A REVIEW OF THE RELATIONSHIP BETWEEN SULPHUR LEVEL IN DIESEL FUEL AND AFRICAN AIR QUALITY

November 2016

The African Refiners Association

BACKGROUND

There is a considerable amount of discussion going on about the relationship between fuel quality (especially diesel) and air quality. This paper, prepared by the ARA Specifications Work Group, sets out to explain the truth and myths surrounding the "Dirty Diesel" issue in a simple form that can be understood by non-technical people. For this reason there are some simplifications of complex technical issues.

1) European data suggests that there is a significant reduction of PM2.5 (the most harmful particulates) as fuel quality has improved

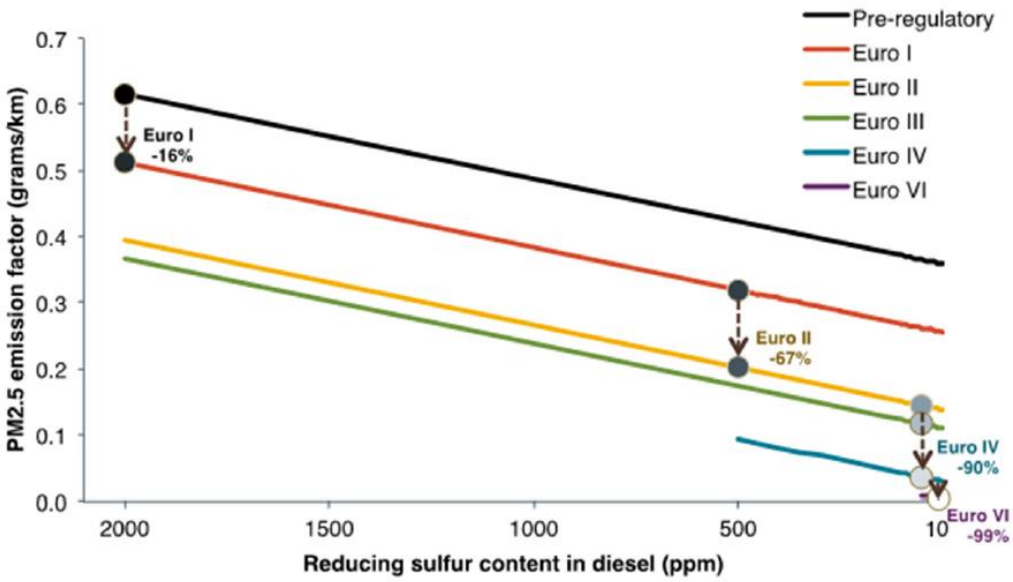


Figure 1.2. Impact of fuel sulfur levels and emissions control standards on $PM_{2.5}$ emissions from heavy-duty diesel vehicles (grams/km)

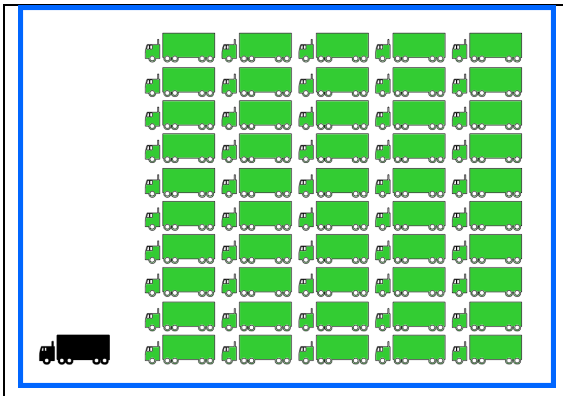
The graph above is taken from the August 2016 report by the Climate and Clean Air coalition (CCAC– see Reference section for more information). The report states that:

"A combined approach of introducing low-sulphur fuels and cleaner vehicles standards will result in major particulate matter (PM) reductions. This figure shows the impact of Euro I-VI standards in heavy-duty diesel vehicles. While lowering sulphur in diesel fuel results in direct and proportional reductions in PM2.5 emissions in all vehicles (even those without emission controls), cleaner fuel ***combined with emission controls*** *at Euro IV and above results in drastic reductions in both PM2.5 and black carbon emissions.*

Vehicles and fuels must be treated as a system to achieve the optimum benefits from emissions control policy, which means matching vehicle emissions standards to fuel quality. (CCAC report page 13)

Lowering sulphur content will reduce sulphur oxide (SOx) emissions. The reduction in other emission levels is dependent upon the age of the vehicle, emission control technology and how well it has been maintained. It also has the potential to reduce vehicle maintenance, such as improved exhaust system durability, and service intervals but this is dependent on vehicle technology, lubricants and operating environmental conditions.

