



# Sub-Saharan Africa Refinery Sector Project

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# Sub-Saharan Africa Refinery Project

**The Sub-Saharan Africa Refinery Project estimates the costs of improving the quality of transportation fuels consumed in Sub-Saharan Africa and compares these with the potential health benefits of reduced emissions in urban areas of the region out through 2020.**

# Sub-Saharan Africa Refinery Project

## The project consists of:

### 1. Health Study

- Estimated decreases in air emissions and health impacts due to:
  - The use of better quality transport fuels.
  - The use of better quality transport fuels, vehicles with emission controls, an I&M program, and controls on 2-stroke engines.
- Estimated the monetary benefits associated with the decrease in air pollution-related health impacts.

## 2. Refinery Sector Study

- Outlined the changes necessary in the Sub Saharan Africa (SSA) refining sector to respond to global trends towards clean transportation fuels.
- Modeled the costs associated with improved transportation fuels in SSA.
- Evaluated the competitiveness of the SSA refining sector in the global market

## 3. Regional Analysis

- Compared the health benefits and costs in three regions: Africa West, East, and South.

# AFRI specifications significantly advance SSA transport fuel quality

GASOLINE				
	AFRI-1	AFRI-2	AFRI-3	AFRI-4
Ron, min*	91	91	91	91
MON, min	81	81	81	81
Lead content**	Unleaded	Unleaded	Unleaded	Unleaded
Sulphur content, % mass, max	0.1	0.05	0.03	0.015
Benzene content, % vol, max	to be reported	to be reported	5	1
DIESEL				
	AFRI-1	AFRI-2	AFRI-3	AFRI-4
Sulphur 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

# Sub-Saharan Africa Refinery Project

Key results:

## 1. Health Study

- A decrease in air-pollution-related mortality and cases of disease was associated with improved transportation fuels.
- A more significant decrease was associated with improved fuels combined with improved vehicles and attendant programs.
- Monetary benefits are likely to be high.

## 2. Refinery Sector Study

- SSA refineries that are efficient and complex with access to markets and good quality local crude oils, can economically supply AFRI-4 products, will improve their margins, and likely will expand.
- SSA refineries that are small and/or inefficient will face growing challenges.

# Sub-Saharan Africa Refinery Project

- Key results (cont'd):

### 3. Comparison of Health Benefits and Costs

- Benefits are greater than costs in West Africa than in East Africa. South Africa already has good quality fuels and fewer diesel vehicles.

# Overview of the Health Study

## Three scenarios were developed:

- **Base Case** - current estimates of emissions from all primary sources of air pollution:
  - **Vehicle Sources**
  - **Area Sources** (wood burning, gasoline stations, etc.)
  - **Industry Sources**
- **Scenario 1** - improved fuel quality specifications (i.e. AFRI-4).
- **Scenario 2** - improved fuel quality specifications, the use of pollution control equipment on all vehicles, phase-out of 2-stroke motorcycles, and increase in number of automobiles.

# Overview of the Health Study (continued)

## 1. Air quality modeling

- Based on data availability, three cities were selected for quantitative analysis: Cotonou (West), Kampala (East), and Johannesburg (South).
- Also conducted qualitative evaluations for 6 other cities.

## 2. Health impact assessment

- Mortality rate and rates of chronic bronchitis in adults.
- Asthma symptoms and respiratory disease mortality in children.
- Published studies used to estimate air pollution/health relationships.

## 3. Valuation of health impacts

- Valuation used the “willingness to pay” approach; an appropriate method for benefit/cost analysis, reflecting different income levels in SSA countries.

## 4. Extrapolation to regional level

- City results were extrapolated to the three sub-regions.

