

美麗的香港

Beautiful Hong Kong



A Report to the Government of HKSAR giving a practical, cost-effective and timely way to remove pollution from the air of Hong Kong and restore its traditional status as “The Fragrant Harbour”.

By: John Robertson MA OBE

This report identifies the real air quality problem in Hong Kong, shows why it has not been solved by the well-intentioned measures taken to date and lays out a strategy to give Hong Kong clean air within a structured 6-year time span.

Why does Hong Kong still have SMOG when many comparable cities around the World got rid of SMOG decades ago? Given the demanding circumstances of compact, populous and prosperous Hong Kong, the reason is that some of the measures taken to remove air pollution have been misdirected or, when correctly directed, have been inadequate to do the job properly.

This report identifies and concentrates on the correct targets and puts forward practical measures which are fully sufficient (>90% pollution reduction) to bring clean air to Hong Kong.

It asks readers to be wary of superficially attractive but flawed proposals which are, yet again, misdirected or inadequate for the job.

Money spent on the wrong things now will not be there to spend on the right things later.

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Then he was a fighter pilot for 8 years in the RAF reaching the rank of Wing Commander and gaining the Queen's Commendation for Valuable Service in the Air. Later he was made an OBE.

He has three sons, one daughter, ten grandchildren and marvellous wife, Julie. His civilian life was spent engineering and farming. He loves walking in clean air and swimming in clean sea.

He was prompted to produce this personally funded report by questions and suggestions about air quality from friends in Hong Kong over some 18 months. Hopefully it will be a useful contribution to making Hong Kong an even more attractive and important City than it is today.

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The Fragrant Harbour with Clean Air by Day and Night



Improving Air Quality in Hong Kong

A Report to the Government of the Hong Kong Special Administrative Region

by

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20th October 2012

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Prologue

Bad air quality in Hong Kong is all too familiar. The harm it does to the amenity, well-being and health of all has been described and reported countless times. The damage it does to Hong Kong's economy, "*the most polluted air of any world financial center*" (Bloomberg News) is also a painful fact. Public perception and official reports indicate that matters are getting worse rather than better. A recent leading article in the South China Morning Post reported that air quality in Hong Kong in 2012 is the worst that has ever been measured.

So what to do? Answer: capture the two villains responsible: **PM (RSP)** and **NO_x**. Much more about them follows later.



These villains are home grown and lurk in the exhausts of every internal-combustion engine in Hong Kong. Their favourite hideout is in old diesels.

This report is about how to capture them and convert them into good citizens. When captured and reformed, **PM** becomes benign carbon dioxide (CO_2) - the vital basis of all plant growth. **NO_x** becomes nitrogen (N_2) - the main constituent of clean air - plus pure water (H_2O).

Lasting credit will accrue to those who make the capture and bring about the reformation. All who live and work in Hong Kong will experience massive and continuing benefit as a result.

What action is needed to make this happen? Legislate for high emission standards for **all** vehicles, construction plant, vessels and other engines in Hong Kong by means of **HK1** to **HK6**. (Details and timeline are on page 6). Monitor and enforce those standards rigorously.

Executive Action Summary

1. Recognise that bad air quality in Hong Kong damages the health of its citizens, reduces their amenity, harms the environment, wounds the economy and is unworthy of 'The Fragrant City'.
2. Resolve to clean up the old and dirty engines which are the main cause of bad air quality Hong Kong. Simultaneously require all new engines to meet the highest international emission standards. Doing this is essential to give Hong Kong clean air. Consistently clean air will benefit all citizens' well-being, improve the environment, strengthen the economy and bring lasting credit to those who make it happen.
3. Create new HK1 to HK6 emission standards related to the EURO equivalent but applying to existing vehicles and engines as well as to new ones. Existing engines will require to be upgraded or, if upgrading is not possible, to be scrapped progressively from 2013 onwards until all are of HK6 standard by 31/12/2018. See time-line on page 6.
4. Apply the HK standards to all internal combustion engines on the land or the waters of HKSAR be they in cars, trucks, buses, construction plant, port or airport equipment, ferries or other local vessels.
5. Leave owners of vehicles or engines to choose how they meet the standards and require them to pay the costs of doing so.
6. Accept that this will cause real hardship for some and establish a fund to alleviate it. In this context 'real hardship' means a threat to employment or livelihood – not mere cost or inconvenience.
7. Extend the existing requirement that all road vehicles in Hong Kong use ultra-low-sulfur (<10 ppm sulfur) diesel to all diesel engines used in HKSAR including those in ferries.
8. Filter out diesel smoke in diesel exhausts; not in human lungs. Get rid of the NO_x and the SMOG will get rid of itself.

Clean from the Bottom Up

Europe has led the way in successfully cleaning up what was notoriously dirty air in some of its big cities. A key element has been control of exhaust emissions from vehicles and other engines. Please see tables of EURO standards on pages 18-22.

In most countries emission standards apply to new vehicles coming on to the road but not to existing ones. Because of the very large fuel use per Km² of land area in HKSAR compared to world average, this process will not suffice for Hong Kong. High standards for new vehicles will, of course, be essential but they alone will not be sufficient to clean Hong Kong's air within a reasonable period. Old and polluting engines on the roads, construction sites or waters of Hong Kong will need to be upgraded or removed from service to meet the higher standards. This will be a very big task and will require total concentration to achieve it. The prize is great.

The **HK** technical standards will lie securely within the envelope of international EURO standards to ensure that vehicles are available from the international market to meet Hong Kong's needs. For those diesel engines which are not on the roads but on construction sites or ferries for example, the EURO standard for heavy duty diesels based on allowable emissions per KW_{hr} will apply from **HK1** to **HK6**. **HK6** will apply the European requirement relating to particle emission per kilometre to vehicles but not to off-road diesels or to those in ferries and other vessels.

HK1 to **HK6** will also apply to all existing engines (in this it will differ from the EURO standards). After 2018 **HK6** will apply one uniform, high standard to new and old right across the board. Until that time the **HK** standards, on a scale which rises annually, will derive from the 'EURO' standards and will be as follows over the years 2013 to 2018:

	Year	Existing Engines by year end	New Engines all year
HK1	2013	EURO I or higher	EURO V or higher
HK2	2014	EURO II or higher	EURO V or higher
HK3	2015	EURO III or higher	EURO V or higher
HK4	2016	EURO IV or higher	EURO VI (HK6)
HK5	2017	EURO V or higher	EURO VI (HK6)
HK6	2018	EURO VI (HK6)	EURO VI (HK6)

Existing engines which do not comply must be upgraded to the required level or withdrawn from use. By the end of 2016 only EURO IV or better (**HK4**) will remain in Hong Kong. The **upgrade or removal of dirty engines cannot be optional**.

Improving Air Quality in Hong Kong

Distribution of Vehicles in HKSAR according to Emission Category for Year 2011 - Courtesy of EPDHK – the Environmental Agency of the Hong Kong Government

EPDHK maintains excellent statistics on the factors affecting the air quality of Hong Kong. They have kindly made the following tables available to the author who has added **totals in bold**.

	Emission Categories							
Vehicle Class	Pre-Euro	Euro I	Euro II	Euro III	Euro IV or above	Pure Electric Vehicles		
	No of Licensd Vehicles							
Private Cars (Petrol)							Totals	
<1500 cc	3,798	16,560	16,506	26,306	37,108	172	100,450	
1501-2500cc	5,828	20,304	23,050	61,028	99,326		209,536	
2501-3500cc	2,032	6,473	8,866	30,589	45,110		93,070	
3501-4500cc	806	1,211	638	5,170	6,783		14,608	
>4500cc	938	709	1,403	3,219	8,867		15,136	
Private Cars (Diesel)								
<1500 cc	1	0	0	0	0			1
1501-2500cc	568	231	19	1	0			819
2501-3500cc	404	407	46	2	328			1,187
3501-4500cc	13	1	0	0	0			14
>4500cc	0	0	0	0	0		0	
Goods Vehicles								
<=1.7 tonnes	13	0	1	3	0	6	23	
> 1.7 tonnes	17,802	12,061	21,894	27,449	31,935		111,141	
Public Buses	449	1,056	4,143	3,636	3,500	0	12,784	
Private Buses	47	22	108	151	164	1	493	
Public Light Buses	21	328	492	2,860	644	0	4,345	
Private Light Buses	343	378	286	343	844	4	2,198	
Taxis	1	1	14,402	1,517	2,322	0	18,243	
Motorcycles	5,211	18,510	0	14,830	0	15	38,566	
Totals	38,275	78,252	91,854	177,104	236,931	198	622,614	
% of Totals	6.1%	12.6%	14.8%	28.4%	38.1%	0.03%	100%	

Remove or upgrade by end of: **2013** **2014** **2015** **2016** **2017**

All vehicles will be HK6 by end of 2018. Hybrid vehicles in the above table are classified as petrol.

Non-Road Mobile Machinery (NRMM) – data courtesy of EPD HK

Number & applications: There are about 13,500 units of NRMMs operating in Hong Kong. 11,300 units are operating at construction sites, 1,600 units at the airport and 600 units at container terminals.

Age and service life: The estimated average age and the average service life remaining of these NRMMs are about 8 years and 14 years respectively.

Type of fuel used: Mostly diesel driven.

Engine size: In great diversity, small engines of several kW to large engines of more than several hundred kW.

Emission contributions: About 7% (6,800 tonnes) and 11% (600 tonnes) of the local emissions of nitrogen oxides and respirable suspended particulates respectively. *(Author's note: these emissions come from some 2% of the total engines in use in Hong Kong.)*



Urban Construction; a Hong Kong Street Scene - July 2012

See also: <http://www.healtheffects.org/Slides/AnnConf2012/Wall-SunPM.pdf>

Distribution of Installed Engines on Ferries for Year 2011 (at June 2011)

Number of Licensed Ferries: 56

Engine Type	Number of Engines Installed	Average Engine Age (years)	Average Engine Power (kW)
Main Engine	98	20.6	859.9
Auxiliary Engine	121	24.2	100.3

All engines are diesels. Engine age was calculated by the built year of the vessels.



Hong Kong Ferry Berth - Sept 2012

What does this mean for Hong Kong's Air Pollution?

The calculations which follow are based on the EPDHK tables above and on the EEC EURO emission tables (on pages 18-22). They total the current levels of NO_x and PM pollution in tons per day from vehicles and other engines in Hong Kong **(in red)** and compare that with the pollution which the same number of vehicles and engines doing the same job would produce if they all met HK6 (EURO VI) emission standard **(in green)**. The improvement is dramatic!

They make the detail assumption that pre-EURO emission levels are, on average, 1.5 times the EURO I figures for PM and 1.25 times for NO_x. They also make assumptions (*shown in italics*) about engine power and the annual hours or kms of use. If those assumptions are in error, the results on both sides of the ledger will change correspondingly. The comparison and the conclusion will not change.

Diesel Trucks & Buses

A truck or bus is assumed to average 80 Kw and to run for 1,000 hours per year.

	PreEURO	EURO I	EURO II	EURO III	EURO IV		EUROVI/HK 6	
	17,802	12,061	21,894	27,449	31,935	Trucks		
	449	1,056	4,143	3,636	3,500	Public Buses		
	47	22	108	151	164	Private Buses		
						Total Diesels	124,417	
Totals	18,298	13,139	26,145	31,236	35,599	Euro Limits	0.4	grams/Kwhr
NOx	10	8	7	3.5	2	Euro limits	0.01	grams/Kwhr
PM	0.9	0.61	0.15	0.1	0.02			
Pollution Emitted in Tons/Day						Current Totals	HK6 totals	
NOx	40	23	40	24	16	143	11	Tons/Day
PM	3.6	1.8	0.9	0.7	0.2	7	0.3	Tons/Day

Non-Road Mobile Machinery (NRMM) – data courtesy of EPDHK

Average machine is assumed to be 80 Kw and to operate for 3,000 hours/yr

Emissions at present as per EPDHK estimate.

			EUROVI/HK 6	
			13,500	
			0.4	grams/Kwhr
			0.01	grams/Kwhr
			Current Totals	HK6 totals
NOx	13,500	Per EPDHK	18.6	3.6
PM	1.6	Per EPDHK	1.6	0.1

Ferries - data courtesy of EPDHK

Engines as per EPDHK. They are over 20 years old so are assumed to be pre-EURO.

They are assumed to operate for 3,000 hours per year.

83,888	98 @ 856 Kw each		EUROVI/HK 6	
12,100	121 @ 100 Kw each		95,988	
95,988	Kw total		0.4	grams/Kwhr
NOx	10		0.01	grams/Kwhr
PM	0.9			
			Current Totals	HK6 totals
Pollution Emitted in Tons/Day			7.9	0.3
NOx	7.9		0.7	0.01
PM	0.7			

Private Cars, Taxis, Light Buses, Commercials and Motorbikes

Average petrol/LPG vehicle is assumed to travel 10,000 km per year

	PreEURO	EURO I	EURO II	EURO III	EURO IV		EUROVI/HK 6	
Total s	19,977	65,113	65,709	145,868	201,332		497,999	
NOx	0.25	0.2	0.2	0.15	0.08	Euro Limits	0.06	grams/Km
PM	0.9	0.61	0.15	0.1	0.02	Euro limits	0.005	grams/Km
Pollution Emitted in Tons/Day						Current Totals	HK6 totals	
NOx	0.1	0.4	0.4	0.6	0.4	1.9	0.8	Tons/Day
PM	0.5	1.1	0.3	0.4	0.1	2.4	0.1	Tons/Day

Summary of Change:-		Current	HK6	
NOx	179	15.9	11:1	
PM	12	0.4	30:1	

The tables above show that the change from the present emissions regime in Hong Kong to HK6 standards will reduce the SMOG-producing, throat-irritating, eye-watering NOx emitted per day from its present 179 tons to 16 tons. Emissions of lung-cancer-inducing PM (RSP) will be reduced from 12 tons to less than half a ton per day. Those large improvements will make Hong Kong's air among the best for any big city in the World.

Observe that the reduction of PM by 11.6 tons/day means that this amount of PM is captured in the vehicle exhausts and there burned off to harmless CO₂.

11.6 tons/day less PM  42.5 tons/day more CO₂

They also underline once again that older diesels are the main problem and that their upgrading or removal is the key to good air quality in Hong Kong.

'Criteria air pollutants'

'Criteria air pollutants' is a term used internationally to describe air pollutants that are regulated and used as principal indicators of air quality. The regulations or standards are based on criteria that relate to health and/or environmental effects. The six pollutants are:

Carbon Monoxide (CO)
 Lead (Pb)
 Nitrogen Dioxide (NO₂)
 Ozone (O₃)
 Particles, i.e. smoke or very fine dust, (PM₁₀, PM_{2.5}) - Called RSPs by EPDHK
 Sulfur Dioxide (SO₂)

Carbon monoxide (CO) is the product of incomplete combustion of any solid or liquid fuel. In a piston engine the fuel-air mixture has a very short time to burn (0.01 seconds at 3,000 rpm) and so combustion is often not complete when the exhaust valve opens. This is exacerbated if the mixture is 'rich', e.g., when starting. A petrol engine typically has around 0.7% of CO in the exhaust as it leaves the cylinders. CO is fatal at about 0.08% in the atmosphere.