A good example of emission control benefits would be the "magnitude: provided for by Diesel Particulate Filters:



***Fifty trucks** fitted with emission control will emit less emissions than one without*

Without DPF ***With DPF***

2) Many African countries are still high on this trend line. A high proportion of the vehicle fleet is over 10 years old and emission controls are virtually non-existent.

The basis of the above chart is that, under the European clean air acts, improvements in fuels and vehicles were introduced in parallel. In fact, European fuels specifications (EN 590 for Diesel and EN 228 for Gasoline) are linked to enable vehicle technology to achieve Euro exhaust emission specs which are based on European air quality conditions.

In Africa there some regulations on the supply of used vehicles (mainly imports from Europe and Japan) but, unlike OECD countries, there is very little effort to ensure these vehicles have operational emission control systems.

3) Published data suggests that, unlike Europe, many of the air quality problems in Africa are from unique local issues such as road dust and domestic sources such as biomass and charcoal burning and that the use of low sulphur diesel only has limited effect on PM2.5 vehicle emissions

The chart below is taken from the World Bank/ARA Refining and Health Study (2009). The data was developed from quantitative air quality studies that have been performed in three cities - Kampala, Johannesburg and Cotonou (for details of data collection and modelling see study report).

The base case is the current situation. Scenario 1 is the estimated impact if the only change is the introduction of low sulphur fuels (AFRI-4). Scenario 2 is the estimated impact if low sulphur fuels are accompanied by vehicle supply controls and emissions testing.

The data shows that, in the cities chosen for quantitative analysis, the % age of PM2.5 air quality problems associated with vehicle emissions range from:

- Base case: a low of 3.4% to a high of 33.8%
- Scenario 1: a low of 2.9% to a high of 33.1%Scenario 2: a low of 1.2% to a high of 8.2%

In all cases the majority (64.6% to 96.5%) of PM2.5 pollution is from other sources such as road dust and domestic sources (mainly biomass and charcoal burning).

For Benzene pollution the figures are higher but this is mainly a gasoline issue -- very important but not the

subject of this study. It does however highlight the benefits of emission controls.

The data suggest that the impact of introducing low sulphur diesel on its own without vehicle quality control and emissions testing is relatively limited, whereas, improving the quality of the vehicle parc and implementing emissions testing has a major impact. The range of reductions in PM2.5 are as follows:

- Base case to Scenario1: Reductions from 3.4 to 2.9%, 33.8 to 33.1%, 18.5% no change
- From Scenario 1 to scenario 2: 2.9 to 1.2%, 33.1 to 8.2% ,18.5 to 6.9%

