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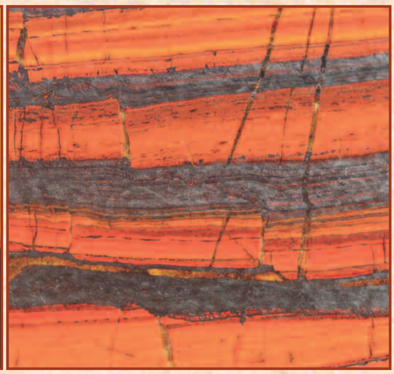
Extractive Industries for Development Series #12
July 2009

Sub-Saharan Africa Refinery Study



Report Summary

EnSys Energy & Systems,
ICF International,
James Hammitt,
Lisa Robinson

ESMAP
Energy Sector Management Assistance Program

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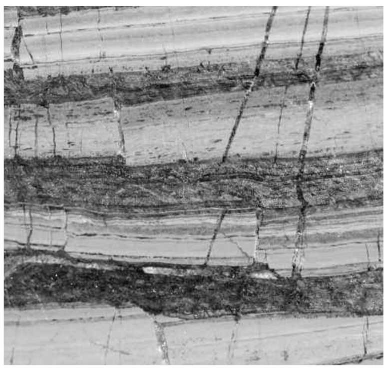

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Cover Photos: Oil rig, hematite-banded ironstone, LNG tanker

Table of Contents

List of Figures

List of Tables

Acknowledgements

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ICF International was selected as consultant. The ICF International team included: Zeta Rosenberg, project leader and Refinery Study project manager, Amy Rosenstein, Health Study project manager, Martin Tallett, EnSys, Refinery Study subcontractor, Lisa Robinson, independent consultant, Health Study subcontractor, valuation section, and James Hammitt, Harvard School of Public Health, Health Study subcontractor, valuation section.

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Special thanks go to Esther Petrilli-Massey for managing production of the *Summary Report* in the *Extractive Industries for Development Series*.

NOTE: For copies of the full report, please send a message to:
ogmc@worldbank.org

List of Acronyms and Definitions of Terms Used in the Report

ACS	American Cancer Society
AFRI	Fuel specifications adopted by the Africa Refiners Association
AFRO D	Africa Sub-Region D, classified based on mortality data; WHO Global Burden of Disease project
AFRO E	Africa Sub-Region E, classified based on mortality data; WHO Global Burden of Disease project
AP-42	Air Pollution-42, US EPA's Compilation of Air Pollutant Emission Factors
ARA	African Refiners Association
asl	Above sea level
AVHRR	Advanced Very High Resolution Radiometer
BenMAP	US EPA's Environmental Benefits Mapping and Analysis Program
BTU	British thermal units
CI	Confidence interval
CO	Carbon monoxide
COEE	Canada Office of Energy Efficiency
COI	Cost of illness
CPS-II	Cancer Prevention Study II
DAAPs	South Africa's Dynamic Air Pollution Prediction System
DALY	Disability-adjusted life-year
deg	Degrees
°C	Degrees centigrade
DEM	Digital elevation model
DHS	Demographic and Health Surveys
DOC	Diesel oxidation catalyst
EPA	California Environmental Protection Agency
E-R	Exposure-response
EURO	European Commission, Transport & Environment standards for gasoline and diesel
g/kg	Grams/kilogram
gal	Gallons
GDP	Gross domestic product
GNI	Gross national income
GNP	Gross national product
NO3	Nitrate
I/M	Inspection/Maintenance program
ICD	International Classification of Disease

IMO	International Maritime Association
IPPS	Industrial Pollution Projection System
IR	Incidence rate
IVEM	International Vehicle Emissions Model
kg	Kilograms
km	Kilometers
LAMATA	Lagos Metropolitan Area Transport Authority
m	Meters
_g/m3	Micrograms per cubic meter
m/s	Minimum wind speed
MARPOL	International Convention for the Prevention of Pollution from Ships
MW	Megawatts
n	Number
NO2	Nitrogen dioxide
NOAA	U.S. National Oceanographic and Atmospheric Administration
NOx	Nitrogen oxides
O3	Ozone
OR	Odds ratio
p	Probability
PM	Particulate matter
PM10	Particulate matter less than or equal to 10 microns
PM2.5	Particulate matter less than or equal to 2.5 microns
ppm	Parts per million
PPP	Purchasing power parity
PR	Prevalence rate
psi	Pound per square inch
QALY	Quality-adjusted life year
RFO	Residual fuel oil
RIVM	Dutch National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu)
RR	Relative risk or risk ratio
RSA	Republic of South Africa
RVP	Reid vapor pressure
SCR	Selective catalytic reduction
SO2	Sulfur dioxide
SO4	Sulfate
SSA	Sub-Saharan Africa
t/y	Metric tons/year
tpy	Metric tons/year
TSP	Total suspended particulates
US EPA	United States Environmental Protection Agency
UNEP	United Nations Environment Programme
USAID	U.S. Agency for International Development
VKT	Vehicle kilometers traveled
VOC	Volatile organic compounds
VSL	Value per statistical life
VSLY	Value per statistical life year
WGS UTM	World geodetic system universal transverse Mercator
WHO	World Health Organization
WRAP	Western Regional Air Partnership (US)
WTP	Willingness to pay

INTRODUCTION

The World Bank and the African Refiners Association (ARA), with the concurrence of the United Nations Environment Program (UNEP) and International Petroleum Industry Environmental Conservation Association (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 necessary to improve fuel specifications and the 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 Africa (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 data, which are further compounded by the global recession, the project provides an estimate of the potential for health benefits associated with cleaner fuels, as well as the potential costs to the SSA refining industry to upgrade its conversion capacity and ensure clean fuel supply in competitive conditions.