Piping the exhaust into a closed car was quite a common resort of intending suicides before the advent of modern catalytic converters. Today these catcons oxidise about 95% of the CO to **benign CO₂**. This brings CO below the fatal level when leaving the exhaust. In the open air it dilutes rapidly to become innocuous.

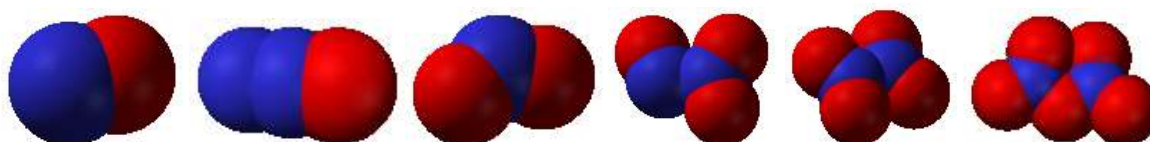
CO is dangerous if indoor combustion heaters, however fuelled, are inadequately ventilated. Beware also that **small petrol engines** on, say, lawn mowers or household generators, do not usually have catcons so the **CO in their exhaust fumes can be fatal** in closed spaces.

'Town-gas' is still used by about 1.7 million Hong Kong residents. This gas has **1% to 3% of CO**. This concentration is well into the fatal range so 'putting your head in the gas oven' is still a lethal possibility for those users. The gas has a special odour added to prevent accidental poisoning.

Lead (Pb) was a very important pollution from vehicles thirty and more years ago because it was used widely to improve the octane rating of petrol. Now in most parts of the world it is no longer a significant pollutant as lead in petrol has been banned. There is no lead in diesel fuel and there never was. Lead pollution remains important as dust in the vicinity of Lead-Zinc mines and as a constituent of old paint in old buildings.

Nitrogen Oxides (NO_x)

Nitrogen Oxides, (NO_x) are of especial importance in Hong Kong. There are many such oxides, viz:



Nitric Oxide NO Nitrogen Dioxide NO₂ Nitrous Oxide N₂O Dinitrogen Trioxide N₂O₃ Dinitrogen Tetroxide N₂O₄ Dinitrogen Pentoxide N₂O₅

Nitrogen oxides are produced during high temperature combustion of solid, liquid or gaseous fuel in air. The air itself is about 78% nitrogen so there is ample present but nitrogen

(N₂) is generally very reluctant to combine with the 21% of oxygen (O₂). It takes temperatures over 1,500°C to make it happen.

In addition there are a variety of substances that are not polluting in their own right but which can react with one or more of the nitrogen oxides to give unpleasant or dangerous products. Some of those are components of SMOG. This term was coined long ago to describe the “Smoky Fog” then common in big cities such as London. In those days smog was the product of coal fires. The smoke and SO₂ coming from burning coal in open domestic fires gave choking SMOG. The UK Clean Air Acts of the 1950s cleared that type of smog by banning open coal fires in towns and cities.

Today NO₂ can fill the disagreeable role that SO₂ did in decades past and itself form reddish-brown smog. Today’s smog is also photochemical. That is to say it is caused by reactions between the NO_x and a wide variety of volatile organic compounds (VOCs) under the action of strong sunlight. The smog consists of one or more of NO₂, O₃ and PANs.

Ozone O₃

O₃ has a split personality. When it is high in the stratosphere it provides an essential protective blanket shielding us and other animals from excess ultra-violet rays. All countries, including Hong Kong, agreed to ban the use of fluoro-carbon refrigerants because they were destroying the ‘ozone layer’ and potentially exposing us to skin cancer and other harmful effects. This was a very good example of everyone acting in unison to stop damaging pollution. Sound science brought immediate general consent and action notwithstanding the cost.

However, at ground level ozone is a different beast altogether. It is produced by the interaction of NO_x (NO₂ especially) and VOCs (see below) in strong sunlight. It is a major cause of photochemical SMOG.

Respirable Suspended Particulates RSP, PM₁₀, PM_{2.5}

They have many technical names but are usually called PM – Particulate Matter. PM is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.

The size of particles is directly linked to their potential for causing health problems. Small particles less than 10 micrometers in diameter pose the greatest problems, because they can get deep into your lungs, and some may even get into your bloodstream.

Exposure to such particles can affect both your lungs and your heart. Small particles of concern include "inhalable coarse particles" (such as those found near roadways and dusty industries), which are larger than 2.5 micrometers and smaller than 10 micrometers in diameter; and "fine particles" (such as those found in smoke and haze), which are 2.5 micrometers in diameter and smaller.

Particle pollution - especially fine particles - contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including:

- premature death in people with heart or lung disease,
- nonfatal heart attacks,
- irregular heartbeat,
- aggravated asthma,
- decreased lung function and
- respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing.

People with heart or lung diseases, children and older adults are the most likely to be affected by particle pollution exposure. However, even if you are healthy, you may experience temporary symptoms from exposure to elevated levels of particle pollution.

PM has other bad effects including:

- ***Impaired visibility.*** Fine particles (PM_{2.5}) are one of the main causes of reduced visibility in Hong Kong.
- ***Aesthetic damage.*** Particle pollution can stain and damage building stone and other materials, including culturally important objects such as statues and monuments.

Sulfur Dioxide SO₂ SO₂ is important whenever a fuel containing sulfur (S) is burned. Some coals have 4% sulfur or even more. The coal used in Hong Kong power stations is at the opposite end of that scale with very low sulfur. Allied to Wet Flue Gas Scrubbing, this has led to the level of SO₂ in Hong Kong's air being well below the WHO guidelines. It is the only criteria pollutant (other than lead) in that happy state in Hong Kong and that reflects particular credit on the electricity utility companies. Electricity generation from coal is typically the main cause of SO₂ pollution worldwide. The low levels in Hong Kong are admirable.

For solid fuel, i.e. coal, it is only practicable to absorb and remove the sulfur after combustion. For liquid fuels such as diesel it is much better to remove the sulfur at the oil refinery. The recovered sulfur has a significant value. The ultra-low sulfur fuel now mandated for road vehicles (<10 ppm S) in Hong Kong means that SO₂ from vehicles is negligible. The ultra-low sulfur in diesel is very important to optimize the performance of DPF and SCR pollution controls (see further below) on diesel engines.

Sulfur in Fuel All fossil fuels contain some sulfur. For modern oil fuel, sulfur is removed at the oil refinery so that its level is negligible (0.001%). When sulfur is burned it produces highly toxic and damaging sulfur dioxide (SO₂) which is a critical air pollutant. The burning may also produce smoke. In the jargon of air quality this smoke is called Particulate Matter (PM) or Respirable Suspended Particles (RSP). Such tiny particles, especially those from diesel engines, are very harmful to health.

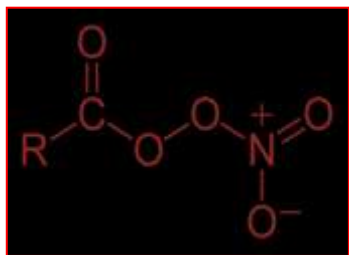
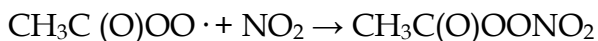
Around the World coal-burning power stations are, by far, the main source of sulfur emissions. It is much to the credit of the power utilities in Hong Kong, therefore, that the current SO₂ levels as measured by EPDHK are about half of the WHO guidelines. This is despite the use of about 11 million metric tons of coal annually to produce Hong Kong's electricity. It is highly commendable and shows the way to go:

Top Technology + Capital = Clean Air

And Two Extras:

VOCs range from petrol spilt and evaporated on a service station forecourt, through unburnt fuel emitted from a car's exhaust to natural oily vapours from trees. For example, in the City of Brisbane in Australia some 60% of the VOCs come from the splendid Eucalyptus trees growing profusely throughout the metropolis. Methane, natural gas, (CH₄) is usually excluded from VOCs and they are sometimes called NMOGs – Non-Methane Organic Gases. The reactions and the balance between NO, NO₂ and O₂ is complex. In strong sunlight they react with the VOCs to produce SMOG – mainly as NO₂, O₃ or PANs. However, if NO_x is not present this does not happen.

PANs, Peroxyacyl Nitrates (also known as APNs), are powerful respiratory and eye irritants. They are produced by the gas-phase oxidation of a variety of volatile organic compounds (VOCs), or by aldehydes and other oxygenated VOCs oxidizing in the presence of NO₂. The final step is a combination of a peroxyacyl radical and NO₂ for example, peroxyacetyl nitrate CH₃C(O)OONO₂.



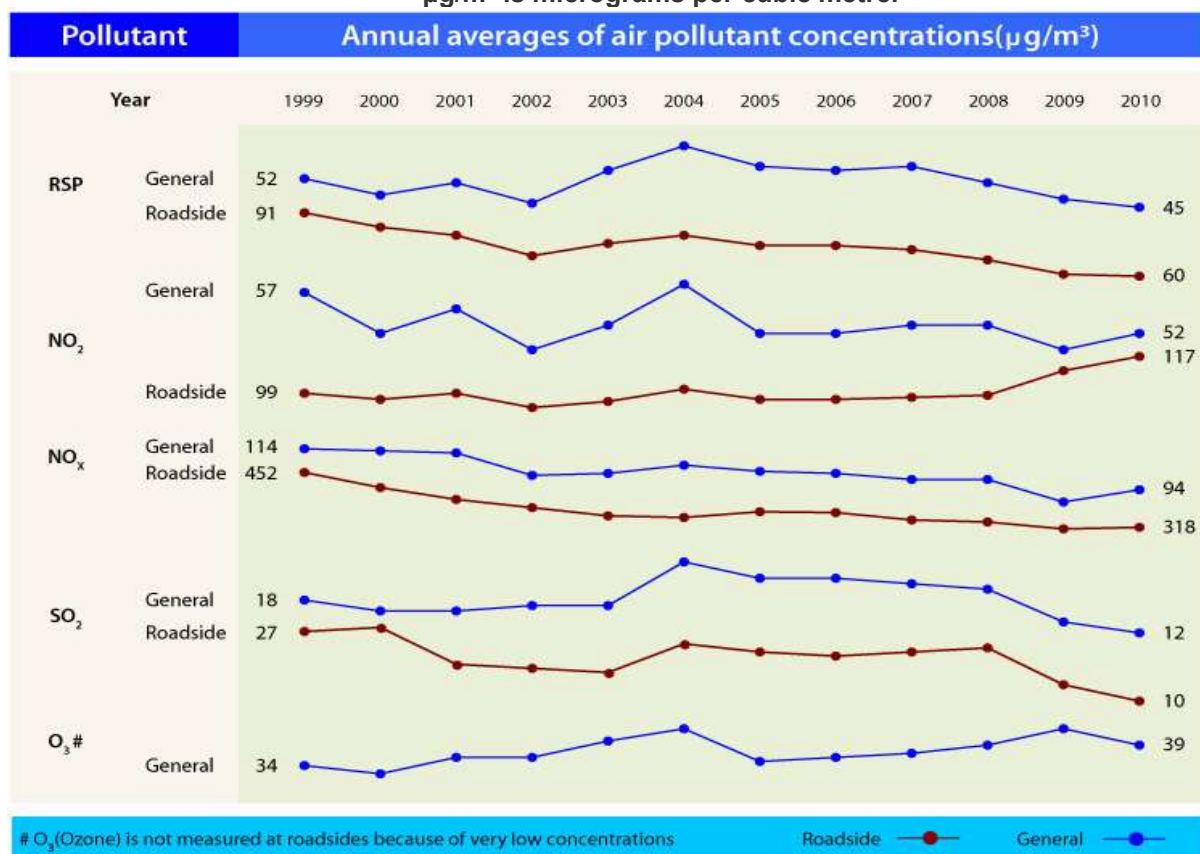
PANs are toxic and irritating because they dissolve more readily in water than Ozone O₃. They are lachrymators, causing eye irritation in concentrations of only a few parts per billion. At higher concentrations they cause extensive damage to vegetation and human tissue. Both PANs and their chlorinated derivatives are said to be mutagenic; that is, they can cause cancer – especially skin cancer.

A PAN molecule schematic

Again, if NO_x is not present PANs do not form.

Air quality trends in Hong Kong 1999-2010 Source: EPD HK

$\mu\text{g}/\text{m}^3$ is micrograms per cubic metre.



On the excellent graphs above it is important to note that in 2010 the NO_x (and NO₂) are much higher at the roadside than they are generally. The same goes for RSP (PM). This shows that those pollutants are mainly being generated on the road and spill out from there into the air of Hong Kong City. Both are at levels far too high to permit clean air. By the same token reducing them is the key to achieving clean air.

Air Pollution Worldwide

What does the **World Health Organisation (WHO)** have to say about air pollution? The information is contained in a 2005 update report, titled as below:

WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide Global update 2005 - Summary of risk assessment

The WHO estimates that some 1.3 million people per year die from the effects of outdoor air pollution. Many more suffer ill health due to it. In its 2005 update WHO identifies the four main pollutants listed above to be the crucial determinants of air quality. It goes on to set guidelines recognising that the circumstances of each individual country may lead that

country to mandate different numbers. The guidelines set different standards for short term (say, 24 hours) exposure and the long-term average over an entire year.

The WHO statement of the purpose of the Air Quality Guidelines reads as follows:

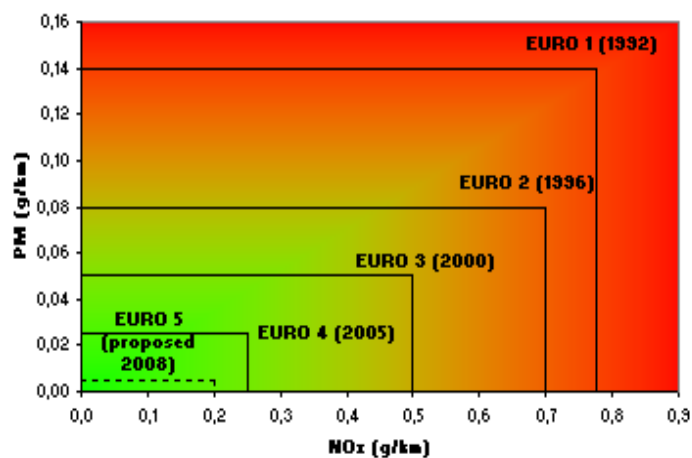
“The following sections of this document present the WHO AQGs for PM, Ozone, NO₂ and SO₂, and in each case give the rationale for the decision to revise the guideline value or to retain the existing value. As noted above, the epidemiological evidence indicates that the possibility of adverse health effects remains even if the guideline value is achieved, and for this reason some countries might decide to adopt lower concentration than the WHO guideline values as their national air quality standards.”

The current WHO air quality guidelines are as below.