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

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

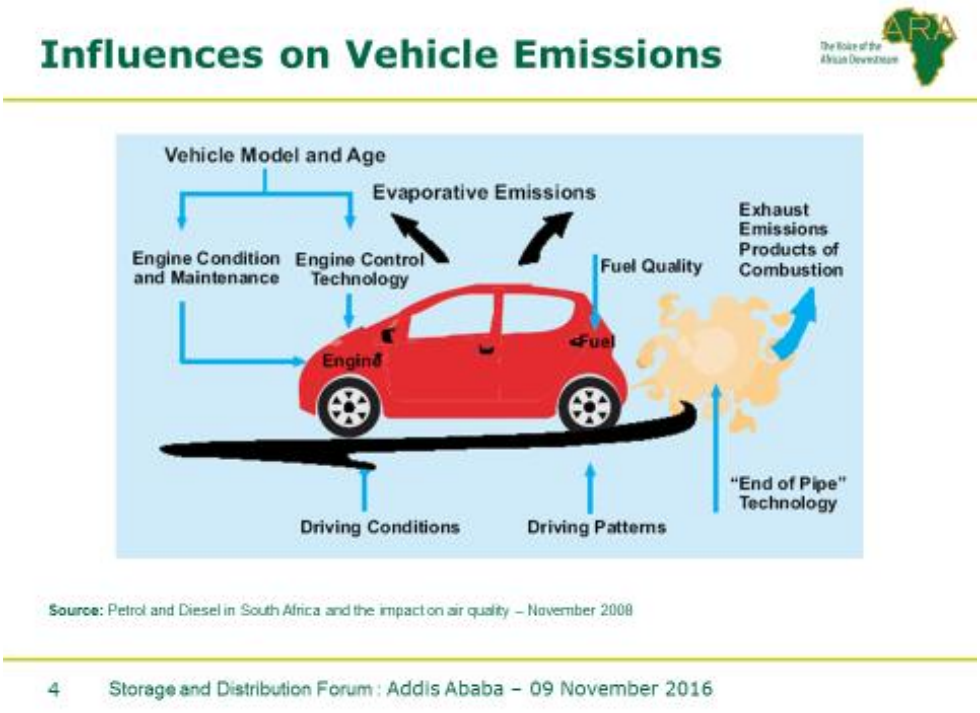
Reading down the columns, this table illustrates the change in the percentage of PM_{10}, $PM_{2.5}$, and benzene emissions from each of the modeled sources (vehicle sources are the **bold** numbers) from Base Case to Scenarios 1 and 2, for each modeled city. Emission reductions for other modeled air pollutants are shown in the study report.

Source: World Bank/ARA SSA refinery and Health study 2009

4) Both the ARA and CCAC consider that, when evaluating policy options it is imperative that fuels and vehicles be treated as an integrated system; in particular, reductions in sulphur need to be linked to the introduction of advanced vehicle technologies and testing regimes in order to ensure significant emission reduction benefits.

The key principles for tackling the reduction of fuel sulphur are defined by IPIECA in their 2006 publication: "Fuel Sulphur: Strategies and options for enabling clean fuels and vehicles" The study underlines that "*fuels and vehicles must be treated as an integrated system, where reductions in sulphur are linked to vehicle technologies in order to maximize emission reduction benefits.*"

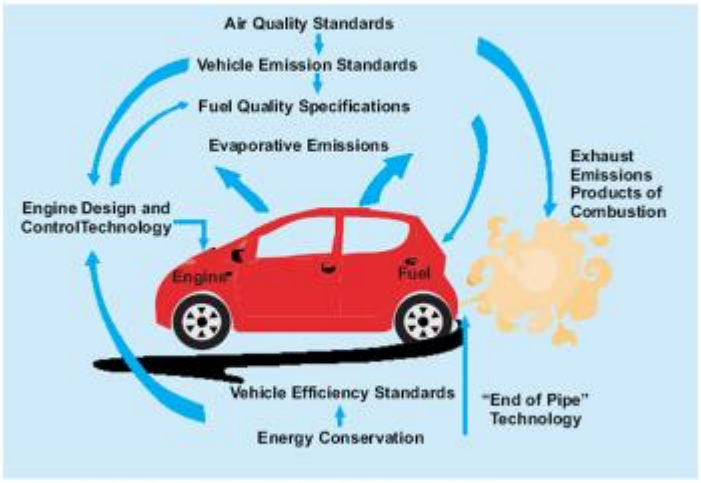
Many factors contribute to the emissions from the vehicle exhaust pipe. Apart from the fuel quality, the vehicle technology (engine design and whether fitted with emission controls etc.), vehicle maintenance and condition, driving patterns and road surfaces all contribute to the impact on air quality.



There are also many drivers of improving vehicle emissions including government policies on air quality, vehicle import regulations, fuel specifications and, most importantly, vehicle testing and emission control. Not all of these drivers are being addressed in Africa and require the same emphasis if the ultimate goal is to improve air quality.

