

Final Report Sub-Saharan Africa Refinery Project Executive Summary



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Submitted to:
The World Bank
and
The African Refiners Association



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Executive Summary

The World Bank and the African Refiners Association (ARA), with the concurrence of the United Nations Environmental Program (UNEP) and IPIECA, wish to encourage the implementation of policies to promote health and improved urban air quality through better fuel quality, greater intra-regional trade of fuel products of standardized quality, and increased investments in the refining industry. The Sub-Saharan Africa Refinery Project evaluated the change to improve fuel specifications and its impacts on refining operations and costs, air quality, and health. The study compared the costs of improving the quality of fuels produced in sub-Saharan (SSA) to the potential health benefits to the people in urban areas of the region. This is one of the first studies of these issues in SSA. Although there are uncertainties associated with the methodology and the data, the project provides an estimate of the potential for health benefits associated with cleaner fuels, as well as the potential costs to the refining industry. An ancillary focus was on whether or not the SSA refining sector could survive in a competitive, global market. Apart from the conclusions of this project, however, it is clear that any decisions related to policy and technology changes require consideration of a wide variety of additional factors.

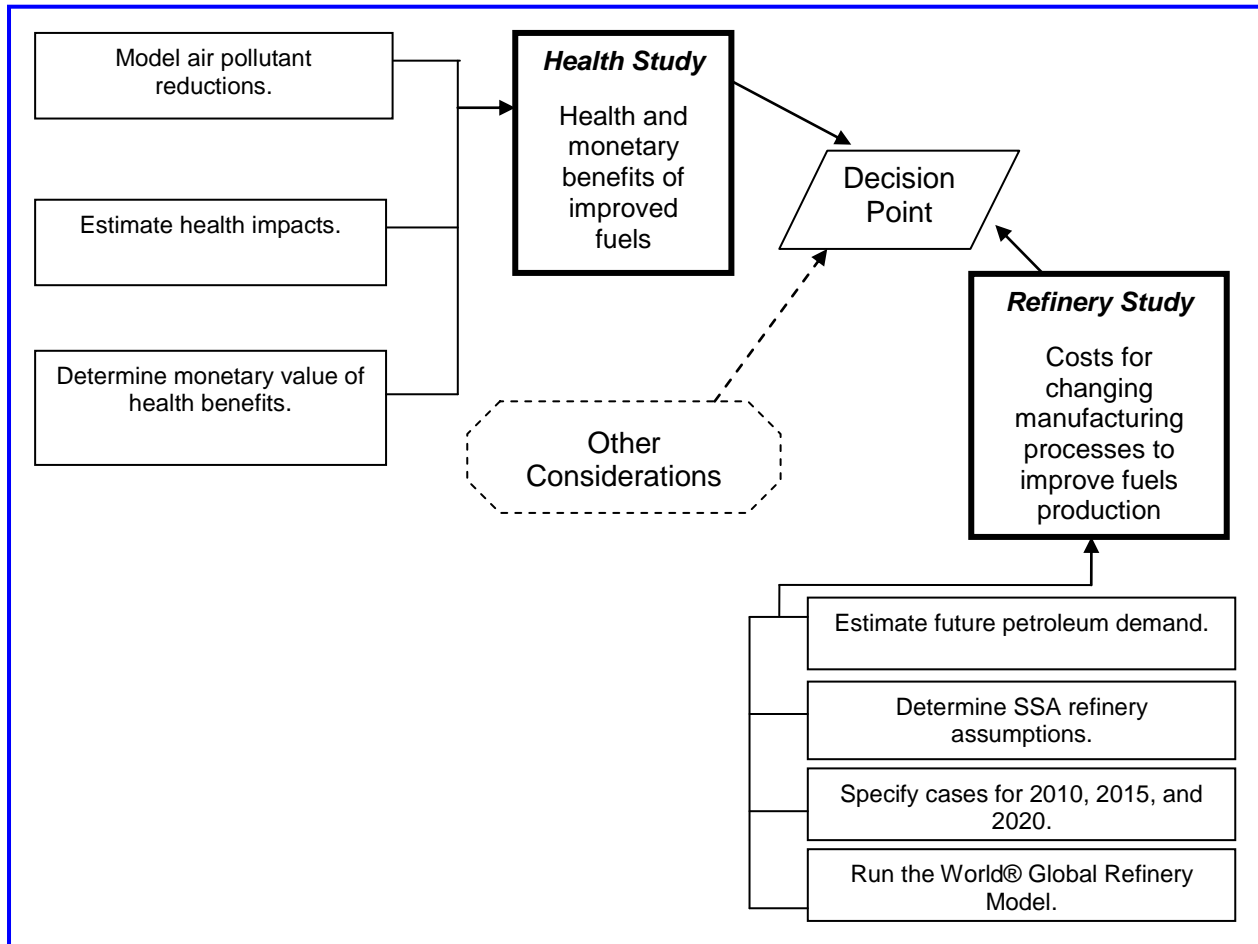
The study consists of two parts that interact as shown in Exhibit ES-1.

Health Study: To estimate the reductions in air emissions associated with improved fuel specifications, analyze the impact of the change on human health, and estimate the health benefits in economic terms.

Refinery Study: To outline the upgrades necessary in the SSA refining sector to respond to global market and clean fuels trends, and to clarify the associated costs.

In order to make decisions regarding the future of the SSA refining industry, the Health Study health and monetary benefit estimates were compared to the costs to the refining industry associated with improved fuel specification, by region, as developed in the Refinery Study. In some cases, the project has been limited by the availability and quality of data, as well as by the level of effort required to develop higher quality data. The project methodology was presented by ICF International and approved by the World Bank and the ARA Steering Committee. Associated methodological uncertainties are discussed at length in the report, and must be kept in mind when reviewing the results.

Exhibit ES-1: Relationship of the Health Study and the Refinery Study



ES.1 Summary of the Main Results

The Health Study investigated two scenarios in addition to the Base Case (representing current or recent historical conditions): Scenario 1 evaluated reduced sulfur in transportation fuels, while Scenario 2 assumed reduced fuel sulfur, improved emission controls, and increased vehicle activity. The reduction of pollutant emissions associated with Scenario 2 resulted in significant reductions in the predicted rates of mortality and respiratory illness associated with particulate matter, despite the domination of particulate matter emissions by road dust and domestic sources.¹ These health benefits were associated with monetary benefits, as shown below (Exhibit ES-2). The South region’s lower benefits reflect the fact that South African fuels already meet higher fuel standards, while the West region’s higher benefits reflect the higher populations and average incomes in that region.

¹ A number of international studies have pointed out the synergistic effects on reducing air pollutants by combining improved fuels and improved vehicles.

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Exhibit ES-2: Monetary Valuation of the Health Benefits

	Total Annual Benefit Million \$2007	5-Year NPV Billion \$2007	10-Year NPV Billion \$2007
SSA West Region			
Base Case	-	-	-
Scenario 1	640	2.6	4.5
Scenario 2	4,500	18	32
SSA East Region			
Base Case	-	-	-
Scenario 1	340	1.4	2.4
Scenario 2	1,300	5.3	9.0
SSA South Region			
Base Case	-	-	-
Scenario 1	0	0	0
Scenario 2	252	1.0	1.8

The Refinery Study modeled costs for eight different cases reflecting both an open market in which refineries would be fully exposed to global competition, and a constrained market in which all existing SSA refineries would be protected and remain open. Apart from the Base Case (2010), for each projected year (2015 and 2020) two cases were run: in the first refineries kept current fuel standards and in the second refineries moved to AFRI-4 fuel standards. By comparing the two cases in each year the incremental costs of moving to more stringent fuel specifications could be identified. Exhibit ES-3 shows the total investment costs facing the SSA refining industry in all cases, while Exhibit ES-4 shows the incremental costs of moving from current fuel specifications to AFRI-4 standards in 2015 and 2020.