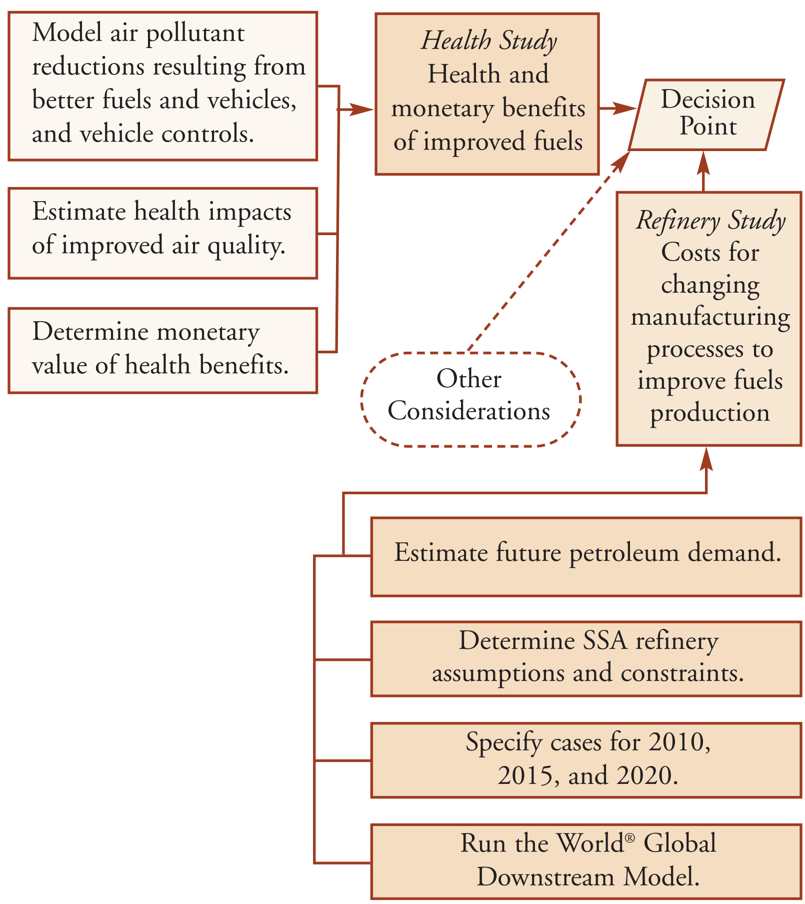
The study consists of two parts that interact as shown in Figure 1.

> *Health Study:* To estimate the reductions in air emissions associated with improved fuel specifications and vehicle emission controls, 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 estimates health and monetary benefits associated with improved fuel specification and vehicle emission controls, by region, which in turn are compared to the costs to the refining industry, as developed in the Refinery Study.

The project methodology was presented by ICF International and approved by the World Bank and the ARA Steering Committee. In some cases, the project has been limited by the availability and quality of data. Associated methodological uncertainties are discussed at length in the report, and must be kept in mind when reviewing the results.

