introduced low-sulfur fuel standards of 50 ppm, East African countries should consider introducing vehicle emission standards in order to maximize emission reductions. At the moment, many low-and middle-income countries have very weak or no vehicle emissions standards and/or poor regulation of used vehicles import.

15 For instance, Canada's Sulphur in Gasoline Regulations require an annual average sulfur level of 30 ppm with a cap of 80 ppm as of 2005 This is changing to a 10 ppm annual average starting 2017 with the cap remaining at 80 ppm. Such measures allow some variable refinery outputs while achieving the emissions reductions from the overall average. There was also a transitional period of two and a half years which included an average of 150 ppm over that period before 2005 which allowed for cost-effective investments to be made first. Such average sulfur measures and transitional provisions should be considered with caution and require an increase in oversight, administration, and accompanying regulatory complexity.

16 MathPro note that "the pioneering large ULS programs had long implementation times primarily because the required process technologies had not yet been proven in commercial use."

1.5.3. Market analysis

In preparation this strategy, the partners of the HDDI of the CCAC commissioned a fuel markets survey. The survey describes the trade in liquid hydrocarbons between countries around the world – both crude oil and refined fuels at different sulfur levels – and the existing market relationships (UNEP, 2014). The market survey looks at the mix of refiners, exporters and importers in a given region by dividing each region into active sub-regions of fuel trade relationships. The market-based sub-regions focused on low-and middle-income markets: East Africa, Central Africa, North Africa, Southern Africa, West Africa, Middle East, Central America & the Caribbean, South America, Eastern Europe & the Caucasus, Central Asia, South Asia, North Asia and South-East Asia. This approach focused on countries that create the demand for low-sulfur fuels, through national standards, assuming that refineries will adapt to supply the demanded products.

The collected fuel flow data (both crude and refined) was used to generate sub-regional maps. The purpose of the maps was to illustrate the major trade patterns and flows within and between regions, as well as highlight key countries in each sub-region. This visual presentation of quantity and quality of fuel flow allows the viewer to identify 'hot spots' or major fuel players in regions and sub regions, along with a clearer understanding of opportunities to support and promote cleaner fuels introduction.

The aim of identifying and illustrating trade flows was to identify market drivers and hubs in order to target efforts on developing standards and incentives. In the case of an export refinery supplying to a group of importing countries, the markets approach combined with a refinery upgrade would be an ideal approach to desulfurization. However, there is no single model for the right policy approach to desulfurization, and thus a global strategy requires diverse approaches to create viable markets for low-sulfur fuels.

The refining and import/export hubs identified make it possible to:

- Identify market pressure points where targeted intervention will have effects throughout a sub-region and, perhaps, region and

- Highlight sub-regional groupings (both economic and political) where a harmonization of fuel quality and emission standards should be prioritized for economic and social benefits.

Figure 1.7 below is an example of one the sub-regional analyses and illustrations included in the market survey: Western Africa. The sub-region has six refining countries, with some producing fuel mainly for their internal market while others produce for export. There is little trade interaction with other African sub-regions, apart from a small volume of sweet crude sales to Cameroon and South Africa. Of the three main producers in West Africa – Cote d'Ivoire, Nigeria and Ghana – Ghana and Nigeria mainly produce finished fuels for their internal market while Cote d'Ivoire exports high-sulfur fuel to 12 of its neighbors, all of which are exclusive fuel importers. This has significant implications for our approach in West Africa. Chapter 2 of this strategy will propose a global roadmap to introduction of low-sulfur fuels, making use of the outcomes of sub-regional and regional analyses like this one.

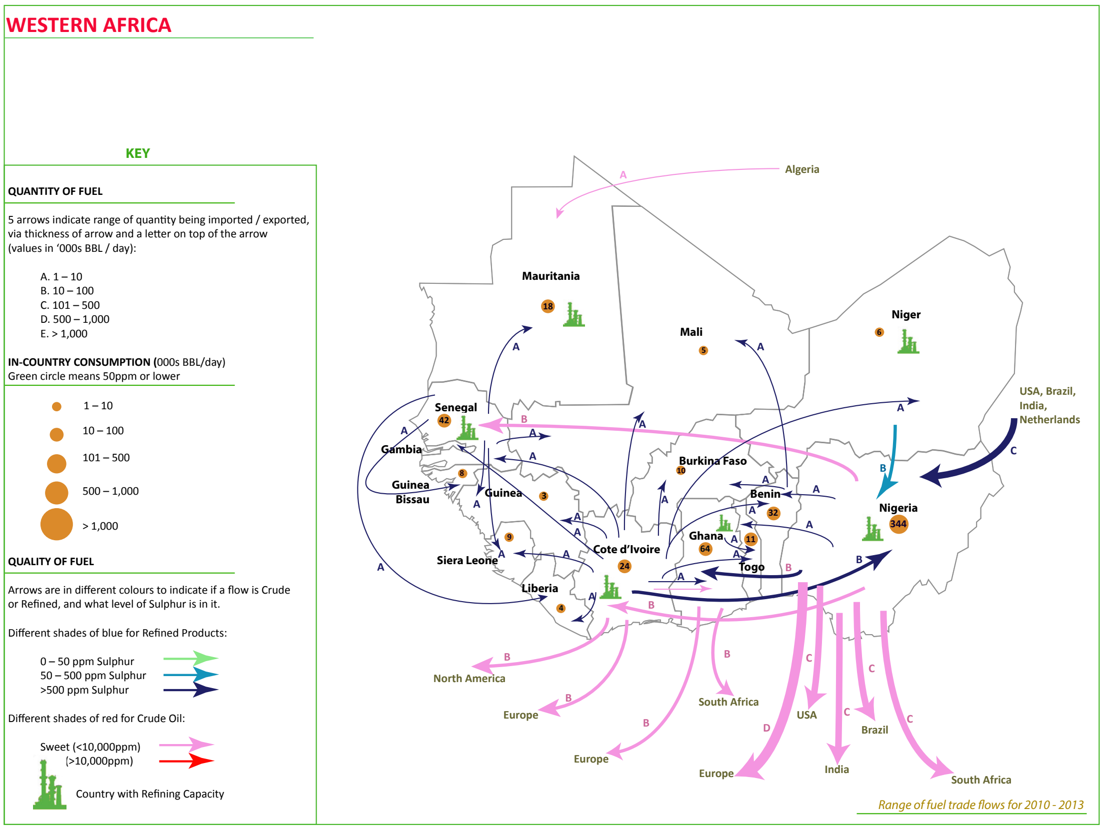


Figure 1.7. Oil and fuel markets in West Africa
Source: UNEP, 2014

1.5.4. Refinery analysis

As part of this strategy HDDI partners also commissioned a study of refineries in low-and middle-income countries.

In order to better understand what will be required to support a global shift to fuel with a sulfur content of 50 ppm or lower, the consultancy Ensys undertook a global refinery assessment to estimate the investment required to add desulfurization capacity to handle all existing gasoline and diesel outputs.[17] The analysis was global, but excluded most OECD countries, some other countries already at 50 ppm fuel standards or below, Russia (which is in the middle of an extensive refinery upgrade program) and China (which has already committed to a pathway to low-sulfur fuel standards). The full list of countries considered and number of refineries modeled is included in Annex D.

The analysis (Ensys, 2015) found that approximately $70 billion of investment would be required at current prices to deliver a global shift to 50 ppm fuel standards. Of the additional hydrodesulfurization capacity required (12 million barrels per day), 83% is for diesel and the other 17% for gasoline. The analysis considers only existing facilities at current utilization rates, and does not reflect possible changes in future refined product demand. Seven billion of investment is needed in Africa, $16 billion in the Middle East, $13 billion in Southeast Asia, $12 billion in the rest of Asia, $11 billion in the Greater Caribbean (including Central and South American nations on the Caribbean coast), $7 billion in South America and $5 billion in Eastern Europe and Central Asia (see Table 1.2).

17 Available from www.theicct.org

Table 1.2. Cost of refinery investment required to deliver low-sulfur fuels by region

REGION	INVESTMENT REQUIRED ($ BILLION)
Africa	7
Middle East	16
Southeast Asia	13
Rest of Asia	12
Greater Caribbean	11
South America	7
Europe and Central Asia	5

A cumulative investment of $70 billion compares to historical (2000-2013) annual refinery investment of around $20 billion in the region assessed, and to predicted cumulative refinery investments of $600 billion in the region assessed[18] in the period to 2035 (IEA, 2014). [19] OPEC forecasts in the 2014 World Oil Outlook that all regions except Africa will have reached average road diesel sulfur content below 50 ppm by 2025, with Africa reaching 45 ppm on average by 2040. An enhanced international focus on desulfurization should bring accelerated adoption well within reach. A $70 billion investment in refinery desulfurization, while significant, is therefore well within the range historic and expected overall refinery investments.

As seen from the case studies in section 1.5.5, in reality it is likely that desulfurization investment will often be combined with investments to improve yields, increase capacity, extend the range of crudes that can be processed and/or meet other fuel quality objectives. For some refineries, these accompanying investments are likely to dwarf the size of investments required for desulfurization alone. However, by improving margins and boosting the financial case for investment in projects, taking on these additional costs can be expected to accelerate rather than delay the low sulfur transition.

As noted above, the refinery analysis shows considerable variation between refineries and regions in the investment required to desulfurize, dependent on starting configuration, location, size, crude supply and so on. While for the most expensive refinery the estimated costs run as high as $35,000 per barrel of additional capacity, these outlier refineries with very high costs represent only a small fraction of overall capacity. The analysis shows that 99% of capacity could be upgraded for an investment of $10,000 per barrel or less, and 70% could be upgraded for less than $5,000 per barrel (as shown in Figure 1.8).

18 Non-OECD excluding China, Russia and Central Asia

19 OPEC (2014) forecasts regional investment of $450 billion in the period to 2040, of a total investment and maintenance spend in excess of $800 billion.

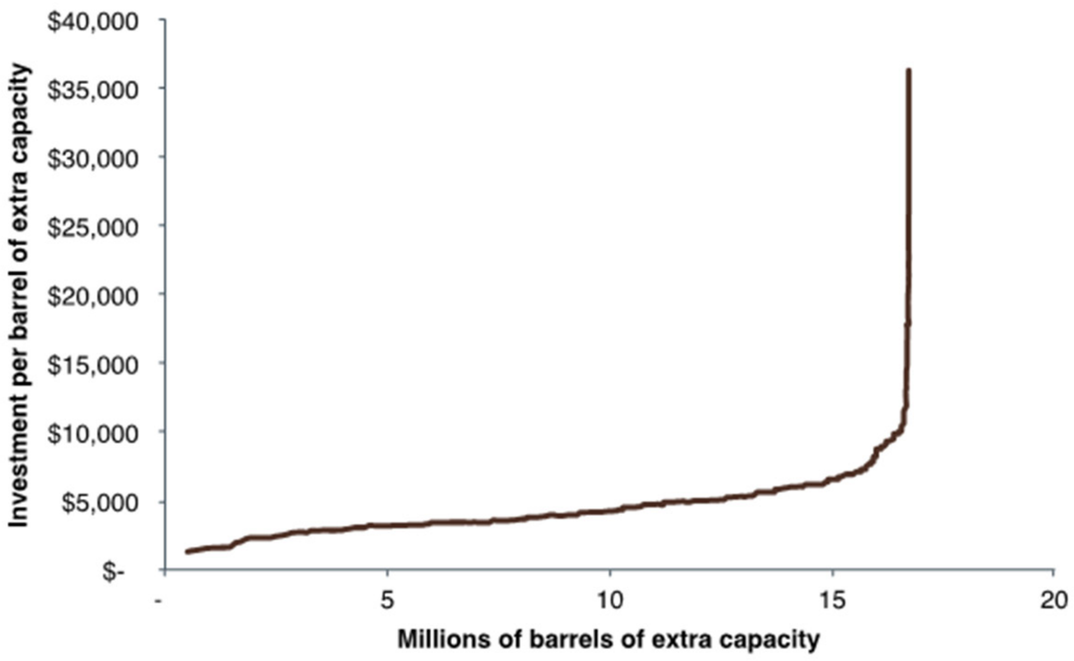


Figure 1.8. Investment cost curve for additional barrels of 50 ppm fuel output

1.5.5. Selected case studies

In addition to the market and refinery baseline studies, a number of case studies inform this strategy. They show how combining government policies, refinery investment and market data lead to successful refinery upgrades.

Peru: Upgrading refineries to meet low-sulfur fuel standard (Galarza and Malins, 2016)

In the context of a fast growing automotive sector, since 2001 Peru's Ministry of Transport and Communications has adopted a series of progressively tighter vehicle emissions standards for new and imported vehicles. From 2016, new light duty vehicles will be required to meet Euro 4 or U.S. Tier 2 standards, and new heavy-duty vehicles will be required to meet Euro IV requirements. In order to make Euro 4/IV vehicle standards possible, Peru also needs to transition fully to 50 ppm diesel and gasoline nationwide. While some urban areas already have 50 ppm fuel available, the national average sulfur content in diesel is still as high as 1,500 ppm and the national standard is 5,000 ppm. Peru has been able to import ultra low-sulfur fuel to meet existing demand, but given that the majority of diesel is still domestically produced, a national standard will require investment in upgrading local refineries. Peru has 6 refineries, and of those, the two largest (Talara and La Pampilla) account for over 90% of domestic diesel production. The Peruvian Government has passed a law requiring the state oil company to upgrade Talara to produce low sulfur diesel, and has engaged with refinery operator Repsol to push an upgrade to La Pampilla. Repsol, a Spanish company, has announced upgrade plans for completion in 2017, including desulfurization and adding heavy crude processing capacity.

The Talara upgrade program will couple additional desulfurization capacity with investments to increase capacity and yields. The project cost is estimated at $3.5 billion in total, compared to an estimated cost of $300 million to desulfurize the existing diesel stream (Ensys, 2015). The Talara upgrade is largely reliant on public investment (77%). Half of the public funding will be raised from the international market through bond issues and loans, and half from domestic sources. The other 23% of funding will come from the private sector, including $500 million from the French bank Société Générale. The La Pampilla project is reliant on private investment raised by Repsol in response to the forthcoming tightening of standards. In 2014, Petroperu lent a $2.7 billion lump-sum turnkey contract to Tecnicas Reunidas for upgrade and modernization of the refinery (Brelsford, 2015).

Key takeaways:

- National government takes the lead in setting an ambitious fuel quality standard, starting with major cities. This builds demand for low-sulfur fuels, sends a clear signal to producers.
- The state-owned refineries are required by law to comply with the new standard, partnering with a private refinery operator to ensure the deadline for upgrade is met.
- Funding for upgrades is often a combination of both public and private funds made profitable by coupling desulfurization capacity with investments to increase capacity and yields.

Vietnam: investing to become a regional hub for refinery operations in Southeast Asia (Searle and Malins, 2016)

In Vietnam, the adoption of more stringent fuel quality standards is scheduled to occur in parallel with a dramatic increase in domestic refining capacity. Starting in 2016, the current 500 ppm requirements will be replaced with a 50 ppm standard, and by 2021 all fuel in Vietnam must comply with a 10 ppm standard. This will be achieved through upgrading the existing Dung Quat refinery, and by expanding the refinery sector with up to three new refineries opening by 2018. If all these projects are delivered and run at capacity, Vietnam would become a net exporter of refined product.

The Dung Quat project would couple desulfurization investment with investment in capacity to process heavier, sour crudes. The project will cost $1-2 billion, but because desulfurization is coupled to other upgrades it is expected to be a profitable project, with a target internal rate of return of over 9%. The margins of the upgraded refinery will be supported by favorable tax treatment from the government. Half of the investment will come from Gazprom Neft, which will acquire a 49% stake in the upgraded refinery.

The first of the planned new refineries is Nghi Son. This refinery, to be co-owned by PetroVietnam, Idemitsu Kosan Co. (Japan's second-largest refiner), Kuwait Petroleum Corp., and Mitsui Chemicals Inc. will produce 50 ppm diesel, and cost about $9 billion to build. Half of the investment will come from the co-owners, and the other half will come from a variety of financial institutions in Japan and Korea. The Kuwait Petroleum International will supply the crude for the refinery.

The second new refinery Long Son, will be co-owned by PetroVietnam, Siam Cement Public Company Ltd, Qatar Petroleum, and Vietnam National Chemical Group. Construction started in 2013 and it will produce 50 ppm diesel, and process imported crude oil including crude supplied by Qatar Petroleum. The third new refinery, Vung Ro, would be the only 100% privately owned and financed refinery in Vietnam, and would produce 10 ppm petrol and diesel

Key takeaways:

- National government sets ambitious target for fuel quality (10 ppm) coupled with an intermediate step (50 ppm) and tax incentives, allowing industry an adequate implementation window.

- Private investment is mobilized for refinery expansion and improvement. This is usually feasible when Investment in desulfurization is coupled with investments in improved capacity, ensuring a profitable upgrade.