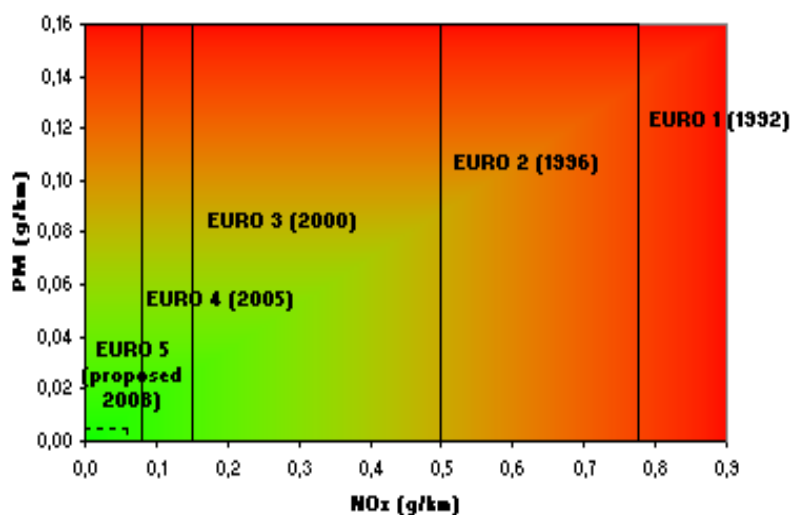
Particulate Matter	PM_{2.5}: 10 µg/m³ annual mean 25 µg/m³ 24-hour mean (<2.5 microns diameter)	PM₁₀: 20 µg/m³ annual mean 50 µg/m³ 24-hour mean (<10 microns diameter)
Ozone O₃:	100 µg/m³ 8-hour mean	
Nitrogen Dioxide NO₂:	40 µg/m³ annual mean 200 µg/m³ 1-hour mean	
Sulfur Dioxide SO₂:	20 µg/m³ 24-hour mean 500 µg/m³ 10-minute mean	

EURO Engine Emission Standards - History and Latest

NO_x and PM emission standards for diesel cars



NO_x and PM emission standards for petrol cars



European emission standards for passenger cars g/km

Tier	Date	CO	THC	NMHC	NO _x	HC+NO _x	PM	P***
Diesel								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)	-
Euro 2	January 1996	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.50	0.56	0.05	-
Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025	-

Euro 5	September 2009	0.500	-	-	0.180	0.230	0.005	-
Euro 6 (future)	September 2014	0.500	-	-	0.080	0.170	0.005	-
Petrol (Gasoline)								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	January 1996	2.2	-	-	-	0.5	-	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-	-
Euro 5	September 2009	1.000	0.100	0.068	0.060	-	0.005**	-
Euro 6 (future)	September 2014	1.000	0.100	0.068	0.060	-	0.005**	-

* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N₁-I

** Applies only to vehicles with direct injection engines

*** A number standard is to be defined as soon as possible and at the latest upon entry into force of Euro 6

† Values in brackets are conformity of production (COP) limits

Emission standards for light commercial vehicles

European emission standards for light commercial vehicles ≤1305 kg (Category N₁-I), g/km

Tier	Date	CO	THC	NMHC	NO_x	HC+NO _x	PM	P
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Diesel

Euro 1	October 1994	2.72	-	-	-	0.97	0.14	-
Euro 2	January 1998	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.50	0.56	0.05	-
Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025	-
Euro 5	September 2009	0.500	-	-	0.180	0.230	0.005	-
Euro 6 (future)	September 2014	0.500	-	-	0.080	0.170	0.005	-

Petrol (Gasoline)

Euro 1	October 1994	2.72	-	-	-	0.97	-	-
Euro 2	January 1998	2.2	-	-	-	0.5	-	-

Euro 3	January 2000	2.3	0.20	-	0.15	-	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-	-
Euro 5	September 2009	1.000	0.100	0.068	0.060	-	0.005*	-
Euro 6 (future)	September 2014	1.000	0.100	0.068	0.060	-	0.005*	-

* Applies only to vehicles with direct injection engines

European emission standards for light commercial vehicles 1305 kg – 1760 kg (Category N₁-II), g/km

Tier	Date	CO	THC	NMHC	NO_x	HC+NO _x	PM	P
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Diesel

Euro 1	October 1994	5.17	-	-	-	1.4	0.19	-
Euro 2	January 1998	1.25	-	-	-	1.0	0.12	-
Euro 3	January 2001	0.80	-	-	0.65	0.72	0.07	-
Euro 4	January 2006	0.63	-	-	0.33	0.39	0.04	-
Euro 5	September 2010	0.630	-	-	0.235	0.295	0.005	-
Euro 6 (future)	September 2015	0.630	-	-	0.105	0.195	0.005	-

Petrol (Gasoline)

Euro 1	October 1994	5.17	-	-	-	1.4	-	-
Euro 2	January 1998	4.0	-	-	-	0.6	-	-
Euro 3	January 2001	4.17	0.25	-	0.18	-	-	-
Euro 4	January 2006	1.81	0.13	-	0.10	-	-	-
Euro 5	September 2010	1.810	0.130	0.090	0.075	-	0.005*	-
Euro 6 (future)	September 2015	1.810	0.130	0.090	0.075	-	0.005*	-

* Applies only to vehicles with direct injection engines

European emission standards for light commercial vehicles >1760 kg max 3500 kg. (Category N₁-III & N₂), g/km

Tier	Date	CO	THC	NMHC	NO _x	HC+NO _x	PM	P
Diesel								
Euro 1	October 1994	6.9	-	-	-	1.7	0.25	-
Euro 2	January 1998	1.5	-	-	-	1.2	0.17	-
Euro 3	January 2001	0.95	-	-	0.78	0.86	0.10	-
Euro 4	January 2006	0.74	-	-	0.39	0.46	0.06	-
Euro 5	September 2010	0.740	-	-	0.280	0.350	0.005	-
Euro 6 (future)	September 2015	0.740	-	-	0.125	0.215	0.005	-

Petrol (Gasoline)

Euro 1	October 1994	6.9	-	-	-	1.7	-	-
Euro 2	January 1998	5.0	-	-	-	0.7	-	-
Euro 3	January 2001	5.22	0.29	-	0.21	-	-	-
Euro 4	January 2006	2.27	0.16	-	0.11	-	-	-
Euro 5	September 2010	2.270	0.160	0.108	0.082	-	0.005*	-
Euro 6 (future)	September 2015	2.270	0.160	0.108	0.082	-	0.005*	-

* Applies only to vehicles with direct injection engines

Emission standards for trucks and buses

For cars, the standards are defined by vehicle driving distance, grams/km, but for trucks they are defined by engine energy output, grams/kWh. The two standards are therefore not comparable. The following table contains a summary of the emission standards and their implementation dates. Dates in the tables refer to new type approvals; the dates for all type approvals are in most cases one year later (EU type approvals are valid longer than one year).

The official category name is heavy-duty diesel engines, which generally includes trucks and buses.

EU Emission Standards for HD Diesel Engines, g/kWh (smoke in m⁻¹)

Tier	Date	Test cycle	CO	HC	NO _x	PM	Smoke
Euro I	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	October 1996	ECE R-49	4.0	1.1	7.0	0.25	
	October 1998		4.0	1.1	7.0	0.15	
Euro III	October 1999 EEVs only	ESC & ELR	1.0	0.25	2.0	0.02	0.15
	October 2000		2.1	0.66	5.0	0.10 0.13*	0.8
Euro IV	October 2005	ESC & ELR	1.5	0.46	3.5	0.02	0.5
Euro V	October 2008		1.5	0.46	2.0	0.02	0.5
Euro VI	31. December 2013 ^[19]		1.5	0.13	0.4	0.01	

* for engines of less than 0.75 dm³ swept volume per cylinder and a rated power speed of more than 3,000 per minute. EEV is Enhanced environmentally friendly vehicle.

Sulfur in Liquid Fuels Mandatory environmental fuel specifications are introduced by EU Directives. The following are the most important steps in the evolution of EU diesel fuel specifications:

- Effective 1994.10, a maximum sulfur limit of 0.2% (2,000 ppm) was introduced for all gas oils, including diesel fuel. The minimum cetane number was 49.
- 1996.10: A maximum sulfur limit of 0.05% (wt.) = 500 ppm for diesel fuel.
- 2000.01: A maximum sulfur limit of 350 ppm and cetane number of 51 for diesel fuel.
- 2005.01: A maximum sulfur limit of 50 ppm for diesel fuel for highway vehicles. "Sulfur-free" 10 ppm sulfur diesel fuel must be available.
- 2009.01: A maximum sulfur limit of 10 ppm ("sulfur-free") for diesel fuel for highway vehicles.

This shows a **200 fold reduction in Europe in the allowable sulfur in diesel fuel over a period of 15 years – a reduction of 99.5%!** Specific fuel consumption did not change over

this period so the amount of SO₂ emitted relative to the amount of CO₂ fell by a factor of 200 in those 15 years. Dramatic! In the 1980s sulfur in diesel was often about 1% (10,000 ppm) so the reduction of SO₂ relative to CO₂ is around 1,000 fold now as compared to then.

PM₁₀ (RSP) in urban centres over 100,000 population in micrograms/m³

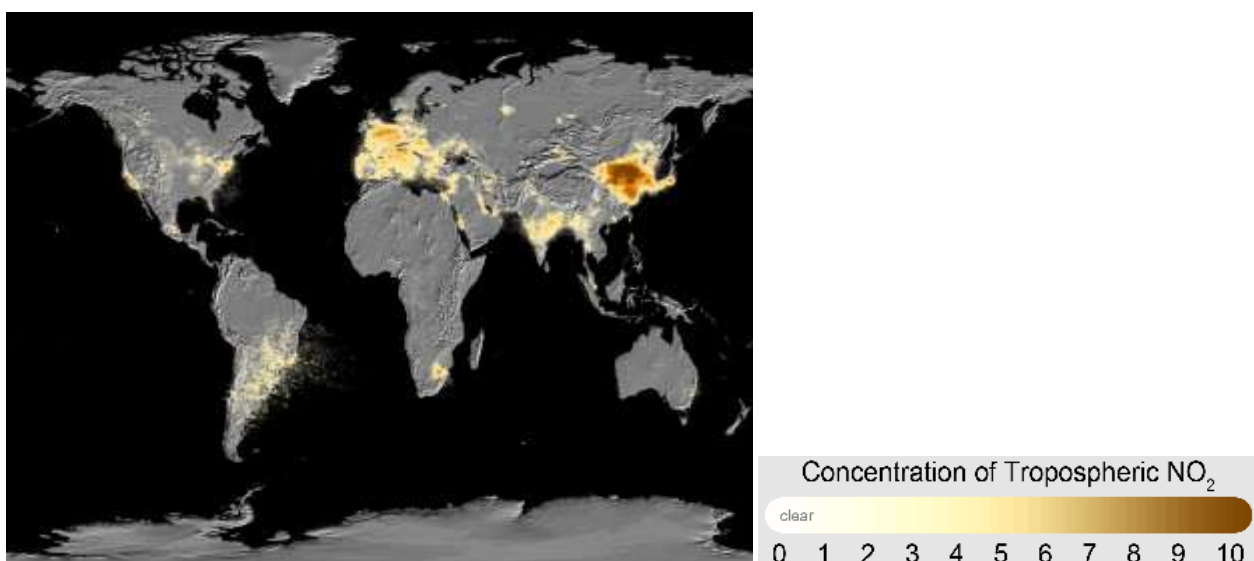
Source: World Bank Development:

Sudan	246 (Highest - worst)	
Pakistan	180	
India	89	
China	87	
Iran	71	
<u>World Average</u>	<u>56</u>	
Hong Kong	52	(Not listed. Mean of general and roadside per EPD HK in 2010)
South Korea	43	
United States	25	
WHO guideline	20	
United Kingdom	19	
Australia	18	
France	16	
Belarus	8 (Lowest - best)	

In this case Hong Kong is slightly better than the world average but is still 2.6 times the WHO guidelines.

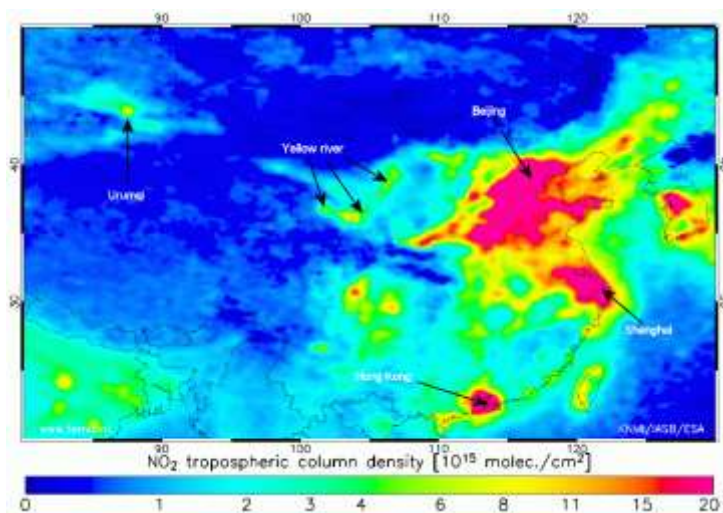
NO_x Emissions - World Comparison Map

Source: <http://www.eldoradocountyweather.com/climate/world-maps/world-nitrogen-dioxide.html> Data is the average for the month of March 2012.



The map above and the map following make it clear how high is the concentration of NO_x in Hong Kong itself and in parts of the adjacent land of China.

In passing, it is worth noting that CO₂ is at a similar level all around the world but it never causes air pollution. The contrast with NO₂ and SO₂, which both produce severe pollution in their respective 'hot spots', is very marked.



Source:

<http://www.temis.nl/products/no2.html>

"The yearly averaged tropospheric NO₂ column measured by SCIAMACHY for 2004 in China. High values are measured above the major cities. The industrial area around the Yellow River (Huang He) is also noticeable and highlights the river stream."

Hong Kong is shown near bottom-centre of the map. 10^{15} molecules of NO₂ seems huge in a column only 1 cm². The map shows that over Hong Kong there are actually 2×10^{16} molecules of NO₂ in a column!

Hong Kong Air Quality Comparisons with WHO Guidelines and World Averages

The WHO guideline for NO₂ is 40 µg/m³ annual mean. This compares with the EPDHK figures for 2010 as follows:

WHO guideline NO₂	40 µg/m³
HK NO ₂ general	52 µg/m ³
HK NO ₂ roadside	114 µg/m ³
HK NO _x general	94 µg/m ³
HK NO _x roadside	318 µg/m ³

The very high levels of nitrogen oxides in Hong Kong by world comparison on the one hand and relative to the **WHO** guidelines on the other are apparent. The roadside levels in Hong Kong are 2 to 3 times the general levels. This shows that road vehicles *are* the main source of Nitrogen Oxides.

Piston Engines and Fuel Comparisons

Some say, 'diesels pollute, let's just get rid of them'. They are less clear on what would take their place. Without sophisticated emission controls diesels do indeed pollute but the answer is keep them and provide controls. Spark ignition engines without emission controls also pollute but good controls in the form of three-way catalytic converters have been in general use for two decades or so.

	<u>CR</u>	<u>Fuel</u>	<u>Hyundai I30 manual</u>	<u>I30 Capital Cost</u>
Compression				
Ignition	17:1	Diesel	4.5l/100Km	AU\$23,090
Spark	} 10:1	Petrol	7.2l/100Km	AU\$19,590
Ignition		LPG*	11l/100 Km	Add AU\$4,000
		13:1 CNG	Not available but a possible option on buses or trucks	

* LPG is often much cheaper per litre than petrol (lower taxes) so fuel cost/Km is often lower with LPG.

