



Feedback on the Vehicle Emissions Discussion Paper

for the Department of Infrastructure and
Regional Development

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ATTAINING IMPROVED VEHICLE EMISSION & FUEL EFFICIENCY IN AUSTRALIA THROUGH THE USE OF MTBE

Dear Sir/Mdm,

We are writing this in response to the Vehicle Emissions Discussion Paper published on February 2016. We applaud your efforts in the implementation of more stringent standards for noxious air pollutant emissions (the 'Euro' standards) and a standards regime for fuel efficiency (CO₂). We are also in full support of the Australian government's move to reduce sulphur levels to 10ppm in fuels and to push for higher RON so as to make it easier for vehicle manufacturers to improve vehicle efficiency through new technologies comprising turbocharged/higher compression-ratio engines.

We, the Asian Clean Fuels Association (ACFA), too believe that the use of cleaner fuels is one of the compelling answers to improving air quality in a prevalent and immediate basis. ACFA is a not-for-profit trade organisation that promotes the use of cleaner automotive fuels. Our core principles are based on sound science and technology, cost efficiency and environmental sustainability. Since our establishment in 2000, we have been working closely with policymakers and regulators in Asia and the Middle East to develop fuel legislation and programs that support the use of cleaner fuels to improve air quality. We work in partnership with international organisations like the United Nations Environment Program and Clean Air Asia, which operates under the auspices of the Asian Development Bank.

We have also recently been actively engaging the Australian Environment Protection Agencies (EPA) and contributed to the review of the Fuel Quality Standards and National Clean Air Agreement that was conducted by Australia last year.

In this paper, we would like to provide our feedback to the questions posed in the Vehicle Emissions Discussion Paper, particularly on the 'Fuel Quality Standards' section. We would also like to share with you on solutions that Australia can take in order to improve vehicle emissions and fuel efficiency. This solution can be found through the use of clean fuel components like MTBE in Australia's fuel. Australia and New Zealand are the only countries in the world which have limit the use of MTBE to 1%vol. No other country has any legislation like this, and no other country seems to need it.

As a consequence of this restriction, Australians are unable to enjoy the air quality improvement benefits which MTBE will bring with it. Additionally, without the use of MTBE, a study done by Stratass Advisors concluded that gasoline in Australia costs a premium of around USD 3 per barrel. Because the main gasolines traded in the Asia region comprise MTBE, the supply availability is reduced by up to 3 times, which impedes its interest on supply security.

Fuel Quality Standards

Q13. Are there changes to fuel quality standards that could assist with reducing noxious emissions and/or CO₂ emissions?

We would like to recommend re-introducing specifications for MTBE allowable in the Australian gasoline. MTBE is a proven clean fuel component recognised by many Environment Protection Agencies (EPAs) around the world (including the US and European EPAs) to reduce vehicle pollutants and CO₂ emissions. Adding MTBE to gasoline allows for a more complete combustion of the fuel due to its oxygenate properties, reducing harmful exhaust emissions. It has been shown to significantly reduce the tailpipe emission of carbon monoxide, benzene, nitrogen oxides, particulate matters and unburned hydrocarbons. Usage of MTBE also reduces evaporative emissions and reduces the formation of ground level ozone or smog.

Using MTBE in unleaded gasoline has resulted in a remarkable reduction of specific pollutants limited by law, such as carbon monoxide (CO) and unburned hydrocarbons(HCs), as well as other serious pollutants such as particulate matter (PM) and ground-level ozone (O₃).

MTBE can act as a substitute for the 'dirty' components in a gasoline blend, such as olefins, aromatics and benzene with fungible ease, whilst at the same time replacing the lost octane from new limits placed on these components, including sulphur. That is why MTBE is known as a clean octane. This is compelling, especially since this works in both current and older technology vehicles. This is why we stated earlier that cleaner fuels provide improvement in air quality in a prevalent and immediate basis.

The US Federal Government has publicly acknowledged after the 2006 Energy Law was instituted that the use of MTBE has helped meet air quality standards. Statistics compiled by the Oxygenate Fuels Association showed that the introduction of MTBE in gasoline has resulted in the reduction of common air pollutants, by the levels shown in Table 1.

Carbon monoxide

CO emission is reduced on average by at least the same percentage as MTBE content in gasoline.

Unburned hydrocarbons

For each 1 or 2% of MTBE, there is a 1% reduction in total HC emissions.

Particulate matter

It is estimated that each 1% of MTBE results in a 2 to 3% PM emission reduction.

Ozone

MTBE generates about half the ozone compared with iso/alkylates and one-tenth that of aromatics.

Benzene

It is estimated that, for each 1% of MTBE, there is an equivalent percentage reduction in benzene emissions, both evaporative and exhaust.

Olefins

MTBE displays low vapour pressure and low volatility compared to olefins. Converting olefins to MTBE in the refinery removes some of the most reactive and volatile components from the gasoline pool.

Lead

MTBE is an ideal substitute for lead, a toxic compound that has been phased out in most parts of the world.

Sulphur

MTBE is sulphur free.

Table 1: Immediate effects of using MTBE in gasoline

A study conducted by Sweden and Finland shows considerable improved emission through the use of MTBE in gasoline (reformulated gasoline). The summary of the results of the study is shown in Figure 1.

Emissions from vehicles in most cases have been reduced due to improved fuels

Estimated range of changes in emissions (in %) relative to normal ungraded fuels (see Appendix A.3)

Finland			Sweden			
	Reformulated gasoline (unleaded)	Reformulated diesel		MK2 gasoline (unleaded)	MK1 Diesel	MK2 Diesel
CO	-25% to -12%	-6% to 2%	CO	-1% to 4%	-6 to 8%	9%
HC	-8% to -5%	-20% to 12%	HC	-3% to 1%	2% to 18%	-10% to 24%
NO _x	-12% to -3%	-12% to -5%	NO _x	-4% to -1%	-11% to -5%	-9% to -4%
PM	-15%	-25% to -10%	PM	-15%	-30% to -10%	-12% to -4%
PAH	-57%	-54%	PAH	-27%	-75%	-36%
SO ₂	-58%	-96%	SO ₂	-59%	-99%	-95%

- Uncertainties regarding the extent of emission changes for CO and HC from diesel vehicles is judged to be higher than for NO_x, PM, PAH, and SO₂.
- A direct comparison of changes in emissions due to improved fuels for Finland and Sweden is not possible since the initial and subsequent fuel qualities and test cycles for estimating emissions are different.

Figure 1: Results of study conducted by Sweden and Finland on the use of reformulated gasoline

In addition, MTBE is a direct replacement for “dirty” and toxic components like benzene, aromatics, olefins and the loss of octane from sulphur.

Q14. Do you have new information that could assist with the assessment of costs and benefits of adopting more stringent fuel quality standards, in particular for petrol?

The Clean Air Asia of the World Bank/ Asian Development Bank has designed a “Roadmap” to provide up-to-date information for decision-makers on how to get to clean fuels in Asia. The roadmap has suggested for Asian countries to achieve Euro 4, and eventually Euro 5 fuel standards, in order to achieve better air quality. This report discussed the interaction between fuels and vehicle technologies, refineries in Asia and approaches these refineries can take to produce cleaner fuels, and recommendations for next steps.

Key conclusions from the report include:

- **The Importance of clean fuels:** Over the course of the past 30 years, pollution control experts around the world have come to realize that cleaner fuels are a critical component of an effective clean air strategy. In recent years, this understanding of the critical role of fuels has grown and deepened and spread to most regions of the world. Fuel quality is now seen as not only necessary to eliminate or reduce certain pollutants (e.g. lead) directly, but also a precondition for the introduction of many important pollution control technologies (e.g. diesel particulate filters). Further, one critical advantage of cleaner fuels has emerged -- its rapid impact on both new and existing vehicles. For example, tighter new vehicle standards can take ten or more years to be fully effective, but the removal of lead in gasoline in Asia has reduced lead emissions from all vehicles immediately.
- **Systems approach:** Fuels and vehicles are part of an integrated system and need to be addressed together. The main emissions reduction benefits will come from the coupling of cleaner fuels with advanced emission control devices.
- **Fuel quality regulation needs to be combined with vehicle emissions standards** to form the backbone of any country’s roadmap for reducing air pollution from vehicles.
- **Sulfur Reduction is Key:** Reducing sulfur levels in both gasoline and diesel fuels is the primary fuel parameter that needs to be considered in developing a country’s fuel roadmap. Reducing sulfur in fuels is a key measure in reducing air pollution from motor vehicles. High sulfur levels reduce the effectiveness of advanced three-way catalysts for gasoline vehicles and clog particulate filters in diesel vehicles. Almost all Asian countries will be adopting increasingly stricter Euro standards, which require reduced sulfur fuels, with an ultimate goal of 50 ppm or less sulfur in diesel and gasoline.
- **Benefits of reducing sulfur are clear:** Extensive studies in developed and developing countries, including the United States, Mexico, and the People’s Republic China, have estimated that the economic benefits of an integrated system of clean fuels and vehicles far outweigh the costs. The estimated benefits of programs on clean fuels and vehicles has a benefit cost ration of 15:1 in the United States, while a recent study devoted to the PRC estimated benefits to exceed costs by a ratio greater than 20:1.
- **Cleaner fuels are cost-effective** The incremental costs of meeting the recommended level of sulfur in fuels in Asia are on average 0.2-0.8 US cents per liter for gasoline and 0.5 – 0.8 US cents per liter for diesel. Further reductions to 10 ppm or below would add about 0.6 US cents per liter to the cost of diesel fuel.

- **Current refinery expansion creates a window of opportunity:** The increasing demand for transportation fuels in Asia is resulting in the construction of new refineries, upgrading or expanding of existing refineries in the region, thereby creating a window of opportunity to produce the clean fuels necessary for reducing emissions.
- **No technical obstacles to produce cleaner fuels in Asia:** The refining technology needed to produce cleaner fuels that meet Euro 4 or equivalent standards is well understood and has been successfully implemented in the U.S. and Europe.
- **Enhancing octane:** Gasoline often needs greater levels of octane than is available in the crude. The use of metallic additives (MMT and Ferrocene) should be carefully evaluated because of potential health concerns and impacts on vehicle emissions and emissions systems components. Decision makers in Asia should take note of the upcoming results of the studies by Health Canada and the US EPA on health impacts of manganese (including MMT). Prominent health experts have raised serious concerns regarding the potential adverse health effects of metallic additives such as MMT. Therefore, the environmentally responsible approach for Asian countries to take concerning the use of metallic-based additives is to apply the precautionary principle for these metallic additives and to not use them until and unless the scientific and health studies show that they are safe. Other additives, such as ethanol, MTBE, ETBE and TAME, have not been shown to cause significant health effects. The longer-term solution applied by many refineries to meet the gasoline octane requirements is through capital investment in enhanced refining capacity and blend stock selection, and the use of certain oxygenates.
- **Taxing policy and incentives:** Experience across the world has shown that governments can accelerate the introduction of cleaner fuels and their uptake through a combination of tax and pricing policies.
- **Fuel adulteration:** Whatever fuel specifications are adopted in Asia, it is important to have routine monitoring at the pump and along the distribution chain to assure that the actual fuels in the marketplace meet the required specifications. Penalties should be imposed if the limits are not achieved.
- **Involve all stakeholders:** Decision making on the introduction of cleaner fuels should include a dialogue among all stakeholders, including environmental and public health officials, the oil refining sector, vehicle and engine manufacturers, and ministries concerned with oil pricing and taxation
- **Need to raise awareness on air pollution and vehicle emissions:** There is a need for intensified awareness-raising at the national and sub-national level to make the case for cleaner fuels. Awareness raising campaigns should be focused on both the general public, as well as decision-makers.

The roadmap report by Clean Air Asia is attached, separately, along with this submission.

Q15. To what extent, if any, do current fuel quality standards limit the choices of vehicles/technologies in Australia and why?

As Australia is interested in improving fuel efficiency and reduce greenhouse gases, higher octane grades of 95RON are important considerations. Studies have shown that interplay between higher octane and the trend of downsizing petrol engines results in reduction of CO₂ emissions, improves air quality and allows consumers to get more miles, yet enjoys cost-savings over time.

One of such report is published by the US Energy Information Administration (EIA), which highlights that new engine design trend is demanding higher octane gasoline. The report can be accessed at <http://www.eia.gov/petroleum/weekly/>. In the report, it explained that smaller turbocharged engines can be used to raise fuel economy while meeting or exceeding the power and torque of larger engines, allowing engine downsizing and improved fuel economy with little or no performance compromise. Turbochargers work by using a turbine driven off the exhaust gas to pressurize the intake air. The pressurized intake air allows a turbocharged engine to produce more power compared with a naturally aspirated engine of the same size.

Because turbocharging forces more air into the combustion cylinder, it increases cylinder pressure and compression. However, because of increased compression there is an increased risk for engine knock (the premature and incomplete combustion of fuel), which can damage the engine. Therefore, turbocharged engines typically require more design and operational features to prevent engine knock than naturally aspirated engines.

The octane rating of gasoline is an indicator of its resistance to spontaneous combustion. The higher the octane rating, the greater the resistance to pre-ignition, the fundamental cause of engine knock. Use of higher-octane gasoline can offset the increased risk of engine knock caused by increasing engine compression. This is why premium fuel has historically been required in performance and luxury vehicles that maximize power and torque.