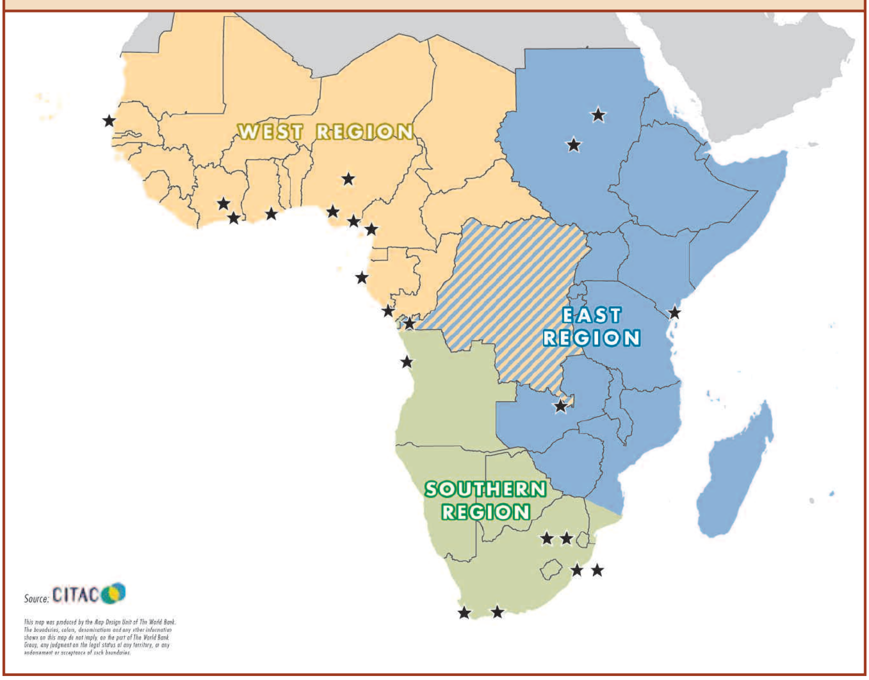
FIGURE E-1: RELATIONSHIP OF THE HEALTH STUDY AND THE REFINERY STUDY



1. Summary of the Main Results

The Health Study started by investigating the level of air pollutants in a given city for each of the three selected SSA regions (see Figure 1.1) under a Base Case (representing current or recent historical conditions) and two scenarios: Scenario 1 evaluates the benefits of reduced sulfur content in transportation fuels alone, while Scenario 2 assumed reduced sulfur fuels, and vehicles with improved emission controls, development of an inspection and maintenance (I&M) program, and phase-out of 2-stroke engines. 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. International experience shows the synergistic effects of reducing air pollutants by combining improved fuels and improved vehicles, an I&M program, and reduction of 2-stroke engines. The estimated health benefits were then associated with estimated monetary benefits. (Figure 1.1).

Exhibit 2: Sub-Saharan Africa – Selected Regions



Source: CITAC Africa LLP

Table 1: Monetary Valuation of the Health Benefits derived from the improvement of fuels quality			
	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 Southern Region			
Base Case	**-**	**-**	**-**
Scenario 1	**0**	**0**	**0**
Scenario 2	**252**	**1.0**	**1.8**

There are significant benefits to be obtained by reducing the causes of air pollution. As the Health study shows, improving the quality of fuels is one of the key steps. The Southern 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. What is also apparent from the table is that while there are benefits from only improving the quality of the transportation fuels, there are significant benefits from the synergistic impact of improved fuels, improved vehicles, an I&M program, and reductions of 2-stroke engines.

Most SSA refineries are not equipped to produce ultra low sulfur fuels. The Refinery Study modeled investments and operating costs associated with the improvement of fuels quality for eight different cases reflecting the economic results both in the case of an "open market" in which the SSA refineries would be fully exposed to global competition, and in the case of a "constrained market" in which all existing SSA refineries would be protected and remain in operation. Apart from the Base Case (2010), for each projected year (2015 and 2020) two cases were run: in the first refiners kept current fuel standards and in the second refiners moved to improved fuel standards, namely the ARA recommended AFRI-4 (see Table 1.2). By comparing the two cases in each year the incremental costs of moving to more stringent fuel specifications could be identified. Because of the impact of the current global recession two economic cases were constructed in order to reflect the realities of the global economy: the cases were favorable and unfavorable growth. In the unfavorable case, GDP growth in SSA was lowered and certain other factors that influence the economic health of the SSA refineries were tightened. The details are discussed in the Refinery report.

Table 1.2: Total SSA Refinery Investments from the Eight Cases (Billions of 2007$)							
Case	**Description**	**Year**	**AFRI Specifications**	**SSA Total**	**West Total**	**Southern Total**	**East Total**
210	Base	2010	Current	0.06	0.01	0.05	-
215	Open Market Unfavorable	2015	Current	1.89	0.02	0.28	1.60
216	Open Market Unfavorable	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

Table 1.2 shows the total investment costs facing the SSA refining industry in all cases, while Table 1.3 shows the incremental costs of moving from current fuel specifications to AFRI-4 standards in 2015 and 2020. The costs are those facing refineries.

The incremental capital costs at port terminals that must expand to cope with increased exports/imports are not included and neither are the incremental costs of consumer distribution infrastructure.

Costs arising from increased regulations and the setting up of an I&M program are also not included.

Table 1.3: Incremental SSA Refinery Investments from Moving to AFRI-4 Fuel Specifications (Billions of 2007$)					
Year	**Description**	**SSA Total**	**West Total**	**Southern 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 SSA refinery sector, are shown in Table 4 as net present value, extrapolated over both a 5-year period and a 10-year period.

Table 1.4: Five-Year and Ten-Year Net Present Value of Refinery Investment Costs versus Health Benefits

Billions 2007 dollars	SSA Total	West Africa	East Africa	East 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. Regulatory authorities should raise the SSA fuel specifications first to current refineries' typical production specifications, and then, in a concerted way, move to AFRI-4 before the year 2015.

While the answer to the cost benefit analysis indicates a clear incentive to implement AFRI-4 standards, and to do so swiftly, 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 from the Middle East and India, regions with growing refinery capacity, and from Europe and the United States, regions with curtailed domestic demand. The implications 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 who have invested in upgrading and de-sulphurisation capacity. However, this cannot be relied upon to reduce the potential for large import volumes foreseen in the Refinery Study. An outcome is that SSA refineries that currently have economic problems and do not invest may well be overwhelmed by future intense competition.

Among the important assumptions of the modeling exercise is that refiners will be receiving prices for products delivered to domestic markets that reflect opportunity costs. If the refiners are not remunerated at economic levels they will not be able to assume the required investments. In this case the supply costs to the respective markets will be higher. Conversely, allowing SSA refineries to recover market costs for the more advanced AFRI-4 fuels will improve refinery margins and viability.

One 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. Such an incremental cost will have to be supported by the economies of countries where these refineries are located.