Egypt: building a financing coalition to upgrade low-value fuel oil (Searle and Malins, 2016)

The case of the Egyptian Refining Company (ERC) is different from the cases in Peru or Vietnam mentioned in previous sections because the commitment to produce 10 ppm fuel is not informed by any government commitment to tighten fuel quality standards. Indeed, diesel sulfur is not regulated and may reach as high as 10,000 ppm in some cases. Rather, the ERC project is being led by private financial interests (Citadel Capital) rather than government objectives, and the decision to produce 10 ppm was made in order to gain access to development funding contingent on delivering improvements in local environmental quality.

The context for the ERC project is that the Cairo Oil Refinery Company (CORC) operates Egypt's largest refinery, a low-conversion refinery, and produces 67% low-value atmospheric residue (fuel oil). Producing such a large fraction of fuel oil reduces the revenue potential of the CORC refinery, and contributes to local air pollution because the produced fuel is sold into local heat and power markets without desulfurization. The ERC project will take this fuel oil as refinery input (instead of processing crude oil directly) and use deep-conversion processes to deliver 4.5 million tons of refined product and byproducts per year (including a 80,000 barrels/day vacuum distillation unit, a 40,000 barrels/day hydrocracker, a 25,000 barrels/day delayed coker, a 23,000 barrels/day naphtha hydrotreater, and a 32,000 barrels/day distillate hydrotreaters), half of which will be 10 ppm diesel. In effect, once the ERC facility is built, the CORC and ERC taken together will represent a single deep-conversion refinery. However, by separating the low-margin business of simple atmospheric distillation (CORC) from the higher-margin business of running the complex refinery units (ERC), the ERC part of the project will offer better margins than achievable for a whole new refinery, improving the case for private and development finance. $1.1 billion of the $3.7 billion investment required for the new facility will come in equity from the Egyptian Petroleum Corporation, Qatar Petroleum International, Qalaa Holdings (formerly Citadel Capital), the World Bank affiliated IFC (3% share), the Dutch and German development banks FMO and DEG, InfraMed Fund, and other investors from Egypt and Gulf Cooperation Council countries. The other $2.6 billion will be provided in debt by an array of private banks, development banks and export credit agencies.

Key takeaway:

- Development funding criteria/conditionality for improvement of air quality paired with projected favorable economic benefits can incentivize decisions to produce low-sulfur fuels.

- International financial institutions and development banks could play a catalyzing role by offering co-financing and risk mitigation and by convening financing partnerships.

East Africa: sub-regional introduction of low-sulfur fuels and closure of Mombasa refinery

In January 2015 the East Africa sub-region (Burundi, Kenya, Rwanda, Tanzania and Uganda) formally completed its transition to low sulfur diesel fuel for cars, trucks and buses, as shown in Figure 1.9. This signaled the completion of the East Africa Community's harmonized approach and its landmark introduction of low-sulfur fuels (maximum sulfur content of 50 ppm in diesel). The process towards adoption of low-sulfur fuel standards began in 2005 follwing the successful elimination of leaded petrol in sub-Saharan Africa in December. Following this, the UNEP-based Partnership for Clean Fuels and Vehicles (PCFV) began working with governments in the sub-region to reduce fuel sulfur content in petrol. The PCFV was joined by the CCAC in 2013, amplifying efforts to desulfurize by addressing diesel fuels in the region.

One major step towards desulfurization in the region was the closure of the only refinery in East Africa: the Kenya Petroleum Refineries Limited plant (KPRL), an outdated facility producing high sulfur fuels (diesel standard at 10,000 ppm). While the refinery could only meet half of Kenya's demand, and also exported to neighboring countries, the decision about how to deal with the refinery was contentious due to economic and strategic considerations. The Kenyan government actively explored options for the 27,500 barrels/day refinery to be upgraded to meet improved fuel quality standards and to produce 172,400 barrels/day. But with cheaper and higher quality product available on global markets, KPRL upgrade plans (valued at USD 450 million) were deemed inefficient and were abandoned in 2013 leading to the closure of the refinery. In June 2013, East African Ministers adopted standards that set the maximum diesel sulfur level at 50 ppm and petrol at 150 ppm and the implementation date for these limits was set for 1 January 2015.

The fact that most East African countries imported their fuel provided a policy window for the revision of standards to lower sulfur fuels requiring the importation of cleaner fuels. In addition, the landlocked countries of Uganda, Rwanda and Burundi relied (and still rely) on fuel imports through Kenya and Tanzania.

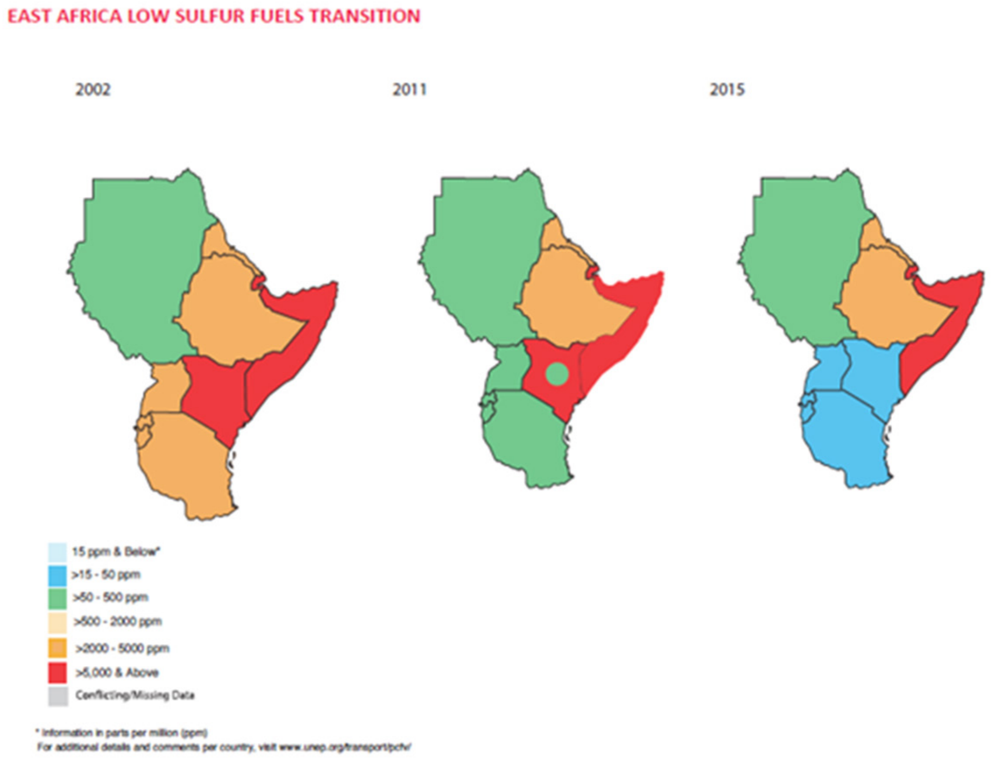


Figure 1.9. East Africa's transition to low-sulfur fuels 2002-2015
Source: UNEP, 2015

The region's adoption of low-sulfur fuel standards and the availability of low sulfur diesel on the market allows major cities like Nairobi to consider advanced vehicle emission standards for planned Bus Rapid Transit projects. The recent move to low-sulfur fuels is particularly timely because countries in the region, including Kenya, have set vehicle import age limits and are importing filter-equipped vehicles, which run most efficiently and cleanly on low-sulfur fuel. The city of Nairobi is currently weighing its technology options for planned BRT corridors, including Euro V, VI and CNG technology.

Key takeaways:

- Supporting a political process at the sub-regional and regional levels can lead to change in fuel quality and vehicle emission standards.

- Due to regional trade reliance and infrastructure (Kenya as import hub) improving fuel quality standards in one key country can change the fuel quality in an entire sub-region.

- Refineries deemed inefficient and unable to keep up with the demand for better quality product may need to close. Policymakers and private sector will need to weigh the costs and benefits of upgrades, both in terms of health and economic benefits.

2. A Global Strategy for Desulfurization

The preceding chapter detailed the vast climate and health benefits possible with the use of cleaner on-road diesel fuels coupled with emission controls on diesel vehicles. It also outlined the obstacles facing the global desulfurization – from a lack of awareness and knowledge of the benefits of low-sulfur fuels and cleaner diesel technology to the challenges faced by countries seeking to upgrade their refineries. And it provided case studies where refinery upgrades were successfully accomplished.

This chapter will detail the approach developed by the co-leads of the CCAC Heavy-Duty Diesel Initiative for accelerating access to low-sulfur fuels and soot-free[20] diesel technology. The goal of this global desulfurization strategy is to reduce outdoor air pollution and global black carbon emissions by enabling low-sulfur fuel coupled with vehicle emission standards.

2.1. Prioritizing Countries and Regions

Every year, 900 billion liters of on-road diesel fuel are consumed worldwide and 30 percent of this contains more than 50 ppm sulfur. According to our analysis, high-sulfur fuel is consumed in over 120 countries, yielding an estimated 4.1 billion people, or more than half of the global population, with limited or no access to low-sulfur fuels. An estimated 80,000 premature deaths from transport-related air pollution occur each year in these countries, and 240,000 annual premature deaths from transport-related air pollution globally (Chambliss et al., 2014b). The global distribution of premature deaths is mapped against local on-road diesel sulfur levels in Figure 2.1. The number of mortalities still occurring in countries with lower sulfur standards reflects the lag time between implementation of the fuel and vehicle emissions standards and the deployment of vehicles equipped with the associated emission control technologies. If nothing else changes, the fraction of mortalities occurring in the countries that still have high-sulfur fuels will increase significantly over time. Desulfurization of the fuel consumed in these high-sulfur countries is the focus of this global strategy.

Beginning in the late 1990s and early 2000s, Japan, North America and the European Union undertook independent, complex regulatory and industrial overhauls to address vehicle emissions, air pollution, and the resultant impacts on large at-risk populations. This transition continues today in other large and rapidly developing countries, such as China.

While desulfurization will, to some extent, always be driven by national concerns and national strategies, vehicles and fuels are manufactured, produced and traded in a global marketplace. Not all countries have the capacity to address air pollution, vehicle emissions, and fuel quality and low- and middle-income countries are uniquely at risk due to a lack of standards, investments and enforcement.

20 For the purposes of this strategy, a soot-free engine will be defined as any fuel and vehicle combination that meets emission levels for particulate matter set by Euro 6/VI or US 2010. This can include compressed natural gas or electric-powered buses, alongside other fuel/engine types including conventional diesel engines.

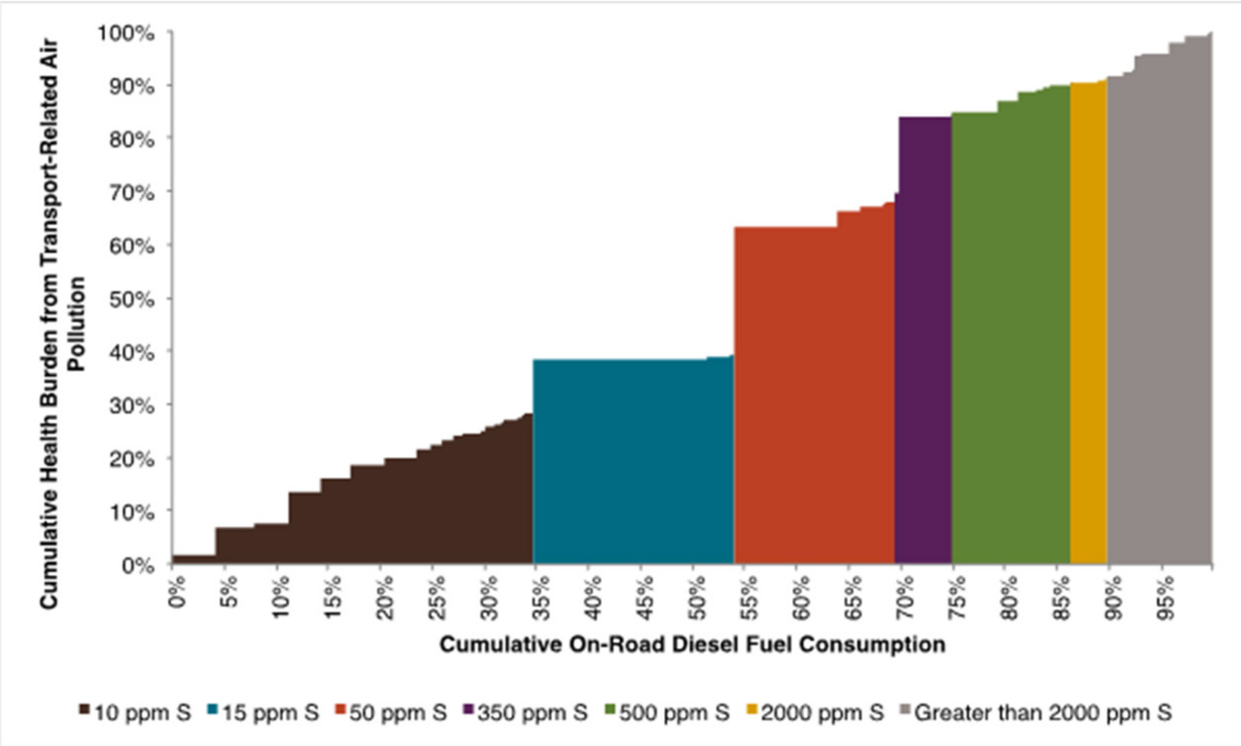


Figure 2.1. Cumulative distribution of global on-road diesel consumption and health burden of transport-related air pollution

Today any country that demands low-sulfur fuels can buy them on the international market. The value-added by producing low and ultra low-sulfur fuels can make refinery operations more profitable and has motivated investment in refinery desulfurization capacity in several regions. In India, for instance, refiners produce low-sulfur fuels for export to markets in Europe and India makes a profit. Singapore produces low-sulfur fuels and exports them to Sri Lanka. Countries willing to pay the modest additional cost of low-sulfur fuels are in a stronger position than ever to adopt low sulfur requirements on imports. Sri Lanka, despite having no fuel quality standard, has chosen to import ultra low-sulfur fuels from Singapore in advance of new fuel and vehicle standards as part of an initiative to reduce vehicle emissions. From early 2015 Kenya and other East African countries have had 50 ppm sulfur standards in place, taking advantage of available capacity in the Middle East and India. Standards adopted by an ever-growing share of the diesel market creates demand to match increasing supply, allowing investments in low-sulfur fuel capacity to be recouped. For the global transition, a progressive adoption of low-sulfur fuel standards by importers and producers must be coupled with measures to deliver refinery investment in order to increase global low-sulfur fuel production capacity.

Global on-road fuel desulfurization will require action in every one of the countries that currently lack access to low-sulfur fuel. Section 2.2 below identifies national and sub-regional desulfurization opportunities. However, the health burden of high-sulfur fuels is not equally distributed. In order to identify the highest priorities for action we ranked the transport air pollution burden in each of the countries with limited or zero access to low-sulfur fuels.[21] Transport air pollution is estimated for each country based on the transportation-attributable fraction of outdoor air pollution and the total estimated outdoor air pollution burden (Chambliss et al., 2014b).

The results of this analysis and global rankings are provided below. Eighty-eight percent of the health burden associated with high-sulfur fuel occurs in just 13 countries as listed in Table 2.1.

21 Note that China is not considered a high-sulfur fuel country since it has implemented 50 ppm diesel in 2014 and will deliver 10 ppm sulfur diesel nationwide from 2017.

These 13 countries account for an estimated 70,000 annual premature deaths and 2.7 million barrels/day of annual on-road high-sulfur diesel fuel consumed. Three quarters of health burden among high-sulfur countries occurs in six countries – India, Pakistan, Indonesia, Ukraine, Mexico, and Egypt – which combined account for just one-third of high-sulfur fuel consumption.