The US Environment Protection Agency (EPA) is also currently conducting a similar study to assess the potential benefits of higher octane gasoline. The study was a direct result of the feedback by the automotive industry. Automakers have said they can continue making engines smaller and more powerful if high octane fuel of about 95 RON were the new regular. High octane gasoline allows engineers to raise the compression ratio of engines. High compression engines produce more power.

Should Australia improves the current fuel standards and supports higher octane fuels, Australian for car manufacturers, consumers, refiners and society can reap these benefits stated above.

Q16. Are there any measures that governments could adopt to encourage the supply and purchase of higher quality fuels?

Yes. MTBE is a known clean octane enhancer that boosts the fuel quality readily that has helped refiners meet improved fuel standards without necessitating large capital expenditures. This is evidenced by developments in Europe, recently in China where the country took only less than 10 years to upgrade its gasoline from Euro 2 to Euro 5 equivalent standards.

By limiting MTBE, the government has restricted the supply availability of imported gasoline by a factor of 3 times, given limited options of gasoline that could be imported from the region, hence impacting its supply security.

We append an excerpt from the study done by Stratas Advisors (MTBE Whitepaper for Australia, October 2015). The premium price of imported gasoline is displayed in page 101 of the whitepaper. The current price differential between Australia imported gasoline and Singapore price is \$3.0 /Bbl. This will add to overall gasoline cost imported to Australia.

MTBE as a clean fuel component

As Australia prepares to adopt stricter fuel standards, with the potential increase in fuel octane for RON95 and above, MTBE being a clean gasoline component and octane enhancer plays an important role in this aspect. This can be seen not only on a global level, but potentially also for Australia. Studies have shown that higher octane gasoline has the potential to improve fuel efficiency.

The Japanese Automotive Manufacturers Association (JAMA) has run engine tests and produced such an evidence of fuel efficiency improvements of between 2% to 10% based on different types of engine. This is also presented in a report by Ricardo, which we are enclosing as a separate document alongside this submission.

In its website, the US EPA also stated that reformulated gasoline (RFG) has been helping improve the air for millions of Americans since 1995. The use of RFG compared to conventional gasoline has resulted in annual reductions of smog-forming pollutants (volatile organic compounds and nitrogen oxides) and toxics (such as benzene). With the second phase (PDF) of RFG program, which began January 2000, EPA estimates that smog-forming pollutants are being reduced annually by at least 105 thousand tons, and toxics by at least 24 thousand tons. Refiners are required to reduce the emissions of volatile organic compounds, toxics, and nitrogen oxides by 27, 22, and 7 percent, respectively, compared to the conventional gasoline they produced in 1990.

Growing use of fuel ethers around the world

There is an established and growing use of fuel ethers around the world. Beginning in 1990's, the EU authorities began to focus their attention on improving air quality. Massive scientific study programmes, engaging both the European Commission and key industries such as oil and vehicle manufacturers, lead to a series of Fuel Quality Directives, mandating gasoline properties which would contribute to a better environment & health.

Fuel-ethers again played a key role in Europe because when they are blended into gasoline they improve its performance. They reduce the levels of many ozone precursor emissions from vehicles such as carbon monoxide and VOCs (Volatile Organic Compounds) by contributing oxygen and octane, and by improving fuel distillation temperatures. They also contribute to lower particulate emissions in the exhaust.

A significant advantage of using ethers in gasoline is that the emission benefits occur immediately across all ages and classes of vehicles using the cleaner burning gasoline. This generally provides immediate air pollution benefits without the need to wait for new technology vehicles to sufficiently penetrate the vehicle fleet population.

In Asia, MTBE is used primarily as an octane enhancer to replace lead and reduce the levels of sulphur, benzene and aromatics in gasoline. The use of MTBE has aided various Asian countries to phase out lead and reduce the level of toxics in gasoline fairly quickly. It is very cost effective and helps expand gasoline volume. China, South Korea, Taiwan, Malaysia and Singapore use MTBE in their gasoline pool. After embarking on an extensive comparative study between ethanol and ETBE, Japan decided on ETBE as its fuel of choice. ETBE seems to be a more favourable fuel blendstock than ethanol for the control of running loss (RL) emissions. Unlike ethanol, ETBE can be directly blended into fuel.

The demand of MTBE in China in particular, is growing strongly, given its commitment to combat air pollution in its major cities through upgrading its fuel standards. Figure 2 below shows the prediction of growing fuel ethers demand in Asia till 2025.

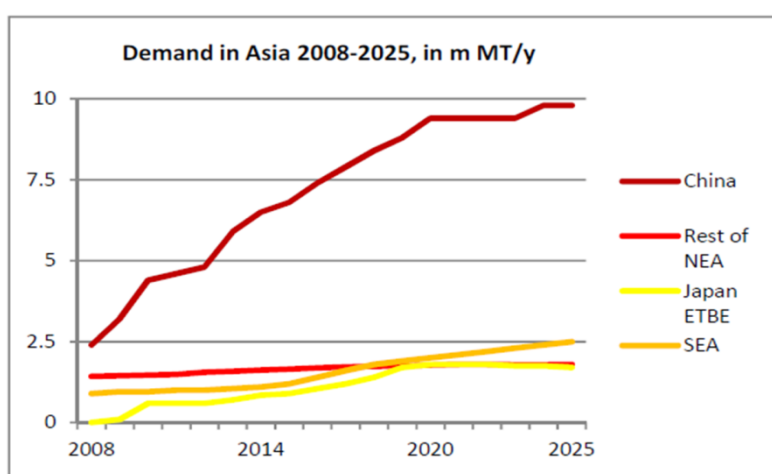


Figure 2: Data for MTBE demand in Asia from 2008 to 2025 by DK& Associates

In the Middle East, MTBE is perceived to be a valuable additive in replacing the lost octane due to cleaner fuels implementation as the region continues with lead phaseout and sulphur reduction

MTBE production in the U.S. is currently exported to Mexico, Venezuela and other South American countries. As countries in South America and Africa embark on gasoline quality improvements, there will be an increased demand for fuel ethers to meet their octane needs.

Fuel ethers usage is preferred worldwide. Car and engine makers in the world stated in the Worldwide Fuel Charter:

On the basis of emission benefits, vehicle performance and existing regulations, where oxygenates are used, ethers are preferred.

We hope our comments and contributions to the discussion paper would be useful for the committee. We would be happy to take in any further queries that you may have regarding our submission or any other related issues. Thank you.

About ACFA

Asian Clean Fuels Association is a not-for-profit ethers trade association that has for the past 15 years dedicated itself in promoting clean fuels usage throughout Asia. We believe that the use of clean fuels is one of the most compelling answers to improving the quality of air. Our mandate is thus: “Clean Air with Clean Fuels”.

ACFA was formed in August 2000 and headquartered in Singapore. Its members are made up of international oil and petrochemical companies. ACFA has been prevalent in its efforts to improve the quality of fuels throughout Asia Pacific, including the Middle East, Greater China, NE Asia, SE Asia, and Australasia.

ACFA is a member of the Coordinating Council in CAI-Asia (Clean Air Initiatives for Asian Cities) which is sponsored by the World Bank and Asian Development Bank. ACFA is also a member of the United Nations Environment Programme (UNEP) Partnership for Clean Fuels and Vehicles.

ACFA works with many government bodies, in particular, MEP of China, the Pollution Control Department of Thailand, the Ministry of Environment in Thailand, the oil industry, auto industry, non-government organisations (NGOs) and even the academia to ensuring a scientific approach to fuels legislation around Asia, based on sound science, cost efficiency and environment protection.



A Roadmap for Cleaner Fuels and Vehicles in Asia

- Second Consultation Draft -

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ABBREVIATIONS

ACEA	–	Association des Constructeurs Européens d'Automobiles (European Automobile Manufacturers Association)
AECC	–	Association for Emissions Control by Catalyst
ARB	–	Air Resources Board
ASTM	–	American Society for Testing and Materials
CO	–	Carbon monoxide
CO ₂	–	Carbon dioxide
CONCAWE	–	Conservation of Clean Air and Water in Europe
CRC	–	Coordinating Research Council
E10	–	Gasoline blend containing 10% ethanol by volume
E85	–	Gasoline blend containing 85% ethanol by volume
EN	–	Standard set by the European Committee for Standardization
EPA	–	Environmental Protection Agency of the United States of America
ETBE	–	Ethyl tertiary-butyl ether
EU	–	European Union
FCC	–	Fuel catalytic cracking
FFV	–	Flexible-fuelled vehicle
HC	–	Hydrocarbon
IQ	–	Intelligence quotient
JIS	–	Japanese Industrial Standards
LEVs	–	Low Emission Vehicles
LRG	–	Lead replacement gasoline
MIL	–	Malfunction indicator light
MMT	–	Methylcyclopentadienyl manganese tricarbonyl
MON	–	Motor octane number
MTBE	–	Methyl tertiary-butyl ether
NIEHS	–	National Institute of Environmental Health Sciences,
NMOG	–	Non-methane organic gases
NO _x	–	Oxides of Nitrogen
OBD	–	On-board diagnostics
OECD	–	Organisation for Economic Co-operation and Development
PAH	–	Polycyclic aromatic hydrocarbons.
PAN	–	Peroxyacetyl nitrate
PRC	–	People's Republic of China
RFG	–	Reformulated gasoline
RON	–	Research octane number
RVP	–	Reid vapor pressure
TAME	–	Tertiary-amyl methyl ether
TBA	–	Tertiary-butyl alcohol
TEL	–	Tetraethyl lead
THC	–	Total hydrocarbons
TML	–	Tetramethyl lead
US	–	United States (of America)
USA	–	United States of America
VOC	–	Volatile organic compounds

NOTE

- (i) In this report, "\$" refers to US dollars.

ACKNOWLEDGEMENTS

The reduction of vehicle emissions has been an important concern of the Clean Air Initiative for Asian Cities (CAI-Asia) since its establishment in 2001. Vehicle emissions are an important contributor to air pollution in all of Asian's cities. CAI-Asia has actively campaigned for the improvement of fuel quality, an essential step in reducing vehicle emissions.

This report is the outcome of a long process which started with a meeting in July, 2003 in Singapore where 12 major regional and national oil companies gave their recommendations to CAI-Asia on how to approach the formulation of a roadmap for cleaner fuels and vehicles in Asia.

CAI-Asia took the lead to compose the report. The report was prepared by a team of authors consisting of Grant Boyle, John Courtis, Cornie Huizenga, John Rogers, and Michael Walsh. Valuable assistance in data collection and references validation and in formatting of the report was provided by Aurora Fe Ables, Agatha Diaz, Herbert Fabian and Gianina Panopio.

A draft of the report was presented at a regional workshop in May, 2006 in Mandaluyong City, Metro Manila, Philippines. The comments received from participants in this workshop were especially useful in revising the text and the preparation of the final report.

Special thanks are due to staff of the Health Effects Institute, Shell and the United States – Environmental Protection Agency (EPA) who carefully reviewed the relevant sections of the report and provided extensive comments and inputs.

CAI-Asia also benefited greatly from the discussions and comments received in the numerous workshops, conferences and meetings on fuels and vehicles where CAI-Asia was invited to participate and present the roadmap as it was being formulated.

The Asian Development Bank, through a technical assistance grant, financed the development of this Roadmap for Cleaner Fuels and Vehicles in Asia. David McCauley, Charles Melhuish, Daniele Ponzi and Masami Tsuji as project officers facilitated CAI-Asia's preparation of the report.

This report is dedicated to the memory of Kong Ha, the late Chairperson of CAI-Asia. Kong was passionate about reducing emissions from the transport sector and he was passionate about this report. The implementation of the recommendations in this report will be a lasting tribute to Kong Ha and help the people of Asia breath cleaner air.

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EXECUTIVE SUMMARY

Air pollution continues to pose a significant threat to the environment, quality of life and health of the urban population in Asia. The World Health Organization (WHO) has estimated that more than 530,000 premature deaths in Asia are due to urban air pollution. In many Asian cities, the source of much of this air pollution continues to be motor vehicles, both passenger cars and heavy-duty buses and trucks. Key emissions from motor vehicles include carbon monoxide, (CO), particulate matter (PM), nitrogen oxides (NO_x), volatile organic compounds (VOC), and unburned hydrocarbons (HC). Emissions of these pollutants depend a great deal on the quality of the fuels used and the design of the vehicles.

In many countries in Asia, vehicle emissions are expected to increase over the next few decades, as the vehicle population increases. If no action is taken to clean up fuels and vehicles, urban air pollution will continue to degrade.

Reducing emissions from motor vehicles is dependent on introducing cleaner fuels, along with advanced emissions control technologies that require these cleaner fuels. A key first step has been the drive to eliminate lead in gasoline world-wide. This approach has resulted in more than 90% of the world's gasoline now being lead-free. It is now time to tackle other fuel issues, including sulfur in fuel, additives, and other fuel components.

This "Roadmap" has been designed to provide up-to-date information for decision-makers on how to get to clean fuels in Asia. This report discusses the interaction between fuels and vehicle technologies, refineries in Asia and approaches these refineries can take to produce cleaner fuels, and recommendations for next steps.