Exhibit ES-3: Total SSA Refinery Investments from the Eight Cases (Billions of 2007\$)

Case	Description	Year	AFRI Specifications	SSA Total	West Total	South Total	East Total
210	Base	2010	Current	0.06	0.01	0.05	-
215	Open Market	2015	Current	1.89	0.02	0.28	1.60
216	Open Market	2015	AFRI-4	3.14	0.47	0.54	2.13
224	Constrained	2020	Current	5.40	3.19	0.60	1.61
220	Constrained	2020	AFRI-4	8.67	5.31	1.00	2.36
221	Open Market	2020	Current	5.32	3.07	0.59	1.66
222	Open Market	2020	AFRI-4	7.65	4.51	0.90	2.25
223	Open Market	2020	AFRI-4	6.19	2.98	0.64	2.56
	Unfavorable						

Exhibit ES-4: Incremental SSA Refinery Investments from Moving to AFRI-4 Fuel Specifications (Billions of 2007\$)

Year	Description	SSA Total	West Total	South Total	East Total
2015	Open Market	1.25	0.45	0.26	0.53
2020	Constrained	3.27	2.12	0.40	0.75
2020	Open Market	2.33	1.44	0.31	0.59

The combined benefits estimated in the Health Study, using the Scenario 2 assumptions, and the costs estimated in the Refinery Study, using the open market scenario, Case 222, the most challenging to the

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SSA refinery sector, are shown in Exhibit ES-5 as net present value, extrapolated over both a 5-year period and a 10-year period.

Exhibit ES-5: Five-Year and Ten-Year Net Present Value of Refinery Supply Costs versus Health Benefits

Billions 2007 dollars	SSA Total	West Africa	East Africa	South Africa
5-Year Refinery Investment Costs	\$2.76 B	\$0.47 B	\$2.13 B	\$0.59 B
Health Benefits over 5 Years ¹	\$25 B	\$18 B	\$5.3 B	\$1.0 B
10-Year Refinery Investment Costs	\$6.14 B	\$4.69 B	\$2.48 B	\$0.99 B
Health Benefits over 10 Years ¹	\$43 B	\$32 B	\$9.0 B	\$1.8 B

1. Central value shown for elasticity=1.5; ranges for elasticities of 1.0 and 2.0 are shown in the report. For Scenario 2 (lower sulfur fuel and pollution control equipment) and alternate 2-stroke motorcycle emissions assumptions.

These results indicate that, over time, the potential health benefits from Scenario 2 outweigh the costs to the SSA refineries of improving fuel specifications.

While the answer to the cost benefit analysis is reasonably clear, despite ambiguities in the methodology and data, the answer to the question about the SSA refiners' ability to function in the competitive global refining market is more complex. The global refining scenario underlying these cases is one of slack refining capacity through much of the period to 2020. Thus the SSA refiners in an open market will be faced with considerable competition from imports. The implications of this are that SSA refineries will have to focus on costs and efficiency to function effectively in the open market. There is, if the slackness continues throughout the period, substantial potential for refinery closures in Europe and the United States, which, should they occur, will substantially improve the outlook for the SSA refineries. The outcome is that SSA refineries that currently have economic problems, may be overwhelmed by worse problems.

One other result of the modeling which may be of importance to policy makers is that the cost of maintaining all the existing SSA refineries through 2020 and requiring the investments to produce gasoline and diesel to AFRI-4 fuel specifications was estimated at an incremental \$1.02 billion (2007 \$) over the free market case.

SSA refineries that do well in the competitive global market usually:

- Are larger and have scale
- Have invested over time and are more complex
- Are more efficient
- Have access to good local quality crude oil
- Have access to larger markets

However, despite the problems arising from global competition facing the SSA refiners and despite the costs of moving to AFRI-4 standards, those refiners that do invest will see improved refinery margins and increased revenues.

ES.2 Health Study Overview

The Health Study evaluated a Base Case, Scenario 1 (reduced sulfur in transportation fuels), and Scenario 2 (reduced fuel sulfur, improved emission controls, and increase in vehicle activity), with the following steps:

- **Air Quality Modeling**
 - Select modeling locations (representative cities in Sub-Saharan Africa)
 - Select air quality model
 - Select pollutants and emission sources to be modeled
- **Health Impact Assessment**
 - Select health endpoints
 - Identify appropriate studies to evaluate air pollution/health relationship
 - Compile baseline health data
 - Calculate the reduction in mortality or cases of disease
- **Valuation of Health Impacts**
 - Determine the appropriate approach for valuation in Sub-Saharan Africa
 - Identify relevant studies and assess quality and applicability
 - Estimate the value of mortality risk reductions
 - Estimate the value of reductions in the risks of chronic bronchitis and exacerbation of asthma symptoms

Each step is associated with important uncertainties that are summarized below and discussed in detail in the report.

ES.2.1 Air Quality Modeling

To model the air quality for SSA, three representative cities were selected for quantitative analysis (Exhibit ES-6) based primarily on the availability of emissions data. Two additional cities in each region were selected for qualitative analysis. Quantitative analysis involved compilation of emissions inventories and utilization of an air quality model to estimate ambient air quality resulting from local emissions of air pollutants. Emissions inventories for vehicle, area, and point sources were compiled. Emissions data included variables such as percent of vehicle kilometers traveled (VKT) by various types of vehicles, VKT on paved and unpaved roads, dust emissions factors, and industrial mix. Qualitative analysis compared local conditions (including population, total emissions, industrial mix, vehicle fleet composition, meteorology, etc.) to conditions of the quantitatively analyzed city in the same region.

Exhibit ES-6: Cities Modeled in the Health Study

Assessment	West	South	East
Quantitative	Cotonou, Benin	Johannesburg, South Africa	Kampala, Uganda
Qualitative	Lagos, Nigeria	Cape Town, South Africa	Dar Es Salaam, Tanzania
Qualitative	Ougadougou, Burkina Faso	Maputo, Mozambique	Nairobi, Kenya

Modeled air pollutants were those associated with potential health impacts - particulate matter (PM), sulfur dioxide (SO₂), nitrogen dioxide (NO_x), and benzene (Exhibit ES-7).

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Exhibit ES-7: Air Pollutants and Related Health Effects

Air Pollutant	Related Health Effects
Particulate matter, both PM _{2.5} and PM ₁₀ ²	Premature mortality; chronic bronchitis; asthma symptoms
Sulfur dioxide (SO ₂)	Increased incidence of asthma attacks
Nitrogen dioxide (NO ₂)	Increased mortality and asthma attacks
Benzene	Increased incidence of cancer

Ambient air concentrations were estimated for areas in each modeled city with population density greater than 1,000 people per kilometer, to permit comparison between cities. The modeled regional annual average total PM (primary and secondary PM, plus sulfate and nitrate) concentrations are shown in Exhibit ES-8. The concentrations shown in the table illustrate the change in annual average total PM_{2.5} and PM₁₀ concentrations from Base Case to Scenarios 1 and 2. The results for other air pollutants are shown in the report.

Exhibit ES-8: Modeled Annual Average Total Particulate Matter Concentrations for Three Cities (population density greater than 1,000/km)

Annual Averages (µg/m ³)	Kampala, Uganda		Cotonou, Benin		Johannesburg, South Africa	
	Total PM _{2.5}	Total PM ₁₀	Total PM _{2.5}	Total PM ₁₀	Total PM _{2.5}	Total PM ₁₀
Base Case	224	371	363	567	4.6	19.7
Scenario 1	222	369	359	563	4.6	19.7
Scenario 2	219	366	275	469	4.1	19.3

Although the modeled Base Case air concentrations for Kampala and Cotonou appear somewhat high relative to the limited monitoring data, the focus of the study is on the relative change between scenarios, rather than the absolute number. In Johannesburg, the Base Case concentrations and the relative changes are small because baseline sulfur content in fuels is already low, there are relatively few diesel vehicles in use, and domestic use of wood as a fuel is low. The emissions results shown in Exhibit ES-9 indicate that the dominant PM emissions are from road dust and domestic sources; still, the relative contribution of vehicles to PM is reduced with each scenario as shown graphically in Exhibit ES-10 for PM_{2.5}. In addition, there is a clear reduction in benzene emissions, in particular with Scenario 2. As will be described, these incremental changes translate into health benefits.

² PM_{2.5} is particulate matter of 2.5 microns in diameter or less; PM₁₀ is particulate matter of 10 microns in diameter or less.