Table 2.1. Top 13 high-sulfur* nations, ranked by health burden of vehicle emissions

RANK	COUNTRY (THOSE IN BOLD ITALIC ALSO IN TOP PRODUCERS)	CUMULATIVE SHARE OF TRANSPORT-RELATED OUTDOOR AIR POLLUTION DEATHS AMONG HIGH SULFUR NATIONS	CUMULATIVE SHARE OF ON-ROAD DIESEL CONSUMPTION AMONG HIGH SULFUR NATIONS**	NATIONAL DIESEL SULFUR LIMIT (PPM S)
1	India	43.9%	14.9%	350
2	Pakistan	52.3%	17.6%	7000
3	Indonesia	58.2%	23.3%	500
4	Ukraine	64.2%	24.4%	200
5	Mexico	70.2%	31.0%	500
6	Egypt	75.6%	33.6%	10000
7	Iran	79.1%	41.1%	N/A
8	Bangladesh	81.5%	41.8%	5000
9	DPR Korea	83.0%	41.9%	N/A
10	Vietnam	84.5%	44.2%	500
11	Malaysia	86.0%	46.3%	500
12	Brazil	87.1%	60.4%	500
13	Nigeria	88.1%	60.6%	3000
Total (13 countries)		**70,000 annual premature deaths**	**2.7 million bbl/d on-road diesel consumption**	

**In this context, 'high sulfur' means countries with on-road diesel sulfur content above 50 ppm. Countries excluded from consideration include China, Russia and the OECD nations.*

***Annual road sector diesel fuel consumption is taken from Econ Stats (2011).*

Table 2.2. Largest producers of high-sulfur on-road diesel, from countries assessed by Ensys (2015)*

COUNTRY (NAMES IN BOLD ARE ALSO IN TOP 30 FOR HEALTH IMPACTS)**	NO. REFINERIES	HIGH SULFUR DIESEL PRODUCTION (BBL/D)	TOTAL INVESTMENT TO DESULFURIZE ($ BILLION)***	COST PER BARREL PER DAY ADDITIONAL CAPACITY	CUMULATIVE FRACTION OF HIGH-SULFUR FUEL	NOTES
India	22	831,000	10	6,100	10%	50 ppm available in major metros. National target of 50 ppm by 2017
South Korea	6	685,000	4.6	4,100	19%	Domestic standard of 10 ppm
Brazil	13	507,000	4.1	4,200	25%	10 ppm fuel available in some metropolitan areas; 500 ppm elsewhere
Saudi Arabia	8	503,000	5	7,900	31%	Target of 10 ppm fuel by 2016
Iran	9	479,000	3.4	5,500	37%	No target
Indonesia	8	360,000	.6	5,400	42%	It has been reported that PERTAMINA may be preparing to implement a program of investment to 50 ppm
Mexico	6	344,000	4	4,800	46%	15ppm available in major metros. Developing national target of 15 ppm by 2017
Venezuela	5	302,000	3.7	5,800	50%	No target
Singapore	3	281,000	1.5	3,500	53%	Domestic standard of 50 ppm
Thailand	4	257,000	1.1	2,800	56%	Domestic standard of 50 ppm
Taiwan, Province of China	4	244,000	1.9	3,800	59%	Domestic standard of 10 ppm
UAE	5	228,000	1.4	5,400	62%	Target of 50 ppm by 2018
Egypt	9	215,000	2	6,800	65%	No target
Argentina	10	208,000	1.7	5,000	67%	Target of 30 ppm by 2016
Malaysia	7	195,000	1	3,900	70%	Target of 50 ppm by 2016
Iraq	9	155,000	1.7	7,300	72%	No target
Belarus	2	145,000	0.4	1,500	74%	Domestic dual standard of 50/10 ppm
Algeria	4	131,000	0.5	4,200	75%	Target of 50 ppm by 2015
Ukraine	6	131,000	1.9	7,900	77%	No target
Philippines	2	109,000	0.7	4,200	78%	50 ppm by 2016
Azerbaijan	1	108,000	0.8	4,300	80%	Target of 50 ppm by 2015
Pakistan	7	101,000	0.8	7,600	81%	No target
Kuwait	3	96,000	1.5	8,700	82%	Target of 50 ppm by 2018

COUNTRY (NAMES IN BOLD ARE ALSO IN TOP 30 FOR HEALTH IMPACTS)**	NO. REFINERIES	HIGH SULFUR DIESEL PRODUCTION (BBL/D)	TOTAL INVESTMENT TO DESULFURIZE ($ BILLION)***	COST PER BARREL PER DAY ADDITIONAL CAPACITY	CUMULATIVE FRACTION OF HIGH-SULFUR FUEL	NOTES
Syria	2	89,000	0.6	5,800	83%	No target
Nigeria	4	88,000	1.1	6,800	84%	No target
Colombia	5	86,000	0.9	5,600	85%	Domestic standard of 50 ppm
South Africa	4	84,000	1.3	6,300	86%	Domestic dual standard of 500/50 ppm; target of 10 ppm by 2017
Kazakhstan	3	84,000	1	7,900	87%	Target of 50 ppm by 2016
Netherlands Antilles	1	81,000	0.6	4,100	88%	No target (refinery linked to Venezuela)
Libya	5	80,000	0.6	5,500	89%	No target

**The refinery capacity analysis excludes the EU, U.S., Canada, Russia and China, but does include several countries with domestic 50 ppm standards (or better). A full list of the countries whose refinery capacity was assessed is provided in Annex D.*

***For the countries that also appear in the top 13 for health impacts, green coloration denotes that there is a trajectory in place for adoption of low-sulfur fuel standards, while red denotes no firm trajectory.*

****Note that investment cost, taken from Ensys (2015), includes desulfurization of gasoline production capacity.*

Increasing the global low-sulfur fuel supply will require investment in refinery upgrades by high-sulfur fuel producers. Table 2.2 shows the top high-sulfur diesel fuel producing countries. Thirty countries produce 89 percent of high-sulfur diesel, according to Ensys analysis (2015). Ten of the countries with high health burdens identified in Table 2.1 are also among the 30 countries with the most high-sulfur diesel production capacity. The data show that several countries and regions that have adopted low-sulfur fuel standards domestically are still producing substantial volumes of high-sulfur fuel. Since South Korea, Thailand, Singapore, Taiwan (Province of China), Belarus, and Colombia all limit national sulfur in diesel to 50 ppm or below, the high-sulfur fuel produced is presumably for non-road markets and/or export. Ever-growing market demand for low-sulfur fuels in the rest of the world will provide an impetus for the remaining refineries in these countries to invest and improvements. Investing in additional desulfurization capacity will also provide flexibility to these refineries by allowing them to sell product into a wider range or markets. It may be possible to accelerate this transition by making finance for other refinery investments contingent upon phasing out this high-sulfur fuel supply, or otherwise by using domestic policy in refining nations to encourage investment and discourage exports of dirty fuels.

Of the ten countries that fall on both lists, having both high health burden and high volumes of production, seven countries – India, Pakistan, Indonesia, Malaysia, Nigeria, Brazil, and Ukraine – are prioritized in section 2.2 below as countries in need of support for refinery upgrades and for the adoption of higher standards. Of these, India already has low sulfur diesel available in some areas and has target dates for national availability. Malaysia does not yet have significant low-sulfur fuel availability but does have a target date for adoption of standards. Brazil, Indonesia and Pakistan do not yet have target dates in place for low sulfur standards, although Brazil already supplies 10 ppm diesel in key regional markets.

Of the three countries falling within both lists that are not considered first priorities, Egypt is discussed in section 2.2 as a country that is (currently) dependent on imported fuels to meet national demand and, therefore, would require national standards on imports in tandem with refinery upgrades (see the Egypt case study in section 1.5.5 for discussion of a recent upgrade project). It is not on the list of first priorities as engagement on desulfurization is considered relatively challenging given recent political instability. Mexico is not identified as a priority for action in this strategy as it is already well along the path to desulfurization.[22] The remaining country featured on both lists is Iran. This may be a more challenging case for CCAC engagement, and is therefore not identified in the strategy as a high priority for CCAC action.

A global strategy is outlined in the next section that shows not only how these countries can move to low-sulfur fuels and vehicle emissions standards, but also how, through a combined regional and national approach, all countries worldwide can achieve this.

2.2. A Global Strategy: Priorities for Action

The preceding section identifies the individual countries that currently suffer the highest health burdens due to the use of high-sulfur fuels, and the countries that have the largest high-sulfur diesel refining capacity and require the most investment to desulfurize the global on-road diesel supply. These are major factors in identifying priority countries and regions and interventions, but a cohesive strategy for global engagement also requires identifying opportunities where intervention can be most effective and where the adoption of standards by one country (or one group of countries) can act as a driver for wider change. This strategy proposes that driving this change requires raising the profile of desulfurization as a health policy priority, helping governments understand the costs and benefits of action on desulfurization, and by building the case for more aggressive investment in desulfurization projects by refiners and by public, intergovernmental and private financiers.

This section outlines proposed actions in regions, sub-regions and countries for a global shift to low-sulfur fuels. It provides analysis of specific regional and country contexts, including the way in which a country imports and/or refines fuels, the current fuel quality and vehicle emission standards (or lack thereof), market positions, the policy networks within which countries operate, and decision-making pressures including national balance of payments, energy security, and costs to consumers, e.g. subsidies and fuel costs. The strategy is based on a combined approach and envisions working both with major refiners and with importing countries. The impetus to invest in desulfurization can come both from domestic standards and external demand and so a markets approach to desulfurization, in which importing countries are included as market drivers and drivers of desulfurization, is provided here.

As mentioned earlier, several studies form the basis of this strategy; an analysis of the health benefits deliverable through global fuel desulfurization (see section 1.1.1); an analysis of the fuel and oil markets countries are operating in ("the market study", see section 1.5.3); an assessment of the investment needed for refineries to produce low-sulfur fuels ("the refinery study", see section 1.5.4), and a set of case studies of previous desulfurization projects (see section 1.5.5). The market and refinery studies identified regional and sub-regional hubs for refining and distribution, along with the countries that have the market and political influence for near-term decisions that will drive a move to low-sulfur fuels. Based on these studies and on accumulated global experience in promoting cleaner fuels and vehicles, the authors of this strategy prioritize countries on two levels: i) the categorization of markets based on country operating environments and ii) prioritization of countries for near-and longer-term action within these categories. The first priority countries for

22 In 2006 Mexico adopted a 15 ppm nationwide diesel standard, but the target date of 2009 was not met by PEMEX; 15 ppm fuel is now only available on the U.S. border and in major metro areas. The rest of the country is still at 500 ppm with revised plans for 50 ppm by 2015. A number of ongoing refinery upgrades are meant to meet growing domestic demand. The CCAC has supported Mexico's ongoing nationwide desulfurization since 2014.

action and support are drawn from those where there is the greatest chance of delivering rapid change, the largest health benefit to be gained, and those that operate as hubs of influence and fuel trade for other countries. They include many of the countries identified in 2.1 as having the largest health burden from high sulfur fuels, but also include a number of smaller markets that have regional importance, or where there is an opportunity to deliver immediate progress through targeted interventions.

2.2.1. Categories of Countries

The market and refinery studies[23] identify categories of fuel and vehicle operating environments where similar approaches could help to move countries or groups of countries to low-sulfur fuels and commensurate vehicle emissions standards. The four categories include countries which share key features that determine the actions necessary to deliver progress on desulfurization.

Category 1, "importers" are countries that are dependent on fuel imports and that can switch to low-sulfur fuels relatively quickly;

Category 2, "refiners" are countries that require upgrade of their refineries and need financing for this. They may produce fuels only for their local market or may also export fuels to other markets;

Category 3, "vehicle standards" are countries that already have introduced low-sulfur fuels but need to strengthen their vehicle policies to match the fuels and maximize the benefits of having low-sulfur fuels introduced;

Category 4, "cities first" are countries where low-sulfur fuels and cleaner vehicles have been (first) introduced in urban areas prior to full national introduction.

This strategy prioritizes countries based on these four categories in order to describe how a country, a region and eventually the whole world can transition to low-sulfur fuels accompanied by vehicle emissions standards. By combining the refinery, market and health studies, 103 countries were categorized according to fuel quality, refinery investment needs, vehicle emission standards (or lack thereof), and city-led opportunities. The 36 countries that have been prioritized are described in detail below, along with longer-term opportunities.

Note that, while in reality countries may fit within several categories, we have tried to organize countries according to their main category to facilitate analysis and recommendations. Where nuances exist, these are included in the country description. Additional information on each country is available in the relevant studies as described in Annexes A and B.

The approaches described here build on years of experience and effort on cleaner fuels and vehicles by initiatives such as the Climate and Clean Air Coalition, the Partnership for Clean Fuels and Vehicles and the Global Fuel Economy Initiative. This strategy represents the strengthening of ongoing global action on lowering emissions from the transport sector.

23 Studies available from www.ccacoalition.org/en/initiatives/diesel

2.3. Category 1, 'Importers': Countries Dependent on Fuel Imports

Countries in this category import their fuels for the majority of their consumption, if not for the entirety. They lack a refinery or the refining capacity to meet national demand. They import high-sulfur fuel and usually do not have vehicle emission standards in place. Import-dependent countries, which are the majority of developing countries still using high-sulfur fuels, can be important market drivers for desulfurization. These countries are powerful drivers of demand for cleaner fuels and technology both regionally and globally through national standards, import standards and restrictions, and incentive schemes (including fiscal programs). The costs of improved fuel standards can be passed directly to fuel consumers. Where countries are part of a well-established regional fuel supply network, the adoption of new standards should be accompanied by intra-regional dialogue. In some cases, action in these countries may be coordinated with actions on domestic standards in refiner countries to ensure a harmonized approach.

Overall Approach: Countries in this category would benefit from targeted national, regional and sub-regional efforts to adopt policy for low-sulfur fuels along with the complementary vehicle emissions standards to utilize those fuels for maximum emission and efficiency benefits. Support should combine intergovernmental dialogue, awareness and knowledge building and direct technical assistance for countries that currently import high-sulfur diesel fuel for the adoption of policies for low-sulfur fuels. On the ground, this means supporting (through funding and technical expertise) national processes, cooperation and dialogue platforms specific to fuel quality standards, namely:

- national and/or sub-regional platforms for discussion and training,

- the formation of specialized national working groups at the national and/or regional levels that integrate the public and private sectors and are aimed at the revision or development of policy to support low sulfur fuel imports and

- the provision of specialized technical expertise on strategic implementation issues identified at the national and/or sub-regional levels and ensuring linkages with other related policies (particularly fiscal). Engagement with industry experts who can advise on fuel supply sourcing, contracting and financing is key.

Countries that import a substantial share of their diesel fuel can shift to low- and ultra low-sulfur fuel relatively quickly through changes to fuel import contracts; however past experience shows that the mechanisms for sourcing and financing higher value low-sulfur fuel on the global market can be an obstacle to these countries. Guidance on this issue can identify best practices among countries that have successfully shifted their fuel import contracts in favor of lower sulfur diesel fuel. There is also need for enforcement of a clean fuels and vehicles program, e.g. through an associated program, which would include reporting on implementation and an adequate system of verification (the PCFV Toolkit in Section 3 below includes guidance on enforcement and governance).

The following 13 countries are priorities for action in the near-term (i.e. next 5 years) based on considerations of: key market position (i.e. role as sub-regional import/export hubs); ability to adopt and implement low-sulfur fuel policies within a short timeframe; and size of health burden. The choice of priorities for action is explained in more detail in section 2.3.1 below.

Table 2.3. List of priority countries in the 'Importers' category

Africa	Ethiopia
	Mozambique
	Nigeria
Asia	Bangladesh
	Pakistan
Latin America & The Caribbean	Central America region: El Salvador, Guatemala, Nicaragua and Honduras
East Europe	Georgia
	Moldova
Middle East	Lebanon
	Tunisia

Detailed analysis based on the markets study is provided below for each, including longer-term opportunities in each region.

2.3.1. Regional Assessments and Approaches

Africa

According to the market study, a significant number of African countries import their fuel from outside the region and are therefore not dependent on the region's refineries. Because large investments in local refineries are not required, these countries could quickly improve their fuel specifications and import cleaner fuels. From our experience in the region, countries were able to introduce new fuel specifications in 6-12 months. The first two African countries that are prioritized in this category are ***Mozambique and Ethiopia***. The third is ***Nigeria***. Although Nigeria is identified in Table 2.2 above as a major fuel producer, it is also a major importer in West Africa due to low refinery capacity use (see detailed explanation below). Therefore, Nigeria is addressed in this strategy in both the importers and refiners categories (see also Section 2.4 below for refinery analysis).

Mozambique imports refined fuels and re-exports to two other countries: Malawi and Zimbabwe. With the East African countries now using low sulfur diesel, Mozambique could adopt the same fuel specification given that they sometimes share fuel supply vessels with East Africa. Malawi and Zimbabwe could also move quickly on standards with leadership from Mozambique due to their reliance on shared storage facilities in Mozambique.