Key conclusions include:

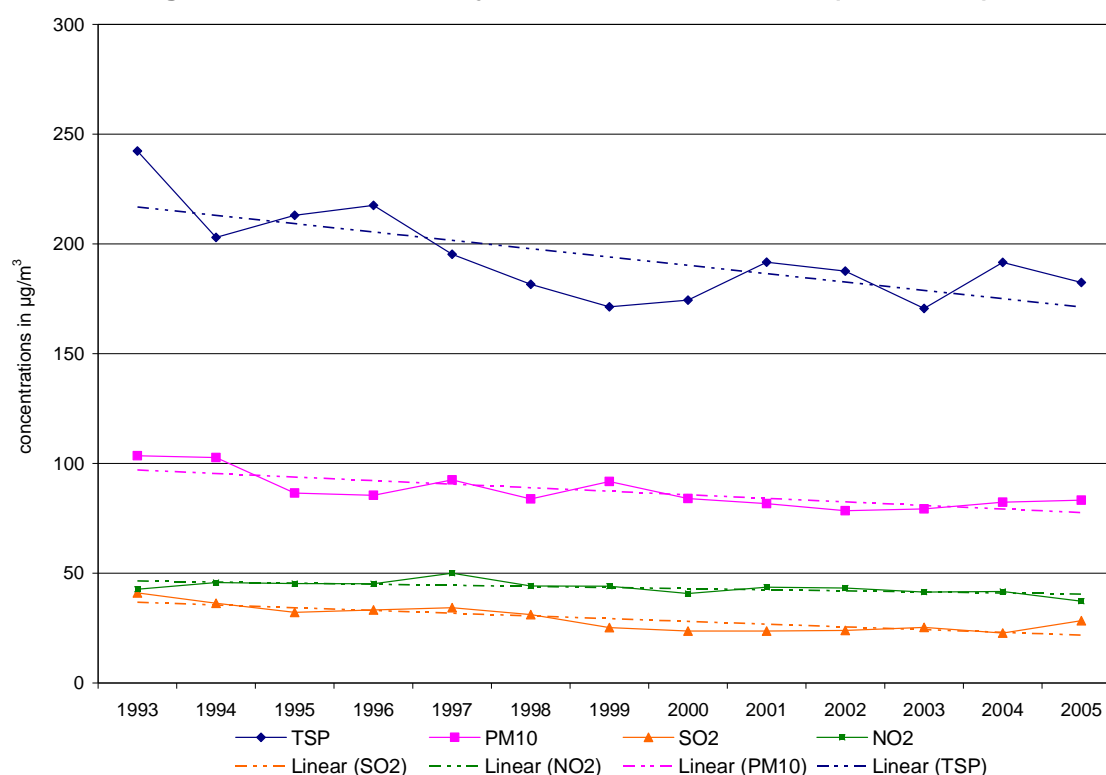
- **The Importance of clean fuels:** Over the course of the past 30 years, pollution control experts around the world have come to realize that cleaner fuels are a critical component of an effective clean air strategy. In recent years, this understanding of the critical role of fuels has grown and deepened and spread to most regions of the world. Fuel quality is now seen as not only necessary to eliminate or reduce certain pollutants (e.g. lead) directly, but also a precondition for the introduction of many important pollution control technologies (e.g. diesel particulate filters). Further, one critical advantage of cleaner fuels has emerged -- its rapid impact on both new and existing vehicles. For example, tighter new vehicle standards can take ten or more years to be fully effective, but the removal of lead in gasoline in Asia has reduced lead emissions from all vehicles immediately.
- **Systems approach:** Fuels and vehicles are part of an integrated system and need to be addressed together. The main emissions reduction benefits will come from the coupling of cleaner fuels with advanced emission control devices.
- **Fuel quality regulation needs to be combined with vehicle emissions standards** to form the backbone of any country's roadmap for reducing air pollution from vehicles.
- **Sulfur Reduction is Key:** Reducing sulfur levels in both gasoline and diesel fuels is the primary fuel parameter that needs to be considered in developing a country's fuel roadmap. Reducing sulfur in fuels is a key measure in reducing air pollution from motor vehicles. High sulfur levels reduce the effectiveness of advanced three-way catalysts for gasoline vehicles and clog particulate filters in diesel vehicles. Almost all Asian countries will be adopting increasingly stricter Euro standards, which require reduced sulfur fuels, with an ultimate goal of 50 ppm or less sulfur in diesel and gasoline.

- **Benefits of reducing sulfur are clear:** Extensive studies in developed and developing countries, including the United States, Mexico, and the People's Republic China, have estimated that the economic benefits of an integrated system of clean fuels and vehicles far outweigh the costs. The estimated benefits of programs on clean fuels and vehicles has a benefit cost ration of 15:1 in the United States, while a recent study devoted to the PRC estimated benefits to exceed costs by a ratio greater than 20:1.
- **Cleaner fuels are cost-effective** The incremental costs of meeting the recommended level of sulfur in fuels in Asia are on average 0.2-0.8 US cents per liter for gasoline and 0.5 – 0.8 US cents per liter for diesel. Further reductions to 10 ppm or below would add about 0.6 US cents per liter to the cost of diesel fuel.
- **Current refinery expansion creates a window of opportunity:** The increasing demand for transportation fuels in Asia is resulting in the construction of new refineries, upgrading or expanding of existing refineries in the region, thereby creating a window of opportunity to produce the clean fuels necessary for reducing emissions.
- **No technical obstacles to produce cleaner fuels in Asia:** The refining technology needed to produce cleaner fuels that meet Euro 4 or equivalent standards is well understood and has been successfully implemented in the U.S. and Europe.
- **Enhancing octane:** Gasoline often needs greater levels of octane than is available in the crude. The use of metallic additives (MMT and Ferrocene) should be carefully evaluated because of potential health concerns and impacts on vehicle emissions and emissions systems components. Decision makers in Asia should take note of the upcoming results of the studies by Health Canada and the US EPA on health impacts of manganese (including MMT). Prominent health experts have raised serious concerns regarding the potential adverse health effects of metallic additives such as MMT. Therefore, the environmentally responsible approach for Asian countries to take concerning the use of metallic-based additives is to apply the precautionary principle for these metallic additives and to not use them until and unless the scientific and health studies show that they are safe. Other additives, such as ethanol, MTBE, ETBE and TAME, have not been shown to cause significant health effects, although MTBE is not used in the US due to groundwater contamination issues. The longer-term solution applied by many refineries to meet the gasoline octane requirements is through capital investment in enhanced refining capacity and blend stock selection, and the use of certain oxygenates..
- **Taxing policy and incentives:** Experience across the world has shown that governments can accelerate the introduction of cleaner fuels and their uptake through a combination of tax and pricing policies.
- **Fuel adulteration:** Whatever fuel specifications are adopted in Asia, it is important to have routine monitoring at the pump and along the distribution chain to assure that the actual fuels in the marketplace meet the required specifications. Penalties should be imposed if the limits are not achieved.
- **Involve all stakeholders:** Decision making on the introduction of cleaner fuels should include a dialogue among all stakeholders, including environmental and public health officials, the oil refining sector, vehicle and engine manufacturers, and ministries concerned with oil pricing and taxation
- **Need to raise awareness on air pollution and vehicle emissions:** There is a need for intensified awareness-raising at the national and sub-national level to make the case for cleaner fuels. Awareness raising campaigns should be focused on both the general public, as well as decision-makers.

I. INTRODUCTION

1. Air pollution continues to pose a significant threat to the environment, quality of life and health of the urban population in Asia. A study by the Clean Air Initiative for Asian Cities (CAI-Asia), summarizing air quality data from 20 cities¹ in Asia for the period 1993 to 2005 showed that, on average, there has been a moderate to slight decrease in pollution levels for sulfur dioxide (SO₂), total suspended particulate matter (SPM), and fine particulates or particulate matter with diameter less than or equal to ten micrometers (PM₁₀) (Figure 1.1). Although particulate matter remains at levels harmful to human health, SO₂ levels are now, on average, below the guideline values set by the World Health Organization (WHO) – proving that air quality management policies and measures can work in Asia. Ambient concentrations of nitrogen dioxide (NO₂) are seen to remain at gradually increasing levels and just above the WHO guidelines.

Figure 1.1: Trends of Major Criteria Air Pollutants (1993-2005)



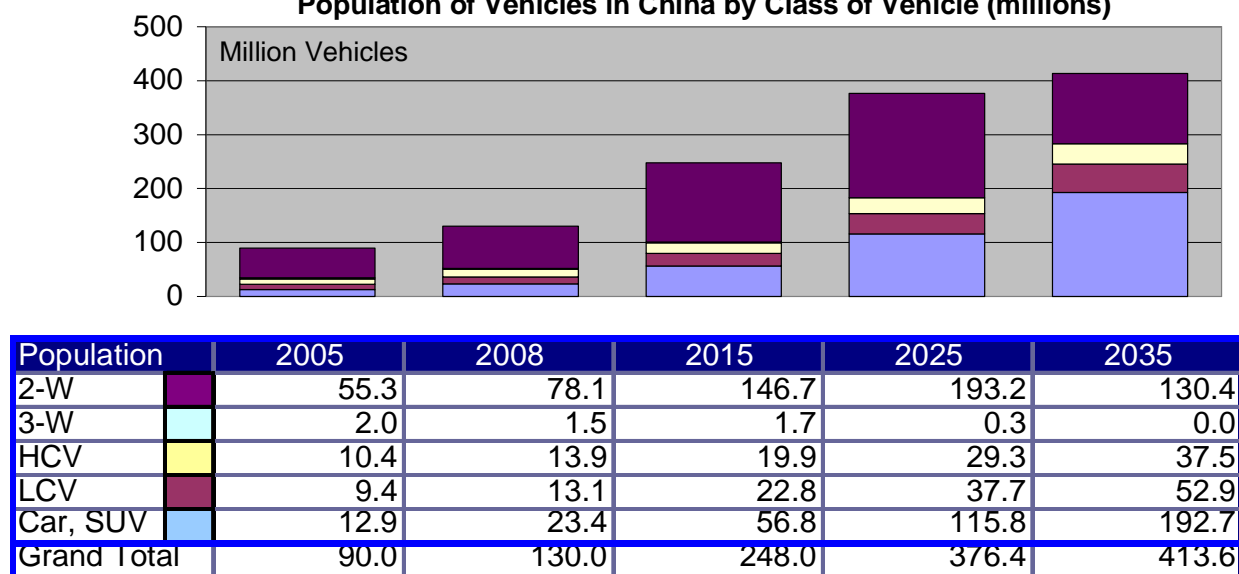
µg/m³ = microgram per cubic meter; PM₁₀ = particulate matter with diameter less than or equal to 10 micrometers; NO₂ = Nitrogen dioxide; SO₂ = Sulfur dioxide; TSP = total suspended particulates

Source: CAI-Asia. 2006. Urban air quality and its management in Asia Status Report 2006. Presented at the Regional Dialogue of Air Quality Management Initiatives and Programs in Asia. 12 October. Bangkok, Thailand.

¹ CAI-Asia. 2006. Urban air quality and its management in Asia Status Report 2006. Presented at the Regional Dialogue of Air Quality Management Initiatives and Programs in Asia. 12 October. Bangkok, Thailand. The 20 cities that are included in the study are the following: Bangkok, Thailand; Beijing, PRC; Busan, South Korea; Colombo, Sri Lanka; New Delhi, India; Dhaka, Bangladesh; Hanoi, Viet Nam; Ho Chi Minh City, Viet Nam; Hong Kong; Jakarta, Indonesia; Kathmandu, Nepal; Kolkata, India; Metro Manila, Philippines; Mumbai, India; Seoul, South Korea; Shanghai, PRC; Singapore; Surabaya, Indonesia; Taipei, China; Tokyo, Japan.

2. Emissions in Asia come from three main sources: stationary sources of pollution such as power plants, area sources including road dust and mobile sources of pollution. The relative contribution differs by city and by pollutant. The capacities to compose reliable emission inventories and source apportionment studies are still limited in many parts of Asia. Scientists and policy makers have, however, acknowledged the importance of the contributions of mobile sources of pollution towards urban air pollution and the need to act to reduce emissions on a per vehicle basis and for the transport sector as whole.² Of course, efforts are also required to reduce the emissions from stationary sources and area sources including road dust.