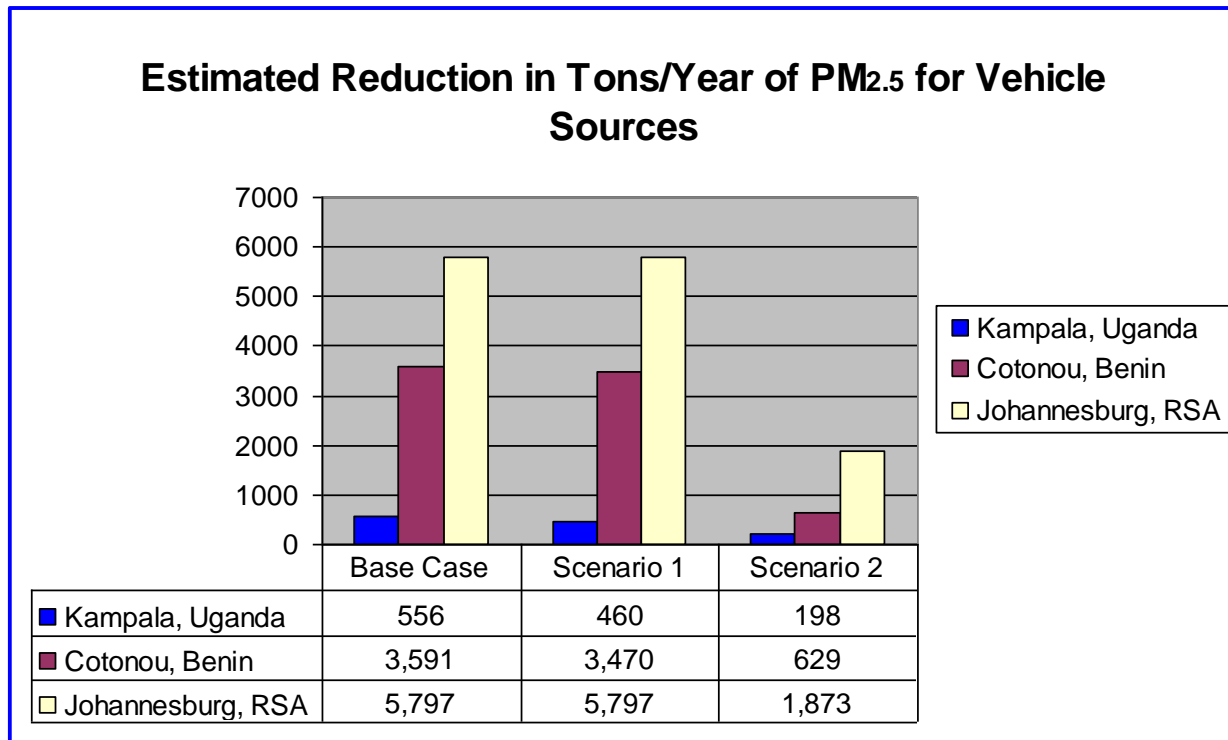
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Exhibit ES-9: Percentage of Emissions for Each Scenario and Each Modeled City

Modeled City	Kampala, Uganda			Cotonou, Benin			Johannesburg, South Africa		
Sources	PM ₁₀	PM _{2.5}	Benzene	PM ₁₀	PM _{2.5}	Benzene	PM ₁₀	PM _{2.5}	Benzene
Base Case									
Roadway Dust	47.5%	10.0%	-	35.5%	5.8%	-	86.1%	67.1%	-
Domestic Sources	50.4%	86.5%	30.9%	39.9%	58.8%	2.4%	8.1%	6.9%	1.3%
Vehicle Sources	2.0%	3.4%	69.1%	22.9%	33.8%	97.6%	3.3%	18.5%	98.7%
Marine Sources	-	-	-	1.0%	1.5%	-	-	-	-
Industrial Sources	0.0%	0.1%	-	0.7%	-	-	2.5%	7.5%	0.0%
Scenario 1									
Roadway Dust	47.7%	10.1%	-	35.8%	5.9%	-	86.1%	67.1%	-
Domestic Sources	50.6%	87.0%	49.4%	40.3%	59.6%	4.9%	8.1%	6.9%	2.5%
Vehicle Sources	1.7%	2.9%	50.5%	22.4%	33.1%	95.1%	3.3%	18.5%	97.4%
Marine Sources	-	-	-	1.0%	1.5%	-	-	-	-
Industrial Sources	0.0%	0.1%	-	0.5%	-	-	2.5%	7.5%	0.0%
Scenario 2									
Roadway Dust	48.1%	10.3%	-	43.9%	8.1%	-	88.0%	76.8%	-
Domestic Sources	51.1%	88.4%	96.4%	49.3%	81.7%	70.2%	8.2%	7.8%	20.9%
Vehicle Sources	0.7%	1.2%	3.4%	5.0%	8.2%	29.8%	1.1%	6.9%	78.9%
Marine Sources	-	-	-	1.2%	2.0%	-	-	-	-
Industrial Sources	0.0%	0.1%	-	0.6%	-	-	2.6%	8.5%	0.2%

Reading down the columns, this table illustrates the change in the percentage of PM₁₀, PM_{2.5}, and benzene emissions from each of the modeled sources (vehicle sources are the **bold** numbers) from Base Case to Scenarios 1 and 2, for each modeled city. Emission reductions for other modeled air pollutants are shown in the study report.

Exhibit ES-10: Modeled Reductions of PM_{2.5} (tons/year) for Vehicle Sources in Three Cities



The large reduction in percentage of PM emissions from the Base Case to Scenario 2 in Cotonou, Benin (from 22.9% to 5% for PM₁₀ and from 33.8% to 8.2% for PM_{2.5}, as shown in Exhibit ES-9) is based on vehicle activity data used for the Base Case that shows a large use of 2-stroke motorcycles in that city³ and the assumption that in Scenario 2, all 2-stroke motorcycles are banned. This large reduction was initially used to derive benefit estimates for the West region. The data for the East region city, Kampala, Uganda, indicated a lower current usage of 2-stroke motorcycles. Thus, initially, higher benefits were estimated for the West region (based on the Cotonou data) as compared to the East region (based on the Kampala data).

The ARA Steering Committee expressed concern that the Health Study emissions inventory under-represented motorcycle emissions in Kampala, Uganda (extrapolated to the East Africa region) and over-represented these emissions in Cotonou, Benin (extrapolated to the West Africa region) for the Base Case and Scenario 1.⁴ These concerns were based on anecdotal observations that:

- (1) Motorcycle use has increased in recent years in East Africa, and
- (2) Motorcycle use may have decreased in West Africa because of bans on the use of 2-stroke motorcycles in some areas. Therefore, regionalizing the Cotonou analysis may be problematic because some large cities in West Africa, particularly in some states of Nigeria, have banned 2-stroke engines. While 2-stroke engines have not entirely disappeared from those cities, their prevalence has decreased so using Cotonou's inventory for these cities may not be realistic.

³ Clean Air Initiative, Banque Mondiale. Benin. Ministère de l'environnement de la protection de la nature (MEPN). *Etude de la qualité de l'air à Cotonou. Rapport Final*, November 2007. (Translation from French to English.)

⁴ Scenario 2 assumed the complete phase-out of 2-stroke motorcycles.

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Emissions from motorcycles, as well as other motor vehicles, are a function of the total vehicle activity, that is, kilometers driven. While the number of vehicle types registered is useful when vehicle activity data are not available, emissions are not directly scalable with the number of vehicles. For example, buses make up a small fraction of the number of vehicles in most cities, but they are operated nearly continuously, meaning that the emissions from buses are not in proportion to their number. Therefore, whenever available, travel fraction data, which is nearly proportional to vehicle emissions, were used as a basis for quantifying vehicle activity. Motorcycle travel fractions in Cotonou and Kampala were based on published vehicle activity data.

Although some data regarding new motorcycle purchases and their use were available to support these impressions of the changes in motorcycle use in the East and West regions of SSA, quantitative data on the most recent vehicle activity levels of 2-stroke motorcycles was not available. Nevertheless, the air modeling results were scaled using the following assumptions:

Alternate 2-Stroke Motorcycle Assumptions for the Base Case and Scenario 1:

- **West Region: VKT from 2-stroke motorcycles was reduced from 50% to 10%**
- **East Region: VKT from 2-stroke motorcycles was increased from 20% to 50%**
- **South Region: no changes**

The alternate air concentrations were calculated by scaling the air modeling results previously presented. The alternate air modeling results are shown in Exhibit ES-11.