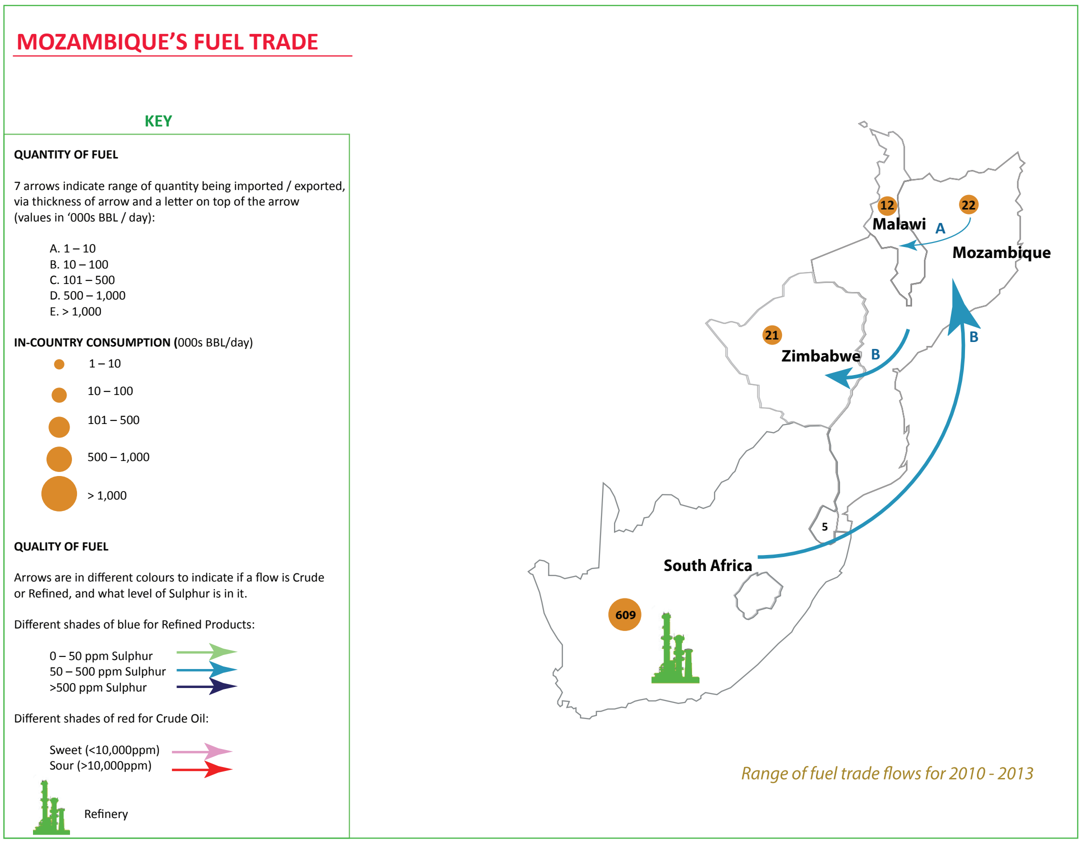


Figure 2.2. Mozambique's fuel export relationships in Southern Africa
Source: UNEP, 2014

Nigeria (which is a major fuel producer in the region and also a nation with a very high health burden of vehicle emissions – see Table 2.1 and Table 2.2 above) imports fuel and has several refineries. With a nameplate capacity of 445,000 barrels/day production could, in principle, exceed domestic demand. However, due to operational challenges the refinery utilization rate is low (estimated to be around 50%) and Nigeria imports close to 50% of its fuel. Therefore, introducing low sulfur import standards in Nigeria could help to shift a significant part of the fuels used in Nigeria to low sulfur. In addition, tankers supplying Nigeria often also supply smaller countries in West Africa (Togo, Benin, Ghana). A national standard applicable to imports could be accompanied by fixed-term waivers while local refineries make the necessary investments (see also Section 2.4.1). The approach here would be to harmonize fuel import specifications across all 18 West African countries – including Nigeria – as they often share vessels importing fuel.

According to the market study, Ethiopia, which has diesel sulfur levels up to 5,000 ppm, imports refined product (at 2,000 – 500 ppm sulfur in diesel) from Kuwait and Saudi Arabia and is planning on constructing a refinery in anticipation of the commercial development of its oil fields. However, the planned refinery is still a decade away and Ethiopia will remain an importing country. Ethiopia is already engaging with fuel suppliers on the availability of cleaner fuels; the import of cleaner fuels by Ethiopia would also affect fuel specifications in Djibouti due to shared fuel import facilities.

Longer-term opportunities for desulfurization exist with countries that import from refineries in the region. These include Guinea, Liberia (both import from Cote d'Ivoire), DR Congo (imports from South Africa and Kenya) and Botswana and Namibia (import from South Africa). Fuel specification changes in Liberia and Guinea could spread to more countries in the region including Sierra Leone and Guinea Bissau. Benin, Togo and Mali are linked in that implementation of cleaner fuels in any of these countries would impact the other two. All three import from Nigeria. A change in fuel specifications in these countries would help to drive refinery upgrades in the supplying countries. Another option to access a low-sulfur fuel supply is to diversify from regional refineries to the global market.

Asia:

There are near-term opportunities for support in **Bangladesh** and **Pakistan**. Bangladesh has the eighth highest health burden from vehicle emissions in the world due to high-sulfur fuel consumption (see Table 2.1 above) and imports most of its fuel. Given that most of the fuel consumed in Bangladesh is imported, it should be possible to improve the import standard to 50 ppm. A similar situation exists in Pakistan, which despite having considerable refining capacity (Table 2.2) is also a major fuel importer with more than 50% reliance on imports from countries that will soon have low-sulfur fuels (Saudi Arabia and Kuwait). It also has one of the highest health burdens from vehicle emissions, second in the world behind India in terms of mortality (see Table 2.1). Therefore, the import standard could be changed from the current 5,000 ppm to 50 ppm or below in a phased approach to match the timelines for refinery improvement in Saudi Arabia and Kuwait. Similarly to Nigeria, full desulfurization would require refinery investment, but introducing an import standard could allow either a phased introduction of low-sulfur fuels on a cities first basis, or a reduction in average sulfur content ahead of delivery of refinery investment.

Longer-term opportunities are available in Afghanistan, Mongolia, Nepal and Sri Lanka. Afghanistan is a net importer of refined product, relying on Turkmenistan, Uzbekistan and Pakistan for petrol and diesel at 150 ppm and 350 ppm sulfur levels, respectively. However, Afghanistan's legislated national standard for diesel is still 10,000 ppm. This presents an opportunity to implement a phased approach in Afghanistan with support to revise the national standard down to match the quality of imports plus a roadmap for 50 ppm diesel. This, in turn, could help to support low sulfur refining in Turkmenistan, Uzbekistan and Pakistan. Keeping in mind the complexities of refinery upgrades, the phased road map should explore switching to other markets for low sulfur diesel imports to Afghanistan.

Similarly, most of Mongolia's fuel imports are at 500 ppm or below, but the national standard is currently 5,000 ppm. We can support Mongolia to develop standards that reflect the quality of fuel it is actually importing, with a longer-term target of low-sulfur fuels.

Nepal imports refined product exclusively from India and the sulfur level of this product is approximately 500 ppm. Because India has a robust refining industry - exporting ultra low-sulfur diesel to Japan, Singapore, Europe and North America - there is an opportunity for Nepal to consider a national standard for ultra low-sulfur fuels.

Sri Lanka imports crude oil from Saudi Arabia for domestic refining to meet half of its fuel needs and it imports crude and refined products from Oman, Singapore and Vietnam. As mentioned above, Sri Lanka does not have fuel quality standards. Changing the import standard of refined product to low or even ultra low-sulfur diesel levels, especially in more populated urban centers, would significantly improve the air quality in urban areas and serve as a catalyst to improve national refining standards.

In South East Asia the Philippines (despite being a major producer of fuel, see Table 2.2 above) is already importing low-sulfur fuels from Singapore and Thailand and so is Vietnam (with the tenth highest health burden of vehicle emissions, see Table 2.1). Both countries already have roadmaps for reaching Euro 4/IV vehicle emission standards and 50 ppm sulfur levels in fuels. UNEP already supports the Philippines for January 2016 implementation of new fuel and vehicle standards, but there is scope for a further reduction to 10 ppm sulfur in fuels and higher vehicle emission standards. Vietnam is aiming for a major program of new refinery capacity additions, but could preempt a growing local supply of low-sulfur fuels by adopting import standards in advance. Longer-term opportunities for desulfurization and fuel quality standards in South East Asia also exist in Myanmar, Lao PDR (Laos) and Cambodia who also import from Singapore and Thailand.

Latin America:

Many countries in Latin America are oil producers (notably Brazil, Colombia, Ecuador, Mexico, Peru and Venezuela) and most are net crude exporters, supplying the USA, China and India as well as smaller markets within the region. Yet despite access to vast crude resources, most countries in the region continue to rely on refined product imports – primarily from the USA but also from other markets, including West Africa. Intra-regional flows fall within the scope of regional trade agreements, including MERCOSUR and the Andean Community.

Central America and the Caribbean countries have a broader trade network than South America. While these countries import mainly from Venezuela and Mexico, the market study shows that there are some flows coming from Russia, West Africa, South America and the USA. Medium-term opportunities for desulfurization exist in El Salvador, Guatemala, Nicaragua and Honduras; these are countries that could update their national fuel specifications to import 50 ppm. The fuel for Central America comes mainly from the Gulf of Mexico. All of the countries in Central America, with the exception of Panama, are part of the Sistema de la Integración Centroamericana (SICA). The decision-makers for SICA are the Consejo de Ministros de Integración Económica group that is made up of all the relevant national ministries who approve or ratify agreements. The working group that designs the technical regulations for fuel quality standards for the member countries is the Reglamento Técnico Centroamericano (RTCA). The RTCA is charged with regulating fuel specifications that are binding to member states; however, country adoption is variable. In April 2014 Resolution No. 341-2014, was approved that targets 500 ppm with target dates for Guatemala and Honduras by 2015, El Salvador by 2017 and Nicaragua by 2018. The approach here would be to target the sub-regional agreement while also working at national level to modify the fuel quality target to 50 ppm and update the target dates. As cost is the most important barrier, a sub-regional strategy is important because a single regional tanker delivers fuel to many countries in the sub-region. Therefore, harmonization will help to lower costs.

In the Caribbean the majority of countries are import-dependent from Venezuela via the Petrocaribe agreement, under which countries in the region get access to oil and refined product imports at below-market prices. The long-term future of Petrocaribe is unclear given challenges to the Venezuelan economy from low oil prices, but while it is in place the engagement of Petróleos de Venezuela, S.A. (PDVSA) and the Government of Venezuela will be necessary to make low-sulfur fuels available to these countries and to support the local adoption of low sulfur standards. A longer-term target for regional low-sulfur fuels would involve refinery upgrades in Venezuela.

Eastern Europe:

Georgia and ***Moldova*** are prioritized in this region. According to the market study Georgia imports fuel from neighboring Azerbaijan, Turkey and Russia. Currently at 150 ppm diesel, Georgia could leapfrog to ultra low-sulfur fuels since Turkey and Russia are already producing ultra low-sulfur fuels and Azerbaijan is transitioning to 10 ppm in 2018-2020. All major fuel distributors in Moldova (Lukoil, Petrom, Rompetrol) sell European-grade diesel and petrol fuel (10 ppm) but national fuel quality legislation does not support clean fuels. Its proximity to European markets and its reliance on imports make Moldova a good candidate for a rapid transition to ultra low-sulfur fuel standards and corresponding Euro-level vehicle emission standards.

Middle East and North Africa:

Most countries in the Middle East are net exporters with the exception of Jordan, Egypt, Algeria, Syria, Morocco and Iraq that also import refined products. Lebanon and Tunisia are fully import-dependent

For this category, both ***Lebanon*** and ***Tunisia*** are good prospects for improving diesel quality in the near-term due to their reliance on imports where international pricing patterns for diesel fuels of different quality demonstrate small differences. Capacity building in global fuel markets forecasting and procurement to guarantee optimum prices and terms for fuel imports should be prioritized.

The second group of longer-term opportunities is formed of countries that cannot meet local demand through their own refinery and have an import share in marketed fuels of more than 10%. Furthermore, these countries (Jordan, Egypt, Morocco and Iraq) have poor fuel standards (> 500 ppm diesel) but they also have plans in place to upgrade their refineries. Therefore, while refinery upgrades are taking place, national polices can be developed in tandem to drive upgrades and ensure regulatory guidance.

2.4. Category 2, 'Refiners': Countries Requiring Refinery Upgrade Financing

Countries included in this category have refining capacity and have demonstrated some sort of a commitment to low-sulfur fuels via national standards, declarations and/or regional agreements. Some may act as regional hubs for refined fuel flows to surrounding countries. However, they all lack the necessary financing for refinery upgrading to produce low-sulfur fuels. Fuel desulfurization in refining countries is key to unlocking the deployment of soot-free diesel engines, but it is also challenging. Major barriers to producing low-sulfur fuels include access to capital, access to technical capacity, governance, existing policy, and economic factors (including fuel subsidies). However, international best practice demonstrates that a portfolio of tools is available to refiners to meet new and more sophisticated fuel quality standards. Therefore, it is feasible for low-and middle-income countries considering desulfurization to effectively leapfrog both in terms of technology and timeframe.

Similarly to the approach in importing countries (above) support to these countries should enable strategies (including financing) for upgrades that ensure all on-road diesel fuel produced in the year 2025 reaches 50 ppm sulfur levels and, where feasible, a leapfrog/reduction to 10 ppm by 2030.

Overall Approach: Our strategy for refining countries is to:

i) Identify key countries that, with targeted refinery investments, would unlock cleaner fuels for large local populations and/or entire sub-regional markets,

ii) Quantify the investment necessary for desulfurization in order to provide a benchmark for investors and national negotiators (as already done through the refinery study),

iii) Ensure that both policymakers and multilateral financial institutions are aware of and act upon information that shows where a relatively lower cost investment (as compared to the wide range of investment costs given in the refinery study) would affect the largest markets for clean fuels, and

iv) Seek to facilitate dialogue between multilateral financial institutions, government officials and private finance for upgrades. Based on our experience, refinery investments usually go hand-in-hand with support for policy development at the national and regional levels as a key driver for continued improvement and to prevent any backsliding or significant delays.

The refiners approach will prioritize low-sulfur fuel policy and investments and will identify economies of scale and knowledge-sharing that may overcome barriers that would be more difficult if faced on a country-by-country basis. On the ground, the types of support provided may include national and/or sub-regional dialogues and training events, the formation of specialized national working groups that include the public and private sectors, the provision of technical expertise specific to refinery upgrades for both private and state-owned refineries, and support for the development of refinery upgrade plans (including investment analysis). The final aim of this type of support is the development of detailed plans that will support the modernization of refineries to produce low and ultra low-sulfur fuels. In this category, opportunities could also be sought for climate finance for projects demonstrating health, climate and air pollution co-benefits.

Support to refining countries should integrate private sector participation and assistance by engaging with industry experts who can advise on public/private financing and strategies for project financing, design and management. When it comes to financing for upgrades, the emphasis at the national and global levels will be on building partnerships between private, public and development/donor actors. In addition, engaging with industry experts who can advise on creative financing models will ensure that both policymakers and multilateral financial institutions are provided with analysis that shows where a relatively lower-cost investment would affect the largest markets for clean fuels.

The following 13 countries are priorities for action in the near-term (i.e. next 5 years) based on considerations of: key market position (i.e. role as major regional/global refiner), ability to adopt and implement low-sulfur fuel policies and upgrade plans within a short time-frame; size of health burden; and high sulfur fuel production capacity. The choice of priorities for action is explained in more detail in section 2.4.1 below.

Table 2.4. List of priority countries in the 'Refiners' category

Africa	Cote d'Ivoire
	Ghana
	Nigeria
	South Africa
Asia	Malaysia
	Indonesia
	India
	Pakistan
Latin America & the Caribbean	Venezuela
East Europe	Ukraine
Middle East	United Arab Emirates
	Kuwait
	Bahrain

Detailed analysis based on the markets and refinery studies is provided below for each, including longer-term opportunities in each region.

2.4.1. Regional Assessments and Approaches

Africa:

Priority countries for investment in the region include ***Cote d'Ivoire***, ***Nigeria***, ***Ghana***, and ***South Africa.*** Based on the refinery study the cost of transitioning Africa's 39 refineries to 50 ppm gasoline and diesel would be nearly $7 billion. The cost of upgrading the 10 refineries prioritized in theses 4 countries totals around $2.7 billion.

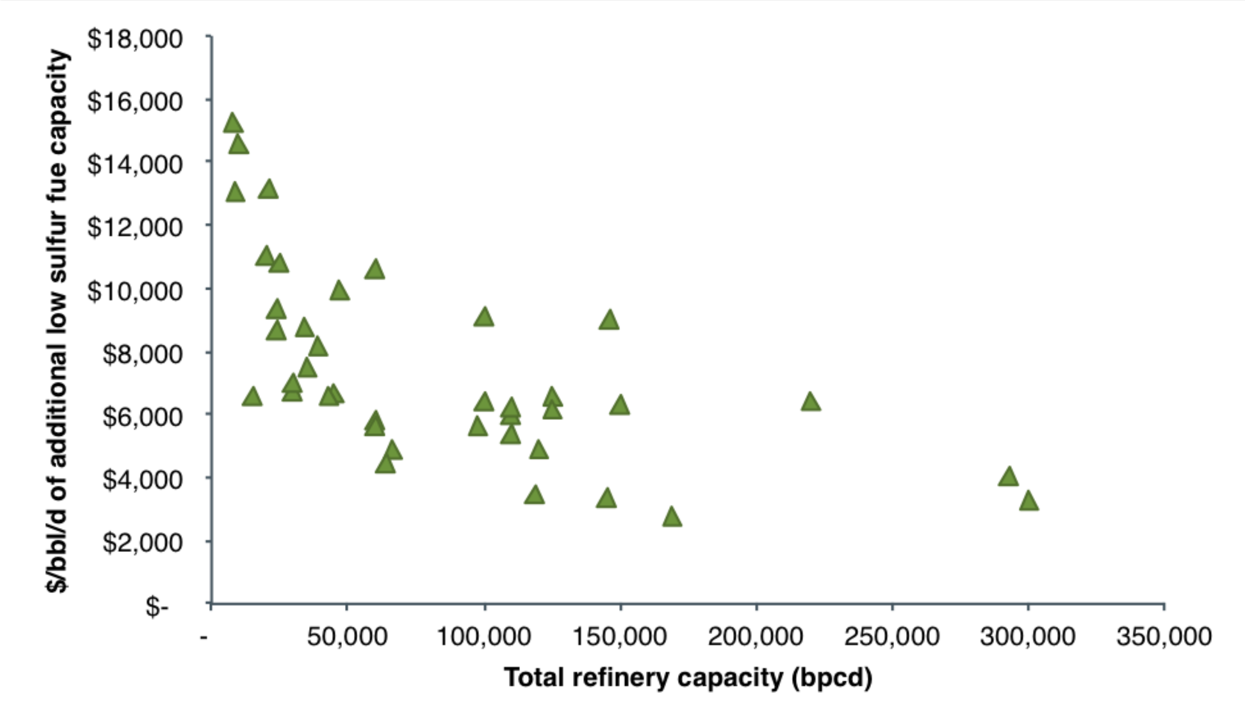


Figure 2.3. Investment costs vs. refinery size in Africa
Source: Ensys, 2015

Figure 2.3 shows that there are broadly three groups of refineries in Africa: i) a group of a few larger refineries where the per-barrel costs to upgrade to produce low-sulfur fuels are relatively low (on the right hand side in the graph); ii) a group in the middle with a larger range in costs; and iii) a third group, the largest group, on the left in the graph, of relatively small refineries that see a wide range in investment costs needed to enable them to produce low-sulfur fuels.