Figure 1.2: Forecast of Vehicle Populations in People's Republic of China
Population of Vehicles in China by Class of Vehicle (millions)



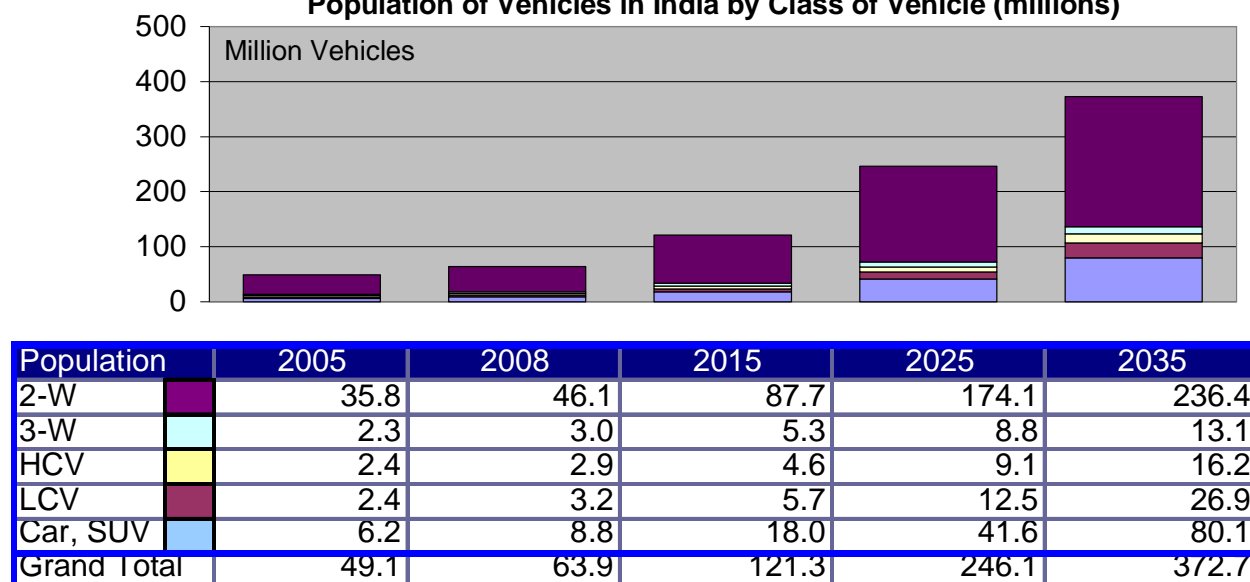
Note: The forecasts are generated using Segment Y Ltd. (www.segmenty.com) In the graphs, 2-W = motorcycles; 3-W = three-wheeled motorcycle; HCV = heavy duty commercial vehicle; LCV = light duty commercial vehicles; SUV = sports utility vehicle; and cars are self-explanatory.

Source: Asian Development Bank (ADB). 2006. Energy Efficiency and Climate Change Considerations for On-road Transport in Asia. December. Manila: ADB. Available: <http://www.adb.org/Documents/Reports/Energy-Efficiency-Transport/default.asp>.

3. The rapid economic growth in Asia in recent years has triggered a rapid growth in motorization in Asia and it is expected that this growth will continue in the time to come. Motorization in Asia differs from the historic trends in Europe and the USA. Instead of moving from non-motorized forms of transport or public transport, as was the case in most parts of Europe and the USA many of the Asian countries have seen the wide spread introduction of motorized 2-3 wheelers as an intermediate form of motorization. The widespread use of 2-3 wheelers needs to be reflected in the formulation of vehicle emission control strategies. Developing and introducing emission standards for 4 wheeled vehicles in cities like Hanoi and Ho Chi Minh City, without simultaneously issuing and enforcing stricter standards for 2 wheelers, will contribute relatively little to the improvement of urban air quality

² Schwela, Dieter, Gary Haq, Cornie Huizenga, Wha-Jin Han, Herbert Fabian and May Ajero. 2006 *Urban Air Pollution in Asian Cities: Status, Challenges and Management*. London: Earthscan Available URL: <http://shop.earthscan.co.uk/ProductDetails/mcs/productID/730>. This publication is based on the Benchmarking Study on Air Quality Management Capability in Selected Asian Cities. Please refer to <http://www.cleanairnet.org/caiasia/1412/article-59072.html>

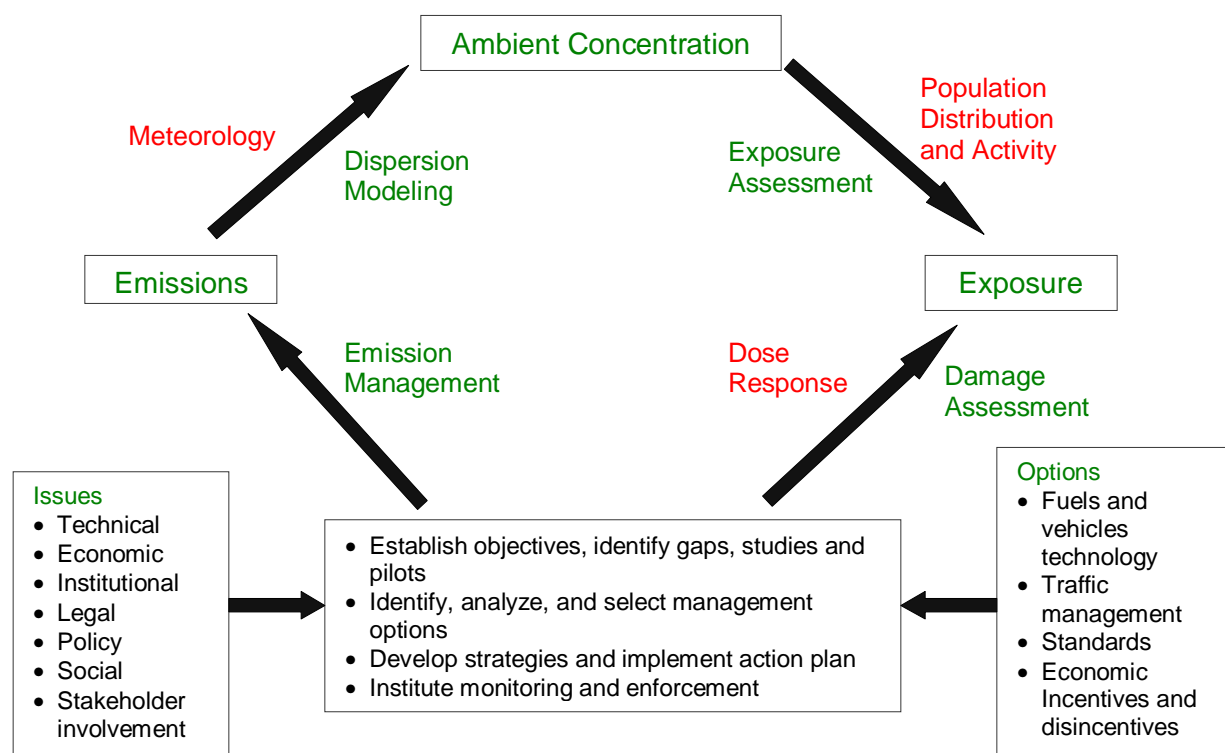
Figure 1.3: Forecast of vehicle populations in India
Population of Vehicles in India by Class of Vehicle (millions)



Note: The forecasts are generated using Segment Y Ltd. (www.segmenty.com) In the graphs, 2-W = motorcycles; 3-W = three-wheeled motorcycle; HCV = heavy duty commercial vehicle; LCV = light duty commercial vehicles; SUV = sports utility vehicle.

Source: Asian Development Bank (ADB). 2006. Energy Efficiency and Climate Change Considerations for On-road Transport in Asia. December. Manila: ADB. Available: <http://www.adb.org/Documents/Reports/Energy-Efficiency-Transport/default.asp>

4. Over the course of the past 30 years, pollution control experts around the world have come to realize that cleaner fuels must be a critical component of an effective clean air strategy. Cleaner fuels are considered to be fuels that result in lower emissions of air pollutants when used in powering motor vehicles. In recent years, this understanding on the critical role of fuels has grown and deepened and spread to most regions of the world. Improving fuel quality is now seen as not just a means necessary to directly reduce or eliminate certain pollutants (e.g. lead) but also a precondition for the introduction of many important pollution control technologies (e.g. diesel particulate filter). Further, one critical advantage of cleaner fuels has emerged - its rapid impact on both new and existing vehicles. (For example, tighter new car standards can take ten or more years to be fully effective whereas the removal of lead in gasoline in Asia has immediately reduced lead emissions from all vehicles.)

Figure 1.4: Integrated Air Quality Management Framework

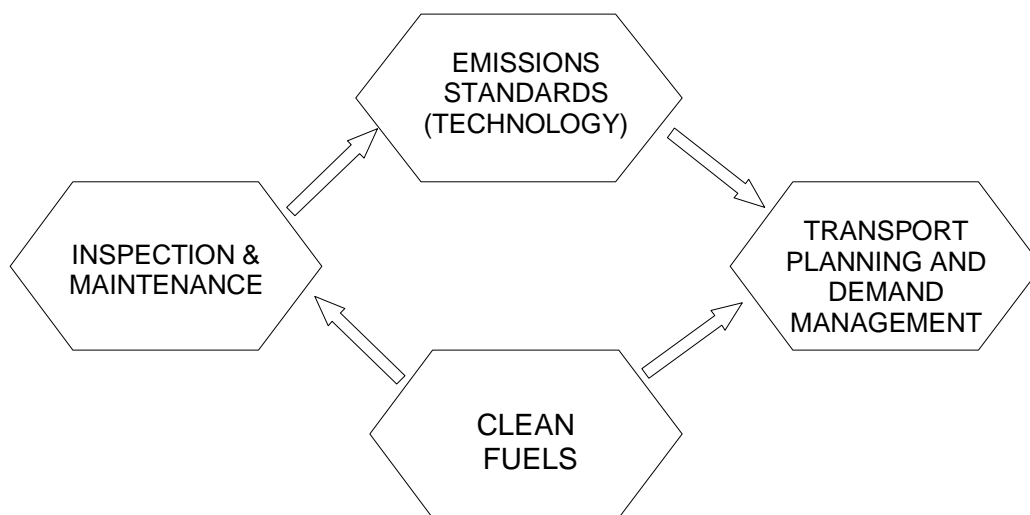
Source: Faiz, Asif. 1999. Air Quality and Transportation Strategies and Options for Controlling Motor Vehicle Pollution. Paper presented at the International Roundtable for Transportation Energy Efficiency and Sustainable Development, Cairo, 5-7 December.

5. In developing strategies to clean up vehicles, it is necessary to start from a clear understanding of the emissions reductions from vehicles and other sources that will be necessary to achieve healthy air quality. Depending upon the air quality problem and the contribution from vehicles, the degree of control required will differ from location to location. As illustrated in figure 1.4 regarding Integrated Air Quality Management Framework, one should start with a careful assessment of air quality and the sources' relative contributions to the problem of air pollution.

6. Where vehicles are major sources of pollution, a broad based approach to the formulation and implementation of policies and actions aimed at reducing their pollution will be needed.

7. Reducing vehicular pollution will usually require a comprehensive strategy that includes four key components: (1) emissions standards for new vehicles, (2) specifications for clean fuels, (3) programs to assure proper maintenance of in-use vehicles, and (4) transportation planning and demand management (figure 1.5). One critical lesson is that vehicles and fuels should be treated as a system. These emission reduction goals should be achieved in the most cost effective manner available. While acknowledging the importance of a systems approach the emphasis of this report is on the contribution of cleaner fuels to reducing urban air pollution.

Figure 1.5: Elements of a Comprehensive Vehicle Pollution Control Strategy



Source: Michael P. Walsh

8. Europe, Japan and the USA started to regulate emission standards in the 1960's. Since then they have gradually made the requirements for both new vehicles and in-use vehicles more stringent, especially targeting CO, HC and NO_x for gasoline vehicles and PM and NO_x for diesel vehicles. While most PM that comes from vehicles is actually smaller than PM₁ (i.e. the size of particulates is smaller than 1 micron), the standards are not based on size so far but on mass. The adoption of the increasingly more strict emission standards in Europe, Asia and the United States has been made possible by the introduction of cleaner fuels, where the lowering in sulfur levels has been particularly instrumental in facilitating the use of advanced emission control devices required to achieve the reduced emissions on a per vehicle basis. Notwithstanding differences between Asia and Europe and the United States in terms of fleet and driving characteristics Asia can benefit from the experiences in other parts of the world in introducing cleaner fuels and vehicles.

9. Asian countries so far do not have harmonized emission standards.³ While many of the countries started to develop emission standards in the 1990s, there are still countries, especially the smaller ones, which do not yet have emission standards in place for new vehicles. The emphasis so far has been on the development of emission standards for light duty 4-wheeled vehicles, followed by emission standards for 2-3 wheelers and heavy duty vehicles. Table 1.1 indicates that the average lag time between Asia and Europe is gradually being reduced and for several countries, such as Thailand, Singapore, Hong Kong SAR, and parts of India and PRC the lag-time is likely being reduced to less than 5 years.

Table 1.1: Emission Standards for New Light-Duty Vehicles (as of November 2007)

³ In the context of this report, Asia refers to Afghanistan, Bangladesh, Bhutan, Cambodia, India, Indonesia, Laos PDR, Malaysia, Myanmar, Nepal, Pakistan, Peoples Republic of China, Philippines, Taipei, China, Singapore, Sri-Lanka, Thailand, Viet Nam.