Diesel engines can emit high levels of harmful emissions (PM) and substantially reduce benefits associated with sulphur reduction if they are poorly maintained. Examples of this are over fuelling or high oil consumption. Inspection & Maintenance (I&M) programs help to improve air quality by identifying these high-emitting vehicles in need of repair and putting measures in place to get them fixed.

Drivers of Fuel Quality



Source: Petrol and Diesel in South Africa and the impact on air quality – November 2008

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One way to view Air Quality "dependants" is to consider it like a 3 legged stool (see below), the seat being air quality. The first leg is the vehicle technology – in most of African this in Government policy on vehicle imports. The second leg is the fuel quality; and the third, and most important, is the vehicle inspection controls.

Unfortunately, in Africa there are very few countries (only Rwanda and some testing in South Africa) that have introduced the kind of systematic vehicle control infrastructure that exists in the OECD countries.

5) For nearly 10 years the ARA has been pioneering the improvement of vehicle specifications in Africa

The AFRI specs (1 to 4) were first introduced in 2007. They were modelled on the European system but only focused on fuel quality (one of the ARA's statutory duties) and not on air quality as in Europe.

Since 2009 there has been significant improvement in fuel quality imposed by governments but some governments have been slow to respond. As stated in the CCAC report it has been due to: *"Often, governments in low-and middle-income countries own, or partially own, refineries and exercise control over the national fuel market. In these cases governments may be reluctant or unable to fund refinery upgrade projects through direct public expenditure (and borrowing)"* (Page 21)

And:

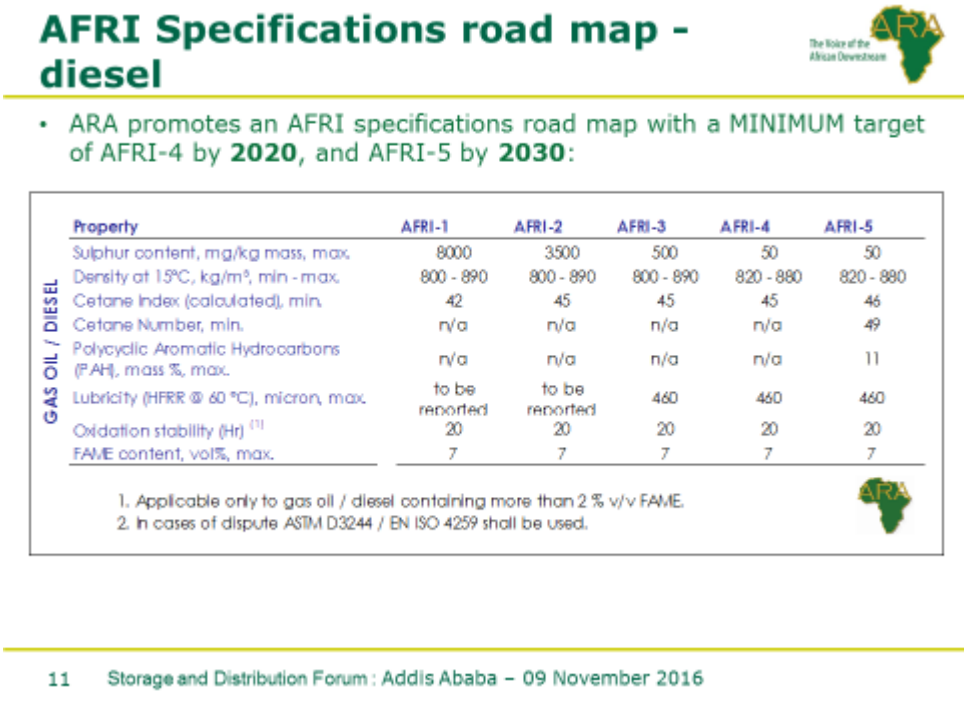
"*For energy security reasons, governments may be unwilling to allow the closure of ailing refineries with a*

questionable long-term future, but are also unwilling to encourage further investment" (Page 21)

And:

"Lack of political prioritization of low-sulphur fuels…..Cleaner fuels and vehicles are rarely prioritized in developing countries, competing for resources and attention with other national developmental issues" (Page 22)

The AFRI specs are a simple system that sets a "road map" towards improving fuels quality and reaching AFRI-5 (introducing PAH limits) by 2030 with an interim 2020 target of all African countries achieving AFRI 4 (50 ppm) by 2020.