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, and
- 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.

The consequent improvement in refinery margins from these investments, based on the model assumptions, can be seen in Exhibits 6-1 through 6-3 in the main Refinery report. What these tables show are that the three crack spreads representing the three typical types of refineries improve markedly in 2015 and 2020 cases, both constrained and open market, where the refineries move to AFRI-4 standards. Crack spreads represent the gross margins achieved by the refineries.

The focus of this study was the cost benefit analysis of the impact of clean transportation fuels on human health in the urban areas of SSA. As mentioned earlier there are considerable uncertainties associated with the health data and the global recession has compounded the uncertainties associated with the demand projections.

Nevertheless, the health benefits are in line with similar work undertaken in Mexico and China, and are of sufficient magnitude that even if the refinery costs were doubled, on a NPV basis the benefits would still be positive.

There are two other aspects of transportation fuels and their emissions to keep in mind, apart from the potential health benefits:

- Looking out beyond 2020 the trends that have been apparent in SSA will likely continue, as in other developing nations. Populations will continue to grow, GDP will continue to expand and urbanization and traffic congestion will also likely grow. The net result of this is that in the next few decades vehicle missions will overwhelm pollution from other sources such as road dust in most capital cities of Sub-Saharan Africa.
- SSA imports vehicles. Global vehicles, both gasoline-powered and diesel-powered, make use of increasingly sophisticated and effective control

technology. However, this technology requires clean fuels with increasingly stringent specifications in order to optimally perform. Clean fuels are required for technological reasons as well as for health benefits.

Table 1.5 summarizes the major investments proposed by the model for the constrained and open market AFRI-4 2020 cases for the existing refineries. The capacities and dollar

TABLE 1.5: MAJOR INVESTMENTS PROPOSED BY THE WORLD® MODEL FOR THE 202

Case No.	Description	Unit		
All units in MT, unless otherwise specified			**SGI**	**CAM**
220 2020 AFRI-4 Constr	**Revamping**	Cat ref to CCR		
		DDS to ULSD		
		Cost $ Millions		
	Debottlenecking	Crude distillation	275,000	90,000
		Vacuum distillation	59,000	
		Cat cracking		
		Hydrocracking		
		Cost $ Millions	10	
	New Units	Crude Distillation		
		Vacuum distillation		7,000
		Cat reforming	55,000	
		Naptha desulfurization	113,000	
		FCC gasoline desulfurization	117,000	
		Distillate desulfurization	1,686,000	312,000
		VGO / FCC feed desulfurization		
		Hydrogen Plant Mill (SCFD)	8,641	
		Sulfur plant (T / day)	30,000	10,000
		Aromatics recovery	97,000	26,000
		Isomerization	61,000	
		Cost $ Millions	460	70
		Total Investment $ Millions	**470**	**70**
222 2020 AFRI-4 Open Market	**Revamping**	Cat ref to CCR		
		DDS to ULSD		
		Cost $ Millions		
	Debottlenecking	Crude distillation		
		Cat cracking		
		Hydrocracking		
		Cost $ Millions		
	New Units	Crude Distillation		
		Vacuum distillation		6,000
		Cat reforming	69,000	
		Naptha desulfurization		
		FCC gasoline desulfurization	10,000	
		Distillate desulfurization	1,048,000	190,000
		Hydrogen Plant Mill (SCFD)	8,055	
		Sulfur plant (T / day)	20,000	10,000
		Aromatics recovery	104,000	18,000
		Isomerization	61,000	
		Cost $ Millions	350	50
		Total Investment $ Millions	**350**	**50**

amounts are shown by the refinery groupings. Similar data for all eight cases can be found in the report. The refinery groupings shown in the table are as follows:

SGI: Senegal, Ghana, Cóte d'Ivoire
CAM: Cameroon
NIG: Nigeria
COG: Congo, Gabon
ANG: Angola
SAF: South Africa
ZAM: Zambia
KEN: Kenya
SUD: Sudan

20 Constrained and Open Market Cases

Refinery Groupings						
NIG	**COG**	**ANG**	**SAF**	**ZAM**	**KEN**	**SUD**
			1,918,000			
			734,000			
			260			
			925,000			229,000
			199,000			
			23,000			
			30			
			350,000			
		36,000				
999,000	51,000	20,000				
				23,000		
						118,000
6,602,000	214,000	362,000		126,,000	290,000	1,753,000
			105,000			
	3,340	393	9,823	1,572		4,715
50,000	10,000	10,000		30,000	30,000	
		26,000	498,000	2,000	38,000	86,000
1,190	120	90	620	90	100	330
1,190	**120**	**90**	**910**	**90**	**100**	**330**
			1,918,000			
			736,000			
			260			
			925,000			
			199,000			
			23,000			
			30			
			121,000			
407,000						
				23,000		
48,000			929,000			104,000
3,643,000		46,000	3,092,000	128,000		1,791,000
			9,627	1,375		5,305
50,000		10,000		30,000		
		4,000	512,000	2,000		87,000
620		10	600	90		340
620		**10**	**600**	**90**		**340**

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.