Country	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	
European Union	E1	Euro 2					Euro 3				Euro 4			Euro 5						E6	
Bangladesh ^a											Euro 2										
Bangladesh ^b											Euro 1										
Hong Kong, China	Euro 1	Euro 2					Euro 3				Euro 4										
India ^c							Euro 1				Euro 2					Euro 3					
India ^d					E1	Euro 2					Euro 3				Euro 4						
Indonesia											Euro 2										
Malaysia				Euro 1										Euro 2				Euro 4			
Nepal						Euro 1															
Pakistan																					
Philippines								Euro 1				Euro 2									
PRC ^a							Euro 1			Euro 2			Euro 3			Euro 4					
PRC ^e							Euro 1			Euro 2			Euro 3		Euro 4 Beijing only						
Singapore ^a	Euro 1						Euro 2														
Singapore ^b	Euro 1						Euro 2					Euro 4									
Sri Lanka									Euro 1												
Taipei,China					US Tier 1										US Tier 2 for diesel ^g						
Thailand	Euro 1						Euro 2			Euro 3							Euro 4				
Viet Nam													Euro 2								

Notes: Italics – under discussion; a – gasoline; b – Diesel; c – Entire country; d – Delhi, Chennai, Mumbai, Kolkata, Bangalore, Hyderabad, Agra, Surat, Pune, Kanpur, Ahmedabad, Sholapur, Lucknow; Other cities in India are in Euro 2; e – Beijing and Guangzhou (as of 01 September 2006) have adopted Euro 3 standards; Shanghai has requested the approval of the State Council for implementation of Euro 3; f – Euro 4 for gasoline vehicles and California ULEV standards for diesel vehicles; g – Gasoline vehicles under consideration

Source: CAI-Asia. 2007, November. Emission standards for new vehicles (light duty). Available: http://www.cleanairnet.org/caiasia/1412/articles-58969_new.pdf

10. For light duty vehicles, the European Union (EU) adopted Euro 4 standards in 2005 and the EU has just completed adoption of light duty vehicle standards, so called Euro 5 and Euro 6 standards to go into effect in 2010 and 2015 respectively. Asian countries can be divided into three groups with respect to light duty emission standards:

1. Countries which have put in place road maps leading up to Euro 4. In 2010, People's Republic of China will move to Euro 4 and India will reach Euro 3 nationwide although both have prior introduction in major cities.⁴ Malaysia will likely⁵ reach Euro 4 light duty standards in 2012; Thailand will have them also in

⁴ CAI-Asia. 2007, May. Emission standards for new vehicles (light duty). Available: http://www.cleanairnet.org/caiasia/1412/articles-58969_new.pdf Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad and Ahmedabad have Euro 3 standards since 2005 and Beijing will adopt Euro 4 in 2007

⁵ Department of Environment, Malaysia. 2007, August 21. "Regulation on control of petrol and diesel content 2007." In Loke, EB. 2007. In E-mail to Ms. Aurora Ables re: Roadmap for cleaner fuels and vehicles in Asia. 09 Nov, 1452h. From the E-mail: "There were two official letters from the Government on delay implementation of Euro2M (modified). The government has assured oil companies that Euro 4M will be implemented 4 yrs after Euro 2M to allow time for capital investment and construction of new process unit. ...It said that the Government has made the decision to defer the regulation to a later date (yet to be decided)... These letters are in Malay language."

⁶ Ministry of Finance, Malaysia. 2007, August 14. "Delay implementation of Euro 2M specification for petrol and diesel." In Loke, EB. 2007. In E-mail to Ms. Aurora Ables re: Roadmap for cleaner fuels and vehicles in Asia. 09 Nov. 1452h. From the E-mail: "There were two official letters from the Government on delay implementation of Euro2M (modified). The government has assured oil companies that Euro 4M will be implemented 4 yrs after Euro 2M to allow time for capital investment and construction of new process unit. ... It said the government has delayed the implementation of Euro 2M in the whole country to a date to be decided later... The letters were in Malay language."

2012. So far, only Hong Kong, China has indicated that it is considering the adoption of Euro 5 standards.
2. Countries which have developed road maps for Euro 2 but have not finalized roadmaps leading to Euro 4. This includes Philippines, Indonesia and Viet Nam.
 3. Countries which have no formal fuel quality or vehicle emissions road maps in place. This includes Bhutan and Cambodia, Nepal, Pakistan and Sri-Lanka.⁷

11. Asia has proven that it could act quickly with the removal of lead from gasoline in the light of evidence on the harmful impact of lead on human health. Bans on the use of leaded gasoline were promulgated and implemented within a couple of years with the exception of Indonesia, which only recently (July 2006) eliminated lead from gasoline nationwide.

Table 1.2: Current and Proposed Sulfur Levels in Diesel in Asia, EU and USA

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Bangladesh							5000										
Cambodia					2000				1500								
Hong Kong, China		500					50					10 ^a					
India (nationwide)	5000				2500					500					350		
India (metros)	5000				2500	500				350 ^a					50 ^a		
Indonesia	5000										2000				350		
Japan ^b	500									50		10					
Malaysia	5000		3000				500 ^c			500 ^d							50 ^a
Pakistan	10000						7000 ^e										
Philippines	5000					2000			500						50		
PRC (nationwide)	5000						2000			500 ^a					50 ^a		
PRC - Beijing	5000						2000		500	350			50 ^a				
Republic of Korea	500							430	100		30	15(10) ^f					
Singapore	3000		500								50						
Sri Lanka	10000							5000 ^d			500						
Taipei, China	3000			500			350		100						50		
Thailand	2500			500					350		150				50		
Viet Nam	10000											500					
European Union					500					50(10) ^f			10				
United States	500										15						

Notes: a - under consideration/ discussion; uncertain; b = nationwide supply of 50 ppm commenced in 2003 and for 10 ppm in 2005 due to voluntary goals set by the oil industry; c = marketed; d = mandatory; e = recommended; f = various fuel quality available;

Source: CAI-Asia. 2007 December. Current and Proposed Sulfur levels in Diesel in Asia, EU and USA. Available: http://www.cleanairnet.org/caiasia/1412/articles-40711_SulfurDiesel.pdf

State Environment Protection Administration, PR China. 2000. GB 252-2000 "Light Diesel Fuels" national mandatory standard. In Li Shuang. 2007. E-mail to Ms. Aurora Ables re: Fuel and Vehicle Standards in China. 09 Nov.

State Environment Protection Administration, PR China. 2003. GB/T 19147-2003 "Automobile diesel fuels" national recommended standard. In Li Shuang. 2007. E-mail to Ms. Aurora Ables re: Fuel and Vehicle Standards in China. 09 Nov.

"South Korea makes official 30-ppm diesel sulfur limit from Jan. 1, 2006 - Around the World of Diesel - Brief Article". Diesel Fuel News. June 9, 2003. FindArticles.com. 06 Dec. 2007. http://findarticles.com/p/articles/mi_m0CYH/is_10_7/ai_103382170

12. In line with a step-by-step tightening of vehicle emission standards, Asian countries are also addressing the issue of fuel quality. The importance of linking vehicle emission standards and fuel quality standards is increasingly well-understood. Table 1.2 gives an overview how

⁷ CAI-Asia. 2006, May. Emission standards for new vehicles (light duty). Available: http://www.cleanairnet.org/caiasia/1412/articles-58969_new.pdf

sulfur levels in diesel are evolving in Asia in comparison to Europe and the United States which like Japan are now moving towards sulfur levels of well below 50 ppm. As in the case of vehicle emission standards, noticeable improvements have been achieved in recent years and several countries have formally announced further lowering of sulfur levels to 50 ppm or less in or before 2012.

13. The rapid growth in motorization in Asia has affected the refining industry in Asia. After a period in which no new refining capacity was added, new capacity has been added in PRC and India and plans for additional refining capacity are currently being discussed in PRC, India and some other countries. Planning for cleaner fuels in Asia therefore needs to take into account specifications of such new refineries as well as the specifications of existing refineries that will continue to produce the bulk of transportation fuels in the years to come.

14. CAI-Asia has taken an interest in vehicle emissions and fuel quality because of the direct relationship among vehicle emissions, air quality, and health in Asian cities. The expected continued rapid growth in the number of vehicles entering the fleet in Asian cities call for forward planning and the design of roadmaps for vehicle emission standards and fuel quality. The formulation, adoption and implementation of such roadmaps can help to ensure that new vehicles entering the fleet will be covered by more strict emission standards, thereby lowering the pressure on the urban environment.

15. The discussion on fuel quality road maps supported by CAI-Asia intends to support the processes that are already in place in several countries in Asia to develop further policies and regulations on fuel quality and vehicle emission standards.

16. The activities of CAI-Asia related to fuels and vehicle emissions⁸ are guided by the same underlying principles that guide all other activities of CAI-Asia. Effective policy-making requires dialogue among all stakeholders and needs to be based on sound science. Transparency of the policy-making process can help to increase understanding and buy-in for policy decisions. It is important for policy processes to be predictable in order for key stakeholders to be able to prepare properly for their implementation. It can take up to 4 years before refineries are actually producing cleaner fuels after the decision has been made to upgrade an existing refinery or to construct a new one. The need for transparency and predictability underscore the need for Asian countries to develop fuel quality road maps which can guide investment decisions in the refining and vehicle manufacturing industry.

17. This report aims to bring information together in a structured manner and intends to help shape the fuel roadmaps in Asian countries. It focuses on fuels and assumes that the availability of new vehicles that can comply with stricter emission standards will not be a constraining factor. For efforts to promote cleaner fuels to be successful and have an impact on urban air quality in Asian cities it is important to:

1. Adopt an integrated approach, in which mobile; stationary and area sources of pollution are all included.⁹

⁸ In 2003 ENSTRAT performed a study for ADB on "Cost of Diesel Fuel Desulphurisation for Different Refinery Structures Typical of the Asian Refining Industry." See <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf> and http://www.cleanairnet.org/caiasia/1412/articles-40677_EnstratSulphurReport.pdf. CAI-Asia and the International Fuel Quality Center, with support from the Australian Department of Environment and Heritage, held a "Fuel Quality Strategy Training Workshop" in the last quarter of 2003 and produced 5 modules on the subject. See <http://www.cleanairnet.org/caiasia/1412/article-58140.html>

⁹ Stockholm Environment Institute (SEI), Korea Environment Institute, Ministry of Environment Korea. 2004. Strategic Framework for Air Quality Management. Manila.

2. Address emissions from both new and in-use vehicles, and combine prevention of air pollution through traffic demand management with reducing emissions through tailpipe solutions,¹⁰ whereby appropriate attention is given to two and three wheeled vehicles in countries where such vehicles form an important part of the vehicle fleet.
3. Build on the current status of fuel quality standards and ongoing discussions in the different countries in Asia.

18. This roadmap report for cleaner fuels and vehicles for Asia deals with gasoline and diesel. Biofuels are an important alternative source of transport fuel, as is compressed natural gas and liquid petroleum gas. The use and production of these alternative fuels is outside the scope of this report. The increased attention for these fuels, both in Asia and elsewhere merits a separate study. Technologies such as coal to liquid and gas to liquid are also not a topic in this document. This report focuses on emission related characteristics of transport fuels. There are other characteristics, such as safety, driveability and fuel economy that are important as well and which need to be considered in formulating fuel quality improvement strategies. They fall, however, outside the scope of this report and will not be dealt with in detail.

19. Chapter 2 gives an extensive overview of the relationships between vehicle engine technology including emission control devices, fuel characteristics and vehicle emissions. In Chapter 3 presents an analysis of the costs of producing cleaner fuels in Asia. Chapter 4 assesses the impacts of the use of octane enhancing additives on health and vehicle emissions. Chapter 5 describes the role of pricing, taxation and incentives in promoting the use of cleaner fuels. The report concludes with chapter 6 which provides recommendations on the timing and approach in the introduction of cleaner fuels in Asia.

¹⁰ For further information, refer to ADB Guidelines on Reducing Vehicle Emissions in Asia, World Bank Source Book and GTZ Sourcebook on Mobile Sources of Pollution.

II. FUELS AND VEHICLES

A. Introduction

20. Motor vehicles emit large quantities of carbon monoxide, hydrocarbons, nitrogen oxides, particulate matter, and toxic substances such as benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and lead. Each of these, along with secondary by-products such as ozone, can cause serious adverse effects on health and the environment. Motor vehicles also emit carbon dioxide. Because of the growing vehicle population and the high emission rates from many of these vehicles, serious air pollution and health effect problems have been increasingly common phenomena in modern life, especially in cities in developing countries, including in Asia.

21. Over approximately the last twenty years, extensive studies have been carried out to better establish the linkages between fuels and vehicles and vehicle emissions. One major study, the Auto/Oil Air Quality Improvement Research Program (AQIRP) was established in 1989 in the US and involved 14 oil companies, three domestic automakers and four associate members.¹¹ In 1992, the European Commission also initiated a vehicle emissions and air quality program. The motor industry (represented by Association des Constructeurs Européens d'Automobiles (European Automobile Manufacturers Association (ACEA)) and the oil industry (European Petroleum Industry Association (EUROPIA)) were invited to cooperate within a framework program, later known as "the tripartite activity" or European Auto/Oil Program. In June 1993, a contract was signed by the two industries to undertake a common test program, called the European Program on Emissions, Fuels and Engine Technologies (EPEFE).

22. The Japan Clean Air Program (JCAP) was conducted by Petroleum Energy Center as a joint research program of the automobile industry (as fuel users) and the petroleum industry (as fuel producers), supported by the Ministry of Economy, Trade and Industry. The program consists of two stages: the first stage called JCAP I commenced in 1997 and ended in 2001; the second called JCAP II commenced in 2002 and will continue until 2007 to provide a further development of the research activities of JCAP I. In JCAP II, studies are focused on future automobile and fuel technologies aimed at realizing Zero Emissions while at the same time improving fuel consumption. It has a special focus on studies of fine particles in exhaust emissions.