## Air Quality Modeling – Key Results

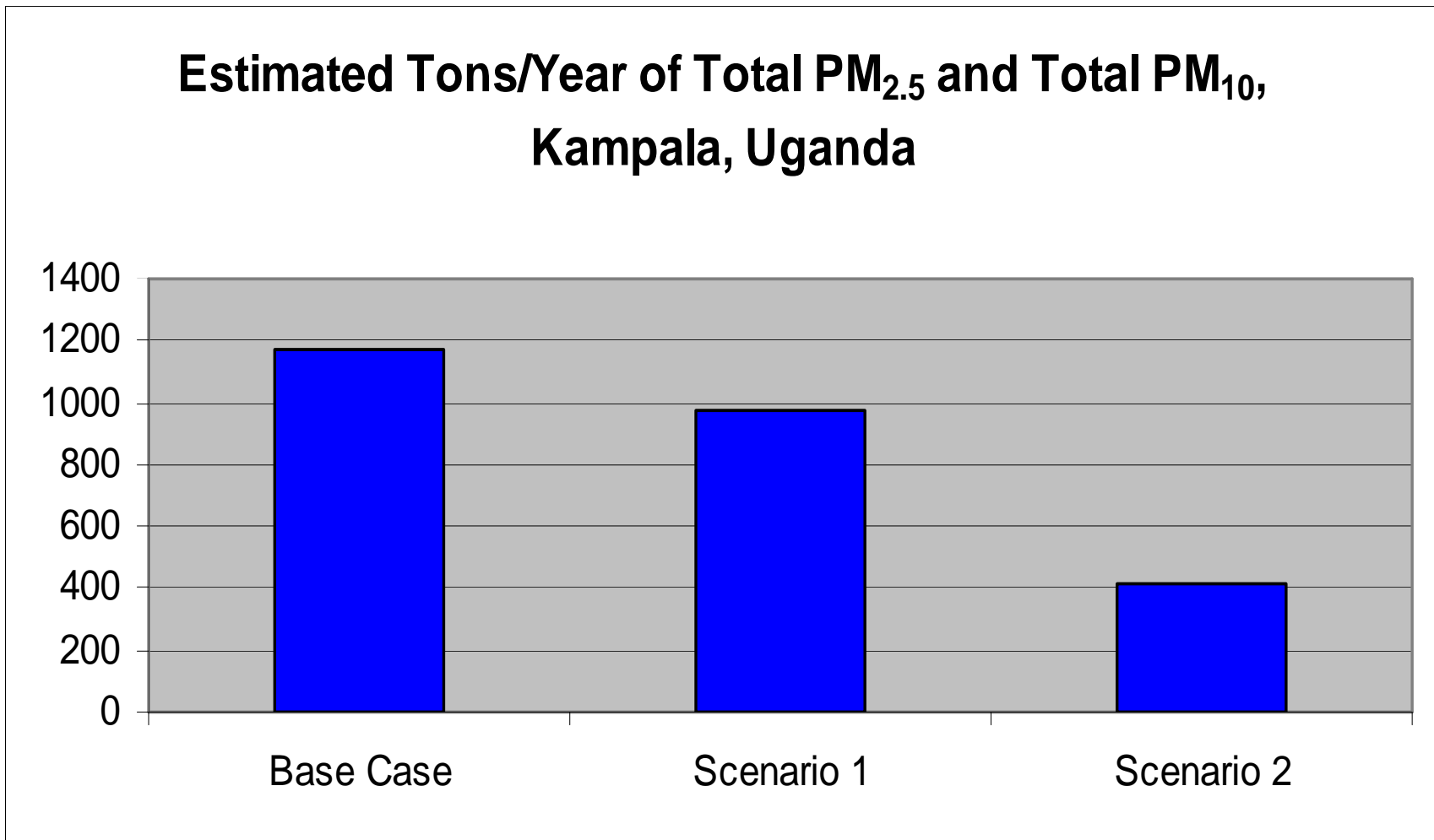
- Improved transportation fuel quality results in a decrease in the contribution of vehicle emissions to particulate matter concentrations.
- Road dust and domestic burning emissions contribute significantly.
- Modeled baseline numbers are high relative to monitoring data and air quality standards.
- However, the focus has been on the **relative change** in each scenario, which is translated into health benefits.
- The relative change between the base case and the improved fuels case is small in Johannesburg, because:
  - Baseline fuel quality is good.
  - There are few diesel vehicles in use.

## Air Quality Modeling – Summary of Key Assumptions

Key Assumption	City		
	Cotonou, Benin	Kampala, Uganda	Johannesburg, RSA
Population	875,763	1,883,298	2,850,509
City Domain Area	96 sq km	784 sq km	2,304 sq km
Industrial Description	Light	Light to Medium	Heavy
Marine Activity	Heavy	Light	None
Domestic Cooking Fuel	Charcoal and wood	Charcoal and wood	Coal
Baseline Fuel Sulfur Levels	Petrol – 500 ppm S Diesel – 4,000 ppm S	Petrol – 600 ppm S Diesel – 5,000 ppm S	Petrol – 300 ppm S Diesel – 500 ppm S
Baseline Fuel (Petrol Only) Benzene Levels	6.8 percent	3 percent	3 percent
Vehicle Age	15 years	12 years	10.5 years
Total vehicle kilometers traveled (VKT)	4,945 million	798 million	24,700 million
% VKT on paved roads % VKT on unpaved roads	95 percent 5 percent	94 percent 6 percent	99 percent 1 percent
% VKT from diesel vehicles % VKT from gasoline vehicles	17 percent 83 percent	45 percent 55 percent	8 percent 92 percent
% VKT from 2-stroke motorcycles % VKT from 4-stroke motorcycles % VKT from 4-wheeled vehicles	48 percent 10 percent 42 percent	20 percent 0 percent 80 percent	0 percent 0 percent 100 percent