The fuel efficiency of any piston engine rises as the compression ratio rises. The production of NO_x/NO₂ also rises as compression ratio rises and this must be removed from the exhaust. One great merit of diesels is their fuel economy. There used to be a further advantage in that diesel was cheap relative to petrol but that is seldom so today. Diesel engines are also reliable and have a long life – a diesel taxi or truck may run for 1 million Km before replacement. A diesel does need somewhat more skilled and expensive maintenance than a petrol engine. Capital cost is somewhat higher.

The **bus companies**, for example, *might* choose to meet the higher standards by adopting **CNG (Compressed Natural Gas) fuel**. The use of CNG either as a substitute for or as a supplement to diesel fuel has much to commend it. However, its economics depend crucially on having a natural gas infrastructure supplied by pipeline or LNG carriers. If Hong Kong establishes such an infrastructure, CNG will be a good transport fuel option; but if not, not.

From EURO I to EURO VI permissible PM has been reduced by 61 fold and NO_x by 20 fold. The reductions relative to *pre*-EURO emissions are even more.

This measurement of engine pollutants per KWhr is equally applicable to engines which are in trucks, earth-moving equipment, cranes and generators, airport handling machines, vessels, **ferries** or the like. The HK emissions standards will apply across the board to **all diesel engines** in HKSAR.

Note that measurements of Lead Pb and Sulfur S are absent. This is because they are controlled by very strict limits on how much may be in the fuel – effectively none. Thus it is not necessary to specify emission limits from engines. No S or Pb in the fuel going makes sure there is none in the exhaust coming out.

**EEC study 2007: Sales weighted average cost per diesel vehicle
(2005 prices)**

	<u>EURO 6</u>	<u>EUR 5</u>	<u>EUR 4</u>
PM mg/Km	5	5	25
NOx mg/Km	75	200	250
Cost above EURO 4	€ 590	€ 377	€ 0
Cost above EURO 5	€ 213	€ 0	N/A

Costs of EURO VI Compliance for Vehicle and Plant Owners

Please see the website below for details of costs for a wide range of vehicle sizes when moving from EURO IV (the present HKSAR standard) to EURO VI.

http://ec.europa.eu/environment/air/pdf/euro_6.pdf

Questions and Answers on Hong Kong's Air Quality

Q. Why is Hong Kong often covered in SMOG?

A. **Mainly because of pollution from internal combustion engines - in vehicles, in plant used off-road and in vessels on the waters of Hong Kong. Removing that pollution, PM and NO_x specifically, will clear Hong Kong's SMOG. Failure to do so will keep the SMOG.**

Q. How does Hong Kong's air quality compare with that in the rest of the World?

A. That depends on the pollutant.

For SO₂, which is a very damaging pollutant in some countries, Hong Kong does very well indeed. SO₂ pollution is less than 1/4th of the World average and only half the strict WHO (World Health Organisation) guidelines. This is a splendid result.

RSP (also called PM) in Hong Kong is slightly less than the World average but exceeds the WHO guideline by 160%. RSP (PM) must be reduced by a factor of 3 to come comfortably within the WHO guideline.

NO_x and NO₂ in Hong Kong are altogether excessive by international comparison or by WHO criteria. These pollutants are prime producers of photochemical SMOG and reducing them drastically is the key to having good air quality in Hong Kong. Diesel engines, particularly older ones, are the main emitters of NO_x and NO₂. NO_x needs to be cut back severely - particularly by the roadside where levels are even higher than they are generally.

Q. What about the power stations?

A. The power stations do produce most of the SO₂ in Hong Kong's air but, as above, the total amount of SO₂ is well below the WHO guideline and is excellent by international comparisons. The power stations have made an outstanding job of cleaning up their emissions - especially given that they use about 11 million tons of coal. see: <http://www.indexmundi.com/energy.aspx?country=hk&product=coal&graph=consumption>

Q. Can't pollution from vehicles be cleaned up? Why is that not done in Hong Kong?

A. Yes, pollution from vehicles can be cleaned up and this is done in other places by imposing strict regulations. The regulations presently imposed in Hong Kong are not strict enough to achieve clean air. The standards for new engines are below international best practice and this needs to be changed. More important still is the need to upgrade or remove the many dirty old engines on the roads, work sites or waters of HKSAR.

There is very high consumption of oil fuel in a compact area by many vehicles with poor emission standards (EUROIII to pre-EURO) so that it would be strange indeed if the result was *not* air pollution. It should be no surprise whatsoever that Hong Kong gets a lot of SMOG from diesel and, to a lesser extent, petrol engines.

Q. In Hong Kong smoke often blows from ferries and other vessels in the Harbour over Central Hong Kong. How will controls on vehicles stop that?

A. Hong Kong's own emission standards, **HK1** to **HK6**, will include **ALL** diesel engines used in HKSAR including ferries and other local vessels. The emission standard for heavy diesel trucks is per KWhr of power output and that standard can readily be applied to engines in vessels, on construction sites and in other non-road uses. The **HK** standards will so apply it. **They will apply forthwith to all new engines and, progressively over a 6-year time period, to all existing engines also. This is a key issue.**

Q. Is it carbon dioxide in the air that causes pollution?

A. No. Carbon dioxide, CO₂, is an invisible, tasteless, odourless, harmless gas which has nothing whatsoever to do with SMOG or pollution in the streets of Hong Kong or elsewhere. Pollutants, not CO₂, cause SMOG. Reducing CO₂ will not improve air quality in the least.

Q. But doesn't removing CO₂ remove the nasty, polluting chemicals?

A. No. Whenever any fuel - coal, diesel, petrol or natural gas - is burned a fixed amount of CO₂ is produced for each Kg or litre of fuel used. The nasty chemicals can and should be removed by using the best available technology to filter them out or to convert them *into* CO₂. Indeed producing a little more CO₂ is often the way to achieve large reductions in harmful emissions; e.g. when PM (smoke) emission is catalytically converted to benign CO₂.

CO₂ is not a proxy for air pollution.

Q. Why do new cars carry windscreen stickers giving the emission of CO₂ as well as fuel consumption if CO₂ does not measure pollution?

A. Why indeed! When fuel consumption is given, it is redundant and pointless to give CO₂ emission also. For any given fuel - CNG, LPG, petrol or diesel - and quite irrespective of the make, design, age or state of maintenance of the vehicle, fuel consumption and CO₂ emission move inexorably in lockstep. For example a petrol engine which uses 10 litres/100 Km **always** produces 232 grams of CO₂ per km - and pro rata up and down the consumption scale. A diesel with the same consumption **always** produces 265 grams of CO₂ per km and pro rata (but a diesel will use much less fuel for a given task). It makes sense to give fuel consumption *or* CO₂ but not both.

Q. Why do vehicles not carry a sticker showing the amount of real pollutants such as PM and NO_x?

A. Why not indeed! This curious illogicality, which applies around the world and not only in Hong Kong, is one of life's little mysteries. For HKSAR a statement of the PM and NO_x emissions per km would be of critical relevance to Hong Kong's air quality. They vary greatly relative to fuel consumption depending on the make, design, age and state of maintenance of the vehicle. Emissions of PM and NO_x should replace CO₂ emissions on windscreen stickers in Hong Kong.

Q. Surely if we stopped burning coal, diesel, petrol and other fossil fuels we would get rid of the nasty chemicals?

A. Yes; but that is not all we would get rid of. We would have no electricity and no rail, road or sea transport for starters. Jobs would be few and far between. Life in modern Hong Kong depends crucially on energy, especially electricity, from burning fossil fuels. We need to continue using the fuels but to clean up the resultant exhaust gases thoroughly. The power stations have already shown how well this can be done while generating very large amounts of reliable power at reasonable cost.

Q. If all the vehicles in Hong Kong were electric would that stop the pollution?

A. Yes – provided all other engines such as those on construction sites and in ferries were also electric. Hopefully that will happen one day but realism is also needed. If Hong Kong has to wait for clean air until most of its vehicles and vessels are electric, the wait will be of unconscionable duration.

There *is* a good case today for going over to electric-hybrid taxis rather than using LPG.

Q. Why can't we go all-electric right now?

A. Because all-electric heavy trucks are not available anywhere and because the relatively small electric cars that are available are very expensive and have limited range. At present, all-electric is a non-starter for ferries and other vessels. All-electric vehicles are 0.03% of the total vehicles in Hong Kong today.

Quotation from: *Hong Kong Economic Journal*, 9 Aug 2012.

'Electric car technology has not arrived'

"Based on Nomura's discussion with industry players, the existing battery technology cannot meet consumer requirements. Electric vehicle technology today is not mature enough. Rechargeable batteries for electric cars are still bulky, heavy, costly, low capacity; it may be quite a while before a meaningful electric vehicle market can be developed".

Q. Is there something wrong with having an electric vehicle?

A. Certainly not. They are most welcome wherever owners find they make economic sense but owners must accept a 'level playing field' with others as regards Government help. They will have the benefit that excise is not applied to their 'fuel'.

Q. Would air quality be improved if road congestion in Hong Kong were reduced?

A. Yes, it certainly would - and there are many other benefits from reduced road congestion. However, big cities around the World have tried without success to cut road congestion. With ever more vehicles trying to use the same amount of road, congestion often gets worse, not better. So by all means try to reduce congestion but do not be misled into thinking that this can be a substitute for the crucial task of reducing vehicle emissions.

Q. Those are things we can't do; what *can* we do to get clean air?

A. Encourage the Government to legislate for World's-best-practice emission controls on all engines in Hong Kong and to enforce those standards strictly.

Q. What are those standards?

A. They are the European 'EURO' standards for vehicle emissions. Hong Kong presently requires EURO IV. The latest standard is EURO VI and Hong Kong should, after a reasonable period of grace, make its own, compatible standard - **HK6** - mandatory for all engines, especially diesels, operating anywhere in HKSAR. In applying to **ALL** engines, whenever they were built and wherever they are being used, **HK6** differs crucially from EURO and from most national standards which apply only to new vehicles. **HK6** will reduce Hong Kong's emissions sufficiently to make our air clean within an acceptable time period.

Q. Isn't it risky for Hong Kong to have its own standards because they may not fit in with the rest of the World?

A. Hong Kong's **HK** standards will be set within the 'envelope' of World standards. This will ensure that vehicles and engines which will meet Hong Kong's requirements are available internationally. The very highest standards must be mandated for controlling NO_x and PM. On the other hand Hong Kong will have flexibility to add to, omit or modify requirements imposed by other countries to best meet the specific needs of HKSAR. Hong Kong will be able to apply the standards to **all** (not just new) engines. In this key respect Hong Kong standards will be higher than those in other Great Cities.

Q. How do emissions of older trucks, say 1990 vintage, compare with **HK6** trucks?

A. With **HK6** the nasty emissions of NO_x and PM for a given size of truck are reduced by about 98% relative to 1990, i.e. from 100 units to 2 units. This means that **one** 1990 model truck emits as much nasty stuff as 50 **HK6** trucks of similar size. Getting the old and dirty trucks off the road is crucial to giving Hong Kong clean air. The same applies to old and dirty diesels used off-road or on the seas of Hong Kong.

Q. These very clean new trucks and engines sound too good to be true. Are they real or are they just 'pie in the sky'?

A. They are very real. Many are already being made by companies such as Mercedes-Benz, Fuso, MAN, SCANIA, Cummins (engines built in Beijing), Detroit Diesel, IVECO, Guangxi Yuchai and are in service. They deliver what they promise. The European standards require that each truck can maintain its pollution control over a life of 700,000 kms and **HK6** will demand the same.

Q. When and how should Hong Kong implement **HK6**?

A. It should start in 2013 and be fully implemented by **31st December 2018**. It should then cover all new and existing engines e.g. cars, trucks, buses, tractors, generators, construction plant, ferries, other vessels, etc. The important thing is that when the change is completed it covers all new and existing engines, is strictly applied and works consistently. The process will be progressive from 2013 onwards.

Q. What has Hong Kong already done to improve air quality?

A. Some very good things have been done especially in the power stations. This has reduced harmful SO₂ emissions to half the World Health Organisation (WHO) guidelines and that is impressive. Mandating ultra-low-sulfur (ULS <10 ppm sulfur) diesel fuel for road use is really good. This allows the devices which remove NO_x (Selective Catalytic Reduction - SCR) and PM (Diesel Particulate Filter - DPF) to work at their very best. It is an important enabler for applying **HK6** to diesels effectively. ULS diesel (<10 ppm sulfur) should be made mandatory for **ALL** diesel engines in Hong Kong – especially for ferries.

But action has not gone nearly far enough. The level of SMOG-producing, eye-watering roadside NO₂ and NO_x is way above the WHO guidelines and international comparisons.

Q. There are over 600,000 vehicles in Hong Kong; surely it will be far too expensive to replace them, plus the non-road diesel engines, by the end of 2018?

A. The pervasive benefits of better air quality will be so large that even such a huge expense would be worthwhile but, happily, many vehicles will not need to be replaced but merely upgraded. For vessels such as ferries, engine replacement alone will be needed. This will much reduce the cost. Many cars and taxis (EURO IV or better) will be able to meet **HK6** with correct tuning, good maintenance and upgrading of the catalytic converters in their exhausts. What will need removal, or the fitting of new engines, are the old and dirty diesels – pre-EURO IV. It is crucial that they are upgraded or taken out of use. Newer trucks, buses, diesel-powered plant and vessels can meet **HK6** by retro-fitting SCR and DPF units.

Q. That will still be pretty expensive. Who will pay?

A. **The owners of the vehicles, plant or vessels will pay to improve their own engines. No one has a right to hazard the health and well-being of their fellow citizens in the course of their personal or business life. All those who are doing so now have a moral duty to stop it and clean up their act. The HK standards will make that a legal duty also.**

Q. Should the Government help vehicle owners?

A. Yes, but only in cases of genuine hardship. In this context hardship means a threat to employment or livelihood. It does **not** mean mere cost or inconvenience.

Q. Does CNG – compressed natural gas – have a part to play in Hong Kong?

A. In principle, yes. It is easier for a big truck or bus to meet **HK6** using CNG (Compressed Natural Gas, CH₄) fuel than using diesel. Some bus fleets in the USA are already achieving the equivalent of **HK6** by using CNG fuel. A CNG engine is similar to a diesel but has spark ignition, a somewhat lower compression ratio and other detail differences. Singapore presently offers incentives for vehicles using CNG. The downside in Hong Kong is that there is not a suitable Natural Gas supply infrastructure at present. As and when that changes, CNG may have an important role in helping to clean the air of Hong Kong.

Q. Some countries have a phone, SMS and email hotline to report dirty or smelly exhausts – with or without a confirmatory photo. Would that work in Hong Kong?

A. Yes, and the sooner the better.

Q. Diesels seem to be the main problem. Why not get rid of them altogether?

A. Because they are far too useful. Around the world almost all trucks now have diesel engines for very good reasons. They are cost-effective prime movers, economical on fuel, have high torque which gives good lugging power for heavy loads and steep hills, have a long range, are reliable and last well. Hong Kong will need diesel engines for many years to come – **but they can and must ALL have first rate emission controls.**

Q. Emissions may be low when vehicles or engines are new. But what will happen as they get older?

A. Constant checking will be needed. **HK6** will match EURO VI in requiring standards to be maintained for 700,000 kms of use. The Government will need to beef up emissions testing both on an annual basis and with random checks. After 2018 **any** non-compliant engine will summarily be taken off the roads, work-sites or waters of Hong Kong unless and until it does comply. Fines for breaches of emission regulations will also be imposed. These fines will resemble, but be much heavier than, those imposed for littering and other anti-social behaviour on the streets of Hong Kong today.