Exhibit ES-11: Alternate 2-Stroke Motorcycle Assumptions - Scaled Annual Average Total Particulate Matter Concentrations for Three Cities (population density greater than 1,000/km)

Annual Averages ($\mu\text{g}/\text{m}^3$)	Kampala, Uganda		Cotonou, Benin		Johannesburg, South Africa ¹	
	Total PM _{2.5}	Total PM ₁₀	Total PM _{2.5}	Total PM ₁₀	Total PM _{2.5}	Total PM ₁₀
Base Case	227	374	271	470	4.6	19.7
Scenario 1	225	371	270	468	4.6	19.7
Scenario 2	219	366	250	460	4.1	19.3

1. Johannesburg concentrations unchanged from initial modeling.

ES.2.2 Health Impact Assessment

Health impacts are assessed by:

- Selecting health endpoints associated with the air pollutants of concern
- Identifying appropriate studies to evaluate air pollution/health relationships
- Compiling baseline health data
- Calculating the reduction in mortality or cases of disease associated with improved fuels

Exposure-response data from published studies quantifies the relationship between exposure to air pollutants (exposure) and health impacts (response). The most supportable studies, with high-quality exposure and health response data, were selected. However, the selected studies are from U.S. locations with varying demographics. There are many uncertainties associated with extrapolating the U.S. air pollution/health impact studies to Sub-Saharan Africa, although the World Bank has previously concluded that, under certain circumstances, there is support for extrapolating results from developed countries to developing countries. Literature regarding air pollution/health impact data from Africa is

mainly prevalence data, useful for determining baseline rates of the relevant diseases, but providing limited exposure measurements. Other required baseline health data were collected from international organizations and databases.

ES.2.3 Valuation of Health Impacts

Estimating the monetary value of health risk reductions involves four steps:

- Determining the appropriate approach for valuation
- Identifying relevant studies and assessing their quality and applicability
- Estimating the value of mortality risk reductions
- Estimating the value of reductions in the risks of chronic bronchitis and increased asthma symptoms

Previous studies conducted for the World Bank and other international and national organizations have used a variety of approaches to value health risk reductions. These diverse approaches in part reflect differences in the goals of the studies, and in part reflect the limitations of the then-available research. The three approaches most often used are called willingness-to-pay, cost-of-illness, and quality-adjusted life years or disability-adjusted life-years. The preferred approach to valuation in benefit-cost analysis is to rely on estimates of individual willingness-to-pay (WTP), which describe individual preferences; i.e., the affected individuals' willingness to exchange their own income for reductions in their own risks, for example, the risk of mortality or illness. The value of the mortality risk reductions associated with pollution abatement and other policies is commonly expressed as the value per statistical life (VSL). **As described further below, the VSL concept is frequently misunderstood -- it is not the value of saving a "life," nor is it a measure of the moral worth or inherent value of an individual.**

The WTP approach is consistent with the framework for pollution abatement decisions; e.g., deciding whether to allocate funds for further upgrades to refinery operations or for other projects.

These values are only one of many factors of interest to decision makers. For example, they may consider the equity or fairness of different approaches, and face goals or constraints that will lead to outcomes not entirely consistent with the preferences of those affected. In addition, decision makers will need to exercise judgment in weighing the substantial uncertainty associated with these values as well as the inability to quantify some of the effects of air pollutants.

The key conclusions of the health valuation are as follows.

General Framework

- Although there are several current approaches, in benefit-cost analysis, the value of risk reductions is determined by estimating the affected individuals' own willingness to exchange income for the resulting benefits, so that the values reflect their preferences for spending on improved health rather than on other goods and services such as food and shelter.
- Spending for risk reductions is more constrained in Sub-Saharan Africa than in many other countries, because of the relatively low average incomes in this region. Average per capita income, based on purchasing power parity, is \$1,900 annually in Sub-Saharan Africa. In contrast, per capita income averages about \$46,000 annually in the U.S. Significant income disparities underlie these averages both across and within countries.
- Estimates of willingness to pay for risk reductions are very uncertain for residents of Sub-Saharan Africa because little is known about their preferences. Instead, values are typically extrapolated from studies conducted in much wealthier countries, with adjustment for income differences.
- Income is only one of many factors affecting the value of risk reductions. These values may also be influenced by the characteristics of the affected populations (e.g., their age and health status) and of the risks themselves (e.g., whether they involve illness or injury or are incurred

involuntarily). As a result, values will vary across individuals, communities, countries, and regions for many reasons.

- This report recommends the use of ranges to reflect uncertainty. To reduce this uncertainty, more research is needed that directly elicits or reveals the preferences of individuals residing in these countries for reductions in these types of risks.

Mortality Risks

- The value of the mortality risk reductions associated with pollution abatement and other policies is commonly expressed as the value per statistical life (VSL). The VSL is typically calculated by dividing individual willingness to pay by the risk change. For example, if – out of an annual income of \$2,000 – an individual is willing to pay \$5 to reduce his or her annual mortality risks by 1 in 10,000, his or her VSL is \$50,000 ($\$5 \div 1/10,000$).
- The VSL concept is frequently misunderstood. It is not the value of saving a “life,” nor is it a measure of the moral worth or inherent value of an individual. Instead, it represents the rate at which individuals are willing to exchange their own income for a small reduction in their own mortality risk in a particular time period.
- Willingness to pay for mortality risk reductions has not been studied in Sub-Saharan Africa. Thus, this report begins with a U.S. VSL of \$6.3 million in 2007 dollars, then extrapolates to each African country, adjusting for income differences using a range of estimates of the relationship between the VSL and income. In addition, it ensures that the resulting estimates exceed the present value of the goods and services that individuals would consume over a typical life span, as economic theory predicts.
- For Sub-Saharan Africa, the central estimate of the VSL is \$51,900, based on average per capita income (\$1,900) for all countries combined, and assuming that a 1.0 percent change in income leads to a 1.5 percent change in the VSL.
- Because of the uncertainty associated with this extrapolation, this report recommends application of a range of estimates rather than solely this central value. For the region, it suggests a high-end VSL of \$256,900, which assumes that a 1.0 percent change in income leads to a 1.0 percent change in the VSL. The low estimates for the region are generally based on the present value of future consumption and depend on the discount rate used. A rate of 7 percent leads to a low value of \$24,800.
- Variation in income across countries leads to large differences in the VSL estimates, because individuals’ willingness to pay for risk reductions is dependent on the amount of money they have available. For example, the lowest income countries (in terms of purchasing power) are the Democratic Republic of the Congo and Liberia, with reported average per capita incomes of \$290 per year. For these countries, the central estimate is based on the present value of future consumption and is \$3,900 with a 7 percent rate. The highest income country is Equatorial Guinea, with average per capita income of \$21,230 and a central VSL estimate of \$2.0 million.

Chronic Bronchitis and Asthma Risks

- For nonfatal health risks, this report again extrapolates from studies conducted in higher income countries, given that the available research does not directly address the preferences of individuals residing in Sub-Saharan Africa or other low income countries.
- For chronic bronchitis, the central estimate of the value per statistical case (VSC) is \$3,500 on average for the overall Sub-Saharan region, with low and high estimates of \$700 and \$17,000.
- For increases in asthma symptoms, the central estimate for Sub-Saharan Africa is about \$2 per symptom day.

The relatively wide ranges of benefit values indicate the substantial uncertainty in the VSL and VSC estimates appropriate for countries in this region, mostly related to the lack of studies conducted among the populations of concern for this report.

As noted earlier, these benefit values, and the results of the benefit-cost analysis more generally, are only some of the many factors typically weighed by decision makers. Additional considerations include, for example, the distribution of the impacts across different countries and subpopulations, the potential magnitude of effects that are not quantified, and the substantial uncertainties in the estimates. The values developed in this report are intended to indicate the benefits of health risk reductions from the perspective of the affected individuals, estimating how much they would be willing to pay out of their own income. Decisions on related policies are likely to reflect a number of goals and considerations other than these estimated preferences.

Extrapolating from existing studies requires understanding the effects of large income differences, and we are uncertain about the appropriate income elasticity. In addition, differences in other population characteristics and in the characteristics of the risks themselves may lead to higher or lower values. Cultural attitudes towards risks, the age of those affected, and the quality of available medical treatment will affect WTP for health risk reductions. These factors are best addressed by conducting studies in the countries of concern. Additional considerations, such as the equity of the distribution of wealth and health and non-quantified impacts, should be considered separately.