# Air Quality Modeling – Example Results

## Total PM<sub>2.5</sub> and PM<sub>10</sub> Emissions



## Health Study – Regional Analysis

- Identified all cities with greater than 300,000 population in each region.
- Regional population numbers used in the analysis:
  - West Region: 61 million total
  - East Region: 27 million total
  - South Region: 19 million total
- The estimated reductions in cases of mortality or disease for each regional city were extrapolated to the appropriate age group in the regional populations.

## Health Study - Key Results

Example – Potential health benefit of a reduction in **PM<sub>2.5</sub>**, in terms of **Adult Mortality**

- Improved fuel quality, along with increased use of pollution control equipment and phase-out of 2-stroke motorcycles, despite the increase in the number of vehicles, lead to reductions in PM<sub>2.5</sub> emissions and thus in adult mortality:
  - West Region: about 77,000 cases avoided in a modeled regional population of about 17 million people over age 30
  - East Region: about 35,000 cases avoided in a modeled regional population of about 7.5 million people over age 30
  - South Region: about 400 cases avoided in a modeled regional population of about 5.2 million people over age 30
- Additional health benefits are found for reductions in other air pollutants.

Numbers for alternate 2-stroke motorcycle current use assumptions.

## Health Valuation

- This is a first attempt to estimate the value of mortality and respiratory disease risk reductions in SSA.
- Determined the appropriate approach:
  - Willingness-to-pay (WTP) estimates are most appropriate for benefit-cost analysis, because they represent the types of trade-offs to be considered.
  - However, WTP depends on income, and therefore it varies across individuals, countries, and communities with different income levels.
- Appropriate estimates of income elasticity are uncertain.

# Health Study Regional Analysis - Key Results

## *Estimated Annual Benefits – Regional Analysis*

(million 2007 US dollars)	<u>Scenario 1</u> (improved transportation fuels)	<u>Scenario 2</u> (improved transportation fuels and pollution controls on vehicles)
<b>Estimated Total Annual Benefit East Region</b>	<b>\$340</b>	<b>\$1,300</b>
<b>Estimated Total Annual Benefit West Region</b>	<b>\$640</b>	<b>\$4,500</b>
<b>Estimated Total Annual Benefit South Region</b>	<b>\$0</b>	<b>\$252</b>

Notes: 1. Central tendency shown (reflects income elasticity of 1.5). Range shown in report. Using alternate current use 2-stroke motorcycle assumptions.

# ICF – EnSys Refinery Study

## The Refinery Study Served Two Aims

1. What would be the investment and delivered product cost impacts of requiring SSA refineries to meet the AFRI-4 gasoline and diesel standards and how would the additional supply cost compare to the value of the health benefits?
2. What is the outlook for SSA refineries given regional demand growth, competitive world market developments, including the advent of large, modern export refineries in the Middle East and in India?