AFRI Specs – Test Methods are critical

	Property	Methods
GASOLINE	RON	ASTM D2699 / IP 237 / EN ISO 5164
	MON	ASTM D2700 / IP 236 / EN ISO 5163
	Lead content	ASTM D3237 / ASTM D3341 / IP 270 / IP 228 / IP 362 / IP 352 / EN 237
	Sulphur content [1]	ASTM D2622 / ASTM D5453 / ASTM D4294 / IP336 / EN ISO 20846 / EN ISO 20847 / EN ISO 20884
	Benzene content	ASTM D5580 / ASTM D5443 / ASTM D3606 / ASTM D6730 / ASTM D4815 / EN 12177 / EN 238
	Aromatics	ASTM D1319 / ASTM D5580 / ASTM D5443 / EN ISO 22854
	Density [2]	ASTM D1298 / ASTM D4052 / IP 160 / IP 365 / EN ISO 3675 / EN ISO 12185
	RVP	No alcohol: ASTM D323 / IP 69 / ASTM D5191 / ASTM D4953 / EN 13016-1 With alcohol: ASTM D4953 / EN 13016-1
	Ethanol content	EN 1601 / EN 13132 / ASTM D4815 / EN ISO 22854 / EN 14517 / EN 1601 / EN 13132

	Property	Methods
GAS OIL / DIESEL	Sulphur content [1]	ASTM D2622 /ASTM D5453 / IP336 / ASTM D4294 [1] EN ISO 20846 / EN ISO 20884 / EN ISO 13032
	Density [2]	ASTM D4052/ D1298 /IP 160 / IP 365 / EN ISO 3675 / EN ISO 12185
	Cetane Index	ASTM D976 / ASTM D4737 / EN ISO 4264
	Cetane Number	ASTM D613/ ASTM D6890 / ASTM D7668 / ASTM D 7170a / IP 41 / EN ISO 5165 / EN 15195
	Polycyclic Aromatic Hydrocarbons	IP391 / ASTM D2425 / EN 12916
	Lubricity	ISO 12156-1
	Oxidation stability	EN 15751
	FAME content	EN 14078

1. In case of dispute test method ASTM D5453 shall be used.
2. In case of dispute test method ASTM D4052 shall be used.
3. Appropriate method to be selected for applicable specification measurement range.

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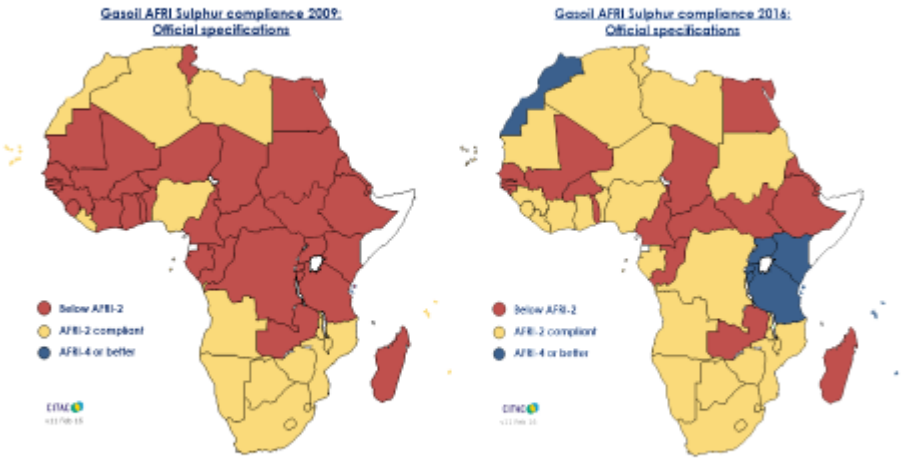
6) Have the AFRI specs worked?