In addition to income, there are a number of other differences between the available research and the mortality risks associated with air pollution in Sub-Saharan Africa. These include population characteristics such as age, life expectancy, health status, and total mortality risk.⁵ The study used for mortality valuation focuses on job-related deaths from accidental injuries, while air pollution leads to deaths from illness. However, the available research is not sufficient to support quantitative adjustment of the VSL to reflect these differences, especially given that these characteristics may be viewed differently across countries and cultures.

The valuation estimates cover a wide range due the significant differences in income across these countries. These values are only one of many factors that must be considered in related decisions. They do not incorporate concerns about the equity of the distribution of income and health.

ES.2.4 Regional Analysis

The health benefit results for each quantitatively evaluated city must be extrapolated to a regional level, in order to compare the benefits with the costs estimated in the Refinery Study. The Sub-Saharan countries included in each region were identified in the Refinery Study. Countries were assigned to regions in the Refinery Study based on the movement of petroleum products around the continent, that is, the source of each country's supply of petroleum products.

The regional extrapolation was accomplished by, first, identifying all cities in each region with a population greater than 300,000. Then, the estimated decrease in the numbers of deaths or cases of

⁵ Due to the limitations of the available research, this report recommends using the same values for adults and children, while noting that mortality risks to children are generally valued more highly.

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bronchitis or asthma in each modeled city, were used to estimate the decrease in the number of deaths or disease cases for the population of each identified large city in the region. Finally, the estimated morbidity values for each country are used to estimate the monetary benefits of the reduction in air pollutants.⁶ Scaling by population and income level assumes that the scaled cities have the same reductions in emissions (including the same vehicle mix, industry mix, etc.), and the same population characteristics (e.g., the same baseline rate of disease). This is certainly an over-simplification, however, it provides an estimate of the potential impact of fuel improvements for each Sub-Saharan African region.

To extrapolate to a regional basis, 13 cities with populations over 300,000 were identified in the East region, including the cities evaluated in the Health Study. In the West region, 53 cities with populations over 300,000 were identified, including the 3 cities evaluated in the Health Study. In the South region, in addition to Johannesburg, 8 cities with populations over 300,000 were identified.

ES.2.5 Health Study Results

This section describes the Health Study regional results. For each region, we present the estimated reduction in the number of cases, and the annual, five-year, and ten-year estimated benefits⁷ associated with the estimated reduction in cases (Exhibit ES-12). As described above in Section ES.2.1, the estimated SSA West region benefits were initially much higher than those estimated for the SSA East region, due to the emissions assumptions used for the percentage of total vehicle activity attributable to 2-stroke motorcycles. In addition, differences in annual benefit estimates across regions result from differences in the total populations in each region and the average income for each region. The estimated West region benefits were initially much higher than those estimated for the East region, because of these differences in the characteristics of the regions (Exhibit ES-12):

Exhibit ES-12: Major Differences Between SSA Regions Reflected in Modeling Results

	West	East	South
Motorcycle Emissions for Modeled City	2-Stroke Motorcycles: 48.4% of total vehicle activity in Cotonou, Benin ⁸ reduced to zero in Scenario 2.	All Motorcycles: 20% of total vehicle activity in Kampala, Uganda ⁹ reduced to zero in Scenario 2.	No 2-stroke motorcycles currently in use. ¹⁰
Regional Population Greater than Age 30	16.8 million	7.5 million	5.2 million
GNI¹	\$1,836 US	\$961 US	\$6,980

Note: 1. West region: \$1,836 is average of GNI for the 20 countries used in the analysis; East region: \$961 is average of GNI for the 14 countries used in the analysis; South region: \$6,980 is average of GNI for 2 countries (Angola and South Africa) used in the analysis

The results shown in Exhibit ES-13 are presented using the alternate assumptions; the benefits for the East region increase from the initial estimates and the benefits for the West region decrease from the initial estimates, bringing the results closer for the two regions, although, still, because of the higher population and reported average income levels for the West region, the West region benefits are higher. The benefits calculations for the South region do not change for the Base Case or Scenario 1, as there are already lower sulfur fuels in use in that region.

⁶ We do not adjust the valuation estimates for income differences within each country.

⁷ Calculated as net present value (NPV) with a 7% discount rate.

⁸ Clean Air Initiative, Banque Mondiale. Benin. Ministère de l'environnement de la protection de la nature (MEPN). *Etude de la qualité de l'air à Cotonou. Rapport Final*, November 2007. (Translation from French to English.)

⁹ *Stuck in Traffic: Urban Transport in Africa. Africa Infrastructure Country Diagnostic Study*. Kumar A; Barrett F. October 31, 2007.

¹⁰ Data provided by the City of Johannesburg.

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Exhibit ES-13: Health Study Regional Analysis Results Using Alternate 2-Stroke Motorcycle Assumptions

East Region - Number of Cases of:	All-Cause Mortality - Reductions in PM _{2.5} (ages>30)	Bronchitis Cases - Reductions in PM _{2.5} (ages>30)	Asthma Exacerbations - Reductions in PM ₁₀ (ages 8-13)	Respiratory Disease Mortality - Reductions in PM ₁₀ (ages<5)	Estimated Total Annual Benefit (million 2007 US dollars)	Estimated Five-Year Benefit (NPV) (billion 2007 US dollars)	Estimated Ten-Year Benefit (NPV) (billion 2007 US dollars)
Base Case	541,823	2,293,281	3,183,871	12,050	--	--	--
Scenario 1	532,449	2,247,042	3,179,640	12,001	\$340 M	\$1.4 B	\$2.4 B
Scenario 2	506,516	2,118,796	3,167,322	11,862	\$1,300 M	\$5.3 B	\$9.0 B
West Region							
Base Case	1,325,880	7,387,399	7,464,977	69,140	--	--	--
Scenario 1	1,316,489	7,334,697	7,462,041	69,006	\$640 M	\$2.6 B	\$4.5 B
Scenario 2	1,249,046	6,952,170	7,444,698	68,238	\$4,500 M	\$18 B	\$32 B
South Region							
Base Case	3,636	108,256	799,209	970	--	--	--
Scenario 1	3,636	108,256	799,209	970	\$0 M	\$0 B	\$0 B
Scenario 2	3,261	107,576	796,852	948	\$252 M	\$1.0 B	\$1.8 B

Notes:

Using the air model results for >1,000 population density with each city, extrapolated to the region.

1. Applying country-specific VSL or VSC, elasticity of 1.5, and GNI using PPP.
2. Net present values calculated with 7% discount rate.

The dollar values presented represent the middle estimate of a range from low estimated values (using an income elasticity of 2.0) to high estimated values (using an elasticity of 1.0). The range of estimates is shown in the study report.

The estimated 10-year benefits of reduced sulfur fuels modeled in Scenario 2 for all of SSA (about \$43 billion) are similar to the benefits shown in other studies. For example, the benefits of reducing health impacts in China, including total mortality and chronic bronchitis, modeled for the years 2008-2030, are about \$45 billion (in 2005 US dollars) for total mortality and \$10 billion (in 2005 US dollars) for chronic bronchitis.¹¹ A similar study conducted in Mexico predicted benefits of about \$40 billion (in 2000 US dollars) modeled for the years 2006-2030.¹²

The decrease in cancer risk due to potential reductions in the exposures to benzene is low in both Johannesburg and in Kampala (less than 150 cases). The larger reductions in benzene modeled for Cotonou result in a potential reduction in cancer cases due to benzene exposure of up to 250 cases in Scenario 2. Because these reductions are small relative to the other benefits estimated, the reduction of cancer risk due to benzene exposure is not included in the valuation or in the regional extrapolation.

¹¹ The International Council on Clean Transportation (ICCT), 2006. *Costs and Benefits of Reduced Sulfur Fuels in China*. Cited in presentation by Ray Minjares of ICCT, *Costs and Benefits of Lower Sulfur Fuels; Implications for Eastern Africa*, Eastern Africa Sub-Regional Workshop on Better Air Quality in Cities, Nairobi, Kenya, 21-22 Oct 2008.