Nigeria ranks thirteenth globally in health burden from vehicle emissions (see Table 2.1), and is also a major producer of high-sulfur fuels (see Table 2.2). Although Nigeria does not directly supply a significant amount of refined product to the Western African sub-region, the market study shows that its high diesel sulfur fuel standard (3,000 ppm) impacts Benin, Mail, Burkina Faso, Togo and Ghana because the ships that bring in refined products for Nigeria also supply other importing countries. The refineries in Nigeria operate well below capacity (estimated to be around 50%). Modernization could result in fuel surpluses, turning Nigeria into a sub-regional fuel-exporting hub. The strategy for desulfurization in Nigeria would be dual: to promote a change in fuel import standards (discussed above) and to support refinery upgrading. The refinery study estimates that a desulfurization investment in Nigeria's four refineries[24] would cost $1.1 billion. A full modernization program would be more costly, but may make a better overall financial case (see section 1.5.5).

While Nigeria is a significant oil producer on the global market, has the largest refining capacity in the region and is home to more than half of the region's population, Cote d'Ivoire also plays an important role as a sub-regional refining hub in Western Africa. Cote d'Ivoire produces some sweet crude, most of which it exports to North America and Europe. It then imports crude from Nigeria, which it refines for its own market and also exports as high-sulfur fuel (2,500 ppm) to twelve of its neighbors. According to the refinery study the cost of upgrading Cote d'Ivoire's refinery is about $130 million or an investment of about $4,500 per barrel of additional low sulfur capacity. This cost is relatively low in absolute terms compared to the average refinery upgrade cost in the region (see chapter 1), and is one of the least expensive upgrade options in the region in terms of cost per barrel per day of additional low-sulfur fuel capacity.

24 Kaduna Refinery & Petrochemical Co., Port Harcourt Alesa Eleme: Port Harcourt Refining Co., Port Harcourt Rivers State: Port Harcourt Refining Co., Warri Refinery & Petrochemical Co.

Ghana's smaller Tema oil refinery would cost $140 million to upgrade, an investment of about $6,500 per additional barrel per day of low sulfur capacity. Refinery upgrading in Ghana has been prioritized for two reasons. With recent oil discoveries, Ghana could become a significant fuel supplier in the region. In addition, the planned bus rapid transit corridors in Accra present a good opportunity to connect cleaner fuels with advanced bus technology.

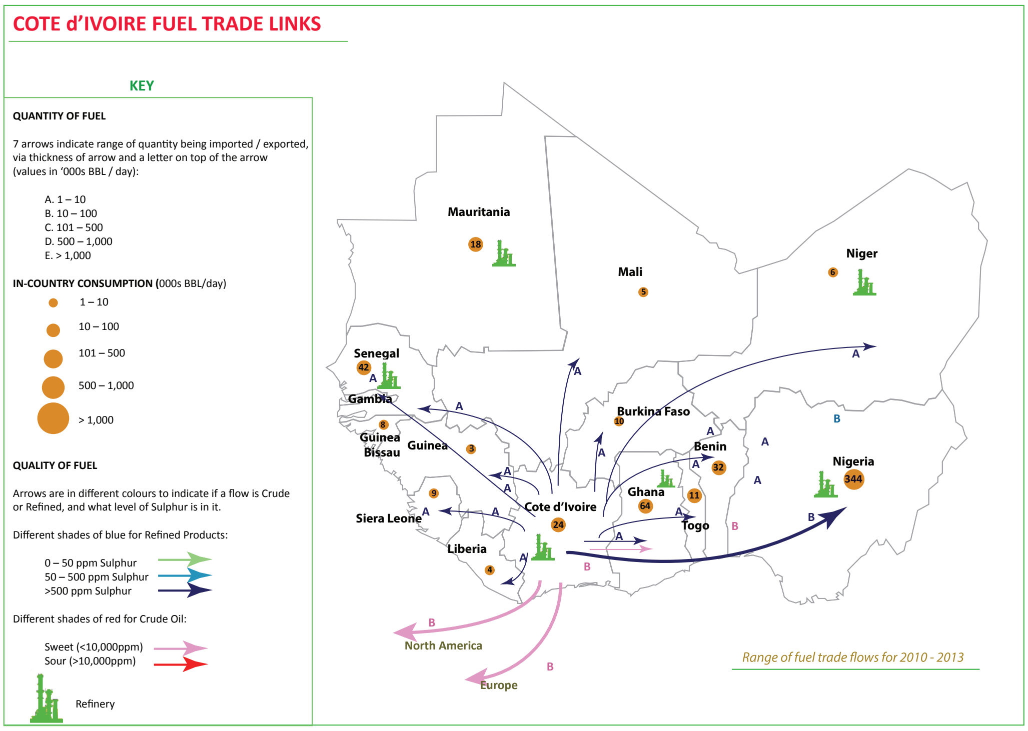


Figure 2.4. Cote d'Ivoire's fuel export relationships in Western Africa
Source: UNEP, 2014

Most Southern African countries are at 500 ppm diesel and the market study shows South Africa serving as refining and export hub for Botswana, Lesotho, Namibia, Swaziland, Mozambique, Zambia, Zimbabwe and Malawi. An upgrade of South Africa's four[25] refineries would cost $1.3 billion according to the refinery study. South Africa is also a major producer of high-sulfur fuels (see Table 2.2 above).

Additional African refining countries with longer-term desulfurization opportunities include Algeria (already planning to move to 15 ppm), Cameroon, Angola and Gabon. These countries still play a significant role in terms of Africa's fuel supply. Angola is one of the largest oil producers in the region and could easily turn into a regional refined fuel supplier. Currently, Angola supplies fuel to Cape Verde and crude oil to South Africa, Cameroon acts as a transit for fuel exports from Chad and supplies refined fuels to its neighboring countries of Congo-Brazzaville and Equatorial Guinea. Gabon is also a major oil producer in sub-Saharan Africa and could become a sub-regional fuel supplier.

Sub-Saharan Africa Refinery Study

A 2009 study supported by the World Bank and the African Refiners Association evaluated the cost of refinery upgrades in the region to low-sulfur fuels (50 ppm diesel and 150 ppm petrol) in terms of potential health benefits in urban areas of the region through to 2020. The estimated refinery costs for upgrades were USD 6 billion while the estimated health benefits we calculated at USD 43 billion. (Rosenberg, 2009)

25 Cape Town: Caltex Oil SA, Durban: Engen Petroleum Ltd., Sasolburg: National Petroleum Refiners of South Africa Pty Ltd., Durban: Shell and BP PLC Petroleum Refineries Pty. Ltd.

Asia:

Asia-Pacific has had the largest growth in refining capacity of any region in recent years at almost 8 million barrels of oil per day (MMbbl/d) since 2002, with most of this growth taking place in China and India (BP, 2013). An additional 6 MMbbl/d of refining capacity is expected by 2018 with 55%, 24% and 21% of this extra capacity in China, India and the rest of Asia, respectively (Gaffney, Cline and Associates, 2014). The countries in the region with domestic oil product but insufficient refining capacity for 50 ppm fuels are India, Malaysia, Indonesia, Pakistan and Vietnam. These are the countries that have plans or are already working on increasing their domestic refining capacities. Based on refinery modeling by Ensys (as described in the refinery study), the cost of transitioning Asian refineries (excluding China) to 50 ppm gasoline and diesel would be just over $25 billion. Of these, ***India, Malaysia, Indonesia*** and ***Pakistan*** are considered the top priorities for near-term action in this strategy. Upgrading refineries in India would require approximately $10 billion of investment. Upgrading refineries in all of Malaysia, Indonesia and Pakistan would require an investment of approximately $5 billion. All four of these countries are among the world's top 13 in terms of the health burden of vehicle emissions (see Table 2.1), and are major producers of high-sulfur fuels (see Table 2.2).

India is currently at 350 ppm diesel nationwide and supplies all major cities with 50 ppm diesel; it will extend Bharat Stage IV (equivalent to 50 ppm) nationwide from April 2017 followed by Bharat Stage VI (10 ppm) from April 2020. A key consideration in India is support for nationwide implementation of Bharat IV-VI, as opposed to only in major cities. This is a major opportunity to move one of the world's largest producers and consumers of fuel to the cleanest diesel fuel and matching vehicle technology.

Vietnam (which suffers from a high rate of vehicle emissions-related mortality, see Table 2.1) is already on a trajectory towards domestic low-sulfur fuel production, as well as importing ultra low-sulfur fuel from Singapore.

Latin America

Priority for refinery investment should be given to ***Venezuela***[26] due to its significant regional fuel trade, high health burden from vehicle emissions (see Table 2.1 above), and large high-sulfur fuel production (see Table 2.2 above).

The main challenge to desulfurization is the weak economy in the country, which is likely to continue to be challenged by low oil prices. Upgrading the five major refining centers[27] would cost around $3.7 billion. The largest refinery, the Paraguana refining center with a total refining capacity of nearly one million barrels per day, would require over $2 billion of investment on its own. China has been lending in the region for refinery upgrades (e.g. to Ecuador, and now in discussions with Costa Rica) and may be willing to do the same for Venezuela. Another possibility is to encourage Petrocaribe members (and MERCOSUR) to integrate cleaner fuels into the trade agreement in the future. Given domestic budgetary challenges, external finance is likely to be vital to achieving progress.

26 In addition to refineries in Venezuela itself, Petróleos de Venezuela, S.A. controls the large refinery in the Netherlands Antilles, which is an important refined product supplier in the region.

27 Cardon/Judibana Falcon, Maracaibo Zulia, El Palito Puerto Cabello, Puerto de la Cruz and San Roque Anzoategui

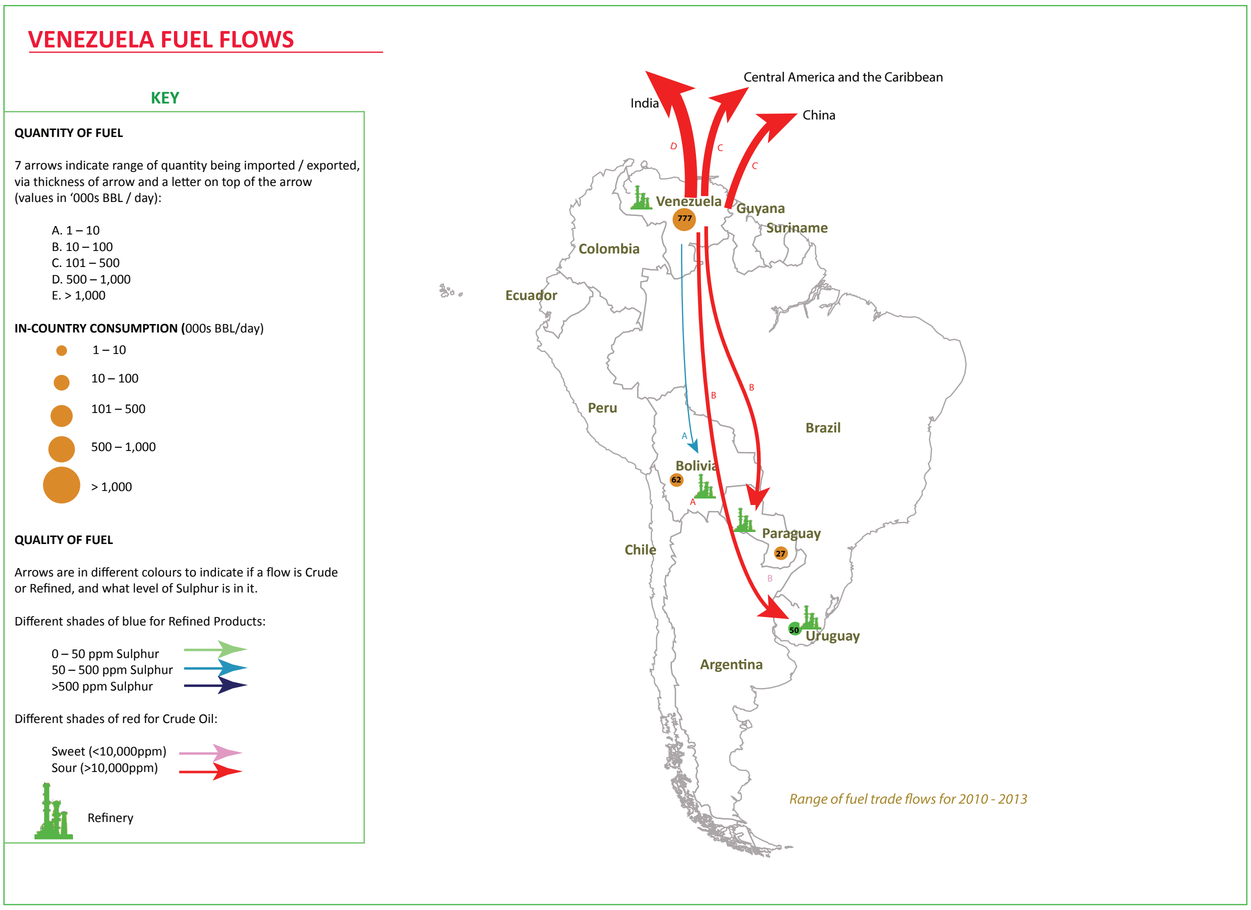


Figure 2.5. Venezuela's fuel trade in Latin America and the Caribbean
Source: UNEP, 2014

Longer-term opportunities exist in countries with refineries that produce for national consumption, have a large internal market and have shown political will to move to low-sulfur fuels. These include Argentina (10 refineries with an estimated upgrade cost of $1.7 billion), Bolivia (one refinery needing investment of $5 million), Dominican Republic (2 refineries requiring $170 million investment), and Jamaica (1 refinery with an investment cost of $65 million). Peru is currently upgrading major state and privately owned refineries, while Ecuador and Nicaragua are in the process of building new refineries, all of which will produce low-sulfur fuels. The investments in Peru appear to be on target for 2017. However, the investments in Ecuador and Nicaragua may be at risk as the $6.6 billion funding is 51% financed with Venezuelan contributions. Brazil, another country with high health burden from transport emissions and significant high-sulfur diesel producer (Table 2.1 and Table 2.2), has 13 refineries requiring $4.1 billion investment. With an existing supply of lower sulfur diesel for cities and key corridors (see below, Section 2.6.1), the strategy for Brazil would be to support continued phased expansion of ULSD availability in parallel to refinery investment.

Eastern Europe

Ukraine should be prioritized in the region for CCAC support, as it has a high health burden associated with transport emissions and a large refining sector in need of upgrade (Table 2.1 and Table 2.2). Recent upgrades of two refineries have allowed the production of low and ultra low-sulfur fuels. Ukraine's growing demand for European-grade fuels and vehicle technology and its shifting geopolitical importance in the region merit attention. In addition, there are plans for a nationwide standard update to 10 ppm in 2018 (Technical Regulation No. 927 on Fuel Quality, currently at 50 ppm). The country's largest refinery is already upgraded: in December 2013 Naftogaz Ukrayiny, Ukraine's national oil and gas company, announced that the Kremenchuk refinery had completed modernization of its equipment in order to start production of diesel fuel that meets 'Euro 5' quality standards with 10 ppm sulfur content, whereas previously the refinery was producing 1,500 ppm diesel. According to the refinery study the cost for upgrading the remaining five refineries to produce 50 ppm fuel is around $1 billion, with costs per additional barrel of low sulfur capacity from $5,000 (Lisichansk:TNK-Ukraina).

As a net importer of refined and crude oil, Ukraine is dependent on Russia, Kazakhstan and Azerbaijan. Low domestic demand for fuel (at just over 30% of the country's refining capacity) meant that the country's six crude oil refineries, with a combined throughput capacity of approximately 1 million barrels/day, were functioning significantly below capacity. However, the refining sector's recent privatization is helping to secure sufficient crude supply by offering oil exporters in Russia and Kazakhstan a stake in the country's refineries.