Q. These proposals may be satisfactory for vehicles registered in Hong Kong but what about badly polluting trucks coming into HKSAR to bring goods from elsewhere?

A. The Hong Kong Government will require such trucks to conform to Hong Kong's emission regulations. The Government may choose to institute a 'certificate of compliance' and require each truck coming into HKSAR to have one.

Q. What about the pollution which blows over Hong Kong from elsewhere?

A. Unfortunately Hong Kong is stuck with that – at least for the time being. During autumn and winter, winds in Hong Kong are from the North for about 20% of the time and that carries pollution from the mainland to HKSAR.

http://www.hko.gov.hk/cis/normal/1971_2000/normals_e.htm#table7

The prevailing Easterly and Southerly wind in Hong Kong comes from the ocean and brings clean air so then Hong Kong's citizens can see that their own air is really like. After 2018 Hong Kong will enjoy pristine air and pass it on to its neighbours. That fine example will surely be rewarded and reciprocated.

Q. What about CCS – Carbon Capture and Storage for Power Stations?

A. CCS for power stations is a seductive and irrelevant trap which is as ineffective as it is expensive. Even in the improbable event of CO₂ capture being successful, less CO₂ will do

nothing to improve the air quality of Hong Kong. Hong Kong should avoid CCS like the plague. There are abandoned CCS projects all around the world. See CCS problems and failures on page 52. There are no CCS schemes operating on a full power station scale, or anything approaching full scale, anywhere.

Q. How quickly can we get much better air quality?

A. In about six years. To get swift improvement it is more urgent to turn ***Bad into Good*** than ***Good into Very Good***. Any engine which pollutes badly should be pinpointed and not permitted to remain in use in Hong Kong for a day longer than necessary. After 2018 it will be **HK6, Very Good**, all round. That is an ambitious but attainable time scale.

Q. Is there a Cost/Benefit analysis for this air quality improvement?

A. Yes. Each time the EURO authority proposes tighter emission standards they have to present an Impact Statement which includes a cost/benefit analysis for the intended change. The cost/benefit analysis is set out at (and in many related links):

http://europa.eu/legislation_summaries/environment/air_pollution/l28159_en.htm

In summary, it finds that costs of €7.1 billion per annum will lead to savings of €42 billion per annum: a very high cost benefit ratio of +6. This applies in Europe where no cities now experience the damaging SMOG which is still frequent in Hong Kong. Given that Hong Kong is starting from a condition of frequent SMOG, the C/B ratio of corresponding air quality improvements in **Hong Kong** will surely **be even higher than the excellent figure of +6**.

Q. Is it good policy for the people of Hong Kong to spend six years, much hard work and considerable sums of money to **implement HK1 to HK6** and achieve really clean air?

A. **Yes!**

Improving Air Quality in HKSAR – Technical Report

References in the Report

Throughout this report extensive use is made of the excellent material published by the HKSAR's Department of Census and Statistics. Almost all Hong Kong-specific data is from this source with calculations as appropriate. USA energy data is from the US EIA. The WHO data is from its website. This basic data is grouped together at pages 7 to 25 above.

Fuel Use in Hong Kong

Populous, prosperous and compact Hong Kong needs a lot of electricity and a lot of transport. In turn this needs coal for the power stations and oil fuel (mainly diesel) for the vehicles. Given Hong Kong's total area of 1,104 Km² this means that *every single day* Hong Kong burns some 26 tons of coal for each 1 Km² and nearly 5 tons of diesel oil per Km². It sounds huge and it is. The equivalent numbers in the energy-intensive USA, for example, are 0.3 tons of coal and 0.3 tons of *total* oil products per day for each Km². With so much fuel being burned, keeping the air clean and maintaining the age-old tradition of "The Fragrant Harbour" is a big task, so;

A decision by the HKSAR Government to achieve progressively higher air quality standards moving NO_x and PM emissions towards and then ahead of the World Health Organisation (WHO) guidelines is the key to giving Hong Kong really clean air.

Skilled deployment of existing top technology will solve the problem at reasonable cost and reasonably quickly – extravagant measures such as a major move to hybrid or electric vehicles are not needed. They would divert resources from the main game and so slow the change to clean air.

The power station example should be rigorously applied to all sources of air pollution across the whole HKSAR with the aim of bringing each scheduled air pollutant in HKSAR below the WHO guidelines. It is for the Government to set achievable high standards and enforce them and for users and operators to choose how they will meet and pay for them.

NO_x in Exhaust Gas

Burning anything needs oxygen, i.e., air. Air is about 78% nitrogen and the high temperatures of combustion in a piston engine make the Nitrogen (N₂) and the Oxygen (O₂ - 21%) combine to form various oxides of nitrogen (NO_x). These oxides of nitrogen are toxic and harmful in their own right and can form SMOG. In strong sunlight they may create Ozone (O₃) which is likely to form photochemical SMOG. The term SMOG means 'Smoky

Fog' – when it was originally coined a century ago the SMOG agent was mainly SO₂; in Hong Kong today it is mostly NO_x and NO₂.

It is of critical importance to reduce the amount of NO_x emitted on the roads of Hong Kong. Progressively upgrade or remove the worst vehicles and engines.

Ozone Formation near the Ground

When it is high in the stratosphere, Ozone (O₃) protects us from excess UV rays – the kindly 'Ozone Layer'. At ground level, however, it causes smog and itself is very unpleasant and bad for health. It is also harmful to growing plants. Thus O₃ is correctly classed as an air pollutant when present near the Earth's surface. The chemical reaction whereby NO_x produces O₃ can go both ways. When NO_x is low (within the WHO guidelines) very little O₃ is formed. As the level of NO_x rises high above WHO, ever more O₃ forms. However when NO_x rises still further to extreme concentration it destroys O₃. **Thus the negligible levels of roadside O₃ in Hong Kong reflect the extremely high level of NO_x. It is bad, not good. It leads to the formation of very harmful PANs and to their version of eye-watering SMOG.**

Carbon Monoxide – a Killer

If combustion in an engine is not complete, **carbon monoxide (CO)** is formed. It is fatal at over 0.08% in the air. There is about 0.7% of CO in the exhaust gas leaving a gasoline or LPG engine but nowadays this is reduced to a small fraction of that - being **converted to benign CO₂ by the catalytic converters now fitted to petrol or LPG cars.**

VOC – Volatile Organic Compounds – also called HC

These cover a wide variety of low boiling point hydrocarbons; from spilt and evaporated petrol to obscure, special-purpose chemicals. Vehicles produce VOC's and so do trees and shrubs. VOCs may be directly harmful and may, by reaction with NO_x in sunlight, promote O₃ formation. They are harmless when fully converted to CO₂; for example, by catalytic converters in vehicles. It is much more effective to remove SMOG by reducing NO_x than by trying to reduce VOCs.

WHO Guidelines for Air Quality

In Hong Kong today, measurements show that the level of NO_x and RSP (PM) are far above the World Health Organisation (**WHO**) guidelines. The health, well-being and amenity of 7 million people require that they be brought within the WHO guidelines. The HKSAR Government has made consistent and strenuous efforts over decades to improve the air

quality in Hong Kong. Despite this good work, reputable newsagencies such as Reuters report that air quality in Hong Kong has deteriorated over the past decade.

The 'big ticket' item in Hong Kong's air pollution today is exhaust from diesel engines – especially old ones – EURO III and lower.

Diesels are marvellous engines with high power, good fuel efficiency, excellent reliability, long life and sustained pulling power for heavy loads of all kinds. The answer is not to stop using them but to clean up their exhausts. They should be cleaned to the extent needed to make their emissions consistent with Hong Kong meeting the WHO guidelines. It makes no sense to go with half measures at this stage. Improvements in other, less emission-intensive, sectors are always welcome but must not divert attention from the critical main game. Just as for power stations, there are several technologies which yield clean running diesels. The 6-Rs for clean diesels are below:

The 6 R's of Diesel Clean Up:

Refuel; Retrofit; Repower; Replace; Repair; Rebuild.

This report recommends that the Hong Kong Government motivates users and operators of diesel engines to clean up their act as necessary by using one or more of the above methods. The motivation should be by setting strict emission standards together with comprehensive and rigorous enforcement. **Any vehicle, plant or vessel in Hong Kong which fails to meet the standards required by the required date in the HK1 to HK6 schedule should be taken off the roads, work sites or waters of Hong Kong unless and until it does so.**

The Power of Hong Kong's Example to the World

From the end of 2018, Hong Kong's clean air will match its already clean streets and will be an exemplar of health, well-being and high amenity to big cities right around the World.

Cost Benefit Analysis

Whenever the EURO authority proposes tighter emission standards they must present an Impact Statement which includes a cost/benefit analysis of the intended change. The C/B analysis and many related links are at:

http://europa.eu/legislation_summaries/environment/air_pollution/l28159_en.htm

It finds that costs of €7.1 billion per annum will lead to savings of €42 billion per annum: a very high C/B ratio of +6. This applies in Europe where no cities now experience the

damaging SMOG which is still frequent in Hong Kong. Given that contrast, the C/B ratio of corresponding air quality improvements in *Hong Kong* will be at least as high and probably much higher.

Wind Borne Pollution from Neighbours

One obstacle to achieving clean air is pollution coming from neighbours. When the wind is from the north or the west, pollution from the mainland may blow over Hong Kong. However, the wind in Hong Kong prevails from the East and South-East which is from the open sea with negligible pollution. Therefore pollution from elsewhere should *not* be a reason to hold back on giving Hong Kong itself the World's cleanest urban air. Whenever the prevailing wind blows or when it is calm the people of Hong Kong will be able to see just what *their* air really looks like. They can take pleasure in passing pristine air on to their neighbours and in setting them a fine example.



Vehicle Pollution from Neighbours

This is a very different issue. If vehicles from outside Hong Kong with poor emission controls enter HKSAR, just one of those vehicles can cause more air pollution in Hong Kong than many local vehicles with good emission equipment. To give Hong Kong cleaner air it is essential that vehicles entering HKSAR be routinely checked for the

cleanliness of their exhausts and that entry be forbidden if they do not meet HKSAR standards.

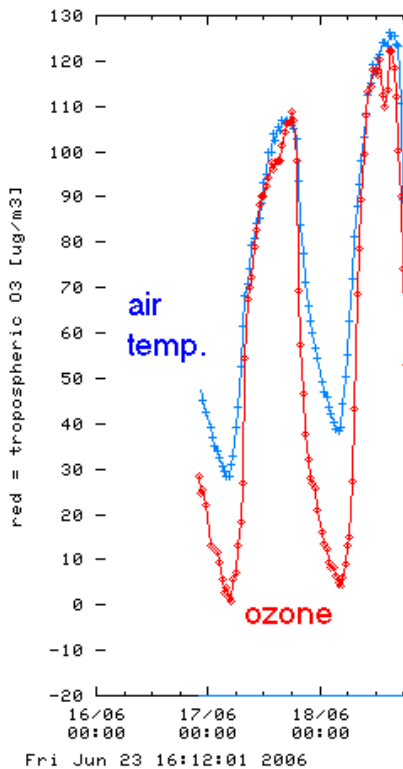
The photo shows one of the things that London did in this respect prior to the 2012 Olympics. Something similar might be appropriate permanently at entry to HKSAR?

It might be argued that, notwithstanding its small land area, Hong Kong is surrounded on three sides by sea and so the product of the burnt fuels can disperse over the ocean. When the wind blows that is true but that is not when pollution is critical. Critical pollution occurs on calm, hot days and then it stays right on top of the land of Hong Kong and its 7 million people. Furthermore the density of high buildings in Hong Kong is such that there can be a stiff breeze on the coast but calm in the City Centre.

Because HKSAR has probably the most intense concentration of diesel burn in the World it follows that if it is to match, let alone better, the air quality elsewhere **Hong Kong's emission standards need to be stricter than elsewhere.** In that Hong Kong adopts emission standards developed elsewhere, i.e. USA, EEC and Japan, it must as a minimum, adopt the latest and best standard. It should be strict in imposing this standard on **all emissions**

whether from new or old vehicles and whether a vehicle is based in Hong Kong or visits Hong Kong from elsewhere. It must also apply to **all engines**, on-road or off. So: **control all emissions from all engines anywhere in HKSAR.**

Daily variations of ground ozone and temperature at meteoLCD station - Meteorological Station of the Lycée Classique de Diekirch, Luxembourg



The odd-man-out in the HKEPD graph on page 16 is Ozone (O₃) at the roadside. It “not measured because of very low concentration”. The graph opposite shows that O₃ typically has a very strong diurnal variation. It increases in response to sunlight and falls off in darkness. In the example opposite the O₃ level measured at 6 am is negligible but at 6 pm is about 120 µg/m³. The 8-hour average between midday and 8 pm is around 100. The measurement of O₃ needs to be positioned and timed so as to detect **peak** levels. It is short term peaks of O₃ that cause smog – not the long term average and these may initially increase as the now extremely high NO_x level at roadside falls.

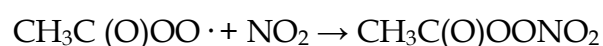
The Hidden Enemy - PAN - Peroxyacyl Nitrates

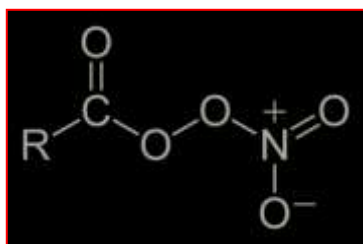
When there is a high level of NO_x and VOCs these two react under strong sunlight to release a free Oxygen atom (O). This then combines with an oxygen molecule to give Ozone O₃ which is toxic to humans and plants and is a common component of photochemical smog. It seems from the absence of roadside O₃ that this is not the case in Hong Kong. But there is often smog so where does it come from?

When the level of NO_x is extreme, rather than just high, the reactions take a different path. The excess NO_x captures the Oxygen atoms before the Oxygen molecules (O₂) do and converts itself to NO₂.



This accounts for the negligible level of O₃ where there is an extreme level of NO_x. Although that sounds like good news it is **not**. With extreme levels of NO_x, in strong sunlight a different reaction between the VOCs and NO₂ happens and very unpleasant PANs are produced.