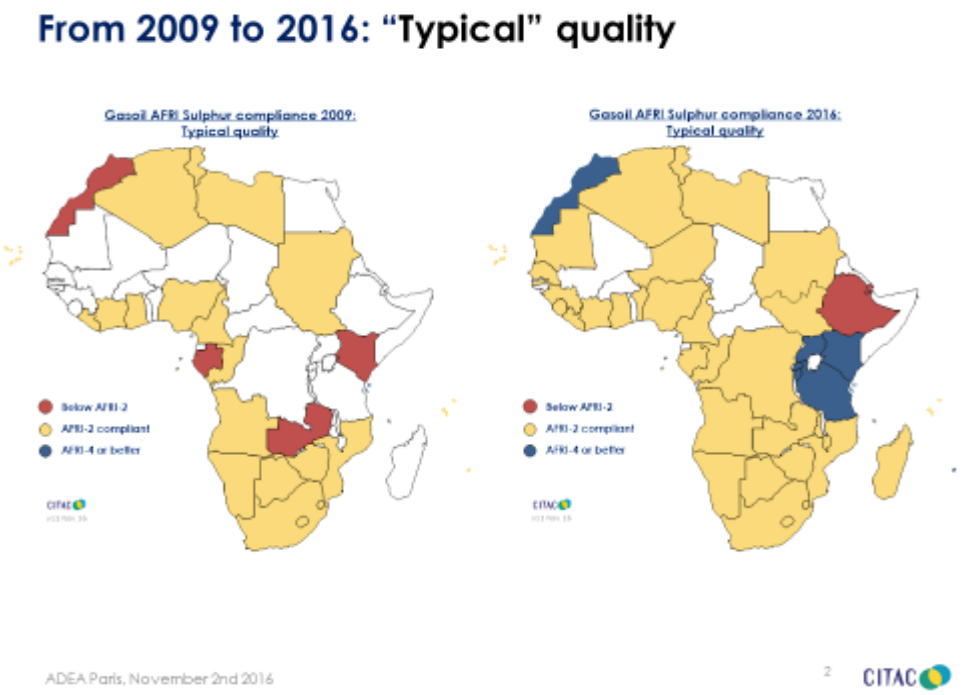
There have been significant improvements since countries started to consider AFRI Specs as their road map. For diesel, between 2009 and 2016, 18 countries improved their specs but 12 of the 55 countries are still below AFRI 2. Recently the East African Community and Morocco moved to AFRI 4

From 2009 to 2016: 18 countries improved



ADEA Paris, November 2nd 2016 CITAC

It is important to note that these are only **maximum specifications.** Data collected by CITAC Africa Ltd suggests that the **actual** ("typical") quality being used is significantly better than the official specifications predominately resulting from imports.



Typical quality is identified by tracing the normal supply path and the normal quality of product produced by refineries or imported.

Whilst there has been improvement, the ARA is not complacent about this. The ARA has:

a) Had regular meeting of the Specifications Work Group (3 or 4 per year) to discuss how further pressure can be placed on governments to improve specifications
b) Co-financed with the World Bank a study into the health impact of low quality fuels and concluded that sub-Saharan African refinery shareholders (mainly governments) should invest to produce AFRI 4 quality products as soon as possible. The study, conducted by ICF international and ENSYS, concluded that, over a 10 year period, an investment of $6.14 billion in the 22 operating refineries would produce a health benefit of $43 billion. The recent CCAC study (also using the

ENSYS model) put the cost estimate of converting all 39 African refineries to produce 50ppm sulphur gasoline and diesel at $7 billion (Page 46)

c) ARA has arranged training courses and forums to present the conclusions of this and other studies to a wide variety of industry, government and regional officials Including UNEP, PCFV, IPIECA, ECOWAS, IEA, African Union and the EU.

7) What can be done to reduce air pollution in the short term?