Middle East and North Africa: The Gulf Cooperation Council countries of ***United Arab Emirates (UAE), Kuwait,*** and ***Bahrain*** present opportunities for near-term support. Most countries in the Middle East are producers of sour crude and the region has some of the highest fuel sulfur rates in the world. UAE is currently at 5,000 ppm sulfur in fuels, planning to move to 10 ppm fuel by 2018. Jordan is at 5,000 ppm; Iraq (a major global producer of high-sulfur fuels, Table 2.2) is currently at 10,000 ppm sulfur in diesel. It is not self-sufficient in refined products, and imports fuel mostly from Kuwait. Kuwait and UAE have significant high-sulfur refining capacity (see Table 2.2 above), which would need to be upgraded to enable a full regional transition to low-sulfur fuels. All countries (except Jordan and Lebanon) are net oil exporters with some refining capacity.

In the Middle East, most refineries are at least partially state-owned and often in need of upgrades. Political instability creates additional challenges in many Middle Eastern countries.

Saudi Arabia is the region's largest refiner with 8 refineries whose upgrade cost is over $5 billion according to the refinery study. As a major producer of high-sulfur fuels (see Table 2.2 above), the country is investing in refinery upgrades and aiming for 10 ppm diesel from 2016.

2.5. Category 3, 'Vehicle Standards': Adopting Vehicle Emission Standards Commensurate with Fuel Quality

The countries in this category have already adopted low sulfur standards but lack the corresponding vehicle emission standards. This means that they are missing an immediate opportunity to benefit from already-available cleaner fuel by adopting compatible vehicle emissions standards. The adoption of standards would create favorable markets for low-emission, more fuel-efficient vehicles resulting in reductions in $PM_{2.5}$, black carbon and CO2. Countries in this category have made the move to low-sulfur fuels, but have yet to gain the maximum societal health and environmental benefits from desulfurization. Adopting vehicle emissions standards for this group presents an opportunity that can generate major emissions reductions.

As more countries, including those listed in categories 1 and 2 above, move to low-sulfur fuels, this category will grow. Our goal is that category 1 and 2 countries also tighten vehicle emission standards.

The 'Systems Approach' to vehicle emissions

The Partnership for Clean Fuels and Vehicles (PCFV) offers the PCFV Clean Fuels and Vehicles Regulatory Toolkit to promote the systems approach to deliver optimal emissions reductions by matching fuel and vehicle improvements. The toolkit supports developing and transition countries to prepare clear long-term strategies to reduce vehicle emissions through a combined cleaner fuel and vehicles strategy. It offers case examples on how to build a regulatory strategy, establish enabling legislation and regulatory standards, and set up enforcement.

Source: UNEP, 2015a

Overall Approach: Building on the availability of low-sulfur fuels, support at the national level (including policy expertise and resources to convene practitioners) would prioritize the development of vehicle emissions standards. This would build on coalitions already formed around the adoption of fuel quality standards. In addition, where regional harmonization of standards has been the approach for cleaner fuels the same regional consensus approach would be taken for the adoption of emissions standards and timelines.

In practice, this may mean building a technical support facility to address common technical and policy barriers among countries seeking to implement soot-free engine requirements, and to respond to direct requests from national governments for technical support to implement such requirements. The aim is to facilitate technical and policy exchange among participating governments with an interest in shifting their existing and future diesel engine fleet towards soot-free engines, including new vehicles, existing vehicles, and imported vehicles. Working with industry experts (manufacturers as well as emission controls manufacturers) is necessary to advise on the cost and performance of soot-free engine technology, while policy experts will be invited to advise on policy design, governance and implementation. This will include emissions standard design and the proper design and implementation of performance standards for imported diesel engines and equipment.

The following 12 countries are priorities for action in the near-term (i.e. next 5 years) based on considerations of: the size of health burden from transport emission and the ability to adopt and implement vehicle emission standards within a relatively short time-frame. The choice of priorities for action is explained in more detail in section 2.5.1 below.

Table 2.5. List of priority countries in the 'Vehicle Standards' category

Africa	East Africa: Kenya, Uganda, Tanzania, Rwanda and Burundi
Asia	Malaysia
	Indonesia
	Brunei
Latin America & the Caribbean	Panama
	Barbados
Middle East	Oman
	Tunisia

Detailed analysis based on the markets study is provided below for each, including longer-term opportunities in each region.

2.5.1. Regional Assessments and Approaches

Africa

Countries in the East African region, where low-sulfur fuel is now available, are prioritized in this category: ***Kenya, Uganda, Tanzania, Rwanda*** and ***Burundi***. According to the market study Kenya acts as a major conduit for petroleum products to its East African neighbors, along with new and used vehicles through its port in Mombasa. The January 2015 transition of the sub-region to 50 ppm fuels (following on an earlier East African Community decision, see section 1.5.5 above) provides an opportunity to match the cleaner fuels with more advanced vehicle technology, particularly in diesel vehicles. In addition, support at the sub-regional and national levels can help to develop vehicle emissions standards commensurate with the fuel quality available (Euro 4/IV), and pilot cleaner technology for selected fleets in urban centers.

Additional countries that could benefit from support for vehicle emissions standard development include Mauritius and Tunisia.

Asia:

The *Association of Southeast Asian Nations (ASEAN)* is prioritized as most of the countries in Asia have developed, or have begun to develop, vehicle emissions standards and fuel quality road maps. There is more integration within the Southeast Asian market both in terms of trade (refined and unrefined fuels) as well as policy harmonization. The market is expected to become more integrated along with the ASEAN Community initiative. ***Brunei*** and ***Malaysia*** will implement 50 ppm fuel sulfur limits by 2016; these ongoing harmonization efforts in the ASEAN present a good opportunity to add on vehicle emissions standards that track the fuel quality standards roadmaps. Malaysia is one of the world's top 13 nations in terms of the health burden from vehicle emissions (see Table 2.1 above).

Priority should be given to supporting the countries leading in the implementation of cleaner fuels (Brunei, Malaysia) as well as ***Indonesia***, given its significance in the ASEAN and its position as the third highest ranked country based on the health burden of vehicle emissions and the 6th largest producer of high-sulfur fuels (Table 2.1 and Table 2.2 above). Efforts in the region should also include a strategic plan to replicate a national approach for desulfurization in Laos, Cambodia and Myanmar. This would help influence the other regional blocs (such as the Central Asia Regional Economic Cooperation and the South Asia Co-operative Environment Programme) in implementing similar agendas.

The Philippines (a major producer of high-sulfur fuel, see Table 2.2 above) and Vietnam (ranked 10th among the world's high-sulfur nations based on the health burden of vehicle emissions, see Table 2.1 above) are already importing low-sulfur fuels from Singapore and/or Thailand. Both countries already have roadmaps for reaching Euro 4/IV vehicle emissions standards and 50 ppm sulfur levels in fuels. UNEP has supported the Philippines for January 2016 implementation of new fuel and vehicle standards. Meanwhile, Thailand has implemented Euro 4/IV vehicle emission standards since 2011. However, there is scope to further encourage an additional reduction to 10 ppm sulfur in fuels, particularly in the Philippines, and corresponding filter-forcing standards.

Latin America

In the Latin America region several countries have recently moved to low-sulfur fuels, yet many still lack the corresponding vehicle emission standards. The countries that should be the near-term focus are ***Panama*** and ***Barbados***, where low-sulfur fuels are already mandated and available at 50 ppm and15 ppm. None of these countries manufacture vehicles and are all fully importing. Barbados is the first Caribbean country to have made the move from 5,000 ppm directly to 15 ppm from December 2013. However, there are no vehicle emissions standards to complement this new fuel for optimal emission reductions. Support for this transition would send an important signal in the Caribbean on the potential for a combined cleaner fuel and vehicles approach.

In some cases, countries require technical advice to support the development of vehicle emission standard proposals that can then be submitted for consideration by the government. There is a need to showcase the progress and results in other countries, including Chile, Colombia, Uruguay and Costa Rica.

Middle East and North Africa

Oman has a diesel fuel quality standard of 500 ppm but has 50 ppm fuel available, yet lacks vehicle emission standards; it would be a quick mover on policies that combine low-sulfur fuels and cleaner vehicles. ***Tunisia*** is already at 50 ppm but existing vehicle standards can be improved.

2.6. Category 4, 'Cities First': Promoting Cities with Low-Sulfur Fuels

While the highest-impact approach for desulfurization is at the national level, some countries choose to introduce dual sulfur standards for urban and rural areas first. This entails making lower-sulfur fuels available in cities for a period prior to rolling out low-sulfur fuels at the national level. A phased approach is often a compromise that allows for a gradual and lower-cost introduction of cleaner fuels for selected fleets. However, this phased approach can be logistically difficult as fuel flows of different qualities may not be easy to segregate. The introduction of soot-free technology where low-sulfur fuels are already available is an approach that would allow countries to build on and expand efforts for desulfurization at the national level by helping to demonstrate the benefits and possibilities of cleaner diesel technology. Investments in cleaner buses, for example, would be a high-profile way to highlight the availability and benefits of cleaner fuels. While a national approach is preferred for desulfurization, selective city-level introduction of cleaner fuels and vehicles is an alternative when countries are not yet prepared for full adoption.

Overall Approach: In existing dual-standard countries we would prioritize cleaner fleets in cities, concentrating on municipal buses and trucks. Documenting city progress would allow for the promotion of low-sulfur fuels and vehicle emissions standards at the national level. A city-level approach would engage ongoing CCAC soot-free city bus efforts, building a city network committed to clean fleet technology and low-sulfur fuels and providing targeted in-depth support for selected cities.

2.6.1. Regional Assessments and Approaches

Latin America

In South America there are several countries that have had dual sulfur standards prior to moving to 50 ppm nationwide. These include Chile, Colombia, and Uruguay and they can serve as examples to countries that are still in a dual-standard situation - namely Argentina, Brazil, and Peru. These countries have 50 ppm or lower diesel available in cities but fuel with sulfur levels up to 1,500 ppm, 1,800 ppm, and 5,000 ppm nationwide, respectively. In Brazil, for example, 10 ppm is supplied in urban areas and along major transit corridors to support the PROCONVE P-7 standards (equivalent to Euro V) that have been in place since 2012, while the rest of the country's diesel sulfur contains 500 ppm. Brazilian refiners have committed to increasing the supply of 10 ppm diesel to meet demand as new heavy-duty vehicles are integrated into the fleet and replace older vehicles. Peru has set a target date for 50 ppm nationwide by 2017, but other countries have yet to follow.

The strategy for dual-standard countries is to support cleaner fleets in cities, concentrating on public fleets. Demonstrating benefits in cities by combining low-sulfur fuels with matching technology would allow for the promotion of low-sulfur fuels and vehicle emissions standards country-wide. In Lima there is already a CCAC-supported clean fleet (diesel particulate filter) pilot that aims to demonstrate cleaner diesel technology. Public transport buses are fitted with thermocouples to measure the exhaust gas temperature and the profiles are used to select the correct particulate filters. The project results test the program capabilities and gauge the feasibility of advancing in other city fleets. A similar approach could be replicated in other dual-standard countries in the region.

3. Conclusion

In this strategy document, we have shown that the benefits of fuel desulfurization, when combined with vehicle emissions control technologies, greatly outweigh the costs of new emissions controls and the production of low-sulfur fuels.

The co-leads of the Heavy-Duty Diesel Vehicles and Engines Initiative of the Climate and Clean Air Coalition have identified thirty-six countries for priority action by the CCAC that do not yet have the combination of 50 ppm or lower sulfur fuel and Euro 4/IV equivalent or more stringent vehicle emissions standards. This was done by organizing countries into four categories ('refiners', 'importers', 'vehicle standards' and 'cities first') based on in-depth analysis of fuel markets, refineries, and the possible health and climate gains. The absence of a country from this assessment of priority opportunities does not mean that that country would not accrue significant health and environmental benefits from adopting better fuel quality and vehicle emission standards. However, the countries listed in the strategy should be targeted for support in the form of shared expertise, assistance with financing and development of regional partnerships. The success of these strategies depends on interaction and agreement among groups of countries; the concurrent adoption of low-sulfur fuel standards by refiner and importer countries in a region can deliver complementarity, while a failure to coordinate could disrupt fuel markets and pose a challenge to the successful implementation of new standards. International associations and initiatives like the RTCA in Central America, ASEAN in Asia, Male' Declaration (South Asia) and ECOWAS, SADEC, and EAC in Africa can help align national goals across regions showcase successful implementation and results and facilitate the desired push-pull policy dynamics between refiner and importer countries.

This strategy is targeted at global achievement of 50 ppm or lower sulfur in fuels, and Euro 4/IV equivalent or more stringent emissions standards for vehicles by 2025 by focusing on the countries highlighted to catalyze global action. Therefore, in addition to laying out a roadmap for how to achieve 50 ppm diesel worldwide by 2025, this document is also an invitation to partner to achieve this goal. Finally, it is important to understand that the health burden of vehicular emissions can still be significant even in countries that have already achieved this baseline standard. It is therefore of great importance that alongside progress towards global adoption of low sulfur standards, support should continue for tighter standards and for a move toward ultra low-sulfur fuels.

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Annex A Methodology for refinery analysis

The refinery analysis involves the estimated assessment of refined product output capacity at 245 refineries worldwide.[28] Based on information about refinery capacities and these estimated product outputs, Ensys (2015) undertook refinery-by-refinery modeling of the cost of adopting 50 ppm sulfur standards for all refinery gasoline and diesel output. The modeling required fuels to be delivered at 40 ppm sulfur content, to reflect the need of refiners to allow for a certain amount of potential contamination in the distribution chain.

For the product output assessment, the overall goal was to assess the "best" yields that each refinery could realistically produce, with primary focus on gasoline and diesel, together with their associated sulfur levels. The assessment was based generally on data from the Oil and Gas Journal (OGJ, 2013) estimating January 2014 refinery capacity.

In undertaking the analysis Ensys identified frequent errors and omissions in the January 2014 OGJ data used as a starting point for refinery capacities. For each refinery, Ensys modeled a realistic crude slate for each refinery and sought to identify as accurately as possible refinery process capacities. The bottom line goal in the Baseline analysis was to arrive for each refinery at a simulation that fully or largely used the available distillation and secondary processing capacity while employing a realistic crude slate. Those factors essentially entirely determined the product volumes and sulfur levels and represented a situation where the refinery could not be expected to do any better in terms of Baseline yields or product sulfurs.

In establishing the refinery baseline, several modeling decisions were made for each refinery to maximize the utility and real life applicability of the results. These included:

- Estimating rate of capacity utilization (for instance, Nigerian refineries currently have a reported average utilization rate of 30%). The estimated costs of desulfurization may in some cases be overstated for refineries with low utilization rates, as the modeling requires sufficient desulfurization capacity to reflect the nameplate throughput.
- Setting product output spread based on product prices and the assumption that diesel, gasoline and jet fuel yields would be optimized. Jet fuel output was based on regional averages.
- Where specialty products were reported in the capacity data (such as lubes, aromatics or asphalt), production of these was forced in the modeling.
- Where Ensys had reason to believe that refinery capacity data was wrongly listed or incomplete in the OGJ data, the capacities were adjusted on a refinery-by-refinery basis.
- For most refineries, Ensys assumed industry-typical operating modes for the generic refinery units listed in the OGJ data.
- An estimated crude slate for each refinery.
- Product specifications based on Ensys' WORLD model database supplemented by additional research.

28 The refinery is global, excluding the U.S., EU, Russia and China.

Having assessed the baseline configuration of all 245 refineries, Ensys estimated the costs to lower sulfur content in both the gasoline and diesel streams. This assessment followed the following principles:

- The study only allowed capacity additions with the direct purpose of limiting sulfur output (hydrotreating units) plus supporting plant units (such as additional hydrogen and sulfur plant capacity). The study did not consider options to reduce sulfur through additional hydrocracking capacity or FCC feed hydrotreaters, as these would have altered yield patterns, and to consider such options was outside the scope of the study. As noted in the report above, in reality it is likely that desulfurization will often be coupled to yield improvement, in which case there may be some complementarity between capacity added to improve product yields (and hence margins) and investments to reduce sulfur levels.

- The study did not allow for revamping of existing units to support increased severity of desulfurization. This will tend to overstate costs in some cases, as where revamps to convert existing hydrotreating units to deep-hydrotreating duty are possible this would almost always deliver cost savings compared to installing new plant.

- The study did not allow refineries to reduce output as a strategy to achieve lower sulfur standards.

- The analysis considered only desulfurization costs – it did not model any additional cost associated with full compliance with other aspects covered by fuel quality standards.

- Refineries were forced to use an identical or similar crude slate in investment case, to prevent switches to low sulfur crudes being used as a strategy to achieve lower sulfur standards.

The investment costs for new process units were taken from the Ensys WORLD model. The costs are based on a reference location on the U.S. Gulf Coast, construction in 2014 and a reference refinery scale of 100,000 barrels/day throughput. These costs were adjusted by the application of scale factors and location factors. Scale factors are based on the 0.6 power factor method. Scale factors led to costs up to 25% higher than those for a U.S. Gulf Coast refinery. Where refineries were simulated as running below full capacity, this was taken into account in setting the scale factors (increasing costs per additional barrel of desulfurization capacity).