¹² *Estudio de Evaluación Socioeconómica del Proyecto Integral de Combustibles*, Instituto Nacional de Ecología. 2006. Cited in presentation by Ray Minjares of ICCT, *Costs and Benefits of Lower Sulfur Fuels; Implications for Eastern Africa*, Eastern Africa Sub-Regional Workshop on Better Air Quality in Cities, Nairobi, Kenya, 21-22 Oct 2008.

ES.2.6 Uncertainties Associated with the Health Study

Although we believe we have selected and applied the best available information to evaluate the health benefits associated with improved fuels, there are uncertainties associated with the Health Study.

There are important uncertainties associated with each step of the Health Study, in particular, associated with extrapolating data from studies conducted in developed countries to Sub-Saharan Africa.

The key uncertainties are listed below, and are described in more detail in the study report:

- **Air Modeling:** Emissions information used in the air modeling is the major source of uncertainty. Data was collected from available sources but may not be accurate; however, the use of available city-specific emissions data, as opposed to assuming input numbers, reduces uncertainties. Other important sources of uncertainty include: re-entrained road dust emission factors for paved and unpaved roads, the percent of unpaved roads in each city, and domestic emission rates for PM.
- **Health Impact Assessment:** Uncertainties are associated with the use of U.S. studies to evaluate the impacts in urban areas of Africa because of differences in baseline health status, age distribution, and baseline exposures to air pollutants. Using the well-supported U.S.-based study for the relationship between all-cause mortality and PM, for example, the Health Study may not capture mortality effects in the adult population under age 30. Air pollutants not considered quantitatively in the Health Study, in addition to PM, may be associated with adverse health effects. Additionally, there are other potential health impacts associated with air pollution that were not quantitatively considered. Scaling to a regional level by population assumes same baseline rate of disease, the same mix of emissions sources, similar meteorological and geological characteristics, as well as other factors, resulting in the same decrease in air concentrations from Base Case to Scenario 1 and Scenario 2. This is likely an over-simplification of the actual conditions that certainly vary from one urban area in Sub-Saharan Africa to another.
- **Health Valuation:** Extrapolating from existing valuation studies conducted in developed countries requires understanding the effects of large income differences; though we have presented evidence supporting our selected estimate of income elasticity, the appropriate estimate is highly uncertain. The lack of studies conducted in Sub-Saharan Africa is associated with uncertainties, such as differences in population characteristics and in the characteristics of the risks themselves, cultural attitudes towards risks, the age of those affected, and the quality of available medical treatment, which cannot be addressed without more primary research in these countries.

In addition, it should be noted that in areas where PM is currently dominated by domestic and road dust sources, in the future these sources may decrease with improved domestic fuel sources and with increased road paving.

ES.3 Refinery Study Overview

Over the past two decades, the growing awareness of the role that emissions play in human health and environmental degradation had led to a general movement in many parts of the world to control emissions to reduce the impacts. This movement has mainly taken two forms: 1) the development and subsequent required use of control devices for stationary sources and vehicle sources and, 2) changes in the specifications of transportation fuels to reduce emissions of the major pollutants. These trends originated in the industrialized countries of the OECD and are now spreading, at different rates, throughout the world.

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As in the West, the first improvement in the specifications of transportation fuels in Sub-Saharan Africa was the reduction of lead. The phase-out of lead is now close to complete and the World Bank and its partners are looking at the next step - the reduction of sulfur in transportation fuels. The ARA has taken the lead in presenting “fuel specification bands” known as the AFRI Specifications modeled after the specifications now in force in the European Union (EU). Exhibit ES-14 following shows the main AFRI parameters for both gasoline and diesel. The assumption was made in the study that by 2020 the AFRI-4 level would be reached by all SSA refineries (sulfur content for gasoline 150 ppm, for diesel 50 ppm, and benzene content for gasoline 1%).

The growing complexity of the vehicle emission control technologies for both personal vehicles and commercial trucks, and the growing awareness of the human health and environmental impact of vehicle source emissions, have placed increasing requirements on refineries. Sulfur is not an additive but a natural part of crude oil. The removal processes presents both technological and economic challenges to refiners.

Exhibit ES-14: AFRI Standards for Sub-Saharan Africa Transportation Fuels

	AFRI-1	AFRI-2	AFRI-3	AFRI-4
GASOLINE				
RON, min*	91	91	91	91
MON, min	81	81	81	81
Lead content**	Unleaded	Unleaded	Unleaded	Unleaded
Sulfur content, % mass, max	0.1	0.05	0.03	0.015
Benzene content, % vol, max	To be reported	To be reported	5	1
DIESEL				
Sulfur content, % mass, max	0.8	0.35	0.05	0.005
Density at 15 C, kg/litre (min/max)	800/890	800/890	800/890	820/880
Centane index (calculated), min	42	45	45	45
Lubricity (HFRR @ 60 C), micron, min	To be reported	To be reported	460	460

*A higher grade of gasoline may be marketed if required

** “Unleaded means <0.013g of lead per litre

ES.3.1 Refinery Study Methodology

The methodology used by ICF and its subcontractor EnSys Energy, centered around the use of a global refining model WORLD®, which allowed us to not only calculate the impacts of stricter fuel specifications on the SSA refiners but also put the SSA refiners in the global context.

With agreement from the Steering Committee, ICF/EnSys modeled refining activities and investment costs for the global refining sector with horizons of 2010, 2015, and 2020. Modeling 2010 (Base Case) enabled calibration against conditions close to those of 2009. Stepping the model forward to 2015 and then 2020 captures the evolution of product demand and mix in the regions and the advance to AFRI-4 specifications in each refinery subgroup, with the attendant costs and impacts.

In order to model the various cases that were developed the following data had to be generated:

- Annual demand for petroleum products for every SSA country out to 2020, as well as supply
- Base Year configuration of each SSA refinery with information on technologies used, capacities and the type of crude oil and other feedstocks used
- Expansion projects and other refinery assumptions

- Delineation of the cases for 2015 and 2020

ES.3.1.1 Demand Projections

Energy demand within an individual country is largely a function of gross domestic product (GDP), population, and the energy intensity/efficiency of the overall economy and specific sectors within the economy. Demand is also impacted by Government policies that influence the exploitation of domestic natural resources, control imports and/or exports, affect prices in country, and impact the efficiency of energy end-use technologies. Further impact comes from the state of the domestic infrastructure and the percentage of GDP derived from the export of raw commodities¹³. Using prices to estimate demand is complicated. In an unfettered market, the market clearing price would determine the level of demand by consumers in the different economic sectors. While this may be the most rigorous approach to estimating demand substantial amounts of data are required. There is also a good deal of dissension over the correct elasticities to use. Therefore, initially ICF concluded that an accepted publicly available projection would be the best approach.

ICF has been unable to find publicly available substantive projections of energy demand by country in SSA. In the various projections, such as those from OPEC, one can find Angola and Nigeria, the major oil producers identified. Other projections will identify South Africa, usually broken out because of the size of its GDP. ICF was unable to find a projection that addressed the major countries in SSA, let alone the smaller countries. A further complication is that very few countries in SSA, with the exception of South Africa have a mixed industrial economy which works best with the normal analytical approach. Many of the SSA countries have very rapidly growing GDPs driven largely by resource exports during a period when global commodity prices were at an all-time high and this does not translate directly into petroleum demand.

ICF has therefore developed its own methodology to project petroleum demand by country out through 2020. Total projected petroleum demand for Africa was based on the projections from the Energy Information Administration tied to the price projection discussed above. North African demand was subtracted from the totals. The primary source of data for the demand model is the CITAC Africa LLC data base which provides total consumption from 2000 to 2007 for eight petroleum products and the International Energy Agency's Energy Balances which provides data from 1992 to 2007. The latter is used to extrapolate CITAC data back to 1992 and to fill in certain items missing from the CITAC database such as refinery fuel use. Regressions were then run on the consumption time series to give the trends by product and by sector and to relate the trends to population and GDP

Given projected population and GDP from the World Bank, the United Nations, the IMF, and the U.S. Census Bureau trends from the regressions can be then superimposed on the SSA total demand to give estimates of country level demand.

ES.3.1.2 SSA Refineries

With the agreement of the Steering Committee three large demand regions were created for SSA: West, Sout, and East. These regions reflected the logistics of petroleum product supply to meet demand within SSA. Then within the larger three regions 9 refinery supply sub-regions were created. These sub-regions varied from individual refineries, i.e., Cameroon, to groups of refineries, i.e., all the Nigerian refineries. This allowed us in the modeling to represent the global context, the SSA context, the 3-region context, and the sub-regional context.