PANs, Peroxyacyl Nitrates (also known as APNs), are powerful respiratory and eye irritants. They are produced by the gas-phase oxidation of a variety of volatile organic compounds (VOCs), or by aldehydes and other oxygenated VOCs oxidizing in the presence of NO_2 . The final step is a combination of a peroxyacyl radical and NO_2 for example, peroxyacetyl nitrate $\text{CH}_3\text{C}(\text{O})\text{OONO}_2$ as above. PANs are toxic and irritating because

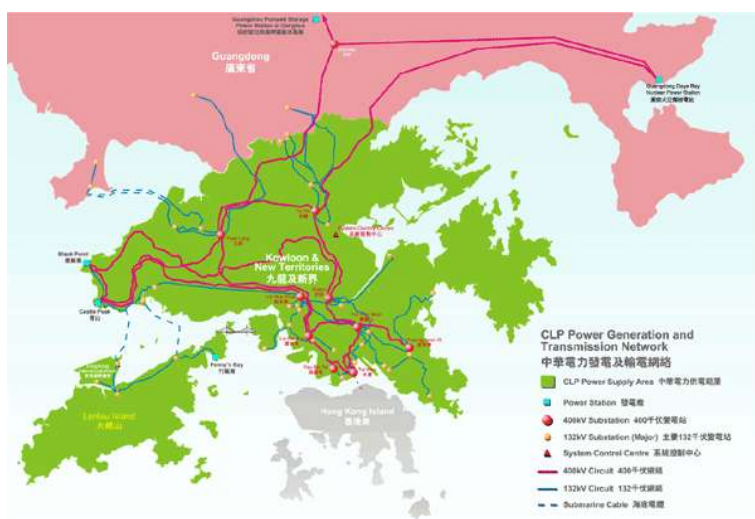
they dissolve more readily in water than Ozone O_3 . They are lachrymators, causing eye irritation in concentrations of only a few parts per billion. At higher concentrations they cause extensive damage to human tissue and vegetation. Both PANs and their chlorinated derivatives are said to be mutagenic; that is, they can cause cancer – especially skin cancer.

The current negligible level of roadside O_3 together with frequent smog is a warning sign that the level of PANs need close monitoring. The action needed to cure the problem is a **drastic reduction in NO_x** . As NO_x levels come down there will be a temporary rise in roadside O_3 until it subsides again when NO_x gets really low. That will mark a major achievement in Hong Kong's advance to really clean air.

Sulfur Dioxide (SO_2) - a Success Story

The SO_2 levels shown on the EPD HK graph on page 16 are, very commendably, about half the **WHO** guidelines. At $12 \mu\text{g}/\text{m}^3$ they are less than a quarter of the world average ($56 \mu\text{g}/\text{m}^3$) and reflect the costly and comprehensive emission control programs of the electricity generating authorities and, to a lesser extent, the use of ultra-low-sulfur road diesel. They show that the electricity generating utilities have 'done their bit' in Hong Kong's air pollution battle. No doubt they will be vigilant to ensure that the high standards are maintained.

Castle Peak Power Station - Clean Air Retro-Fit





"1. Boosted Over Fire Air (BOFA) -- Suppress formation of NOx

NOx is produced when nitrogen and oxygen combine during combustion. BOFA aims to change and optimize combustion of coal so as to suppress formation of NOx during the combustion process and reduce NOx emission. Installation of BOFA equipment in power generating units involves a lot of complex retrofit work and requires 500 tonnes of steel. After retrofitting, BOFA equipment is a part of the coal-fired boiler.

2. Selective Catalytic Reduction (SCR) -- Turn NOx in the flue gas into water vapour and non-toxic nitrogen gas

Flue gas passing through BOFA moves on along the ductwork to the next emissions removal process. Passing through the SCR equipment which makes use of chemical reaction of Ammonia (NH₃) and NOx, NOx in flue gas is converted into water vapour and non-toxic nitrogen gas and become part of the constituents of normal breathing air. NOx emission in the flue gas is further reduced upon processing of SCR.

3. Flue Gas Desulphurization (FGD) -- Remove SO₂ from flue gas

After removing NOx through BOFA and SCR, the flue gas is transmitted to an absorber tower, in which the flue gas is sprayed and reacted with alkaline limestone slurry. During the process, SO₂ in flue gas is neutralized by limestone to form gypsum, a useful construction material. Meanwhile, RSP, which has been 99% removed by the electrostatic precipitator, is also further reduced in the process of desulphurisation.

By-product of the Project - Gypsum

The EC Project brings along additional environmental benefits. Gypsum, a by-product of the desulphurization process, is recycled for making cement and other construction material. Since the phasing-in of three units, nearly 30,000 tonnes of gypsum have been produced by the Project during the past few months."

Lead (Pb) - another Success Story

Thirty years ago tetra-ethyl-lead was a routine additive used to improve the octane rating of petrol. Lead is a serious air pollutant which is especially harmful to children's development. Towards the end of last century leaded petrol was phased out completely and so lead is no longer a significant air pollutant – except in the vicinity of lead-zinc mines or in some old

house paints. Diesel fuel does not contain lead and never did. The level of lead in Hong Kong's air is now well below the **WHO's** tight guidelines. This is admirable.

The EURO vehicle emission standards do not list lead or sulfur. They control them via the fuel by requiring that there shall be no lead and negligible sulfur going into vehicles' tanks.

RSP (PM) and NO_x from Vehicles, Plant and Vessels – a Sad Story

In contrast to the happy story on SO₂ and Pb, RSPs (PM) in general and at the roadside are 125% and 200% respectively above the **WHO** guideline of 20 µg/m³ for PM₁₀. If most of Hong Kong's RSPs are in the (tiny) PM_{2.5} category they are even further over the WHO guideline.

As the maps and tables above show, NO₂ is above the 40 µg/m³ annual average in the WHO guidelines and NO_x is at the very top end of the World scale. No wonder there are air pollution problems in Hong Kong!

It is apparent from press reports and from general observation, that the people of Hong Kong sense that their air quality is getting worse and not better. The Consultative Document on Air Quality issued in 2009 showed that while the officially recorded level of air pollutants was getting steadily less, the air quality of Hong Kong (as measured by days of reduced visibility) was getting steadily worse. The problem is NO₂, NO_x and RSPs (PM). This turns the focus onto vehicles, particularly those with diesel engines. But first a look at petrol and LPG engines in cars.

Petrol and LPG Vehicles

Cars and taxis with petrol or LPG fuel in Hong Kong now have catalytic converters. They remove CO and unburnt hydrocarbons by converting them into harmless CO₂. Some have 3-way catcons which also remove NO_x. Good maintenance is vital for the effective working of those converters. Engines need to be tuned to run consistently within a precise *air to fuel ratio* for their TWCs (three-way catalytic converters) to work at their best. This consistency is more readily attained with a fuel injected engine than in one with a carburettor. If the fuel injection is computer controlled that is better still.

Three-Way Catalyst: The three-way converter (TWC) has been the primary emission control technology on light-duty petrol vehicles since the early 1980s. The use of TWCs, in conjunction with an oxygen-sensor-based, closed-loop fuel delivery system, allows for simultaneous conversion of the three criteria pollutants, HC, CO, and NO_x,



produced during the combustion of fuel in a spark-ignited engine.

Diesel engines are now the main culprits in polluting Hong Kong's air – especially in the emission of NO₂, NO_x and RSPs (PM). But they are also vital to the economy and effective functioning of Hong Kong. The answer: clean up their exhausts comprehensively.

The 6 R's of Diesel Clean Up

- **Refuel.** A switch to cleaner fuels such as ultra-low-sulfur diesel fuel can achieve modest reductions in pollutants. **HONG KONG has already done this with <10 ppm sulfur diesel.**
- **Retrofit.** Engines can be retrofitted with emission control devices that can reduce pollution by as much as 90%. In some cases the cost may approach that of fitting a new engine. **Ultra-low sulfur fuel helps pollution controls to work well.**
- **Repower.** Installing a new low-pollution engine in an older chassis can allow a machine to run for many more years.
- **Replace.** Replacing a vehicle or item of plant with a new, lower-pollution model ahead of schedule can result in substantial pollution reductions.
- **Repair.** Performing routine maintenance can keep pollution rates at or near original levels.
- **Rebuild.** When repair is no longer adequate to sustain top emissions performance an engine rebuild may be necessary. This costs around half that of providing a new engine.

The above actions are at least as applicable to engines in ferries and other vessels as to diesels on land.



See link below for strategies to reduce pollution from bus fleets.

<http://www.unep.org/transport/pcfv/PDF/Retrofit.pdf>

Government Sets the Standards – Users Choose How to Meet the Standards

In the opinion of the author the role of the Government here is to set standards and to enforce them vigorously. It is up to users and operators to choose what they will do to meet the standards – provided they do meet them **and pay for doing so**. There is technology already available to enable Hong Kong to meet **WHO** standards at reasonable cost. For diesel engines the two key technologies, DPF and SCR, are outlined below. They are:

Diesel Particulate Filters - DPF



A neat DPF Retro-fit.

Diesel is by far the dominant vehicle fuel used in Hong Kong. General use of DPF filters is one very good way to clean up Hong Kong's diesels. This includes trucks and buses but also construction and land equipment, stationary engines such as generators or cranes and all diesel powered vessels operating in and adjacent to the Port of Hong Kong. Very roughly it costs HK\$66,000 to retro-fit DPF on a big bus. New diesel trucks with state-of-the-art DPF are now widely available.

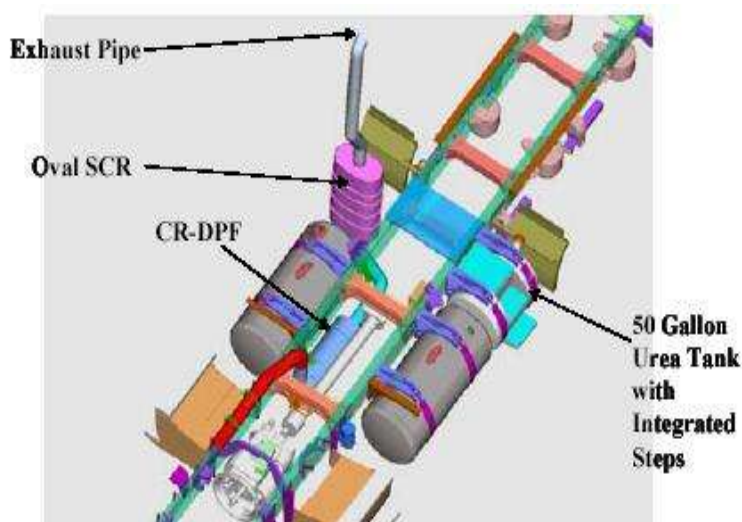
Regenerating Diesel Particulate Filter is standard equipment on this new GM Isuzu, 7.8 litre diesel truck.



These high efficiency ceramic filters have extremely high capture rates (> 99%) for the black carbon portion of diesel exhaust particulates. Studies done by the EPA in the USA indicate that the monetised health benefits from fitting DPF filters to existing diesel buses are up to US\$16 for every US\$1 spent on vehicle upgrades. Ref: UNEP *"Cleaning up Urban Bus Fleets"*, 2009.

Selective Reduction Catalyst – SCR – A Critical Technology for HKSAR

The DPF unit will remove particulates and also unburned hydrocarbons and VOCs emitted from the exhaust. **It will not remove nitrogen oxides, NO₂ & NO_x. This requires a further unit – an SCR.** The SCR can operate continuously and does not affect engine running. SCR offers reduced NO_x emissions and better fuel economy at the same time. The cleaning process is triggered by '*AdBlue*', a nontoxic solution of water and urea, which is injected into the exhaust-gas stream in precisely metered doses. This produces ammonia, which reacts



with NO_x in the SCR system to form nitrogen and water. Thus the exhaust consists of entirely harmless gases already present in clean air; H₂O (as water vapour), N₂ (nitrogen as in the air) and CO₂. The rate of use of the additive solution is about 1 litre to every 50 litres of diesel fuel. It is replenished during a vehicle's scheduled servicing.

Ultra-Low Sulfur Diesel Fuel

Since 2007 all highway diesel sold in Hong Kong has met the <10 ppm sulfur standard. **All diesel fuel sold for use within Hong Kong for whatever purpose, including vessels operating locally, should meet this standard.** It is vital for the long-term effective working of both DPF and SCR. (There was a diesel fuel called ULS introduced in 2001 which had <50 ppm of sulfur. It has been overtaken by the <10 ppm fuel. This further lowering of sulfur content makes little difference to SO₂ emissions but is much better for DPF and SCR units and thus for PM and NO_x emissions.)

Comparison with Diesel Oxidation Catalyst - DOC

Many diesel engines in Hong Kong are already fitted with the cheaper Diesel Oxidation Catalysts. These DOCs do help but they only remove 25% to 35% of the particulates. This is much inferior to the 90% to 95%, even 99%, reduction achieved by a modern, ceramic DPF. DOCs remove up to 40% of the carbon monoxide and 50% of the unburnt hydrocarbons. NO_x or NO₂ are not reduced.

Diesel Retrofit Technologies

Source: <http://www.dieselfetrofit.eu/technologies.html>



Emission control technologies include catalytic converters and particulate filters. They consist of a stainless steel box (or can) mounted in the exhaust system either as original equipment or retrofit emissions control device. In some retrofit applications, they can even be mounted in the original muffler.

Inside the can is an autocatalyst or a particulate filter. The autocatalyst can be a ceramic or metallic substrate with an active coating incorporating chemical compounds (the washcoat) to support a combination of catalytic metals or minerals selected for their effectiveness in the required emissions reductions. It can also be a homogeneous honeycomb-ceramics in which only active compounds are extruded simultaneously. The autocatalyst or the particulate filter is mounted in a can and is protected from vibration and shock by a resilient 'mat'. The emission control device then looks similar to an exhaust muffler. Typical emission control devices available for retrofit applications are [Diesel Particulate Filters \(DPF\)](#), [Diesel Oxidation Catalysts \(DOC\)](#), and [Selective Catalytic Reduction \(SCR\)](#) catalysts. They allow the reduction of Particulate Matter (PM) - soot particles - and NO_x emissions from existing diesel engines and vehicles.



Technology	Emission reduction potential		
	Particulates		NO _x
	mass	number	
Wall-Flow Filter	>95%	>99%	<5%
Partial Flow Filter	30-60 %		<5%
Diesel Oxidation Catalyst	<25%	N/A	<5%
Selective Catalytic Reduction	<10%		>70% (up to 95%)
Combined DPF+SCR	>95%	>99%	>70% (up to 95%)

Typical PM and NO_x reduction potential for various retrofit devices.

Combined systems to reduce both PM and NO_x simultaneously are also available. Fuel economy should not be negatively impacted by the use of a retrofit emissions control device provided the system is properly designed for the particular applications.

DPF and SCR are not prescriptive

The purpose of describing PDF and SCR is to show that effective measures are available at reasonable cost to give diesel engines very clean exhausts when coupled with <10 ppm sulfur diesel fuel. It is for the Government to set and enforce the standards and for users to meet them and pay for them as they think best. There may be other ways of reducing emissions which will be entirely acceptable provided they get the required results.

Electric hybrid power and/or CNG fuel are other possibilities – **provided the standards are met and the owners pay their own costs.**

Installation, Maintenance and Testing - IMT

It will be important that **good IMT facilities with well-trained operators** are available in ample time to install, maintain and test all those new devices carefully. **This is a critical issue and goes hand in hand with setting very high standards.** The Government's responsibility is to ensure good testing to go with high standards and to fund this need. The industry itself will, perforce, take care of the rest.

What Standards should be set?

Emission standards are complicated, with curious names and elaborate testing procedures. These are needed to make the tests objective and reflect the real world as nearly as possible. That being so many countries, including HKSAR, use standards developed elsewhere. The main sources are the USA, the EEC and Japan. Hong Kong refers to all three.