Annex B The market baseline study

Background

The market baseline study complements the refinery study (see Annex A) in that it provides a global overview of auto fuel (both crude and refined) and vehicle markets in various sub-regions where higher sulfur fuels (in particular, diesel fuel) are still in use (i.e. fuels above 50 ppm sulfur). By mapping and analyzing the relative magnitude of fuel and vehicle flows the market study provides insights on the fuel quality in countries, the quantities of crude and refined product traded and produced, and the vehicle fleet in use (both new and used, imported and produced locally).

Methodology and Assumptions

Both online research and direct country contacts were used to collect information on fuel flows for the market study. Updated information on diesel fuel quality and vehicle emissions standards used in the study is available online from unep.org/pcfv. The resulting fuel flow data (both crude and refined) was used to generate regional maps and identify 'hot spots' or major fuel players in regions and sub regions, along with a clearer understanding of opportunities to support and promote cleaner fuels.

The following assumptions were made in the research and analysis of the market study:

- The sub-regional maps show the quality of fuel being imported / exported; to determine the actual tested quality being imported by a country was not always possible. In cases where the actual sulfur level was unknown, the official national standard was used. This is a rather problematic assumption, as the actual sulfur levels will often differ from the standard (which is the maximum level allowed), particularly when a country is importing from a source with low-sulfur fuel. This difference between actual and maximum means that the fuel being used is, at times, of a better quality than the standard shows. However, the maps indicate the standard, unless information was found regarding actual fuel quality, in which case this value was used. For example: India has a national standard of 350 ppm, but this study assumes it is exporting higher-sulfur fuel to African countries because of the lower fuel quality standard in the importing countries.

- Countries regularly change where they import from / export to, depending on price, availability, demand, products required, sanctions, conflict, economics, politics, refinery shutdowns etc. The maps make the trade relations and flows look very static, as they are a snapshot in time; however, this is not the case on an on-going basis. For the sake of analysis, data between 2010-2013 was used.

- An attempt was made to include all the countries that have had trade connections with each other between 2010 and 2013, in order to show all observed trade links in that timeframe; but in any one given month, the actual trade flows might be different.

- In addition, the values of the flows shift regularly as well, for some of the same reasons as mentioned above. The sub-regional maps might provide an impression that a certain country always produces the same amount every day or exports the same amount. In reality, these maps are snapshots of average trade flows and relations and should be understood as such.
- A variety of sources were used for fuel and crude flow data (rather than one source with one time period with all the data required), and in some cases data from different years spanning 2010 to 2013 (and a few data points from early 2014). Given that the aim of the study is to map and analyze the relative magnitude of flows rather than specific and exact values, the authors decided that this approach was acceptable for the purpose of this study.

- Because of the range of data sources and years used, the values do not add up perfectly for many of the countries (i.e.: production + imports ≠consumption + exports), but the differences are, for the most part, minimal and, given the purpose of the study, are acceptable.

- The maps do not provide exact numbers, but rather indicate ranges of fuel flow volumes to give a sense of the relative magnitude and importance of trade. As the data comes from various sources and spans three years, the use of ranges avoids the impression of a precise flow volume, which was not possible to achieve given the limitations outlined above.

- Unless indicated otherwise, fuel quality discussed throughout this strategy is for diesel fuel only; this applies to fuel (i.e. diesel) quality standards, sulfur levels (in parts per million, or ppm, for diesel) and actual, in-use fuel (i.e. diesel) quality.

- However, refinery capacity and trade volumes indicated on maps and in text include all fuel products (unless otherwise specified), as disaggregated values for different fuels were not readily available.

The full study is available for download from www.unep.org/transport.

Annex C The health benefit and emissions control cost modeling

This section describes the underlying assumptions and modeling that, combined with the results of the refinery analysis, is used for the cost-benefit analysis described in chapter 1. This analysis follows a methodology that has been applied, reviewed, and published in several other analyses:

- The methodology to estimate reductions in black carbon, sulfate, and total primary $PM_{2.5}$ emissions resulting from new fuel and vehicle standards is the same as that described in Chambliss et al. (2013), Appendix II.
- The methodology to estimate the health effects of emissions reductions is the same as that described in Chambliss et al. (2013), Appendix III. These methods were reviewed by Bryan Hubbell (U.S. Environmental Protection Agency), Julian Marshall (University of Minnesota), and Thomas McKone (University of California, Berkeley). These methods have also been described and applied by Minjares, Wagner, and Ackbar (2014) and by Miller, Blumberg, and Sharpe (2014).
- The methodology and rationale underlying the valuation of health benefits follows that described and applied by Minjares, Wagner, and Ackbar (2014) in a report that was prepared jointly by the World Bank and the ICCT and reviewed by members of both organizations. These methods are also described in depth and applied by Miller, Blumberg, and Sharpe (2014).
- The methods for assessing the costs of emission control technology necessary to meet more stringent emission standards are described for light-duty vehicles by Posada Sanchez, Bandivadekar, and German (2012). Similar methods have been applied for heavy-duty vehicles and used in the analyses of Miller, Blumberg, and Sharpe (2014), and Shao and Wagner (2015).

The most important details are provided here, but readers are encouraged to look to the documents cited above for longer and more in-depth descriptions of these methods.

C.1 Policy Assumptions

The costs and benefits of a transition to lower-sulfur fuels are calculated be comparing two policy cases:

- Case 1: “No Advancement Beyond Currently Enforced”. The policies modeled in this case do not include commitments to future reductions in fuel sulfur levels and tightened standards (e.g. nationwide ultra low-sulfur fuel commitments in Mexico, Brazil, and India). This case does account for the provision of low-sulfur fuel in areas where it has been required for several years (e.g. urban areas in India and Brazil; all countries in Europe’s non-EU countries excluding Bosnia and Herzegovina, Ukraine, Belarus and Moldova).
- Case 2: “Transition to lower-sulfur fuels”, in which all countries progress to low-sulfur fuel and more stringent emission standards, with all regions meeting at least Euro 4/IV-equivalent standards and 50 ppm sulfur limits in 2025 and many moving to ultra low-sulfur fuel and filter-forcing, Euro 6/VI-equivalent standards in 2030. This accelerated roadmap accounts for both national commitments to low-sulfur fuels and additional international actions to support new standards.

This analysis covers 158 countries in Africa, the Middle East, Asia, Latin America, and Europe with a combined 2015 population of 4.6 billion, or about 64% of the global population. It excludes China, Russia, Japan, South Korea, Australia, the U.S., Canada, and countries in the EU. The full list of countries considered is shown in 1.1.1C.1Table A. This analysis focuses on the sulfur content of diesel fuel and standards pertaining to diesel vehicles, as diesel vehicles contribute much more to on-road vehicle PM emissions than those powered by gasoline or alternative fuels.

The only vehicle emission control policies considered are national standards for sales of new vehicles. Age-based standards and import restrictions are also enforced in many countries, but there is a high degree of uncertainty in how these restrictions affect fleet emissions. Age-based standards and market availability may result in a share of vehicles meeting standards more stringent than those enforced for new vehicles. The impact depends on multiple factors, including the origin of imported vehicles and the average age and condition of these imports. A more detailed assessment of these policies may be appropriate when considering the effects of vehicle standards for a specific country.

Table A: Countries/refineries included in ICCT health benefit modeling

COUNTRIES			
Afghanistan	Dominican Republic	Malaysia	Senegal
Albania	Ecuador	Maldives	Serbia
Algeria	Egypt	Mali	Seychelles
Andorra	El Salvador	Marshall Islands	Sierra Leone
Angola	Equatorial Guinea	Mauritania	Singapore
Antigua and Barbuda	Eritrea	Mauritius	Solomon Islands
Argentina	Ethiopia	Mexico	Somalia
Armenia	Fiji	Micronesia	South Africa
Azerbaijan	Gabon	Monaco	South Sudan
Bahamas	Gambia	Mongolia	Sri Lanka
Bahrain	Georgia	Montenegro	Sudan
Bangladesh	Ghana	Morocco	Suriname
Barbados	Grenada	Mozambique	Swaziland
Belarus	Guatemala	Myanmar	Switzerland
Belize	Guinea	Namibia	Syria
Benin	Guinea Bissau	Nauru	Tajikistan
Bhutan	Guyana	Nepal	Thailand
Bolivia	Haiti	New Zealand	The former Yugoslav Republic of Macedonia
Bosnia and Herzegovina	Honduras	Nicaragua	Timor-Leste
Botswana	Iceland	Niger	Togo
Brazil	India	Nigeria	Tonga
Brunei Darussalam	Indonesia	Norway	Trinidad and Tobago
Burkina Faso	Iran	Oman	Tunisia
Burundi	Iraq	Pakistan	Turkey
Cabo Verde	Israel	Palau	Turkmenistan
Cambodia	Jamaica	Panama	Tuvalu
Cameroon	Jordan	Papua New Guinea	Uganda
Central African Republic	Kazakhstan	Paraguay	Ukraine
Chad	Kenya	Peru	United Arab Emirates
Chile	Kiribati	Philippines	United Republic of Tanzania

COUNTRIES			
Colombia	Kuwait	Qatar	Uruguay
Comoros	Kyrgyzstan	Republic of Moldova	Uzbekistan
Congo	Lao People's Democratic Republic	Rwanda	Vanuatu
Costa Rica	Lebanon	Saint Kitts and Nevis	Venezuela
Cote D'Ivoire	Lesotho	Saint Lucia	Vietnam
Cuba	Liberia	Saint Vincent and the Grenadines	Yemen
Democratic People's Republic of Korea	Libyan Arab Jamahiriya	Samoa	Zambia
Democratic Republic of the Congo	Liechtenstein	San Marino	Zimbabwe
Djibouti	Madagascar	Sao Tome and Principe	
Dominica	Malawi	Saudi Arabia	

C.2 Case 1: No Advancement Beyond Currently Enforced Policies

Fuel sulfur level in this policy case is determined one of two ways. For countries that are modeled individually (Brazil, Mexico, and India), we assume that fuel meets the maximum allowed sulfur content nationwide, and that low-sulfur fuel is available in urban areas as specified. For countries that are modeled in a larger, aggregate region (those in Africa, the Middle East, Asia-Pacific, non-EU Europe and Latin America), the baseline sulfur level is derived from the average sulfur content of the regional refineries compiled by EnSys and adjusted for lower-sulfur fuel imports. Countries with more stringent standards are noted.

C.2.1 Brazil

In Brazil, the baseline diesel sulfur content is assumed to be 500 ppm; it is assumed that 10 ppm diesel is available but used only by Euro V-certified vehicles. All new vehicles introduced to the fleet are assumed to meet Euro 5/V-equivalent standards, in alignment with current PROCONVE standards. As Euro V vehicles increase in their share of the fleet, the share of diesel consumed that is 10 ppm increases accordingly.

C.2.2 Mexico

In Mexico, the baseline diesel sulfur content is assumed to be 15 ppm in 40% of the country, and 350 ppm in the rest of the country. Mexico allows two different compliance options for vehicle emission standards. We assume that vehicles comply with U.S.-based standards, which require less stringent PM controls. These standards are assumed to be equivalent to Euro III standards for heavy-duty vehicles and Euro 3 standards for light-duty vehicles.

C.2.3 Latin America and Caribbean

Of the 31 remaining countries in Latin America and the Caribbean, three countries, comprising 8% of the region's population and 13% of combined gasoline and distillate consumption, have adopted 15 ppm diesel limits. However, these countries have not yet adopted filter-forcing vehicle emission standards for heavy-duty vehicles, and remain at Euro 5/V-equivalent or below. Two other countries, Colombia and Ecuador, have adopted 50 ppm standards, but only Colombia requires the corresponding vehicle emission standards. We assume 10% of the region is at 15 ppm fuel and Euro 5/V-equivalent standards, and an additional 15% is at 50 ppm fuel and meeting Euro 3/III standards.

For the remaining countries, the baseline diesel sulfur content is assumed to be 2000 ppm, based on refinery and import data. New vehicles sold in these remaining countries are assumed to meet Euro 3/III standards.

C.2.4 European countries not in the EU

Of the 19 countries in Europe not in the EU, 10 countries comprising 36% of the region's population and 56% of its combined gasoline and distillate consumption have already passed fuel quality standards restricting diesel sulfur content to 10 ppm. The baseline diesel sulfur content is assumed to be 10 ppm for half the vehicles in the region and 350 ppm for the other half. New vehicles in countries with 10 ppm fuel standards are assumed to meet Euro 6/VI standards, and the other half are assumed to meet Euro 3/III.

C.2.5 Africa

53 African countries are included in the model. Of these, seven countries currently enforce 50 ppm limits on diesel sulfur. These countries account for 20% of the region's population and 14% of the gasoline and distillate consumption. These regions have not adopted emission standards for new vehicles. We assume that 15% of the diesel consumed in this region is 50 ppm. The baseline diesel sulfur content for the remaining countries is assumed to be 1200 ppm, based on refinery and import data. New light-duty vehicles sold in all countries in the region are assumed to meet Euro 2-equivalent standards, while new heavy-duty vehicles are assumed to meet Euro I-equivalent standards.

C.2.6 Middle East

Of the 15 countries in the Middle East model region, two have adopted 10 ppm diesel sulfur limits: Turkey and Israel. These account for 23% of the region's population and 12% of the combined gasoline and distillate consumption. Accordingly, 15% of the region is assumed to consume 10 ppm diesel and enforce Euro 6/VI-equivalent standards. For the remaining 85% of the region, the baseline diesel sulfur content is assumed to be 2500 ppm, based on refinery and import data. New light-duty vehicles sold in these countries are assumed to meet Euro 2-equivalent standards, while new heavy-duty vehicles are assumed to meet Euro I-equivalent standards.

C.2.7 India

In India, select urban areas require a maximum diesel sulfur content of 50 ppm, while the diesel available nationwide has a maximum sulfur content of 350 ppm. Urban areas with 50 ppm sulfur diesel also require Euro 4/IV-equivalent standards for light-duty vehicles and buses. Other vehicles are required to meet Euro 3/III-equivalent standards. We assume that 25% of all in-use diesel vehicles, including all Euro 4/IV-certified LDVs and Buses, use 50 ppm diesel, while the remainder use 350 ppm.

C.2.8 Asia-Pacific

For the 37 countries in the Asia-Pacific model region, two enforce 10 ppm limits on diesel sulfur (New Zealand and Singapore) and account for 1% of the region's population and 6% of gasoline and distillate consumption. These countries require Euro V/5 emission standards. We assume 5% of the region consumes 10 ppm diesel fuel and meets Euro 5/V standards. For the rest of the region the baseline diesel sulfur content is assumed to be 1000 ppm, based on refinery and import data. New light-duty vehicles sold in these countries are assumed to meet Euro 3-equivalent standards, while new heavy-duty vehicles are assumed to meet Euro II-equivalent standards.

C.3 Case 2: Transition to lower-sulfur fuels

In this policy case, all countries move to standards requiring diesel sulfur content of 50 ppm or lower, with many moving to ultra low sulfur diesel and filter-forcing standards. In countries that are modeled individually (Brazil, Mexico, and India), dates for standards adoptions are based on proposed legislation and comments made by national policymakers. In multi-country national regions, it is assumed that a core group of countries will move more quickly to low-sulfur fuel, and then the standards will spread throughout the rest of the region within a 5-year-period.

C.3.1 Brazil

Brazil is assumed to adopt a nationwide 10 ppm sulfur limit for diesel in 2020, and move to Euro 6/VI-equivalent standards in the same year.

C.3.2 Mexico

Mexico is assumed to move to diesel with a maximum sulfur content of 15ppm in late 2017 and to Euro 6/VI-equivalent standards in 2018. This is in line with the proposed NOM-044 heavy-duty vehicle standards.

C.3.3 Latin America and Caribbean

Among the 31 countries in the rest of Latin America and the Caribbean, four, comprising 32% of the population and 33% of gasoline and distillate consumption, have set a date to adopt 50 ppm standards. In this policy case, we model that in the year 2020 an additional 25% of the region will advance to 50 ppm diesel and Euro 4/VI-equivalent standards, and model those at 50 ppm already to advance to Euro 4/IV, resulting in 40% of the total region at 50 ppm and Euro 4/VI in 2020. We also model that the 10% of the region with 15ppm fuel moves to Euro 6/VI-equivalent standards. In 2025, we model that the remaining 50% of the region with less stringent standards will move to 50 ppm fuels and Euro 4/IV, and the share of the region with 15ppm limits and Euro 6/VI-equivalent standards will rise to 25%. In 2030, we assume that 50% of the region moves to ultra low sulfur diesel and Euro 6/VI-equivalent standards, while the remaining 50% enforces Euro 4/IV standards and 50 ppm diesel sulfur limits.