¹³ There are, of course, impacts from random events that cannot be modeled looking out to the future. These can include war, and extreme climate impacts among others.

ES.3.1.3 Refining Assumptions

One goal of the modeling effort in this study was to assess the investment requirements facing the individual SSA refineries if they are to move along the AFRI standards. It became clear during the Kick Off meeting that, at least as far as gasoline and diesel are concerned, that there are three sets of specifications: official government specifications; specifications of the products that the refineries actually make; and specifications of the products sold in the marketplace which are a mix of domestic and imported products¹⁴.

There is a vast difference between the official specifications and the estimated actual qualities, particularly for gasoline. Knowledge of the actual qualities is critical for the modeling. As, in fact, SSA refineries are already making, for example, gasoline at the AFRI-3 level, that changes the whole investment picture. It was initially thought costs would be based on moving from mainly AFRI-1 to AFRI-4. Based on the current qualities identified, the costs relate more to moving from AFRI-2 and 3 to AFRI-4.

The advance of regional specifications, demand and supply, as well as the influences of broader global developments, impact the investments made in the model in both existing refineries and for potential new refining centers. Within existing refineries, the investments potentially range from the relatively inexpensive, such as revamp or debottlenecking of existing units, to high cost investment decisions such as large expansions or installation of a major secondary unit such as a hydrocracker. Wholly new refining capacity can range from a new moderate scale local refinery to large and complex new refining centers. Stepping forward to 2015 and then 2020, with associated product quality, demand and related developments, enables ICF/EnSys and thus the Steering Committee to examine the economics of the different refinery subgroups and whether or not they can make the investments necessary to meet advancing fuel specifications and remain profitable and competitive on the world market.

ES.3.1.4 Modeling Cases

In order to illustrate the various options and to generate a range of costs to evaluate the impact of the various fuel changes, ICF/EnSys developed a series of cases, as shown in Exhibit ES-15. This allowed the examination of a number of possible policy options, in particular, what would happen to SSA refineries and costs in an open market in which they were fully exposed to global competition versus what would happen if all existing SSA refineries were protected (the constrained case). From these cases, ICF/EnSys was able to identify the incremental costs of moving to the AFRI-4 standards, as distinct from the costs of investment driven by normal organic growth. We were also able to identify the cost differentials between the open market cases and the constrained cases.

¹⁴ Currently, importers are required to meet the official specifications for the products they import.

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Exhibit ES-15: Modeling Case Descriptions

Case Description	Case No.	2010	2015	Economic Conditions in SSA	2015/2020 AFRI-Current	2015/2020 AFRI-4
2010 Base Case	210	X			X	
2015 Open Market Case. SSA Refineries in open competition	215		X	Unfavorable	X	
2015 Open Market Case. SSA Refineries in open competition	216		X	Unfavorable		X
2020 Base Case: SSA Refineries kept running:	224			Favorable	X	
2020 Base Case – SSA Refineries kept running:	220			Favorable		X
2020 Open Market Case: SSA Refineries in open competition:	221			Favorable	X	
2020 Open Market Case: SSA Refineries in open competition:	222			Favorable		X
2020 Open Market Case: SSA Refineries in open competition:	223			Unfavorable		X

ES.3.2 Data Uncertainties

There are considerable uncertainties over the demand data which is one of the main drivers in the model. While the methodology is analytically reasonable, there may be countries in SSA that are at a threshold for economic takeoff and this methodology would not indicate this. In addition, there is the issue of “pent up” demand. If consumers in a specific country are faced with government regulations that limit the availability of certain products they may consume less than they wish. Likewise if the infrastructure of a country is poor enough to impede distribution consumers will consume less than they demand. If, at some point in the future, the impediment to demand is lifted whether by revising government regulations or by improving the distribution infrastructure there may be a surge in actual consumption as demands are met. This will have to be evaluated by expert judgment. The complications of the demand estimates are fully discussed in Appendix A in Volume II-B, the Refinery Study.

Apart from the specific problems in generating demand projections ICF was faced with the overwhelming problem of the global recession. Since this was a “moving target” ICF, with the concurrence of the World Bank took the approach of deciding on a projection that was lower than trend indicated. These cases are the ones indicated in the report as having economic conditions favorable to SSA. However, to deal with the continuing fall in demand an alternative case was constructed with even lower demand and these became the cases labeled as unfavorable. To some extent these levels are arbitrary; however all international forecasts do indicate that the consensus belief is that the developing nations will recover in a more timely fashion than the developed world and will then proceed to start growing again.

ES.3.3 Refinery Study Results

Exhibit ES-16 summarizes the total investment costs for the various cases facing the SSA refining sector to both meet normal growing demand and to meet the requirement of moving up the AFRI scale to AFRI-4 fuel specifications. Exhibit ES-17 separates out the investment costs of moving to AFRI-4 specifications compared to the current AFRI specifications. This exhibit also shows the incremental cost

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of moving to AFRI-4 in a constrained versus an open market and shows the incremental difference in moving to AFRI-4 for a favorable economic situation versus an unfavorable situation.

Exhibit ES-16: Total Refinery Investments from the Eight Cases (Billions of 2007\$)

Case	Description	Year	AFRI Specifications	SSA Total	West Total	South Total	East Total
210	Base	2010	Current	0.06	0.01	0.05	-
215	Open Market	2015	Current	1.89	0.02	0.28	1.60
216	Open Market	2015	AFRI-4	3.14	0.47	0.54	2.13
224	Constrained	2020	Current	5.40	3.19	0.60	1.61
220	Constrained	2020	AFRI-4	8.67	5.31	1.00	2.36
221	Open Market	2020	Current	5.32	3.07	0.59	1.66
222	Open Market	2020	AFRI-4	7.65	4.51	0.90	2.25
223	Open Market Unfavorable	2020	AFRI-4	6.19	2.98	0.64	2.56

Exhibit ES-17: Incremental Costs to Move to AFRI-4 Fuel Specifications (Billions of 2007\$)

Year	Description	SSA Total	West Total	South Total	East Total
2015	Open Market	1.25	0.45	0.26	0.53
2020	Constrained	3.27	2.12	0.40	0.75
2020	Open Market	2.33	1.44	0.31	0.59

The refinery cost impacts depend in part on the SSA region, and are a function of the:

- Standards of the transportation fuels already being made
- Technology already installed, particularly FCC capacity
- Types of crude oil being used, for example, West Africa, in general, has good quality sweet crude oil, compared to the imported sour Middle Eastern crude oil used in South and East Africa

Exhibit ES-18 shows the incremental unit costs for the AFRI-4 transportation fuels for both the constrained cases and the open market cases. In line with Exhibit ES-17 which shows that the incremental cost for moving to AFRI-4 in the constrained case is approximately \$1.02 billion more than in the open market case, Exhibit ES-18 shows that the incremental unit costs are also higher.

Exhibit ES-18: Incremental Unit Costs for AFRI-4 Fuels in the Constrained and Open Market Cases

Case	Year	Units	AFRI-4 Gasoline + Diesel Supply Cost			
			SAA Total	Africa West	Africa South	Africa East
Constrained	2020	\$/barrel	\$5.56	\$6.39	\$3.69	\$7.09
		\$/tonne	\$44.26	\$50.86	\$29.37	\$56.44
Open Market	2020	\$/barrel	\$5.46	\$6.25	\$3.66	\$6.99
		\$/tonne	\$43.46	\$49.75	\$29.13	\$55.64

Looking at the SSA refineries in a global context it became clear that the small, older refineries that were already experiencing problems ran into insurmountable problems in the open market cases. On the other hand the SSA refineries that could content with global competition were faced with high costs to move to AFRI-4 standards but wider refinery margins and higher revenues. (See Exhibits ES-19, ES-20, and ES-21)

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Exhibit ES-19: Africa West Price and Crack Spreads (relative to Bonny Light)