Air Quality Modeling

To model the air quality for SSA, based primarily on the availability of emissions data, three representative cities from each of the selected regions of SSA (West, East and South - see Figure 2) were selected for quantitative analysis. Two additional cities in each region were selected for qualitative analysis (Table 2.1).

Quantitative analysis involved compilation of emissions inventories and 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.

Table 2.1: Cities Modeled in the Health Study			
Assessment	**Description**	**SSA Total**	**West Total**
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 (SO_2), nitrogen dioxide (NO_S), and benzene (Table 2.2).

Table 2.2: Air Pollutants and Related Health Effects	
Air Pollutant	**Related Health Effects**
Particulate matter, both $PM_{2.5}$ and PM_{10}[1]	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 square 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 Table 2.3. 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.

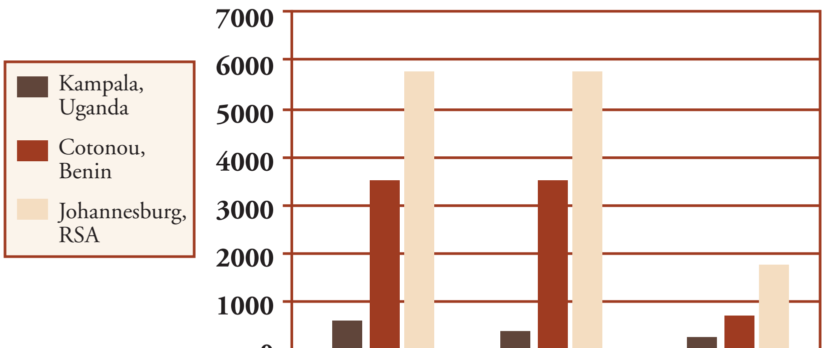
Although the modeled Base Case air concentrations for Kampala and Cotonou appear somewhat high relative to the limited monitoring data, the focus of the study is on the <u>relative change</u> between scenarios, rather than the absolute number. In Johannesburg, the Base Case concentrations and the relative 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.

Table 2.3: Modeled Annual Average Total Particulate Matter Concentrations for Three Cities (population density greater than 1,000/km)						
	Kampala, Uganda		**Cotonou, Benin**		**Johannesburg, South Africa**	
Annual Averages (µg/m³)	**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

The emissions results 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 Figure 2.1 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.

FIGURE 2.1: MODELED REDUCTIONS OF $PM_{2.5}$ (TONS/YEAR) FOR VEHICLE SOURCES IN THREE CITIES

Estimated Reduction in Tons/Year of $PM_{2.5}$ for Vehicle Sources



	Base Case	Scenerio 1	Scenerio 2
Kampala, Uganda	556	460	198
Cotonou, Benin	3.591	3,470	629
Johannesburg, RSA	5,797	5,797	1,873

The large reduction in percentage of PM emissions from the Base Case to Scenario 2 in Cotonou, Benin (from 22.9% to 5% for PM_{10} and from 33.8% to 8.2% for $PM_{2.5}$, as shown in Table 2.2) is based on vehicle activity data used for the Base Case that shows a large use of 2-stroke motorcycles in that city[2] 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

[1] *$PM_{2.5}$ is particulate matter of 2.5 microns in diameter or less; PM10 is particulate matter of 10 microns in diameter or less.*
[2] *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.)*

Cotonou, Benin (extrapolated to the West Africa region) for the Base Case and Scenario 1.[3] 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 accurate.

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.

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

Health Impact Assessment

Health impacts are assessed by:

- Selecting health endpoints[4] 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

[4] *Health endpoints mean the health impact of concern, such as respiratory illness or mortality.*

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 uncertainties associated with extrapolating the U.S. air pollution/health impact studies to Sub-Saharan Africa, although World Bank studies have previously concluded that, under certain circumstances, there is support for extrapolating results from cities in developed countries to cities in 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.

Valuation of Health Impacts

Estimating the monetary value of the selected health risk reductions for this study involved 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 by 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). **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.

The monetary 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 potential health impacts across different countries and subpopulations, the potential magnitude of health effects that are not quantified, and the substantial uncertainties in the valuation estimates. In addition, decision makers may consider the equity or fairness of different approaches, or may have goals or constraints that will lead to outcomes not entirely consistent with the preferences of those affected. 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 underline 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.
- Variation in income across SSA 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.
- 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.
- The valuation section of the Health Study 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.

> 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.

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 – measured by the DDP per capita -, 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 to the significant differences in income – measured by GDP per capita- 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.

Regional Analysis

The estimated health benefits 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 regional extrapolation was accomplished by, first, identifying all large cities in each region, defined as those with a population greater than 300,000. Then, the estimated decreases in the numbers of deaths or cases of bronchitis or asthma in each modeled city were used to estimate the decreases for the population of each large city in the region. Finally, the estimated monetary benefit values for each country were used to estimate the regional monetary benefits of a reduction in emissions of 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.

[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.*

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

Health Study Results

For each region, the estimated reductions are presented in a number of cases, and the associated annual, five-year, and ten-year estimated benefits[7] (Table 2.4). As described above the estimated West region benefits were initially much higher than those estimated for the 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 higher than those estimated for the East region, because of these differences in the characteristics of the regions (Table 2.5):

Table 2.4: 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
GNI[1]	*$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 Table 2.5 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.