C.3.4 European countries not in the EU

In addition to the 10 countries already enforcing 10 ppm diesel sulfur limits, three (20% of regional population) have adopted or committed to 50 ppm limits. Since most of these countries rely primarily on imported fuel, they could choose to move from 50 ppm limits to 10 ppm limits fairly quickly, without concerns for financing upgrades of domestic refineries. We model that 40% of the countries currently at less stringent standards (20% of the total) will enforce 50 ppm diesel sulfur limits and Euro 4/VI standards in 2020, and then this share of the region will move to 10 ppm standards by 2025. We model the remaining share of the region to move to 50 ppm and Euro 4/VI standards in 2025, and then advance to 10 ppm and Euro 6/VI standards in 2030.

C.3.5 Africa

In Africa, we model the 15% of the region already consuming 50 ppm diesel to move to Euro 4/VI standards in 2020. In addition to the share of countries already enforcing 50 ppm sulfur limits on diesel, there are 8 countries comprising 29% of the regional population and 49% of regional gasoline and distillate consumption that have committed to future limits on diesel sulfur content of 50 ppm or lower. We model those commitments as an additional 35% share of the region moving to 50 ppm diesel sulfur limits and Euro 4/VI standards adopted in 2020. In 2025, we assume the whole region has moved to 50 ppm diesel sulfur limits and Euro 4/VI standards. In 2030, we assume that the 50% of the region that were early actors will move to ultra low sulfur diesel and Euro 6/VI-equivalent standards.

Middle East

In the Middle East, of the 13 countries that do not yet require low sulfur diesel, 5 (13% of the population and 38% of gasoline/distillate consumption) have committed to clean fuels policies and in many cases plan to move directly to ultra low sulfur diesel. We model the share of the region at 10 ppm and Euro 6/VI-equivalent standards rising from 15% to 40% in 2020. In 2025 the remainder will meet 50 ppm sulfur limits, and adopt Euro4/IV standards. We model that a 20% share of the region will move from 50 ppm diesel sulfur limits and Euro 4/VI standards to 10 ppm diesel sulfur limits and Euro 6/VI standards in 2030.

India

In India, we model a nationwide move to 50 ppm sulfur limits and Euro 4/VI-equivalent standards in 2017, progressing through Euro 5/V-equivalent standards and 10 ppm diesel sulfur limits in 2019 and finishing with Euro 6/VI-equivalent standards in 2023.

Asia-Pacific

In Asia-Pacific, we model that the 5% already at 10 ppm diesel move to Euro 6/VI standards. An additional 10 countries comprising 32% of the regional population and 50% of gasoline/distillate consumption have committed to 50 ppm standards, so we model that 40% of the region moves to 50 ppm diesel sulfur limits and Euro 4/VI standards in 2020. In 2025, we assume that some of the early actors moving to 50 ppm will advance to ultra low sulfur diesel and Euro 6/VI standards, increasing the share of the region at these standards to 15%. In this same year, we assume all remaining countries advance to low sulfur diesel and corresponding standards, leading to 85% of the region meeting Euro 4/IV fuel and vehicle emission standards in 2025. In 2030, we assume that 45% of the region is enforcing ultra low sulfur diesel and Euro 6/VI-equivalent standards, while the remaining 55% enforces Euro 4/IV standards and 50 ppm diesel sulfur limits.

These standards are summarized in 1.1.1C.3.5Table A below. In Case 1, the standards in place in 2015 (bolded) remain for all remaining years. In Case 2, the regions advance to more stringent fuel and vehicle standards in the stages shown for years 2020-2030. No further advances are assumed after 2030.

Table A: Summary of assumed standards

		2015	2020	2025	2030
Latin America	High sulfur (2000)	75% (Euro 3/III)	50% (Euro 3/III)	0%	-
	Low sulfur	15% (Euro 3/III)	40% (Euro 4/IV)	75% (Euro 4/IV)	50% (Euro 4/IV)
	Ultra low sulfur (15)	10% (Euro 5/V)	10% (Euro 6/VI)	25% (Euro 6/VI)	50% (Euro 6/VI)
Non-EU Europe	High sulfur (350)	50% (Euro 3/III)	30% (Euro 3/III)	0%	-
	Low sulfur	0%	20% (Euro 4/IV)	30% (Euro 4/IV)	-
	Ultra low sulfur	50% (Euro 6/VI)	50% (Euro 6/VI)	70% (Euro 6/VI)	100% (Euro 6/VI)
Africa	High sulfur (1200)	85% (Euro 2/I)	50% (Euro 2/I)	0%	-
	Low sulfur	15% (Euro 2/I)	50% (Euro 4/IV)	100% (Euro 4/IV)	50% (Euro 4/IV)
	Ultra low sulfur	0%	-	-	50% (Euro 6/VI)
Middle East	High sulfur (2500)	85% (Euro 2/I)	60% (Euro 2/I)	0%	-
	Low sulfur	0%	-	60% (Euro 4/IV)	40% (Euro 4/IV)
	Ultra low sulfur	15% (Euro 6/VI)	40% (Euro 6/VI)	40% (Euro 6/VI)	60% (Euro 6/VI)
Asia-Pacific	High sulfur (1000)	95% (Euro 3/II)	55% (Euro 3/II)	0%	-
	Low sulfur	0%	40% (Euro 4/IV)	85% (Euro 4/IV)	55% (Euro 4/IV)
	Ultra low sulfur	5% (Euro 5/V)	5% (Euro 6/VI)	15% (Euro 6/VI)	45% (Euro 6/VI)
Brazil	High sulfur (500)	All but Euro 5/V	-	-	-
	Low sulfur	0%	-	-	-
	Ultra low sulfur	Euro 5/V only	100% (Euro 6/VI)	-	-
Mexico	High sulfur (350)	60% (Euro 3/III)	-	-	-
	Low sulfur	0%	-	-	-
	Ultra low sulfur	40% (Euro 3/III)	100% (Euro 6/VI)*	-	-

		2015	2020	2025	2030
India	High sulfur (350)	75% (Euro 3/III)	-	-	-
	Low sulfur	25% (Euro 4/IV)	-	-	-
	Ultra low sulfur	0%	100% (Euro 5/V)*	100% (Euro 6/VI)*	-

In Mexico and India, standard shifts occur in years between those shown on the charts. See description for exact dates.

C.4 Health Benefits Estimates

The benefits considered are reduced mortality from on-road vehicle primary PM emissions. The monetary value of reduced mortality is estimated using the concept of aggregate willingness to pay, multiplying each prevented premature mortality by a value per statistical life. The cumulative monetized benefits from 2017 through 2050 are converted into present value terms, assuming a future discounting of 3% annually.

This method presents a conservative estimate of the total value of these policies in improving public health. The value does not include reduction in non-fatal health impacts, further reductions in mortality from lower NOx and SO_2 emissions, and health improvement outside of urban areas.

C.4.1 Emissions Modeling

The Global Transportation Roadmap Model produces estimates of historical and future emissions of greenhouse gas and local air pollutants from transportation sources (ICCT 2012a). This analysis uses estimates of tank-to-wheel (tailpipe) emissions of fine particulate matter ($PM_{2.5}$). The model uses a bottom-up emissions calculation based on vehicle activity and emission factors. The effects of sulfur on $PM_{2.5}$ emissions is calculated using a mass-balance approach that assumes that 2% of sulfur in the fuel is converted to sulfates, consistent with research findings (Corro, 2002) and EPA guidance (Glover and Cumberworth, 2003). These methods are described in more detail in Appendix II of Chambliss et al. 2013.

C.4.2 Concentration and Health Effects

This analysis considers the major causes of death associated with prolonged exposure to $PM_{2.5}$ pollution for adults (Krewski et al., 2009): cardiopulmonary disease[29] and lung cancer. It also considers mortality in children from acute respiratory infection associated with long-term $PM_{2.5}$ exposure (Cohen et al. 2004). These health impacts are predicted using concentration-response functions that predict an increase in risk of mortality based on elevated exposure to $PM_{2.5}$ concentrations. Change in concentration is estimated for urban areas using methods described in Chambliss et al. 2013, Appendix III.

This method presents a conservative estimate of the total value of these policies in improving public health. The value does not include reduction in non-fatal health impacts, further reductions in mortality from lower NOx and SO_2 emissions, and health improvement outside of urban areas.

29 This category includes upper and lower respiratory infection, hypertensive heart disease, ischemic heart disease, cerebrovascular disease, inflammatory heart disease, chronic obstructive pulmonary disease, and asthma.

C.4.3 Economic Benefits

To express the social benefit of fewer premature deaths in monetary terms, we rely on the concept of the aggregate willingness to pay for small reductions in annual mortality risk by a population of a given size. We estimate the WTP is as a product of the number of premature deaths avoided due to a mitigation option and the value per statistical life (VSL), a risk reduction-normalized WTP estimate derived from the research literature.

The steps for the estimation of VSL for this analysis are the same as those followed by Miller et al. (2013). Relevant modeling parameters are summarized in Table B below.

Table B: Steps for the estimation of VSL

PROCESS	RESULT	SOURCE
Quantify a central VSL estimate based on studies of the U.S. population	7.4 million (2006 USD), published in 2010	EPA (2010)
Adjust EPA VSL estimate from 2006 dollars to 2010 dollars	8 million (2010 USD)	BLS (2014)
Quantify long-term projected growth rate of real per-capita income	Varies across countries; population-weighted average is used for multi-country regions	World Bank (2014)
Compare per-capita income forecast for each region to the 2010 U.S. per-capita income		World Bank (2014)
Select income elasticity	1.0	Minjares et al. (2014)
Project VSL based on income elasticity and growth rate in per-capita income, 2017-2050		

C.5 Cost Estimates

This analysis offers a rough estimate of both the costs and benefits of the Roadmap to lower-sulfur fuel. The costs considered combine the capital cost of refinery investment, incremental costs of producing lower-sulfur fuel, and the costs of diesel exhaust fluid and vehicle technology. The cumulative costs from 2017 through 2050 are converted into present value terms, allowing an assessment of the net benefits of the regulation.

C.5.1 Fuel production and refinery costs

The costs of producing low and ultra low-sulfur fuel include capital investments in refinery capacity, annual fixed costs of operating these new units (e.g. insurance, local taxes, maintenance, supplies, labor, overhead and environmental expense), and direct operating costs (e.g. energy, catalysts and chemicals, etc.)

We estimate the capital investments necessary for global 50 ppm sulfur gasoline and diesel consumption to be $71.4 billion based on the EnSys refinery study (Ensys, 2015). We assume an annual capital charge ratio of 0.25 (c.f. Hart Energy and MathPro, 2012) and apply capital charges for 15 years, and estimate that the total cost of the investment would be approximately $230 billion.

Delivering ultra low-sulfur fuel in most countries by 2030 would require an estimated additional $70 billion (authors estimate based on MathPro, 2015), for a total capital cost of $300 billion.

Finally, the operational cost to produce lower-sulfur fuel, assuming marginal increase of refinery operational costs of 20 ¢/barrel for 50 ppm diesel, and an additional cost of 10¢/barrel for 10 ultra low-sulfur fuel, would be $16.5 billion to 2030.

C.5.2 Vehicle technology and operating costs

The incremental costs of meeting new emissions standards for diesel vehicles depend on the emission control technology required. Some costs are incurred in the research and development of better engine design and new aftertreatment technologies and are spread across all vehicles sold, while others depend on materials. Material costs include variable costs that depend on engine displacement, such as catalyst volume, substrate, washcoat and urea injection system, as well as fixed costs, such as sensors and other components and accessories. The technologies used to meet successive emissions standards and the estimated cost to the manufacturer is included in Table C below. The compliance cost for heavy-duty trucks and buses assumes an average engine size of 6 liters; this smaller engine size is typical for developing countries.

Table C: Emission control technology used to meet European standards for light- and heavy-duty diesel vehicles

EURO STANDARD (U.S. EQUIVALENT)	VEHICLE TYPE	MOTIVATION	FUEL SULFUR LIMIT	PERCENTAGE REDUCTION					TECHNOLOGY ADOPTION	INCREMENTAL COSTS TO COMPLY
				BC	PM	NOx	CO	HC		
Euro 1	LDVs		2000 ppm	26%	50%				indirect injection, exhaust gas recirculation	$56
Euro I	HDVs			29%	45%				Fuel injection timing retardation to reduce NOx, Improvements in electronic fueling methods	$158
Euro 2	LDVs		500 ppm	58%	64%				Direct injection, EGR with cooling systems	$86
Euro II	HDVs			21%	21%				Turbocharging	-
Euro 3	LDVs	Addresses cold start challenges	350 ppm	44%	38%				Diesel oxidation catalysts, Common rail fuel injection at 900-1,300 bar	$370

EURO STANDARD (U.S. EQUIVALENT)	VEHICLE TYPE	MOTIVATION	FUEL SULFUR LIMIT	PERCENTAGE REDUCTION					TECHNOLOGY ADOPTION	INCREMENTAL COSTS TO COMPLY
				BC	PM	NOx	CO	HC		
Euro III	HDVs			38%	33%				Diesel oxidation catalyst, Adoption of electronic fuel control via single electronic unit injection	$473
Euro 4	LDVs		50 ppm	49%	46%	50%	22%	-	Fuel injection pressure raised to 1,300 to 1,600 bar, turbocharger and intercooler, Cooled EGR	$154
Euro IV	HDVs	Forces NOx aftertreatment and partial-flow filters for PM control		72%	80%	30%	30%	29%	Increased fuel injection pressure, Turbocharger and intercooler, cooled EGR, NOx aftertreatment via selective catalytic reduction for larger vehicles	$2,566
Euro 5	LDVs	Forces PM after treatment with wall-flow filters	10 ppm	95%	86%	28%	-	-	PM aftertreatment via diesel particulate filter, Injection pressure raised to 1,600-1,900 bar	$349
Euro V	HDVs			0%	-	43%	-	-	Variable geometry turbocharger, Injection pressure raised to 1,900 bar	$259

EURO STANDARD (U.S. EQUIVALENT)	VEHICLE TYPE	MOTIVATION	FUEL SULFUR LIMIT	PERCENTAGE REDUCTION					TECHNOLOGY ADOPTION	INCREMENTAL COSTS TO COMPLY
				BC	PM	NOx	CO	HC		
Euro 6 (U.S. Tier 2)	LDVs	Forces NOx aftertreatment and addresses high in-use NOx emissions via real-world driving test	10 ppm	-	-	66%	-	-	NOx aftertreatment via lean NOx trap or selective catalytic reduction, Fuel injection pressure increased to 1,800 - 2,100 bar	$540
Euro VI (U.S. 2010)	HDVs	Shift to zeolite catalyst in SCR addresses high in-use NOx in low-speed environments Forces PM aftertreament to address high PN emissions		95%	50%	80%	72%	-	PM aftertreatment via diesel particulate filter Dual actuator fuel injectors	$1,464

We do not assume further optimization by vehicle manufacturers, which could lead to cost reductions in the future. This gives us a conservative, high-end estimate of compliance costs. Other studies have assumed a 1% annual reduction in control technology costs.

The control strategy used in diesel vehicles to meet the NOx reductions required by Euro 4/IV through Euro 6/VI standards is the use of Selective Catalytic Reduction (SCR) systems. These systems require the use of diesel exhaust fluid (DEF) to function properly. We assume that the level of DEF consumed is 2% of total diesel consumption. Actual use varies depending on duty cycle, vehicle operation, etc., but the industry standard is approximately 2%. We conservatively assume the cost of DEF is to be $0.8USD/liter across all regions, based on projections by Cummins that DEF pricing will be at or below the price of diesel fuel and is forecasted to be in the $2-$3/ gallon range.

C.6 Annex C References

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Annex D Countries considered in refinery analysis

Table D: Countries/refineries included in Ensys (2015) refinery baseline report

Country	# of Refineries	Country	# of Refineries
Algeria	4	Malaysia	7
Angola	1	Martinique	1
Argentina	10	Mexico	6
Azerbaijan	1	Morocco	2
Bahrain	1	Myanmar	3
Bangladesh	1	Netherlands Antilles	1
Belarus	2	Nicaragua	1
Bolivia	2	Nigeria	4
Bosnia	1	North Korea	2
Brazil	13	Oman	1
Brunei	1	Pakistan	7
Cameroon	1	Papua New Guinea	1
Chile	3	Paraguay	1
China, Taiwan	4	Peru	6
Colombia	5	Philippines	2
Congo, Brazzaville	1	Qatar	2
Costa Rica	1	Saudi Arabia	8
Cuba	4	Senegal	1
Dominican Republic	2	Singapore	3
Ecuador	3	South Africa	4
Egypt	9	South Korea	6
El Salvador	1	Sri Lanka	1
Gabon	1	Sudan	1
Ghana	1	Suriname	1
India	22	Syria	2
Indonesia	8	Thailand	4
Iran	9	Trinidad	1
Iraq	9	Tunisia	1
Israel	2	Turkmenistan	2
Ivory Coast	1	UAE	5
Jamaica	1	Ukraine	6
Jordan	1	Uruguay	1
Kazakhstan	3	Uzbekistan	3
Kenya	1	Venezuela	5
Kuwait	3	VIETNAM	1
Kyrgyzstan	1	Yemen	2
Libya	5	Zambia	1
Madagascar	1		
TOTAL # OF REFINERIES		246	