The ARA supports the recommendation made in recent reports by Public Eye and CCAC that governments of importing countries should move as quickly as possible to tighten their specifications. But, as CCAC points out, in West Africa (Page 26),

"*The sub-region has six refining countries, with some producing fuel mainly for their internal market while others produce for export. There is little trade interaction with other African sub-regions, apart from a small volume of sweet crude sales to…… South Africa. Of the three main producers in West Africa – Cote d'Ivoire, Nigeria and Ghana – Ghana and Nigeria mainly produce finished fuels for their internal market while Cote d'Ivoire exports high-sulphur fuel to 12 of its neighbours, all of which are exclusive fuel importers. This has significant implications for our approach in West Africa*"

The highly inter-connected supply chain nature of this region requires a regional approach. The ARA has been meeting with the ECOWAS energy group that oversees refining and import activities to discuss an implementation study and adopting the AFRI specifications in the region.

But, as pointed out by CCAC and Public Eye, there is nothing to stop Ethiopia, Mozambique and even Nigeria (the largest importer in Africa due to very low refinery activity) from raising their import specifications and contributing to the improvement of air quality.

But there is much more that could, and should be done. Unlike the OECD countries, there is very little reliable and regular data in Africa in the form of air quality measuring, car parc analysis and vehicle testing. This is now increasing as the EU, US EPA, NGO's and others put pressure on African governments and provide funding for the collection of data.

8) Government policies are the key to change and some have recently been successful. For example, in many countries the import of 2 stroke motorbikes has been banned and replaced by considerably less polluting 4 stroke motorbikes. This has had a significant effect on air quality.

How do African efforts to improve product quality compare with other regions such as Europe?

"Euro" terminology is used to describe European emission standards for vehicles. Linked to these emissions standards are fuel quality referred to as EN 228 spec for gasoline and EN 590 for diesel.

The emission standards are regulated in the EU legislative acts (regulations) with the progressive introduction of gradually more stringent requirements over time since its initial inception. European institutions have set several directives since the 1970s relating to emissions.

The EU Auto Oil Programs results (shown in the timeline below) confirm that both fuels and engine technologies are important determinants of motor vehicle emission levels. Relationships among fuel properties/engine technologies/exhaust emissions were established and led to the development of equations necessary for input into Air Quality modelling. Main changes to fuel and vehicles were then proposed by the European Commission under Auto Oil I and II versus the fuel quality and vehicles emissions regulations prior to year 2000 (1992: Euro 1, 1996 Euro 2 and EN228:1993, EN 590:1993). These

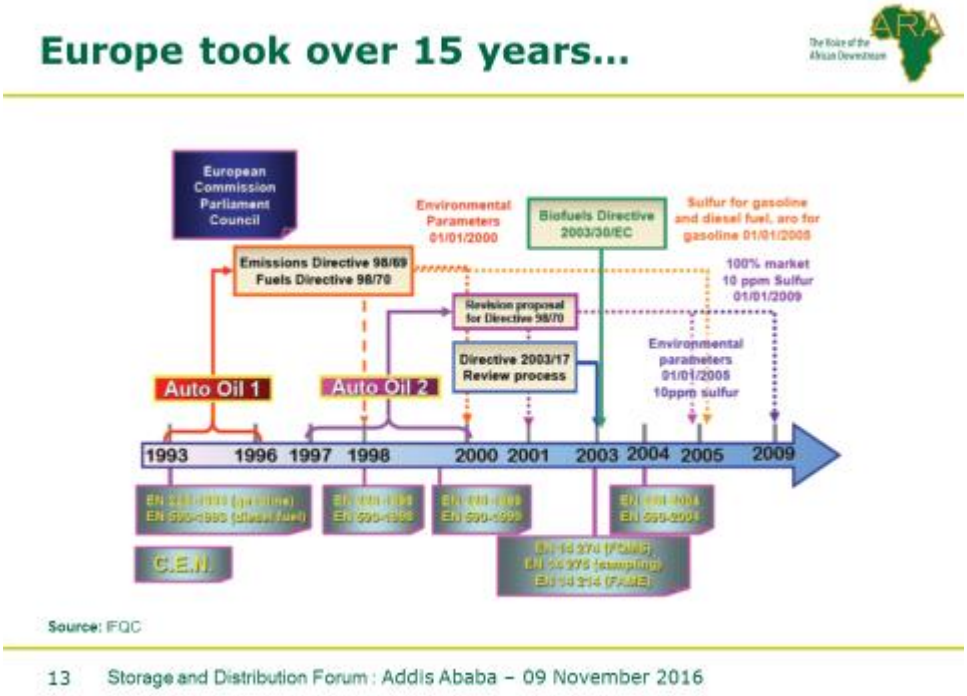
changes included sulphur reduction in both diesel and gasoline over time with 10ppm introduced in 2009 together with Euro 5 emission limits. Euro 6 emission limits were introduced in 2014.