[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.*

Table 2.5: Health Study Regional Results Using Alternate 2-Stroke Motorcycle Assumptions							
- Number of Cases of:	-All-Cause Mortality - Reductions in $PM_{2.5}$ (ages>30)	Bronchitis Cases - Reductions in $PM_{2.5}$ (ages>30)	Asthma Exacerba-tions - 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 (NPV) Benefit (billion 2007 US dollars)	Estimated Ten-Year (NPV) Benefit (billion 2007 US dollars)
East Region							
Base Case	541,823	2,293,281	3,183,871	3,183,871	--	--	--
Scenario 1	532,449	2,247,042	3,179,640	3,179,640	$340 M	$1.4 B	$2.4 B
Scenario 2	506,516	2,118,796	3,167,322	3,167,322	$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 regional 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

[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 Naciónal 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.*

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.

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 and are now spreading, at different rates, throughout the world.

As in other world regions, the first improvement in the specifications of transportation fuels in Sub-Saharan Africa was the elimination of lead. The phase-out of lead is now 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). Table 3.1 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

Table 3.1: 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
Cetane 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*

[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 Naciónal 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.*

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 concomitant need for clean fuels, in addition to 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. Its removal processes presents both technological and economic challenges to refiners. However, by coming later than OECD regions to ultra-low sulfur fuels, SSA refineries are in a position to benefit from the operating experience and process improvements obtained elsewhere in the refining industry.

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 set them in the context of the global refining and downstream system.

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

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 commodities[13]. 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 LLP 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 individual country level demand. A further step was the discounting of the GDP effect in those countries whose GDP was driven largely by raw commodity exports rather than by domestic goods and services.

SSA Refineries

With the agreement of the Steering Committee three large demand regions were

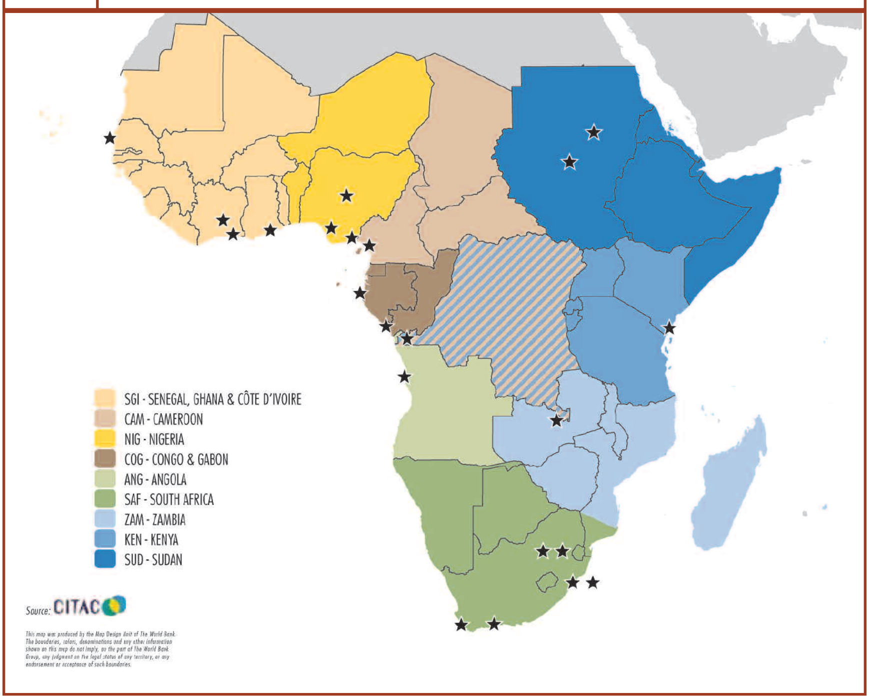
[13] *There are, of course, impacts from random events that cannot be modeled looking out to the future. These can include civil wars, and extreme climate impacts among others.*

created for SSA: West, Southern, and East. These regions reflected the logistics of petroleum product supply to meet demand within SSA. Then, within these three regions, nine refinery supply sub-regions were created. These nine sub-regions varied from individual refineries, e.g., Cameroon, to groups of refineries, e.g., all the Nigerian refineries. The world outside SSA was formulated in WORLD® as 20 demand regions containing a total of 23 refining groups. Explicit refining groups were incorporated for Yanbu, Saudi Arabia and for Reliance/Essar in western India. This formulation allowed the modeling to represent the global context, the SSA context, the 3-region context, and the sub-regional context.

The groupings used in the model for SSA are shown in the table and map of Figure 3.1 below.

Figure 3.1: Sub-Saharan Africa Refinery Regional Groupings

SGI	Senegal, Ghana and Cóte d'lvoire
CAM	Cameroon
NIG	Nigeria
COG	Congo and Gabon
ANG	Angola
SAF	South Africa
ZAM	Zambia
KEN	Kenya
SUD	Sudan



Source: CITAC Africa LLP

Refining Assumptions

One goal of the modeling 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, there are three sets of specifications: "Official specifications" (maximum specifications allowed by the government); and "import specifications". In countries without refineries import specifications may be the same as official specifications, but in other countries with refineries governments may specify/allow a different specification with a view to blending with local production.