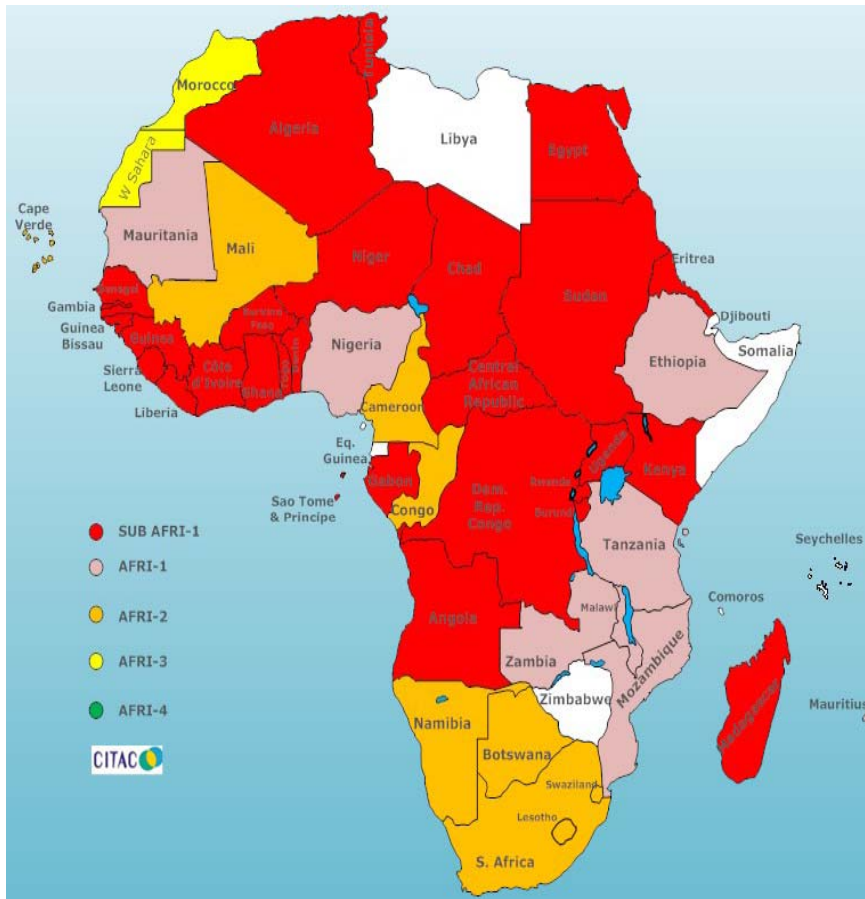
## An Integrated Refining & Market Approach was Used

- To answer these questions, a global refining model (WORLD<sup>®</sup>) was employed. The model was tailored to the SSA study by:
  - Reformulating the global make-up to represent SSA as 3 demand regions.
  - Assigning detailed refinery sub-groups within each SSA demand region.
  - Calibrating the SSA refiners output to actual current SSA refinery output specifications for gasoline and diesel.
  - Developing product demand projections for every country in SSA to 2020.

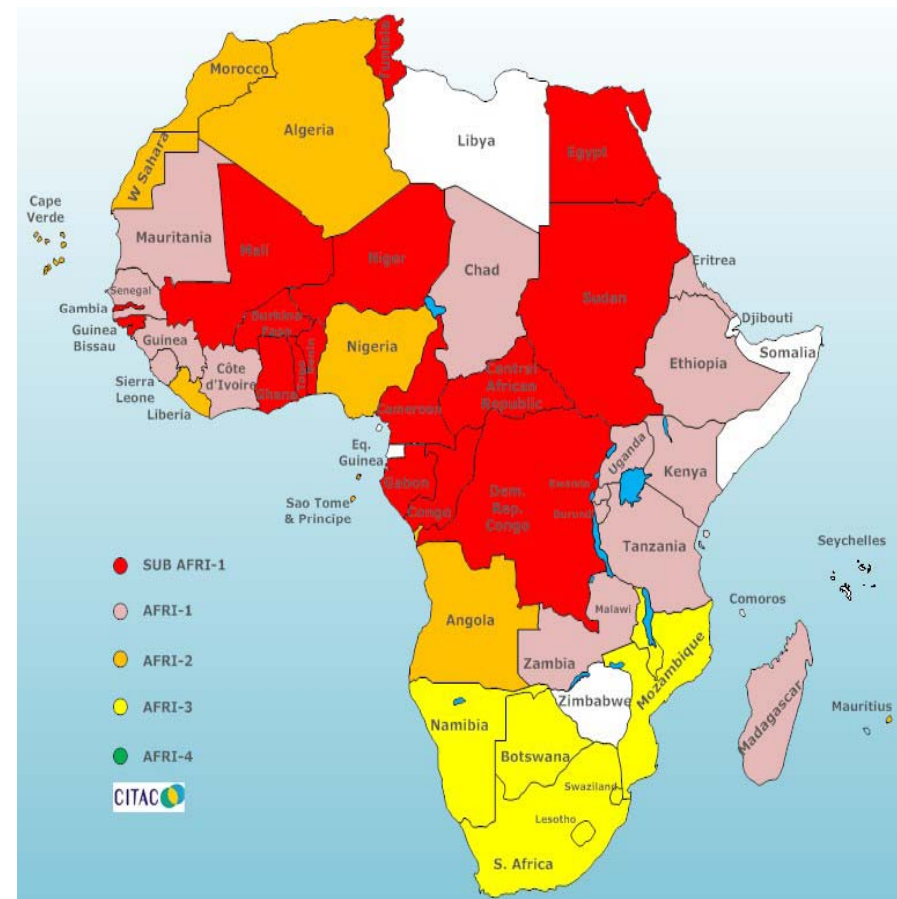
## An Integrated Refining & Market Approach was Used