23. Relying heavily on each of these studies as well as other recent work, the purpose of this chapter is to summarize what is known about the impact of fuel quality on emissions.

24. Most Asian countries have linked their vehicle emissions control programs to the European Union (EU) or the Economic Commission for Europe (ECE) requirements so it is useful to summarize the EU fuel quality specifications. These can usefully be described in terms of 3 classes (effectively Euro 2, 3, and 4). The Euro 2 fuel sulfur level was set at 500 parts per million (ppm) in order to improve the performance of the catalytic converters being used on gasoline vehicles and expected to be introduced for some diesel vehicles. For the Euro 3 and 4 standards, specifications have been set with particular attention given to the 'environmental qualities' of the fuel in addition to a further tightening of sulfur levels to improve the performance or in some cases allow the use of advanced pollution control technologies. The specifications for the key environmental Euro 3 and 4 fuel parameters are presented in Table 2.1. The only change in the specifications for Euro 4 diesel (It had been intended by the Commission to

¹¹ Society of Automotive Engineers (SAE). 1997, January. Auto/Oil Air Quality Improvement Research Program, Final Report. Detroit, MI.

include other changes but they have not done so due to the lack of sufficient resources) has been the establishment of the sulfur content at 50 ppm.¹²

Table 2.1: EU gasoline and diesel fuel quality specifications

Petrol/Gasoline	Euro 3	Euro 4	Diesel	Euro 3	Euro 4
	2000	2005		2000	2005
RVP summer kPa, max.	60	60	Cetane number, min.	51	51
Aromatics, % by vol. max.	42	35	Density 15°C kg/m ³ , max.	845	845
Benzene, % by vol. max.	1	1	Distillation 95% by vol. °C, max.	360	360
Olefins, % by vol. max.	18	18	Polycyclic aromatic hydrocarbons, % by vol., max.	11	11
Oxygen, % by mass max.	2.7	2.7	Sulfur, ppm max.	350	50
Sulfur, parts per million	150	50			

Notes: °C = degrees Celsius; kPa = kilopascals, where 1 atmosphere of pressure equals about 100 kPa; kg/m³ = kilograms per cubic meter; max. = maximum; min. = minimum; ppm = parts per million; RVP = Reid vapor pressure; vol. = volume; EU = European Union

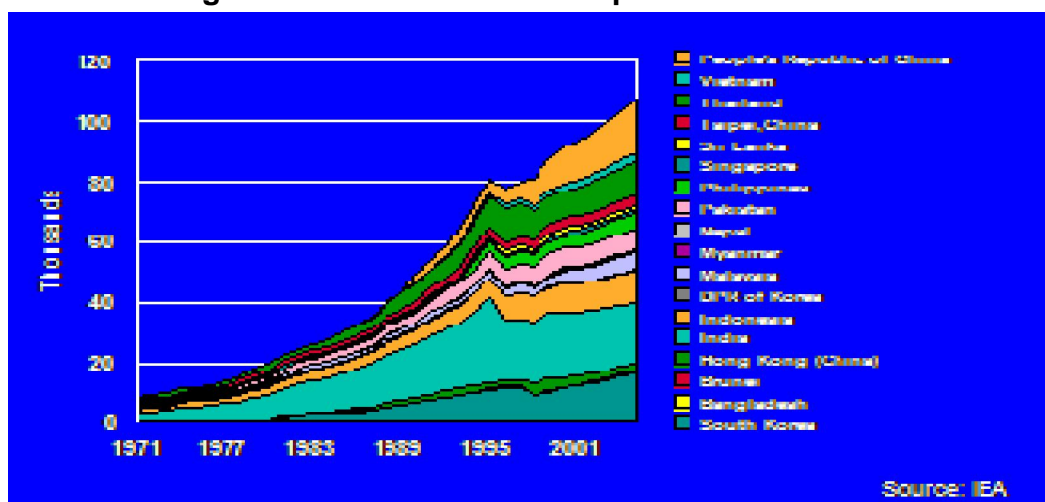
Source: European Parliament and Council. October 13, 1998. Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998, amending Council Directive 93/12/EEC. Available: <http://eur-lex.europa.eu/LexUriServ/site/en/consleg/1998/L/01998L0070-20031120-en.pdf>

B. Diesel Vehicles and Fuels

1. Importance of Diesel as a Transportation Fuel in Asia

25. The use of diesel fuel in Asia has been growing dramatically for the past three decades and shows every sign of continued growth in the future. As shown in the Figure 2.1, while there was a slight decline during the economic downturn during the 1990's, the growth of diesel consumption has more than recovered. The projections in table 2.2 indicate that in Asia diesel will continue to have a larger market share compared to that in Organisation for Economic Co-operation and Development (OECD) countries or the world at large.

¹² A maximum limit of 50 parts per million applied for all diesel and gasoline sold in the EU in 2005 but fuels with a maximum limit of 10 ppm were to be widely available by that year. All fuel must comply with a maximum limit of 10 ppm by 2009 at the latest.

Figure 2.1: Diesel Fuel Consumption Trends in Asia

Source: IEA

26. In many countries, diesel fuel receives favorable tax status since it tends to be the fuel of commerce, used both in diesel trucks and in most transit buses. In addition, certain specialized transit vehicles such as Jeepneys in the Philippines are now also predominantly fueled by diesel after diesel became comparatively more attractive in the 1980's. Before that jeepneys in the Philippines were almost exclusively gasoline fueled.

Table 2.2: Diesel Fuel Consumption Trends in Asia

<i>Country or Region</i>	<i>Diesel fuel consumption of on-road vehicles as percentage of all fuels</i>				
	2005	2010	2015	2020	2025
PRC	32%	31%	29%	28%	27%
India	64%	63%	60%	58%	57%
Other emerging Asia	55%	55%	54%	53%	53%
Emerging Asia (EA)	51%	50%	49%	47%	45%
OECD (for reference)	33%	34%	35%	36%	36%
World total	36%	37%	38%	38%	38%

OECD = Organisation for Economic Co-operation and Development

Source: IEA-SMP transport model reference case projections (see

http://library.iaea.org/Textbase/subjectqueries/keyresult.asp?KEYWORD_ID=4121) in ADB. 2006. Energy Efficiency and Climate Change Considerations for On-road Transport in Asia. December. Manila: ADB. Available:

<http://www.adb.org/Documents/Reports/Energy-Efficiency-Transport/default.asp>

27. Many Asian countries – including South Korea, PRC and Taipei, China have historically restricted the use of diesel in private cars so that the lower tax on diesel fuel would not distort the light duty vehicle marketplace. These restrictions have recently been lifted in preparation for joining the World Trade Organization (WTO).

28. Diesel vehicles emit significant quantities of both nitrogen oxides (NO_x) and particulate matter (PM). Reducing PM emissions from diesel vehicles tends to be the highest priority because PM emissions in general are very hazardous and diesel PM, especially, is likely to

cause cancer. NO_x emissions are also important, however, since they cause or contribute to ambient nitrogen dioxide, ozone and secondary PM (nitrates).¹³

29. The growing awareness of the adverse health impacts of diesel vehicle emissions, especially diesel PM, has led to efforts in some Asian countries to constrain diesel use. Cities such as Delhi and Beijing have converted some or all of their buses to operate on compressed natural gas (CNG) because of the serious diesel health consequences. Hong Kong, alternatively, has retrofitted many of its trucks and buses with particulate control devices¹⁴ and shifted most taxis to the use of liquefied petroleum gas (LPG) instead of diesel.

2. General Description of Diesel Fuel Parameters

30. Diesel fuel is a complex mixture of hydrocarbons with the main groups being paraffins, naphthenes and aromatics. Organic sulfur is also naturally present. Additives are generally used to influence properties such as the flow, storage and combustion characteristics of diesel fuel. The actual properties of commercial automotive diesel depend on the refining practices employed and the nature of the crude oils from which the fuel is produced. The quality and composition of diesel fuel can significantly influence emissions from diesel engines.

31. To reduce PM and NO_x emissions from a diesel engine, the most important fuel characteristic is sulfur because sulfur contributes directly to PM emissions and high sulfur levels preclude the use of or impair the performance of the most effective PM and NO_x control technologies. For the control of PM, most new vehicles in Japan and the US and a growing fraction in Europe are equipped with filters or traps which reduce over 90% of the particles. NO_x adsorbers and Selective Catalytic Reduction systems are also starting to be introduced; NO_x adsorbers are especially sensitive to sulfur levels in the fuel. (See Section 5 for a more detailed discussion of diesel control technology.)

3. Impact of Diesel Fuel Composition on Asian Vehicle Emissions

32. The following tables (2.3 and 2.4) summarize the impacts of various diesel fuel qualities on emissions from light and heavy duty diesel vehicles, respectively.

Table 2.3: Impact of Fuels on Light Duty Diesel Vehicles

Diesel Fuel Characteristic	Pre-Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 ¹⁵	Comments
Sulfur	SO ₂ , PM		If oxidation catalyst is used, SO ₃ , SO ₂ , PM		If Filter, 50 ppm maximum, 10-15 ppm better		If NO _x adsorber used requires near zero sulfur (<10 ppm) With low S, use lubricity additives
Cetane	Lower CO, HC, benzene, 1,3 butadiene, formaldehyde & acetaldehyde						Higher white smoke with low cetane fuels
Density	PM, HC, CO, formaldehyde, acetaldehyde & benzene ,						

¹³ Certain pollutants which are emitted from vehicles as gases undergo transformation in the atmosphere and are converted into particles. For example, some of the gaseous nitrogen oxides (NO_x) emitted from vehicles chemically react with other gases and are converted into nitrates which contribute to urban PM air quality levels.

¹⁴ Prior to retrofitting the vehicles, Hong Kong reduced the sulfur content in diesel fuel to a maximum of 50 parts per million (ppm).

¹⁵ Euro 5 emissions standards for light duty diesel vehicles have recently been adopted by the EU for implementation in 2010; Euro 6 limits were also adopted for 2015 implementation. Both Euro 5 and Euro 6 standards are intended to mandate the use of PM filters on all light duty diesel vehicles.

Diesel Fuel Characteristic	Pre-Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 ¹⁵	Comments
	NO _x						
Volatility (T95 from 370 to 325 C)	NO _x , HC increase, PM, CO decrease						
Polyaromatics	NO _x , PM, formaldehyde & acetaldehyde but HC, benzene & CO						some studies show that total aromatics are important for emissions in a manner similar to polyaromatics

Notes: CO = carbon monoxide; HC = hydrocarbon; NO_x = oxides of nitrogen, PM = particulate matter; ppm = parts per million; SO₂ = sulfur dioxide; SO₃ or sulfur trioxide is an intermediate compound.

Table 2.4: Impact of Fuels on Heavy Duty Diesel Vehicles

Diesel	Pre-Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 ¹⁶	Comments
Sulfur	SO ₂ , PM		If oxidation catalyst is used, SO ₃ , SO ₂ , PM		If Filter, 50 ppm maximum, 10-15 ppm better		If NO _x adsorber used requires near zero sulfur (<10 ppm) With low S, use lubricity additives
Cetane	Lower CO, HC, benzene, 1,3-butadiene, formaldehyde & acetaldehyde						Higher white smoke with low cetane fuels
Density	HC, CO , NO _x						
Volatility (T95 from 370 to 325 C)	Slightly lower NO _x but increased HC						Too large a fraction of fuel that does not volatilize at 370 C increases smoke and PM
Polyaromatics	NO _x , PM, HC						Some studies show that total aromatics are important

Notes: CO = carbon monoxide; HC = hydrocarbon; NO_x = oxides of nitrogen, PM = particulate matter; ppm = parts per million; S = sulfur; SO₂ = sulfur dioxide; SO₃ or sulfur trioxide is an intermediate compound

4. Required Changes in Diesel Fuel Parameters in Asia to Achieve Lower Emissions

a. Sulfur

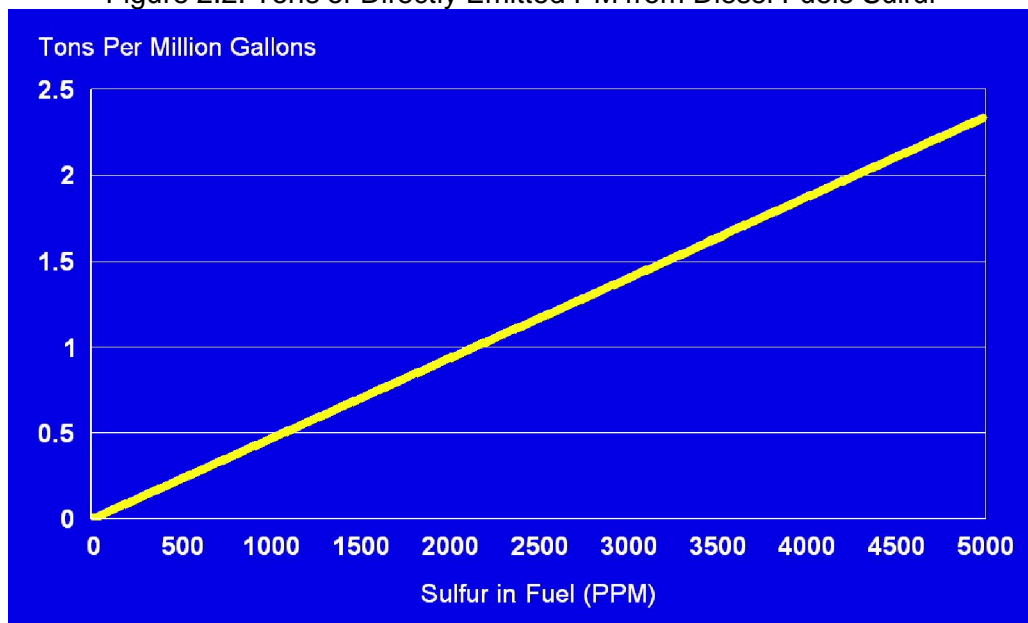
33. Sulfur occurs naturally in crude oil, and the sulfur content of diesel fuel depends on both the source of the crude oil and the refining process.