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. If, in fact, SSA refineries are already making, for example, gasoline at the AFRI-3 level, that changes the whole investment picture. Thus, although it was initially thought costs would be based on moving from mainly AFRI-1 to AFRI-4, based on the current specifications identified, the costs are more likely related 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 the ARA Steering Committee to examine the economics of the different refinery subgroups and to clarify whether or not they can make the investments necessary to meet advancing fuel specifications and still remain profitable and competitive on the world market.

During the steering committee meetings the issue of placing constraints on the model was discussed several times as it is not realistic to allow the model to optimize regardless of the situation on the ground in terms of logistics, politics etc. A simple example of this is that it is highly unlikely that a major crude producer like Nigeria will ever import non-Nigerian crude oils. For this reason, an input was specified blocking such an operation. Table 3.2 below summarizes the main constraints.

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

Table 3.2: WORLD® Model Constraints	
Activity	**Constraint**
Refinery capacity	Capacities established for 2008 are used in the study. The model adds some expansion through revamping and debottlenecking allowed for 2010 and major new investments in later cases.
Refinery projects	Following the model protocol, only new projects that are under construction were allowed, with the exception of the assumed Ugandan refinery (see below). None of the planned projects in SSA refineries were added to the SSA database. Where economic the model adds capacity in the future cases
Refinery activity	Base Case operating rates are based on the 2007 operating rates. For the Constrained Cases all existing refineries continue to operate at Base Case efficiencies. For the Open Market Cases an upper cap has been placed on the throughput at Nigerian refineries. Nigerian refineries were capped at 43 % as their average 7-year utilization between 2001 and 2007 was 32% with the highest level being 47% in 2001. A lower floor of 29% was placed on the Indeni refinery in Zambia
New refinery capacity	Africa East: a new 50 mb/d refinery is entered for all 2015 and 2020 cases. (This was set to run emerging Uganda crude oil.) Africa West: a cap of 200 mb/d is imposed in all 2015 and 2020 cases to reflect the financing limits expected to prevail
Process units	In Nigeria it was assumed that the alkylation units would not run at any time
Crude oil slates	In the 2020 Constrained Cases SSA refineries are required to use the same crude oil slates as in the Base Case. In the Open Market Cases some constraints were imposed such as limiting Nigerian and Angolan refineries to the use of their indigenous crude oils only.
Trade	In all cases the export of high sulfur distillate is not allowed. Trade in most intermediate products is constrained particularly where storage capacities would not allow the export/import of economic cargo sizes. Exports of benzene are allowed but imports are constrained. Imports of MTBE are constrained but some imports of ethanol are allowed.
Infrastructure	The costs of adding infrastructure capacity at ports and in the consumer distribution system (required for increased imports) were not included in the model: incremental capacity and costs for all refinery offsites was included.

shown in Table 3.3. 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, and to distinguish these costs from the costs of investment driven by normal organic growth. Further, the cost differentials between the open market cases and the constrained cases were identified.

Data Uncertainties

There are considerable uncertainties associated with the demand data which is one of the main drivers in the model. While the methodology is analytically reasonable,

Table 3.3: 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

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 Appendices.

Apart from the specific problems in generating demand projections, this study was faced with the overarching problem of the global recession. Since this was a "moving target", the ICF (with the concurrence of the World Bank), took the approach of deciding on a projection that was lower than historic 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; these cases were labeled as unfavorable. In these latter cases, the average annual regional economic growth originally projected in the base case as 4% was scaled down to 2% per year. To some extent these levels are arbitrary. However, all international forecasts indicate the consensus belief that the developing nations will recover in a more timely fashion than the developed world and will then proceed to start growing again.

Refinery Study Results

The model runs using the constraints listed in Table 3.2 above resulted in refinery throughputs as a percentage of nameplate capacity as follows:

It can be seen that the refineries in the SGI (Senegal, Côte d'Ivoire, and Ghana), Cameroon, South Africa and Sudan operate at high levels in most cases. Nigeria has been capped at the typical throughput rate achieved in recent years (2001/07 average =32%) and Zambia has a floor of 29%. But in most cases for the small refineries with little or no upgrading and limited local demand the model forecasts low or zero throughput.

Table 3.4: Refinery Throughputs of Regional Groupings in the Various Cases

Case	Year	AFRI Standards	REFINERY GROUPINGS								
FAVORABLE CASES – CONSTRAINED			**SGI**	**CAM**	**NIG[1]**	**COG**	**ANG**	**SAF**	**ZAM[1]**	**KEN**	**SUD**
210	2010	Current	85%	91%	39%	75%	70%	90%	31%	37%	85%
FAVORABLE CASES – OPEN MARKET											
215	2015	Current	85%	91%	39%	0%	7%	90%	34%	12%	85%
216	2015	AFRI-4	62%	83%	39%	0%	5%	86%	29%	0%	85%
221	2020	Current	85%	91%	43%	49%	36%	90%	31%	7%	85%
222	2020	AFRI-4	85%	91%	43%	0%	26%	90%	29%	0%	86%
UNFAVORABLE CASE –OPEN MARKET											
223	2020	AFRI-4	49%	55%	43%	0%	17%	90%	29%	0%	85%

Table 3.5 summarizes the total investment costs for the various cases facing the SSA refining sector to meet both normal growing demand and the requirement of moving up the AFRI scale to AFRI-4 fuel specifications. Table 3.6 separates out the investment costs of moving to AFRI-4 specifications compared to the current AFRI specifications. This table also shows the incremental cost of moving to AFRI-4 in a constrained versus an open market and the incremental difference in moving to AFRI-4 for a favorable economic situation versus an unfavorable situation.