- The integrated SSA/global method has key benefits:
  - Represents and differentiates SSA refinery groups.
  - Reflects and captures broad developments in the global refining/supply system.
  - Sets SSA refining in the context of the global market.
  - Captures the competitive interactions between SSA refineries and other world regions/refineries:
    - Impacts on location of investment/expansion.
    - Level of product imports.

# Official SSA standards for transportation fuels are poor

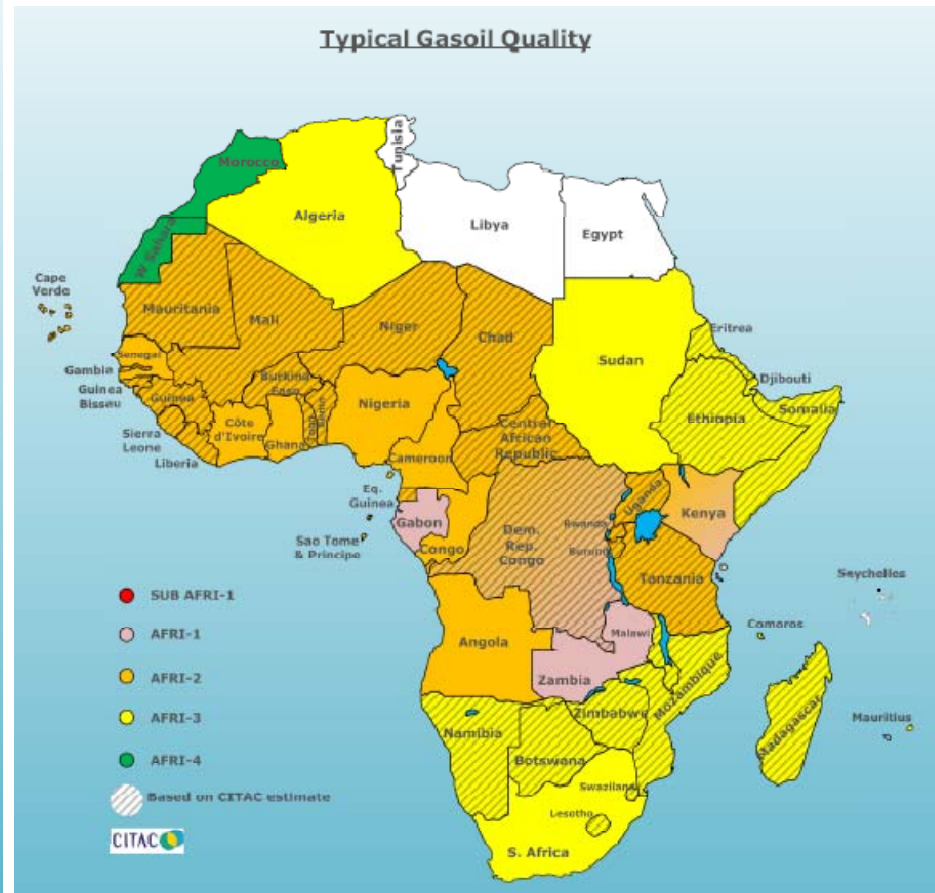
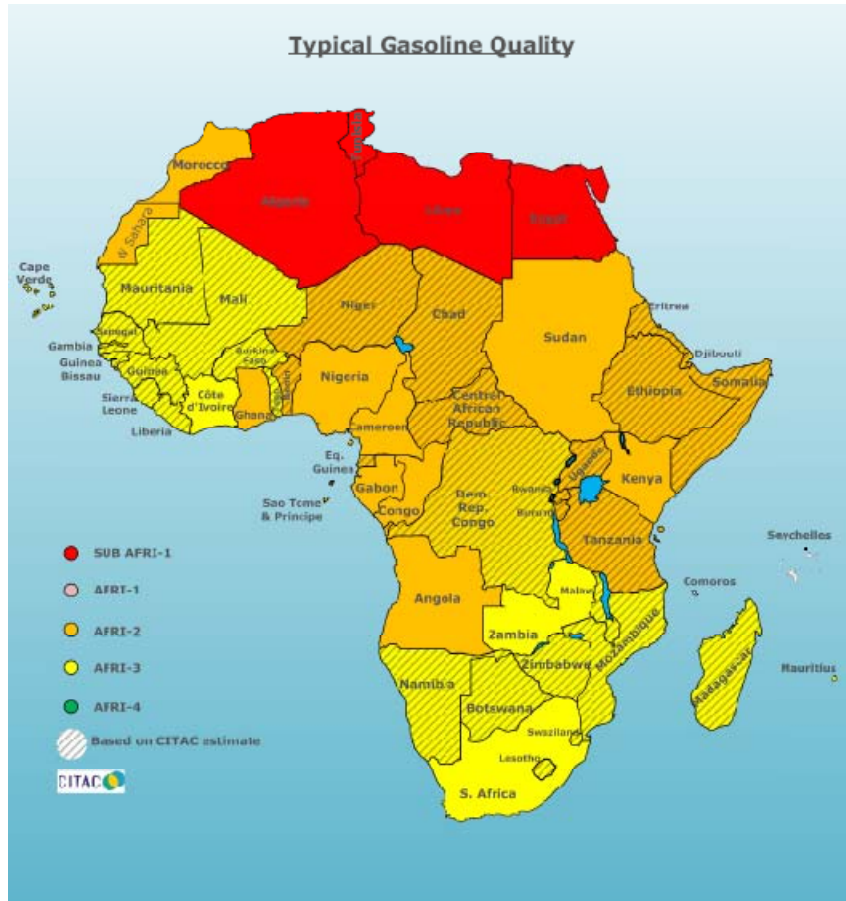