In general, Hong Kong has chosen relatively undemanding targets. As an example; the USA EPA Tier 2 refers to all vehicles up to 3.8 tons whether they use gasoline or diesel. Making the requirements independent of fuel type is a good start. So is requiring that a bigger vehicle emits no more pollution per km than a smaller one.

"From Jan 1, 2006, all new passenger cars with spark-ignition engines in Hong Kong must meet either Euro IV petrol standard, Japanese Heisei 17 standard or US EPA Tier 2 Bin 5 standard. For new passenger cars with compression-ignition engines, they must meet US EPA Tier 2 Bin 5 standard."

Bin 5 is a low Tier 2 standard. The USA now specifies the higher Bin 2. Hong Kong always has to 'try harder' (never less hard) on air quality because of its huge fuel use relative to its compact geographic extent. See link below for an excellent modern study of diesel emissions and standards.

www1.eere.energy.gov/vehiclesandfuels/pdfs/diesel_technical_primer.pdf

China Yuchai International Introduces First Euro VI Automotive Diesel Engine in China. Singapore, July 4, 2011

“China Yuchai” or the “Company”, announced today that its main operating subsidiary, Guangxi Yuchai Machinery Company Limited (“GYMCL”), recently introduced China’s first prototype diesel engine compliant with Euro VI emission standards. As China’s first Euro VI-compliant automotive diesel engine, GYMCL’s heavy-duty model YC6L-60 diesel engine has set another milestone in its history of technological achievement.

*At a press conference hosted by GYMCL at its offices in Yulin City, Guangxi Province, the National Passenger Car Quality Supervision and Inspection Center (Tianjin Automotive Test Center) released the test results of the YC6L-60 engine which was jointly developed over a four-year period, between GYMCL and researchers from Tianjin University’s National Key Laboratory of engine combustion. The results indicate that **the nitrogen oxide emissions and particulate matter emissions of the YC6L-60 were well below the Euro VI emission requirements** hence meeting the Euro VI emission standard. There are three key features of GYMCL’s YC6L-60 engine: (a) a proprietary low-temperature combustion technology which reduces the fuel injection pressure requirement hence improving the life span of the fuel injection system and other core parts of the engine; (b) the use of medium-intensity cooled exhaust gas recirculation (EGR) technology resulting in a clean and economic combustion process; and (c) the use of selective catalytic reduction (SCR) technology combined with diesel particulate filter (DPF) regeneration capability will reduce urea consumption during the after-treatment process resulting in cost savings to end-users.*

Since its introduction in the European Union (EU) in 2009, the Euro VI emission standard is, by far, the most stringent emission standard in the world. As the EU has announced plans to implement the Euro VI emission standards beginning in 2013, most European engine producers have been actively developing their products accordingly. The introduction of China’s first Euro VI-compliant diesel engine by GYMCL demonstrates its world-class research and development capabilities”.



Hong Kong has an international reputation for clean streets which are always kept litter-free and clean. It is a proud and valuable reputation. It should be matched by equally clean air. Clean air demands that stringent emission standards be set for all engines, testing be rigorous and enforcement be firm.



Philosophy of Pollution Reduction

The posters above show the approach which Hong Kong takes to polluting litter, namely no tolerance and on-the-spot fines. This approach is appealing, commendable and effective. Many more countries should use it. The result is that Hong Kong has an international reputation for its clean and tidy streets. The author believes and recommends that a similar approach should be taken to achieving clean air – an even more important objective. As well as its huge health benefits clean air will help towards clean facades on buildings.

Thus the HKSAR Government should achieve **high air quality by setting strict emission standards for all equipment which emits exhaust**. Regular and strict testing should be instituted with on-the-spot fines for those breaching the standards.

The fines should be much higher than those for litter because, at hazard, is not only the amenity of the people of Hong Kong but also their health and well-being. The fines should be pro-rated according to the amount by which any vehicle or item of plant exceeds the permitted emission level. The offending machine should be compulsorily withdrawn from use unless and until it can meet the standards.

Costs to Users and Operators

These strict standards will inevitably impose costs, inconvenience and sometimes hardship on the owners and operators of polluting vehicles or plant.

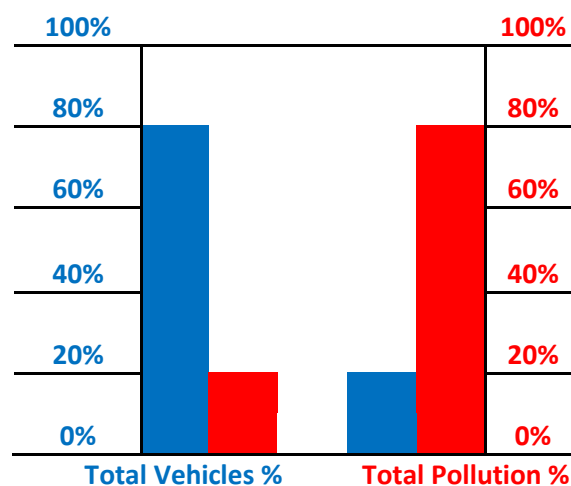
Nobody has a right to hazard the health and well-being of their fellow citizens in the course of their business or personal activities. Polluting the air does just that and so it is quite unacceptable. Competition will tightly constrain the extent to which resulting extra business costs, where they exist, are passed on to customers.

Costs to Government

Costs to Government will come from establishing a stringent, widespread and random pollution-testing regime. This will apply mainly to diesel engines but will also cover petrol and LPG vehicles. **Initially the budget for testing will need to be doubled and the number of tests increased fourfold.** These extra tests will be made possible by using best practice methods. Experience in the field will show what further testing may be needed. There will also be payments made by Government via the transitional 'hardship' fund.

The Pareto Principle and Pollution

Readers will be familiar with the '*Pareto Principle*', often called the 80/20 rule. This says, for example, that 20% of customers account for 80% of a company's sales or that 20% of patients account for 80% of visits to doctors' surgeries. A similar principle applies to pollution from vehicles.



This underlines the importance of targeting the vehicles or other engines which cause severe pollution and giving priority to their early removal. It is a cost-effective way to tackle the problem as those very polluting machines are typically old and of low value.

Some of those vehicles will be essential assets of small businesses and their removal may threaten employment or livelihood. In that case this report recommends the Government offer a 'hardship' payment. It will be for genuine hardship only – not for mere cost or inconvenience.

CCS – Carbon Capture and Storage for Power Stations

This is one of the costly traps into which several nations have fallen and which we urge the Government of Hong Kong to avoid like the plague! It is irrelevant to air quality and is all cost, no benefit and final abandonment. That has been the history of such schemes around the world. A CCS scheme for a power station lasts as long its government subsidy and not a moment longer. Those who advocate for power station CCS are invited to name one successful such plant in operation capturing the full CO₂ output from a power station. It can't be done – there are none.

The following is from a broadcast by the Australian Broadcasting Corporation. It is significant in its own right and more so because the ABC is typically a fan of all things 'climate change'. In this case the facts worldwide speak for themselves.

Broadcast: 14/02/2012

Reporter: MICHAEL ATKIN

"Carbon capture and storage has been touted as one answer to climate change but is Kevin Rudd's \$300 million Global Institute providing Australian taxpayers value for money?"

JOSPEH ROMM, CENTRE FOR AMERICAN PROGRESS: *"No one has put all the pieces together into one commercial effort - have it run, kick the tires, as we say in the States, see what happens to the carbon dioxide."*

MICHAEL ATKIN: *"Carbon capture and storage, or CCS, takes the emissions from power stations and other sources, compresses the CO₂ into liquid and stores it in deep geological formations, or old oil and gas fields. But the enormity of the task hit home last year, with 11 major projects hitting the wall."*

JOSEPH ROMM: *"Almost every major project around the world that has been started in the last few years has either been delayed, stopped or cancelled outright."*

The table below lists some of the power station CCS projects cancelled or 'on hold'. Those nominally still 'alive' are still receiving big Government subsidies and are for operation at some future date – will that date ever come?

Source: Carbon Capture and Storage Projects @ MIT

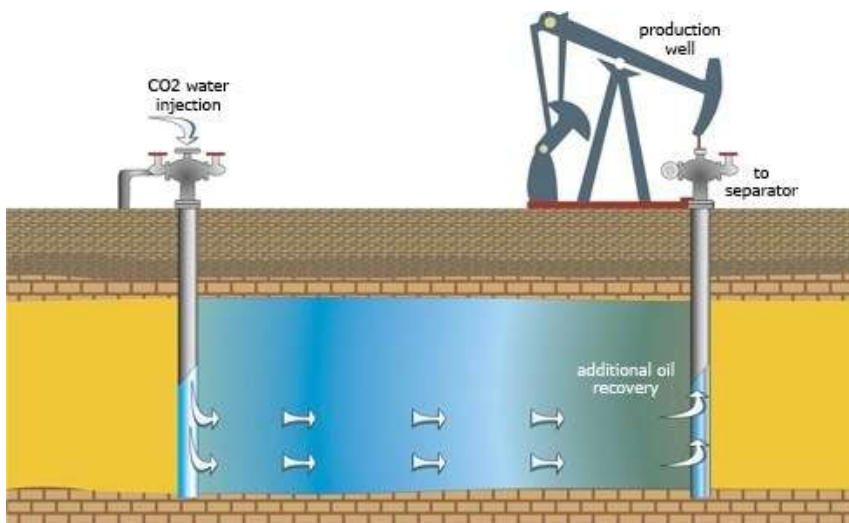
Project Name	Leader		Feedstock	Size MW	Capture Process	CO2 Fate	Start-up	Location
Sweeny Gasification	ConocoPhillips		Coal	680	Pre	Saline/EOR	Cancelled	Texas
AEP Mountaineer	AEP		Coal	235	Post	Saline	Cancelled	West Virginia
Taylorville	Tenaska		Coal	602	Pre	Saline	Cancelled	Illinois
Antelope Valley	Basin Electric		Coal	120	Post	EOR	Cancelled	North Dakota
Porto Tolle	ENEL	Coal	660	Post	Saline	On hold		Italy
Goldenbergwerk	RWE	Coal	450	Pre	Saline	On hold		Germany
Janschwalde	Vattenfall	Coal	250	Oxy	Saline	Cancelled		Germany

The dreadful economics of CCS stems from its absurd physics. Firstly the 20% or so of CO₂ in the hot exhaust gas flowing at thousands of cubic metres per minute must be separated from the other 80% - mostly atmospheric nitrogen. That is very difficult and very costly to do at all, let alone to do consistently 24/7. Then the CO₂ must be compressed and this needs huge power – typically about 30% of the station’s electrical output. In turn this means that a putative CCS power station must produce around 50% more power than it can send out to the electricity grid which means that it must burn up to 50% more coal than a non-CCS station of similar output. It therefore needs bigger and more costly furnaces, boilers and generators. That makes the price of electricity soar – even at this stage.

Then the CO₂ must be piped to a ‘suitable’ underground storage site which may be far away and will need extensive and expensive drilling. The final absurdity lies in the relative volumes concerned. One m³ of coal in the ground weighs around 1.4 tons. When burned that gives over 4 tons of CO₂ which has a volume of over 2,000 m³. So 1 m³ out of the ground and 2,000 m³ back – no wonder the costs go off the clock! Given all this nonsense the question of whether or not the CO₂ will stay underground for centuries is a mere bagatelle.

Some people have been misled by reports of successful ‘CCS’ projects. They all involve injection of CO₂ into oil or gas wells as part of the process of winning oil or gas. ‘Re-injection’ of separated gas into an oil well to maintain reservoir pressure and enhance oil recovery is a long-established practice in the industry. When CO₂ is available at the well-head it makes good sense to substitute it for the natural gas (CH₄). The CO₂ is not saleable but the natural gas commands a good price so it is piped to customers and the CO₂ is injected instead. All the drilling has been done, the pumps are already there and the

compression is needed anyway so the extra cost is negligible. This process has no relevance to CCS for power stations.



Injection of CO₂ in the subsoil for recovery of oil.

http://www.basinelectric.com/Energy_Resources/Gas/CO2_Sequestration

The Port of Hong Kong and World Shipping



The Port of Hong Kong is one of the World's three great container ports and handled some 23,700,000 teu (*twenty foot equivalent unit*) in 2010 – nearly 5% of the entire World's container traffic. What Hong Kong already does for the environment and for maritime safety is to ensure that all vessels passing through the Port and all bunker fuel supplied by the Port comply fully with the latest requirements of the International Maritime Organisation (IMO).

The Port should also ensure that all local vessels under its jurisdiction which have diesel engines fit DPF and SCR units and use only <10 ppm sulfur fuel oil. In 2010 the Port of

Hong Kong supplied some 3.8 million tons of marine diesel and 6.4 million tons of fuel oil as bunkers to visiting ships.

As a long term aim the Port might, with cooperation of the IMO, require visiting vessels to burn only low sulfur fuel within a given distance, say, 24 nautical miles of the Port. The State of California, for example, imposes such a requirement on all vessels up to 24 miles off its west coast.

Air Pollution from 2-Stroke Motors

Two-stroke engines produce a steady stream of unburnt lubricating oil plus other pollutants. This is inherent in how they work. One small, 2-stroke motor bike can produce more air pollution than many cars. Thus **2-strokes (below left) are bad news and they need to be phased out** in favour of 4-strokes or all-electric bikes such as that shown below right.



Photo - June 2012



This boat uses twin 4-stroke outboard motors. This is much better for water and air quality than using 2-stroke outboards. It also saves fuel.

Conclusion

Hong Kong, The Fragrant City, should have clean air to benefit the health and well-being of its citizens, to match its clean streets, and to maintain the strength of its economy. This requires emissions from vehicles and all other engines to be controlled very strictly. Lasting credit will accrue to those who make this happen.

For all new equipment it means imposing the highest international standards which will be embodied in **HK6**. For all existing engines it means, over a period of 6 years, upgrading those engines to that same **HK6** level or, if upgrading is not practicable, scrapping the engines. **HK6** limits based on emissions per KWhr will apply to all diesel engines within HKSAR whatever their use and whatever their location. In particular, **HK6** will apply to all vessels using Hong Kong harbour on a regular basis and to all equipment on construction sites.

The resultant clean city air will be a fine example from Hong Kong to other cities in the World.

This will need much effort, money and concentration on the essential task of **implementing HK6 by 31st December 2018**.

So: *Clean up Hong Kong's old and dirty diesels as the highest priority.*

This report invites everyone in Hong Kong, whatever their role, to get stuck in vigorously to the hard but entirely achievable job of making their home air clean.

Appendix A - The Relationship between Emission of CO₂ from a Diesel Engine and Emission of Criteria Pollutants

There is a widespread belief among many sincere and well-meaning people that emissions of CO₂ and emissions of harmful (criteria) pollutants from diesel or other engines are closely linked. Taken over time, this belief is the opposite of the facts.

For a *given engine using a given fuel* it is true that the more miles it travels or the more hours the engine is used, the amount of CO₂ emitted and the amount of the various criteria pollutants emitted will rise together.