Table 3.5: 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

The modeling undertaken in this study examined the incremental costs of SSA refineries moving to AFRI-4 standards only. We are aware that the target in South Africa was EUROIV and EUROV. The specifications of these standards are more stringent than those in AFRI-4. Thus the costs that were generated for South African refineries, based on AFRI-4, substantially underestimate the costs when applied to the two EURO standards.

Table 3.6: 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
2020	Constrained vs. Open Market	1.02	0.80	0.10	0.11
2020	Open Market Favorable vs. Unfavorable	1.46	1.53	0.26	(0.69)

This Table 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

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 and desulfurization 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

Table 3.7 shows the incremental unit costs for 2020 for the AFRI-4 transportation fuels for both the constrained cases and the open market cases

Assuming no change in the taxation included in the fuel prices, the incremental cost of improving the transport fuels quality up to the AFRI-4 level for the SSA consumer will be 0.036 US dollars per liters,

Table 3.7: Incremental Unit Costs for AFRI-4 Fuels in the Constrained and Open Market Cases

Case	Year	Units	SAA Total	Africa West	Africa South	Africa East
Constrained	2020	$/barrel $/tonne	$5.56 $44.26	$6.39 $50.86	$3.69 $29.37	$7.09 $56.44
Open Market	2020	$/barrel $/tonne	$5.46 $43.46	$6.25 $49.75	$3.66 $29.13	$6.99 $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 contend with global competition were faced with high costs to move to AFRI-4 standards but would gain increased refinery margins and higher revenues.

> What the open market cases show is that a large number of the existing SSA refineries 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. Refinery expansion is focused in the Africa West region, in part because of the much higher population. ICF feels that this expansion will fall in the Ghana- Côte d'Ivoire- Nigeria area and also possibly in Angola, even though technically Angola is included in Africa South in the model. Readers of the report will also note that there is refinery expansion in Africa East. After considerable discussion it was decided to force the model to build a new 50,000 barrel per day refinery to process the new Ugandan crude oil.

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 for vehicles.

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. Tables 4.1 and 4.2 show the results expressed in billions of 2007 U.S. dollars. The tables 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.

As both the Health and Refinery Studies have pointed out, there are considerable uncertainties largely driven by the availability and accuracy of the data.

Table 4.1: 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 and for Scenario 2 (lower sulfur fuel and pollution control equipment) with alternate 2-stroke motorcycle emissions assumptions.

Table 4.2: 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.

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 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.

Drawing on the conclusions of both studies ICF believes that policy makers in the SSA region should consider the following recommendations.

- Governments should instigate a sustained effort to update official fuel specifications to reflect current refineries' actual production.

- Governments should consider upgrading the official fuel specifications in their country to AFRI-4 by 2015.

- SSA refineries that could economically produce transport fuels at AFRI-4 specifications should develop investment plans to meet a 2015 deadline.

- In parallel, Governments should adopt and enforce regulatory measures to improve the vehicle fleets such as:
  - All imported gasoline powered cars must have functioning catalytic converters
  - Establish an inspection and maintenance program
  - Encourage the phase out of old, highly polluting vehicles
  - Encourage the phase out or banning of 2-stroke engines

- To reduce the uncertainties confronted in this study Governments, International Agencies, and Technical experts should conduct additional research with respect to:
  - Data on emissions in major urban centers (including permanent installations for measuring pollution levels)
  - Examination of the appropriate methodology for estimating health costs and benefits in developing nations
  - Improvements of data on product demand

- The WORLD® model output indicates that major expansion will be needed in existing refineries as well as new regional refineries in the Africa West/Angola region. Lesser, but still positive growth is expected in Africa East and refining investment will probably be tied to Ugandan crude oil. More focused technical studies should concentrate on these regions.

- Open market policies should be expanded to allow refineries to improve their revenue as they move to AFRI-4 standards.

- Policy makers need to decide the future of the mainly topping/reforming refiners such as those in Senegal, Congo, Gabon, and Kenya. The study indicates the magnitude of the costs of modernizing and operating these refineries to meet the AFRI-4 specifications.

THE WORLD BANK OIL, GAS, AND MINING POLICY DIVISION

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- Assists governments in setting up environmental and social safeguards in projects in order to promote the sustainable development of extractive industries.
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The Oil, Gas, and Mining Policy Division serves as a global technical advi-sor that supports sustainable development by building capacity and provid-ing extractive industry sector-related advisory services to resource-rich developing country governments. The Division also carries out an advocacy role through its man-agement of the following global programs:

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- The Global Gas Flaring Reduction (GGFR) Public-Private Partnership, which brings governments and oil companies together to reduce gas flaring.
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- The Gender and Extractive Industries Program, which addresses gender issues in extractive industries.
- The Petroleum Governance Initiative (PGI), which promotes petroleum governance frameworks, including linkages to environmental and community issues.
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