Gasoline



Diesel

# Current SSA production/imports are a mix of AFRI-2 and -3



## Major Global Assumptions for Modeling

- Assumed that there will be a slow recovery from the recession in the industrialized world; however the recovery is going to be faster in the emerging markets / nations.
- Global crude oil price is assumed not to exceed in \$(2007) the 75/barrel level by 2020.
- Worldwide, some 4 million bpd of refinery projects under construction are projected to go ahead; announced major export refineries in the Middle East will be operating only after 2015 period.
- These include high levels of conversion and desulfurization capacity.
- Higher refinery capability to produce gasoline, rising ethanol supplies and flat/declining OECD demand will keep gasoline in relative surplus, with downward pressure on its margin.
- Whereas sustained global distillates demand growth, including some move to marine distillates, supports continuing distillate premiums.

# Major SSA Assumptions for Modeling

- Two market outlooks considered:
  - 1. Under “favorable” scenario:**
    - The region soon resumes significant economic growth.
    - This, with growing urbanization and move from non-commercial to commercial fuels, generates rapid demand growth for petroleum products, 3.7% per year to 2020.
  - 2. Under “unfavorable” scenario:**
    - The region recovers but grows more slowly.
    - Petroleum products demand growth is lower at 2% per year to 2020.
- Under both scenarios:
  - Distillates have highest growth, above gasoline.
  - Residual fuel demand also grows (Africa East and West).
  - No changes in qualities for fuels other than gasoline and gasoil/diesel.

# Favorable versus Unfavorable Scenarios

Established by varying key parameters:

	<b>Constrained and Open Market Scenarios Favorable</b>	<b>Open Market Scenario Unfavorable</b>
<b>Annualized SSA Product Demand Growth to 2020</b>	3.7% per year	2.0% per year
<b>Tanker Freight Rates</b>	Base	Lower
<b>Investment Costs Location Factor</b>	Base	Higher
<b>Regional Natural Gas Prices</b>	Base	Higher

## A Set of Scenarios was Developed

- **Base Case 2010** – essentially captures the current situation.
- **Open Market Cases for 2015 and 2020** – for each year two cases were run: in one all refineries operated at the current fuel standards; in the second all refineries that could moved to AFRI-4 standards.
- **Constrained Cases for 2020** – two cases were run assuming that all the current refineries continued to operate: in one cases at current fuel standards, in the other all refineries were forced to move to AFRI-4

The different scenarios in 2015 and 2020 were used to assess SSA refineries operating under current and AFRI-4 specifications to establish the differential impact on investments and product supply costs. The scenarios also showed the cost implications of protecting all refineries versus allowing global competition.