EU Diesel Sulphur:

Specification	**Sulphur**
EN 590: 1993-96	2000 / 500 mg/kg
EN 590: 2000	350 mg/kg
EN 590 : 2005	50/10 mg/kg
EN 590: 2009	10mg/kg

The EN 590: 1993 was the first EU diesel fuel specification established and had a maximum sulphur level of 0.2% by weight.

The diagram below shows the timing of this process.



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Initially, African cities were considerably less crowded and there were many fewer vehicles compared to Europe. In many ways the cities were like provincial towns in Europe and the air quality was acceptable. Steady migration to the cities over the past 20 years and the rise in GDP/capita led to more vehicles on the roads and a rapid deterioration of air quality in major African cities.

The 2009 World Bank/ARA study was one of the first studies to address this growing issue. But the data presented (see earlier table) showed that the air quality was only partly due to vehicle emissions but also due to domestic sources, road dust and, in coastal cities, shipping. So the reception by African governments was muted despite World Bank and ARA pressure.

Seven years later it is clear to all who live in major African cities that the quality of air is often unacceptable. The AFRI spec approach began in 2007 and reaches to 2030 when AFRI 5 should be in place in all countries.

November 2016
ARA Specifications Work Group

REFERENCES

ARA: Founded in 2006, ARA is a Not-for-Profit Association representing the pan-African downstream oil industry.

- It is a platform for debate, policy foundations and development of best practice for all downstream players – not just for refiners.
- Gives a voice not only to African refiners but also to independent importers, distributors, marketers and regulators
- Promotes exchange of experience and best practice between all downstream stakeholders
- Strives to improve communication and cooperation between its Members and the international oil market
- Offers cooperation & coordination with relevant industry groups, governments, regulatory bodies, international agencies, International Financial Institutions, academic institutions and other NGOs
- The ARA has formal anti-trust provisions within its Constitution

CCAC: Climate and Clean Air Coalition:

- The Climate and Clean Air Coalition, working closely with UNEP, is the only global effort that unites governments, civil society and private sector, committed to improving air quality and protecting the climate in next few decades by reducing short-lived climate pollutants across sectors.
- Complementary to mitigating CO_2 emissions, the Coalition acts as a catalyst to create, implement and share immediate solutions addressing near-term climate change to improve people's lives rapidly, and to ensure sustainable development for future generations.
- Study: August 2016: Cleaning up the Global on-road diesel fleet--- A global strategy to introduce Low sulphur fuels and cleaner diesel vehicles

Public Eye: (Formerly Berne Declaration)

- Public Eye fights against injustices with a significant link to Switzerland. For around fifty years, the non-governmental organisation Public Eye has offered a critical analysis of the impact that Switzerland, and its companies, has on poorer countries

- 2016 published "Dirty Diesel" – How Swiss traders flood Africa with Toxic fuels

World Bank/ARA Refining and Health Study (2009)

- A Study co-financed by the World Bank and ARA to measure the impact of raising fuel quality to AFRI 4 across sub-Saharan Africa
- Tender for the study was won by ICF international of Fairfax Virginia , USA who worked with ENSYS Energy (global modelling) of Lexington, Mass, USA and various leading health monitoring professionals in US Universities

IPIECA - International Petroleum Industry Environmental and Conservation Association

- IPIECA is the global oil and gas industry association for environmental and social issues. We have been championing best practice in environmental and social performance for over 40 years.

- "Fuel sulphur: Strategies and options for enabling clean fuels and vehicles" A fuels and vehicles working group report that considers the issues linked to the reduction of sulphur levels in transportation fuels, and discusses appropriate strategies and options to address these issues based on local circumstances.