34. The contribution of the sulfur content of diesel fuel to exhaust particulate emissions has been well established with a general linear relationship between fuel sulfur levels and this regulated emission. Shown below (Figure 2.2) is one estimate of this relationship calculated from data provided by the US EPA. (This figure shows only the sulfur-related PM and not the total PM emitted from a diesel engine.) An indirect relationship also exists as some emissions of sulfur dioxide will eventually be converted in the atmosphere to sulfate PM.¹⁷

¹⁶ The EU Commission has also indicated that it will propose Euro 6 emissions standards for heavy duty engines during 2006 or early 2007, likely mandating the use of PM filters on all heavy duty diesel vehicles from 2010 or 2012.

¹⁷ Similar to the secondary transformation of NO_x to nitrate discussed earlier.

Figure 2.2: Tons of Directly Emitted PM from Diesel Fuels Sulfur



Notes: PPM = parts per million. Only particulate matter (PM) related to sulfur and not the total PM emitted from a diesel engine are reflected in this figure.

Source: Calculated from data provided by the United States Environmental Protection Agency (US EPA)

35. Light duty diesel engines (<3.5 tons gross vehicle weight (GVW)) generally require oxidation catalysts to comply with Euro 2 or more stringent vehicle emission standards. Oxidation catalysts lower hydrocarbons, carbon monoxide and particle emissions, typically removing around 30% of total particle mass emissions through oxidation of a large proportion of the soluble organic fraction. The conversion of sulfur in the catalyst reduces the availability of active sites on the catalyst surface and therefore reduces catalyst effectiveness. This sulfur catalyst 'poisoning' is reversible through high temperature exposure - the sulfur compounds decompose and are released from the catalyst washcoat. However, due to generally low diesel exhaust temperatures, in many diesel engine applications the conditions needed for full catalyst regeneration may rarely be reached. High sulfur content in the fuel can also lead to the formation of sulfates in the converter which are then emitted as additional particles.

36. To enable compliance with tighter particle emission standards for diesel vehicles, tighter limits on the maximum sulfur content of commercial diesel fuel have been, or are being, introduced in many countries. See Table 1.2: Current and Proposed Sulfur Levels in Diesel in Asia, EU and USA. While substantial reductions in particle emissions can be obtained without reducing sulfur levels, compliance with Euro 2 or tighter vehicle emission standards is generally not possible when fuel sulfur levels are greater than 500 ppm because of the relatively greater proportion of sulfates in the total mass of particle emissions.

37. In the case of Euro 3 and Euro 4 vehicle emission standards, even lower sulfur levels (350 ppm and 50 ppm, respectively) in diesel fuel will be required to ensure compliance with the standards. Apart from contributing to the effective operation of catalysts and reducing particle emissions, these further reductions in sulfur levels will enable tighter emission standards to be met by the use of next generation "de-NO_x" catalysts, which are very sensitive to sulfur. Many of these systems give optimum performance with fuels having sulfur levels in the range of 10 to 15 ppm or less. NO_x control systems for diesel vehicles are still evolving with the two major

candidates for Euro 4 and Euro 5 vehicles being Selective Catalytic Reduction (SCR) Systems which are not especially sensitive to sulfur levels in fuel¹⁸ and NO_x adsorber systems which are extremely sensitive to sulfur and require levels in the range of 10 to 15 ppm or less.

38. Sulfur content is also known to have effects on engine wear and deposits, but appears to vary considerably in importance, depending largely on operating conditions. High sulfur content becomes a problem in diesel engines operating at low temperatures or intermittently. Under these conditions there is more moisture condensation, which combines with sulfur compounds to form acids and results in corrosion and excessive engine wear. Generally, the lower the sulfur levels the less the engines wear out.

39. Diesel fuel has natural lubricity properties from compounds including the heavier hydrocarbons and organo-sulfur. Diesel fuel pumps (especially rotary injection pumps in light duty vehicles), without an external lubrication system, rely on the lubricating properties of the fuel to ensure proper operation. Refining processes to remove sulfur and aromatics from diesel fuel tend to also reduce the components that provide natural lubricity.

40. In addition to excessive pump wear and, in some cases, engine failure, certain modes of deterioration in the injection system could also affect the combustion process, and hence emissions. Additives are available to improve lubricity with very low sulfur fuels and should be used with any fuels with 50 ppm sulfur or less.

b. Cetane

41. Cetane number is a measure of auto-ignition quality. It is dependent on fuel composition, and relates to the delay between when fuel is injected into the cylinder and when ignition occurs. It influences the performance of vehicles in cold starts, exhaust emissions and combustion noise. Rapidly igniting fuels have high cetane numbers (50 or above). Slowly igniting fuels have low cetane numbers (40 or below). Aromatic hydrocarbons are low in cetane number; paraffins are high, with naphthenes in between the two.

42. The cetane index provides an indication of the 'natural' cetane of the fuel. It is derived through a calculation process based on the fuel density and distillation parameters. It gives an estimation of the base auto-ignition quality of the fuel, but does not indicate the effects of cetane improver additives.

43. Experiments documented by the EPEFE study show that an increase in cetane number results in a decrease in carbon monoxide and hydrocarbon emissions (notably in light duty engines), nitrogen oxides emissions (notably in heavy duty engines), as well as benzene, 1,3-butadiene, formaldehyde and acetaldehyde emissions from light duty engines.

44. While the EPEFE study found that particle emissions increased from light duty vehicles as the cetane number increased (no significant effect was seen in heavy duty engines) other research has suggested that an increase in cetane number can lead to lowered particle emissions. It is generally agreed that the higher the cetane number the better.

45. Cetane number requirements for diesel vehicles depend on engine design, size, nature of speed and load variations, and on starting and atmospheric conditions. High cetane number

¹⁸ While SCR systems are not particularly sensitive to sulfur levels, they tend to be combined with an oxidation catalyst to reduce ammonia slip and these oxidation catalysts are sensitive to sulfur levels. They will also tend to increase sulfate emissions levels.

fuels enable an engine to be started more easily at lower air temperatures, reduce white smoke exhaust, and reduce diesel knock. With a low cetane number fuel, engine knock noise and white smoke can be observed during engine warm-up, especially in severe cold weather (as can occur for example in parts of PRC). If this condition is allowed to continue for any prolonged period, harmful fuel derived deposits will accumulate within the combustion chamber. While an engine may appear to operate satisfactorily on low cetane number fuel, after prolonged use, severe mechanical damage (e.g. piston erosion) can result.

46. An increase in natural cetane can contribute towards reduced fuel consumption. To avoid excessive dosage with cetane additives, the World Wide Fuel Charter (WWFC) recommends that the difference between the cetane index and the cetane number be no greater than 3. (Generally large quantities of additive are not added for economic reasons, as the additive is expensive). This has also been general practice.

c. Density

47. Density relates to the energy content of fuel in such a way that the higher the density of the fuel the higher its energy content per unit volume. The density of diesel fuel is largely dependent on its chemical composition – typically the aromatic content and distillation range. Higher density diesel fuel is frequently an indicator of high aromatic content of the fuel, for a given distillation range. Increased aromatic content is known to lead to increased particle emissions. Too high a fuel density for the engine calibration has the effect of over-fuelling, increasing black smoke and other gaseous emissions.

48. The EPEFE study found that:

- For light duty vehicles, reducing fuel density decreased emissions of particles, hydrocarbons, carbon monoxide, formaldehyde, acetaldehyde and benzene; increased emissions of NO_x; but had no impact on the composition of the particle load.
- For heavy duty vehicles, reducing fuel density decreased emissions of NO_x; increased emissions of hydrocarbons and carbon monoxide; but had no impact on particle emissions or the composition of the particle load.

49. The EPEFE study also investigated the extent to which the observed density effects on emissions could be decreased by tuning the engine management system to fuel density. The test results indicated that the effect of density on engine emissions is, to a certain extent, caused by the physical interaction of fuel density with the fuel management system. Some density effects still remained after engines were calibrated to specific fuels.

50. Density levels are also influenced by T95 distillation maximum limits (discussed in more detail below) through their impact on the heavy fractions of the fuel. These limits could also be adjusted to compensate for density impacts.

d. Distillation Characteristics (Volatility)

51. Distillation is a reference to the volatility profile of diesel fuel. The distillation or boiling range of the fuel is a consequence of the chemical composition of the fuel meeting other fuel property requirements such as viscosity, flash point, cetane number and density, within a particular refinery's overall product slate.

52. Volatility can influence the amount and kind of exhaust smoke that is emitted. Correct distillation characteristics are therefore essential for efficient fuel combustion. This is achieved by the careful balancing of the light and heavy fuel fractions (parts) during the refining process. Heavy fractions have high energy content and improve fuel economy, but can cause harmful deposit formation inside engines. Light fractions reduce the overall viscosity to provide better fuel injection atomization, easier engine starting and more complete combustion under a variety of engine conditions, but they do not have as much energy per unit volume of fuel (i.e. density) as heavier fractions.

53. The distillation curve of diesel fuel indicates the amount of fuel that will boil off at a given temperature. The curve can be divided into three parts: the light end, which affects startability; the region around the 50% evaporated point, which is linked to other fuel parameters such as viscosity and density; and the heavy end, characterized by the T90 (temperature at which 90% of the fuel will evaporate), T95 and final boiling points (FBP).

54. Investigations have shown that too much 'heavy ends' in the fuel's distillation curve can result in heavier combustion chamber deposits and increased tailpipe emissions of soot, smoke and particulate matter. The effect of T95 on vehicle emissions was examined in the EPEFE study which indicated that exhaust gas emissions from heavy duty diesel engines were not significantly influenced by T95-variations between 375°C and 320°C. However, a tendency for lower NO_x and higher hydrocarbon emissions with lower T95 was observed.

e. Polycyclic Aromatic Hydrocarbons (PAHs)

55. Crude oils contain a range of hydrocarbons including polycyclic aromatic hydrocarbons (PAHs). They are heavy organic compounds found mostly in diesel particulate matter but can also be present in the gas phase. PAHs are also referred to as polynuclear aromatic hydrocarbons and polyaromatic hydrocarbons.

56. A consequence of higher aromatic content in the fuel is poorer auto-ignition quality, increased thermal cracking and peak flame temperatures – and delayed combustion processes. From a combustion perspective, aromatics are, in general, a poor diesel fuel component.

57. PAHs are increasingly attracting special attention because many are known human carcinogens. Testing for the EPEFE study demonstrated that a reduction in the total aromatic content of diesel significantly lowers NO_x, PM, carbon monoxide, benzene, formaldehyde and acetaldehyde emissions.

58. In summary the EPEFE study showed that:

- For light duty vehicles reducing polyaromatics decreased NO_x, PM, formaldehyde and acetaldehyde emissions, but increased hydrocarbon, benzene and carbon monoxide emissions;
- For heavy duty vehicles, reducing polyaromatics decreased NO_x, particles and hydrocarbon emissions

f. Ash and Suspended Solids

59. Ash forming materials (incombustible mineral material) may be present in diesel fuel in two forms - as suspended solids or as hydrocarbon soluble organo-metallic compounds.

60. Ash forming materials present as suspended solids may contribute to fuel injector and fuel pump wear, which are critical issues in engines needed to meet tighter emission standards. Ash forming materials present as soluble organo-metallic compounds have little effect on wear of these components but, like suspended solids, can contribute to combustion chamber deposits, most critically on fuel injector tips, which can then influence emissions performance – specifically of fine particles.

61. While levels of suspended solids may be substantially reduced by engine fuel filters, dissolved organo-metallic compound levels are not reduced in this way, and require management by other means.

62. The issue of the use of recycled waste oil as diesel extender has the potential to increase the ash content of the fuel.

g. Viscosity

63. The viscosity of a fluid indicates its resistance to flow; the higher the viscosity, the greater the resistance. It is a property that, along with density and distillation range, is an important indicator of the fuel's overall character.

64. Viscosity of diesel fuel is important for the operation of fuel injection equipment that is required to accurately measure small quantities of fuel prior to injection and to atomize the fuel in the injection process.

65. Fuel with low viscosity can result in excessive wear in some injection pumps and in power loss due to pump injector leakage. Spray may not atomize sufficiently, therefore, combustion is impaired and power output and fuel economy are decreased. This can have adverse effects on emissions performance.