# Refinery Study – 8 Scenarios and the estimated SSA costs

Units in the table are billions of U.S. 2007\$

Case No	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

# Refinery Study Results: Regional Differences

- Gasoline & Diesel → Sulfur
  - Africa West:
    - Main impact is on AFRI-4 diesel:
      - Target is < 50 ppm sulfur versus <150 ppm for gasoline.
      - Crudes are mainly sweet.
      - Limited FCC gasoline as a source of sulfur.
  - Africa South and East:
    - Impact is on both fuels:
      - Refineries run more/mainly sour crude oils.
      - Several have significant FCC capacity.
- Gasoline → Benzene
  - Potential exists to alter catalytic reforming operations and/or increase benzene extraction.

## Refinery Study Results: Costs of AFRI-4

- Incremental product supply cost (AFRI-4 gasoline and diesel) depends on the region:
  - Lowest in Africa South with already advanced refinery configurations and mainly AFRI-3 standards today (smallest step to AFRI-4).
  - Significantly higher in the other two SSA regions.
    - Distillate desulfurization, hydrogen plant, sulfur plant (also hydro-cracking Africa West).

# Major Investments proposed by the WORLD® model.

Case No.	Description	Unit	Refinery Groupings								
			SGI	CAM	NIG	COG	ANG	SAF	ZAM	KEN	SUD
All units in MT, unless otherwise specified.											
220 2020 AFRI-4 Constrained	Revamping	Cat ref to CCR						1,918,000			
		DDS to ULSD						734,000			
			Cost \$ Millions					\$260 mill			
	Debottlenecking	Crude distillation	275,000	90,000				925,000			229,000
		Vacuum distillation	59,000								
		Cat cracking						199,000			
		Hydrocracking						23,000			
			Cost \$ Millions	\$10 mill				\$30 mill			
	New Units	Crude distillation									
		Vacuum distillation		7,000			36,000				
		Cat reforming	55,000		999,000	51,000	20,000				
		Naphtha desulphurisation	113,000						23,000		
		FCC gasoline desulphurisation	117,000								118,000
		Distillate desulphurisation	1,686,000	312,000	6,602,000	214,000	362,000		126,000	290,000	1,753,000
		VGO / FCC feed desulphurisation						105,000			
		Hydrogen Plant Mill (SCFD)	8,841			3,340	393	9,823	1,572		4,715
		Sulphur plant (T / day)	30,000	10,000	50,000	10,000	10,000		30,000	30,000	
Aromatics recovery		97,000	26,000			26,000	498,000	2,000	38,000	86,000	
Isomerisation	61,000										
		Cost \$ Millions	\$460 mill	\$70 mill	\$1,190 mill	\$120 mill	\$90 mill	\$620 mill	\$90 mill	\$100 mill	\$330 mill
		<b>Total Investment</b>	<b>\$470 mill</b>	<b>\$70 mill</b>	<b>\$1,190 mill</b>	<b>\$120 mill</b>	<b>\$90 mill</b>	<b>\$910 mill</b>	<b>\$90 mill</b>	<b>\$100 mill</b>	<b>\$330 mill</b>
222 2020 AFRI-4 Open Market	Revamping	Cat Ref to CCR						1,918,000			
		DDS to USLD						736,000			
			Cost \$ Millions					\$260 mill			
	Debottlenecking	Crude distillation						925,000			
		Cat cracking						199,000			
		Hydrocracking						23,000			
			Cost \$ Millions					\$30 mill			
	New Units	Crude distillation							121,000		
		Vacuum distillation		6,000							
		Cat reforming	69,000		407,000						
		Naphtha desulphurisation							23,000		
		FCC gasoline desulphurisation	10,000		48,000			929,000			104,000
		Distillate desulphurisation	1,048,000	190,000	3,643,000		46,000	3,092,000	128,000		1,791,000
		Hydrogen Plant Mill (SCFD)	8,055					9,627	1,375		5,305
		Sulphur plant (T / day)	20,000	10,000	50,000		10,000		30,000		
		Aromatics recovery	104,000	18,000			4,000	512,000	2,000		87,000
		Isomerisation	61,000								
		Cost \$ Millions	\$350 mill	\$50 mill	\$620 mill		\$10 mill	\$600 mill	\$90 mill	\$340 mill	
		<b>Total Investment</b>	<b>\$350 mill</b>	<b>\$50 mill</b>	<b>\$620 mill</b>		<b>\$10 mill</b>	<b>\$890 mill</b>	<b>\$90 mill</b>	<b>\$340 mill</b>	