S/bbl								
	2010	2015	2015	2020	2020	2020	2020	2020
Basis	Base	Market	Market	Base	Base	Market	Market	Market
Conditions		Unfavorable	Unfavorable	Favorable	Favorable	Favorable	Favorable	Unfavorable
AFRI Specs	Current	Current	AFRI-4	Current	AFRI-4	Current	AFRI-4	AFRI-4
Spreads vs. Crude								
Gasoline – Crude Oil	\$0.89	\$2.12	\$2.93	(\$3.69)	\$1.38	(\$3.55)	\$1.41	\$0.74
Diesel – Crude Oil	\$12.81	\$10.76	\$17.05	\$12.82	\$22.60	\$13.10	\$22.64	\$19.96
HS Residual – Crude Oil	(\$3.25)	(\$4.58)	(\$6.76)	(\$6.87)	(\$7.05)	(\$7.01)	(\$7.33)	(\$8.30)
Crack Spreads								
3-2-1 (approx FCC cracking)	\$4.87	\$2.17	\$7.64	\$1.81	\$8.45	\$2.00	\$8.49	\$7.14
2-1-1 (approx HCR cracking)	\$6.85	\$4.32	\$9.99	\$4.56	\$11.99	\$4.78	\$12.03	\$10.35
4-1-1-2 (approx hydro-skimming)	\$1.80	(\$0.13)	\$1.61	(\$1.15)	\$2.47	(\$1.11)	\$2.35	\$1.03

Source: Calculated from WORLD® runs, May 17, 2009

Exhibit ES-20: Africa South Price and Crack Spreads (relative to Saudi Light)

S/bbl								
	2010	2015	2015	2020	2020	2020	2020	2020
Basis	Base	Market	Market	Base	Base	Market	Market	Market
Conditions		Unfavorable	Unfavorable	Favorable	Favorable	Favorable	Favorable	Unfavorable
AFRI Specs	Current	Current	AFRI-4	Current	AFRI-4	Current	AFRI-4	AFRI-4
Spreads vs. Crude								
Gasoline – Crude Oil	\$1.07	\$0.37	\$1.97	(\$0.37)	\$3.15	(\$0.14)	\$3.28	\$1.68
Diesel – Crude Oil	\$8.64	\$11.03	\$16.27	\$19.42	\$24.50	\$19.48	\$24.56	\$18.92
HS Residual – Crude Oil	(\$8.15)	(\$6.66)	(\$7.08)	(\$6.96)	(\$7.65)	(\$6.40)	(\$7.65)	(\$8.82)
Crack Spreads								
3-2-1 (approx FCC cracking)	\$3.59	\$3.93	\$6.74	\$6.23	\$10.26	\$6.40	\$10.37	\$7.43
2-1-1 (approx HCR cracking)	\$4.85	\$5.70	\$19.12	\$9.53	\$13.82	\$9.67	\$13.92	\$10.30
4-1-1-2 (approx hydro-skimming)	(\$1.65)	(\$0.48)	\$1.02	\$1.29	\$3.09	\$1.63	\$3.13	\$0.74

Source: Calculated from WORLD® runs, May 17, 2009

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Exhibit ES-21: Africa East Price and Crack Spreads (relative to Saudi Light)

S/bbl								
	2010	2015	2015	2020	2020	2020	2020	2020
Basis	Base	Market	Market	Base	Base	Market	Market	Market
Conditions		Unfavorable	Unfavorable	Favorable	Favorable	Favorable	Favorable	Unfavorable
AFRI Specs	Current	Current	AFRI-4	Current	AFRI-4	Current	AFRI-4	AFRI-4
Spreads vs. Crude								
Gasoline – Crude Oil	(\$0.86)	(\$1.85)	\$3.40	(\$1.93)	\$2.63	(\$1.78)	\$2.72	\$2.40
Diesel – Crude Oil	\$10.35	\$11.14	\$18.40	\$13.56	\$22.79	\$13.76	\$22.84	\$21.08
HS Residual – Crude Oil	(\$3.86)	(\$0.67)	(\$1.07)	(\$3.09)	(\$2.96)	(\$3.09)	(\$2.93)	(\$2.74)
Crack Spreads								
3-2-1 (approx FCC cracking)	\$2.88	2.48	\$8.40	\$3.23	\$9.35	\$3.40	\$9.43	\$8.63
2-1-1 (approx HCR cracking)	\$4.75	\$4.64	\$10.90	\$5.82	\$12.71	\$5.99	\$12.78	\$11.74
4-1-1-2 (approx hydro-skimming)	(\$0.44)	\$1.99	\$4.92	\$1.37	\$4.88	\$1.47	\$4.92	\$4.50

Source: Calculated from WORLD® runs, May 17, 2009

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What the open market cases show is that a large number of the existing SSA refineries more than hold their own against the foreign export refineries. SSA refineries that do well in the global context usually:

- Are larger,
- Have invested over time and are more complex,
- Are more efficient,
- Have access to good quality local crude oils, and
- Have access to a larger market or have a niche market.

In addition, given the projected demand growth there appears to be the opportunity for new (or expanded) refinery capacity between 200,000 and 400,000 b/d depending on economic circumstances.

ES.4 SSA Refinery Project Results and Conclusions

The final step of the SSA Refinery Project was to compare the total refinery investment costs to meet the AFRI-4 standards with the estimated monetary value of the health benefits associated with reduced emissions from cleaner fuels and implementation of pollution control equipment.

The costs and benefits were compared on the basis of the cumulative refinery investment costs in an open market and the health benefits (Scenario 2) over 5 years to 2015 and over 10 years to 2020. The net present value (NPV) was calculated using a 7 percent discount rate. Exhibits ES-22 and ES-23 show the results expressed in billions of 2007 U.S. dollars. The exhibits show that on an NPV basis the benefits to the health of the population of SSA during the period examined far exceed the investment costs required for the refineries to move to the AFRI-4 fuel specifications. The benefits outweigh the costs even in the south region; the south has lower investment costs because that region already has refineries with advanced configurations and largely AFRI-3 fuel standards, so the step to AFRI-4 is the smallest.

Exhibit ES-22: Net Present Value of Refinery Supply Costs versus Health Benefits over 5 Years

Billions 2007 dollars	SSA Total	West Region	East Region	South Region
Refinery Investment Costs to 2015	\$2.76 B	\$0.47 B	\$2.13 B	\$0.59 B
Health Benefit over 5 years ¹	\$25 B	\$18 B	\$5.3 B	\$1.0 B

1. Central value shown for elasticity=1.5; ranges for elasticities of 1.0 and 2.0 are shown in the report. For Scenario 2 (lower sulfur fuel and pollution control equipment) and alternate 2-stroke motorcycle emissions assumptions.

Exhibit ES-23: Net Present Value of Refinery Supply Costs versus Health Benefits over 10 Years

Billions 2007 dollars	SSA Total	West Region	East Region	South Region
Refinery Investment Costs to 2020	\$6.14 B	\$4.96 B	\$2.48 B	\$0.99 B
Health Benefit over 10 years ¹	\$43 B	\$33 B	\$9.0 B	\$1.8 B

1. Central value shown for elasticity=1.5; ranges for elasticities of 1.0 and 2.0 are shown in the report. For Scenario 2 (lower sulfur fuel and pollution control equipment) and alternate 2-stroke motorcycle emissions assumptions.

As both the Health and Refinery Studies have pointed out, there are considerable uncertainties largely driven by the availability and accuracy of the data. Nevertheless, these studies provide a methodology for assessing the costs and benefits of improving the quality of transportation fuels in SSA. Although these studies looked out only to 2020, all indications are that SSA will continue to grow and that growth is likely to be accompanied by further urbanization and vehicle use. In addition, future changes in SSA will

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likely affect results of modeled air emission. For example, although in some cases air pollution was dominated by domestic emissions and road dust, in the future these sources may be reduced with increased modernization, leaving vehicle pollution as the predominant source of air pollution.

The Health Study results indicate that there is a potential for significant health benefits in Sub-Saharan Africa's urban areas associated with the use of improved fuels, and the Refinery Study provides evidence that:

- **SSA refineries are already halfway up the AFRI standards, mitigating the size of the required future investments, and**
- **Many of the SSA refineries are capable of functioning in the larger context of the global market.**

The combined results of the Health Study and the Refinery Study have shown that the estimates of the potential for health benefits outweigh the costs of improving fuel quality over time in SSA. These studies provide one line of evidence for the decisions to be made by Sub-Saharan African policy makers on whether to move forward with the manufacture of improved fuels