But over time, in particular across the years from 1990 to date, there has been a complete disconnect between the emission of CO₂ and of criteria pollutants. During that period the total amount of CO₂ emitted has risen pro rata with the increase in engine and fuel use but the total amount of pollutants emitted has fallen drastically. That is to say the two emissions have moved in exactly opposite directions. Numerous publications, e.g. from USA EPA and the EEC, show this to be the case. More CO₂ and cleaner air have gone hand in hand. A visit to any major European city makes this very obvious.

How can something so contrary to so much intelligent opinion be true?

The very large improvement in emission controls (and thus in criteria pollutant reduction) has far exceeded the increase in engine and fuel use over the same period. CO₂ emission is directly proportional to fuel consumed so it has risen. Simultaneously the ever better emission controls fitted to new engines have reduced criteria pollutants by orders of magnitude. The reducing effect of those better controls has been much greater than the increasing effect of rising fuel use and thus CO₂ emission. Hence pollution has fallen while CO₂ has risen.

This is such a key issue in the Pollution/CO₂ debate that the author decided to risk boring readers by spelling it out with detailed facts and figures. In part, it repeats matters already covered elsewhere in this report.

CO₂ from Diesel Fuel. When a given quantity of diesel fuel is burned completely – whether in a diesel engine or elsewhere – it produces a given amount of CO₂.

Fuel type	Kg of CO ₂ per unit of consumption
Grid electricity	43 per kWh
Natural gas	3142 per tonne
Diesel fuel	2.68 per litre (3.23 per Kg)
Petrol	2.31 per litre
Coal	2419 per tonne
LPG	1.51 per litre

The table above is from Exeter University in the UK:

http://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm

This can be confirmed from countless other sources. The amount can vary slightly with variations in the exact composition of a particular fuel.

Examples of values of BSFC for shaft engines

Source: http://en.wikipedia.org/wiki/Brake_specific_fuel_consumption (BSFC)

The following table takes **selected** values as an example for the **minimum specific fuel consumption** of several types of engine. For specific engines values can and often do differ from the typical values shown below:

year	Engine type	Application	BSFC in lb/(hp h)	BSFC in g/(kW h)	Energy efficiency
	Turbo-prop		0.8	360 to 490	17 to 23%
	Otto cycle gasoline engines		.45 to .37	273 to 227	30 to 36%
	Diesel engine turbocharged diesels		.34 to .30	209 to 178	40 to 47%
1945	Wright R-3350 Duplex-Cyclone gasoline turbo-compound	aircraft engine	0.4	243	33.7%
	Toyota Prius THS II engine only ^[2]	Automobile		225	37%
1931	Junkers Jumo 204 turbocharged two-stroke diesel	aircraft engine		210	39.8%
2002	Rolls-Royce Marine Trent	marine engine		210	39.8%
1949	Napier Nomad Diesel-compound	aircraft engine	0.345	210	39.8%

2000	Volkswagen 3.3 V8 TDI (Diesel)	automobile engine	0.33	205	41.1%
1990	Audi 2.5 litre TDI (Diesel)	auto engine		198	42.5%

The above table from Wikipedia shows how minimum specific diesel fuel consumption has changed very little from the Jumo diesel of 1931 to the Volkswagen diesel of 2000. Both are very economical engines. Comparison of the Audi engine of 1990 and the Volkswagen engine of 2000 indicates that bsfc and therefore CO₂ output per KWhr may have *risen* marginally over that decade.

Average fuel consumption for trucks and similar diesels in everyday use is significantly higher; around 240-250 grams (0.25 Kg)/KWhr. It has changed hardly at all between 1970 and today. In turn this means that CO₂ output per KWhr of diesel power has not altered significantly. It has remained around $3.23 \times .25 = 0.81$ Kg/KWhr over the period 1970 to 2012.

What has happened to emissions of criteria pollutants from diesel engines over the same period? Criteria pollutants are treated in some detail elsewhere in this report. Those that come from diesel engines are: SO₂, CO, NO_x and PM. The first is not a function of the engine design but of the composition of its fuel. If there is sulfur (S) in the fuel it will burn to produce SO₂.

<http://www.dieselnet.com/standards/eu/ld.php>

Carbon Monoxide (CO), Hydrocarbons HC or VOC), Nitrogen Oxides (NO_x) and Particulate Matter (PM or RSP).

The tables from the EEC (pages 18-22 above) show the reductions in allowable emissions of those pollutants from 1992 (EURO I) to 2013 (EURO VI). EURO I itself was a reduction from the high pre-EURO figures.

Between 1992 and 2013 there are mandated reductions by various large factors for the four pollutants as follows: CO 3; HC (VOC) 8.5; NO_x 20; PM 61.

Specific diesel fuel consumption remained the same over that time so in each case the Pollutant/CO₂ ratio was reduced by the factor shown.

The relationship between CO₂ and the pollutants, SO₂, CO, HC, NO_x and PM over the years 1992 to 2013 are set out on the table and graph below. It is based on an engine of 80 KWhr with a specific fuel consumption of 250 grams (0.25Kg)/KWhr running for 1,000 hours. It

may be used in any application, e.g. a bus, a truck, a tractor, a vessel or a stationary generator. As each new EURO specification comes into force the previous engine is replaced with one conforming to the new standards.

The table and the graph show the total fuel used, CO₂ produced and pollutants emitted over the course of a full year. The scale is as shown above the graph. It is based on the EURO figures as above and with sulfur in the fuel being reduced from 0.2% to 0.001%. Broadly similar figures would result from using data for other countries, e.g. USA or Hong Kong.



80 KW diesel engine

Table and graph are calculated by the author from the EURO standards above and show:

Diesel engine of 80 KW running for 1,000 hours each year, i.e. producing 80,000 Kwhr/year.

Upgraded to comply with new rules each time there is a relevant change in the EURO standards.

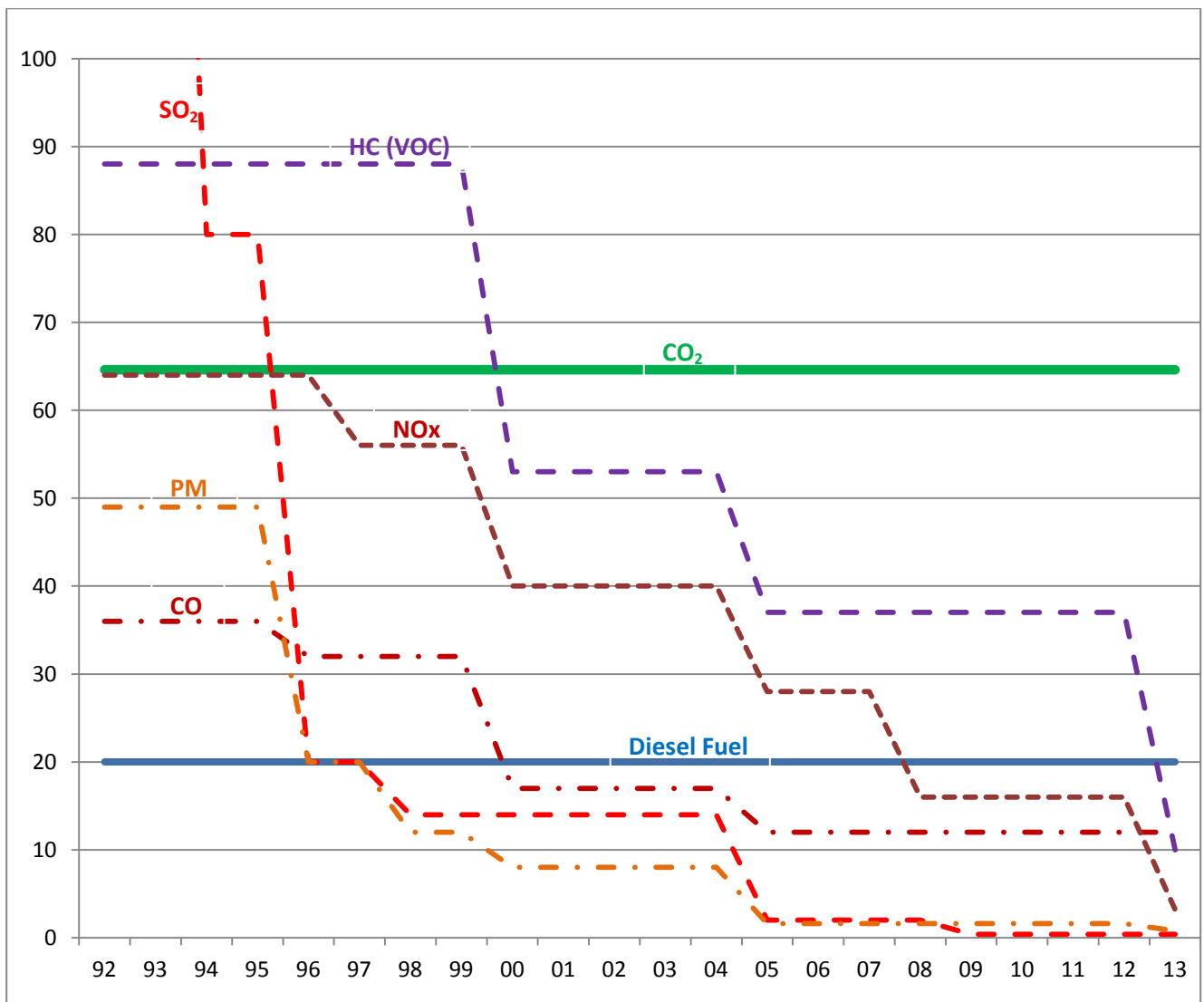
Table shows fuel consumption plus CO₂ produced and emissions of criteria pollutants in total for each year.

Table and graph show how CO₂ production remains steady over the years while pollutants drop dramatically.

Fuel and CO₂ are in tonnes/year. Pollutants are in Kg/year.

Year	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13
Fuel	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
CO ₂	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64
SO ₂	200	200	80	80	20	20	14	14	14	14	14	14	14	2	2	2	2	0.4	0.4	0.4	0.4	0.4
CO	360	360	360	360	320	320	320	320	168	168	168	168	168	120	120	120	120	120	120	120	120	120
HC	88	88	88	88	88	88	88	88	53	53	53	53	53	37	37	37	37	37	37	37	37	10
NOx	640	640	640	640	640	560	560	560	400	400	400	400	400	280	280	280	160	160	160	160	160	32
PM	49	49	49	49	20	20	12	12	8	8	8	8	8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	0.8

Scale: PM, HC & SO₂ = Kg. CO & NOx = Kg x 10. Diesel Fuel & CO₂ = Tonnes All per year



The table and the graph also show how a few, old and high-polluting engines remaining on the far left side of the graph can negate all the good done by many modern, low-pollution new engines on the right hand side.

This again emphasises the critical need to get engines of an old and dirty design upgraded or removed from use in Hong Kong as soon as possible.

Appendix B - Air Quality Action to Date in Hong Kong - Summary

The authorities in Hong Kong have been very well aware of the Region's air quality problems for many years now and (as noted above) a variety of measures have been taken to improve matters. These have had varying degrees of success.

An unequivocal success has been the action on sulfur. The sulfur dioxide gas (SO₂) produced when sulfur containing fuel is burned is one of the most damaging air pollutants. It forms thick smog and has a very harmful effect on human lungs and airways. It also damages buildings and the environment in general with its infamous 'acid rain'.

Hong Kong has made a two-pronged and highly successful attack on SO₂ pollution. The coal burning power stations have retro-fitted the very best FGD (Wet Flue Gas Desulfurization) units which remove almost all the SO₂ from their exhaust gases. Simultaneously the Government has required all diesel fuel for road vehicles to have no more than 10 parts per million (0.001%) of sulfur. These two actions have combined to give Hong Kong a much lower level of atmospheric SO₂ than most comparable cities. Hong Kong is outstanding among its peers in having a level of SO₂ that is only half the strict guidelines set by the World Health Organisation.

For a solid fuel like coal, sulfur can only be removed after the fuel has been burned. For a liquid fuel such as diesel, which goes through a refinery before sale, it is much more effective to remove the sulfur at the refinery. Thus SO₂ emissions from vehicles are controlled by limiting the amount of sulfur permitted in their fuel to near zero.

There is more. The ultra-low sulfur content mandated for road vehicle diesel has laid the essential groundwork for the optimum functioning of DPF and SCR units as and when they are fitted to road vehicles. Any significant amount of sulfur in the exhaust gas can 'poison' a DPF or SCR unit. No such 'poisoning' happens when sulfur in the fuel is at the 0.001% level. Thus Hong Kong has already taken the crucial first step to allow diesel engines in road vehicles to use the very best pollution control equipment effectively and so achieve clean air.

The one qualification to this is that the .001% sulfur limit should apply to all diesel fuel used locally in Hong Kong; that is to diesel used in construction plant, stationary engines and vessels including ferries. This will enable those engines to use DPF and SCR units and thus reach the high standard of emission control needed to give Hong Kong clean air. This will, of course, increase the cost of diesel for those users.

LPG (Liquefied Petroleum Gas) and DOC (Diesel Oxidation Catalyst)

Both of those stratagems are in use in Hong Kong. They 'seemed like a good idea at the time' but in today's world they are but a poor man's solution to pollution control.

LPG: In the early days of pollution reduction in vehicles, LPG did have an advantage over petrol. By the time EURO III, let alone EURO VI, had been reached that advantage had disappeared and LPG had become just one alternative hydro-carbon fuel for use in 'Spark Ignition' engines. In modern engines LPG is neither better nor worse than petrol so far as emissions go. Pollution corresponds to a vehicle's EURO category irrespective of the fuel it uses. Selecting or not selecting LPG must rest on other factors such as price.

In passing; the small red diamond attached to all LPG vehicles is not a badge of merit. It is an internationally-recognised warning, especially to Fire and Rescue authorities, of the dangers inherent in such a vehicle.

DOC: In the 1990s Diesel Oxidation Catalysts were widely used as a quick and fairly cheap 'fix' to reduce PM emissions from diesels somewhat. They were retro-fitted to many diesel engines in Hong Kong.

In general, a modern engine will have far better controls and thus far lower emissions than an older design. For example, a diesel engine fitted with a good DOC will trap about 30% of the very harmful PM whereas one with a fairly modern (EURO V) DPF will trap about 90% of the PM. If the DPF is to the latest (EURO VI/HK6) standard it will trap about 95% of the PM.

At first glance it might seem that either DPF is about 3 times as good as a DOC but, in terms of the pollution that is allowed to escape to atmosphere, the 90% one is 7 times better; the 95% one is 14 times better. These are typical figures for real world engines and underline the great benefit to air quality of using the best modern pollution control system. For a given amount of use and therefore of fuel consumed each engine will produce the same amount of non-polluting CO₂ - but very different amounts of harmful pollution.

DOCs have no effect on the emission of NO_x - nor do DPFs. Good control of NO_x requires the use of an SCR - Selective Reduction Catalyst.

Footnote:

Researchers Find Material for Cleaner-Running Diesel Vehicles

Discovery May Yield a Cheaper, More Efficient Alternative to Platinum in Automotive Engines

Aug. 16, 2012 Mullite is a silicate mineral discovered on the Isle of Mull, Scotland in 1924. Laboratory tests indicate that converters using Mullite would have 45 percent lower emissions than with platinum. [University of Texas at Dallas](#) via [Phys.org](#).