# Refinery Study Results: Incremental Costs to Move to AFRI-4

Units in the table are billions of U.S. 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. Open Market Unfavorable	1.46	1.53	0.26	(0.69)

# Refinery Study Results: Unit Costs of AFRI-4

- Incremental product supply cost (AFRI gasoline & diesel) depends on region and depends on the scenario:
  - Estimated cost range is \$29-\$56/tonne AFRI-4 gasoline/diesel

Case	Year	Units	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

## Refinery Study Results: Impacts of Conditions Less Favorable to SSA

- Lowering projected demand growth rate from 3.7% to 2% per year reduces SSA 2020 demand by over 55,000 bpd.
  - The impact of reduced demand is reflected by roughly two-thirds reduced product imports and one-third reduced SSA refinery runs.
  - Projected SSA total refinery capacity expansions drop by approximately **95,000** bpd and consequently total investments drop from US\$ **7.65 to 6.19** billion.

## Refinery Study Results: Summary of SSA Expansion Potential

- Several SSA regions have the advantage of local, good quality crude supply coupled with local product demand.
- Larger, more complex and efficient refineries look to have the ability to supply AFRI-4 products and to expand.
- In addition, potential appears to exist for new “world-scale” refinery capacity between 200,000 to 400,000 bpd, depending on unfavorable or favorable scenarios.
- Small, simple, inefficient refineries face increasing challenges even when inland and/or with local crude supply.

## Refining/Supply Costs versus Health Benefits

- Comparison of the cumulative refinery investment costs to 2015 and the health benefits (Scenario 2) on a net present value basis over 5 years are shown below.

(in billion US 2007 dollars) <sup>1</sup>	SSA Total	Africa West	Africa East	Africa South
<b>Refinery Investment Costs to 2015<sup>2</sup></b>	\$2.76	\$0.47	\$2.13	\$0.59
<b>Health Benefits over 5-year period<sup>3</sup></b>	\$25	\$18	\$5.3	\$1.0

Notes:1.Open Market AFRI-4 favorable case.

2. Calculated as net present value, 7% discount.

3. Central tendency value shown. Calculated as net present value, 7% discount. **Using values from Health Study Scenario 2** with alternate 2-stroke motorcycle use assumptions (fuel improvements, improvements in vehicle pollution controls, phase-out of all 2-stroke motorcycles, increase in vehicle use).

## Refining/Supply Costs versus Health Benefits

(continued)

- Comparison of the cumulative refinery investment costs to 2020 and health benefits (Scenario 2) on a net present value basis over 10 years are shown below.

(in billion U.S. 2007 dollars) <sup>1</sup>	SSA Total	Africa West	Africa East	Africa South
Refinery Investment Costs to 2020 <sup>2</sup>	\$6.14	\$4.96	\$2.48	\$0.99
Health Benefits over a 10-year period <sup>3</sup>	\$43	\$32	\$9.0	\$1.8

Notes:1.Open Market AFRI-4 favorable case.

2. Calculated as net present value, 7% discount.

3. Central tendency value shown. Calculated as net present value, 7% discount. **Using values from Health Study Scenario 2** with alternate 2-stroke motorcycle use assumptions (fuel improvements, improvements in vehicle pollution controls, phase-out of all 2-stroke motorcycles, increase in vehicle use).

## Final Conclusions

- The Study provides a unique combination of estimates and future capability:
  - Estimates of the potential for health benefits associated with improved fuels in Sub-Saharan Africa's urban areas, based on available information.
  - Estimates of the incremental refining and product supply costs for moving to AFRI-4.
  - A methodology to assess the costs and benefits of future investments in the refining industry in Sub-Saharan Africa.
  - A quantitative basis for assessing the decisions to be recommended to the African Refiners Association and to the Sub-Saharan African governments.

## Messages

- Despite the uncertainties, the study does send other important messages:
  - The health benefits to the SSA urban population outweigh the costs over time.
  - By taking timely steps to move to AFRI-4, SSA may avoid some of the problems encountered by the developed world in cleaning up the air in its growing cities.
  - The greatest benefits come from improving both fuels and vehicles.

## 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.

## Recommendations

- 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.

## Recommendations

- 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.

# Appreciation

- Given the problems with the underlying data we never would have reached this point without the co-operative help of the following people and groups:
- Jane Akumu, UNEP
- CITAC, especially Mark Elliott
- Joel Dervain and other ARA members

Thank you for your attention.

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