5. Emissions Control Technology for Diesel Vehicles

66. Diesels emit high levels of oxides of nitrogen and particulates as noted earlier. Modest to significant NO_x control can be achieved by delaying fuel injection timing and adding exhaust gas recirculation (EGR). Very high pressure, computer controlled fuel injection can also be timed to reduce PM emissions. (Modifying engine parameters to simultaneously reduce both NO_x and PM is difficult and limited since the optimal settings for one pollutant frequently increases emissions of the other and vice-versa.) Very low levels of NO_x and PM therefore require exhaust treatment. Lean NO_x catalysts, selective catalytic reduction, NO_x storage traps with periodic reduction, filter traps with periodic burn-off, and oxidation catalysts with continuous burn-off are evolving technologies that are being phased in at differing rates in various parts of the world. Japan for example, is tending to lead the world in the widespread use of PM filters on new diesel vehicles whereas Europe is tending to lag.¹⁹ A new type of diesel, the homogeneous charge compression ignition engine, provides another approach to reducing NO_x and particulates that is receiving significant attention and may be introduced on some engines for at least portions of the engine map within a few years.

67. Reformulated diesel fuels can effectively reduce oxides of nitrogen and particulate emissions from all diesel vehicles as discussed earlier. These fuels have reduced sulfur, reduced aromatics, and increased cetane number. However, certain technologies are especially

¹⁹ Some European countries are using tax incentives to accelerate the introduction of PM filters beyond the rate required by the Euro new vehicle standards.

sensitive to the sulfur content of the fuel; the linkages between sulfur and diesel vehicles technologies will be summarized below.

a. No Controls/Pre-After-treatment Controls

68. For diesel vehicles with no controls, the amount of sulfur in the fuel is directly related to SO₂ and PM emissions; some SO₂ emissions are converted in the atmosphere to sulfate PM.

69. The amount of SO₂ emissions is directly proportional to the amount of sulfur contained in the fuel. In addition, total PM emissions are proportional to the amount of sulfur in the diesel fuel although the carbon and the soluble organic fractions are not affected. In the oxygen-rich exhaust of diesel vehicles several percent of the SO₂ formed during combustion is oxidized to SO₃, which dissolves in the water vapor present to form sulfuric acid (H₂SO₄) vapor. H₂SO₄ forms very small (so called ultrafine) particles in diesel exhaust which are considered especially hazardous because of their ability to penetrate deeply into the lungs. Even though sulfate particles account for only a small fraction of particle volume or mass, they account for a large fraction of particle numbers.

70. According to the US EPA, approximately 2% of the sulfur in the diesel fuel is converted to direct PM emissions. In addition, SO₂ emissions can lead to secondary particle formation—particles that form in the ambient air. US EPA models predict that over 12% of the SO₂ emitted in urban areas is converted in the atmosphere to sulfate PM. Urban areas would benefit most from reductions in SO₂ emissions, as polluted urban air has higher concentrations of the constituents that catalyze the SO₂-to-sulfate reaction. Even with vehicle stocks without advanced pollution controls, reductions of fuel sulfur levels would likely have a significant impact on primary and secondary PM concentrations in urban areas.

b. Post Combustion Controls

71. With high sulfur levels, diesel catalysts produce high levels of hazardous sulfate. Some advanced catalyst technologies such as NO_x adsorbers are precluded by high levels of sulfur. Finally, PM filter performance is impaired by higher levels of sulfur.

i. Diesel Oxidation Catalysts

72. Diesel oxidation catalysts (DOCs) are the most common after treatment emissions control technology found in current diesel vehicles. DOCs are very similar to the earliest catalysts used for gasoline engines. Oxidation catalysts work by oxidizing CO, HC and the soluble organic fraction of the PM to CO₂ and H₂O in the oxygen rich exhaust stream of the diesel engine.

73. When sulfur is present in the fuel, DOCs also increase the oxidation rate of SO₂, leading to increases in sulfate nanoparticle emissions. Sulfate conversion depends on overall catalyst efficiency, with more efficient catalysts capable of converting nearly 100% of the SO₂ in the exhaust to sulfate. Generally, one should restrict the use of DOCs to areas which have fuel sulfur levels of 500 ppm or below. With low sulfur fuel, a DOC can reduce PM emissions by 25 to 30%.

ii. Diesel Particulate Filters

74. Diesel particulate filters (DPFs) already reliably demonstrate over 95% efficiency with near-zero sulfur fuel use. They are also capable of reducing the total number of particles emitted to levels similar to or even slightly lower than those of gasoline engines. One important

area of research—the area most impacted by sulfur levels—is the passive regeneration or cleaning of the collected particles from the filter surface. Filters need to be cleaned, ideally without human intervention, before reaching capacity in order to maintain vehicle performance and fuel and filter efficiency.

75. The Continuously Regenerating Diesel Particulate Filter (CR-DPF) and the Catalyzed Diesel Particulate Filter (CDPF) are two examples of PM control with passive regeneration. The CR-DPF and CDPF devices were found to achieve 95% efficiency for control of PM emissions with 3 ppm sulfur fuel.²⁰ Efficiency dropped to zero with 150 ppm sulfur fuel and PM emissions more than double over the baseline with 350 ppm sulfur fuel. The increase in PM mass comes mostly from water bound to sulfuric acid. Soot emissions also increase with higher sulfur fuel but even with the 350 ppm sulfur fuel DPFs maintain around 50% efficiency for non-sulfate PM. The systems eventually recover to original PM control efficiency with return to use of near-zero sulfur fuels, but recovery takes time due to sulfate storage on the catalyst.

76. As noted by TERI in its recent study of PM filters and low sulfur fuel in Mumbai, “Continuously Regenerating Technology (CRTTM) proved to be highly effective in reducing PM emissions from ULSD powered BS -II buses”.²¹ It is, however, important to highlight that CRT is very sensitive to the sulfur content in diesel. According to Johnson Matthey, its manufacturer, a CRT can work effectively only if it is used in a modern diesel bus running on not more than 50 ppm sulphur–diesel or ULSD. The conversion efficiency of the CRT, after it was stabilized, was found to be 95% for soluble organic fraction (SOF) and over 98% for insoluble organic fraction (IOF). “The CRT was very effective in reducing the free acceleration smoke too.”

77. Sulfur also increases the required temperature for regeneration of the filter. In moving from 3 to 30 ppm sulfur fuel, the exhaust temperatures required for regeneration increase by roughly 25°C. The CDPF requires consistently higher temperatures but holds stable above 30 ppm, while the CR-DPF requires ever-increasing temperatures.

78. Work continues to develop filters that are less sensitive to sulfur in fuels. One emerging technology, the so-called flow through filter that achieves about 50% PM reduction is, for example, less sensitive to sulfur than the wall flow filter which can achieve 90% or greater PM reductions. There is not yet a sufficient body of data to determine if such systems can perform reliably for extended mileage using fuels with more than 50 ppm sulfur.²²

c. NO_x Control Systems

79. Many diesel engines rely on injection timing retard to meet the NO_x standards currently in place. Injection timing retard reduces the peak temperature and pressure of combustion, thus reducing NO_x formation. Unfortunately, this solution both increases PM emissions and significantly decreases fuel economy. For example, NO_x emissions can be decreased by 45% by retarding the injection timing 8 degrees, but this would result in a 7% loss in fuel economy. Injection timing retard is not impacted by sulfur in fuel.

80. Exhaust gas recirculation (EGR), another NO_x control strategy which is being used extensively today, is only indirectly impacted by fuel sulfur. Two very different technologies—

²⁰US Department of Energy. 1999. Diesel Emission Control—Sulfur Effects (DECSE) Program US Department of Energy: Washington, DC. Available URL: <http://www.ott.doe.gov/decse/>

²¹ Workstream 1: Evaluation of alternative fuels and technologies for buses in Mumbai, Final report, TERI, 2004, New Delhi: The Energy and Resources Institute. 82 pp. [TERI Project Report No. 2001UT41]

²² A retrofit demonstration project is underway in Beijing in which such systems will be run with some higher sulfur level fuels to see if they will be able to perform adequately.

NO_x adsorbers and selective catalytic reduction (SCR) systems—are the most likely alternatives for stringent NO_x control.

i. Exhaust Gas Recirculation

81. Major advances in diesel NO_x control have been made with exhaust gas recirculation (EGR), which lowers combustion temperatures and thus reduces thermal NO_x formation. Fuel sulfur does not impact emissions from EGR systems in diesel engines, but it does hinder system durability and reliability due to sulfuric acid formation. In order for EGR to be effective, the exhaust gases must be cooled, which causes sulfuric acid to condense in the recirculation system. Acid formation raises system costs, due to the need for premium components and increased maintenance costs.

ii. Selective Catalytic Reduction (SCR)

82. SCR is emerging as the leading NO_x reduction technology in Europe to meet Euro IV and Euro V heavy-duty diesel standards. SCR uses a reducing agent, injected into the exhaust gas before the catalyst, to achieve high rates of NO_x conversion in the oxygen-rich exhaust.²³ Stationary systems have over 90% conversion efficiency and are widely used for diesel generators and power production.

83. Sulfur does not reduce conversion efficiency in SCR systems as directly as in other advanced control technologies, but emissions are impacted in a couple of ways. Fuel sulfur will increase the PM emissions from the downstream oxidation catalyst. Sulfur reactions in urea-based SCR systems can also form ammonium bi-sulfate, a severe respiratory irritant.

iii. NO_x Adsorbers

84. NO_x adsorbers are also known as NO_x storage catalysts or lean NO_x traps. NO_x adsorber systems are still under development but are expected to be introduced in the US for some engines in 2007. They have demonstrated 95% efficiency in conversion of NO_x to N₂, with a nominal fuel penalty of 1.5%. However, without significant technological breakthroughs, it is generally recognized that this system can only operate with near zero sulfur fuels.

d. PM Retrofits

85. A growing body of data continues to show that the combination of very low sulfur fuel (usually with 50 ppm sulfur or less) and particulate filters can bring about approximately 90% reductions in PM and further substantial reductions in CO and HC from existing diesel vehicles, even after 400,000 miles of operation.²⁴ The TERI study cited earlier showed similar reductions on a small fleet in India. To obtain these reductions however requires a careful matching of the technology to the vehicles with special attention given to operational patterns and exhaust temperature profiles. Demonstration projects are underway in Bangkok, Beijing and Pune, India to determine if such systems can perform satisfactorily under Asian conditions.

86. Diesel oxidation catalysts can also be retrofitted to existing diesel vehicles as is occurring in Hong Kong, with overall PM reduction on the order of 25%.

²³ SCR systems are completely ineffective if the urea reagent is not added and thus requires great attention to in use enforcement and monitoring when this technology is used. European regulators are taking steps to require fail safe systems that will significantly degrade vehicle performance if the urea tank is not filled.

²⁴ Schaefer, Bob from BP Global Fuels Technology. 2003. The Success of Diesel Retrofits: A Fuel Supplier Perspective. December.

6. Conclusions Regarding Diesel Fuel

87. As a general rule, it is desirable for countries following the progression of Euro vehicle standards to adopt the Euro vehicle fuel standards. From the standpoint of emission control technology, the most important diesel parameter is the sulfur content of the fuel. Once Euro 2 standards are introduced, the sulfur content should be reduced to a maximum of 500 ppm; for Euro 3, the maximum should be 350 ppm; and for Euro 4, the maximum should be 50 ppm. If sulfur levels are higher than these levels, the optimal performance of the pollution control systems will not be achieved and the in use emissions will likely exceed standards. For Euro 4 and cleaner vehicles, depending on the technology selected by the vehicle manufacturer, permanent damage could occur from the use of higher sulfur fuels.

C. Gasoline Vehicles and Fuels

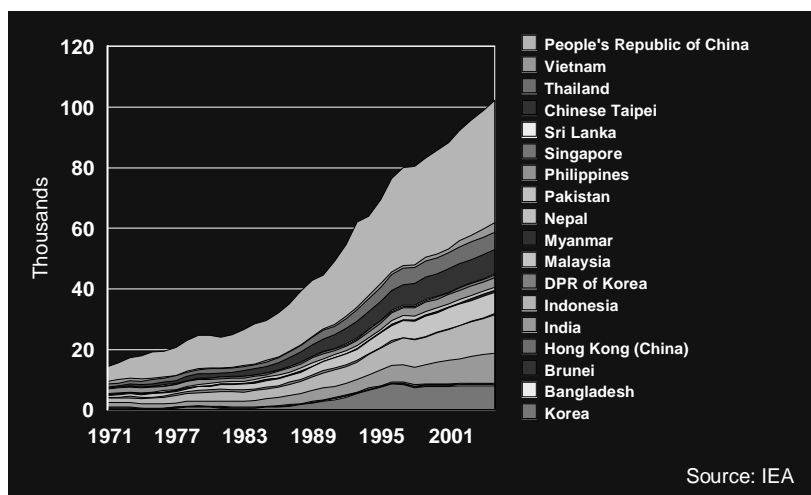
1. Trends With Respect To Gasoline Vehicle Fleet Composition in Asia

88. Most passenger cars in Asia are gasoline fueled although the fraction that is diesel fueled is starting to grow in some countries. There are two unique characteristics regarding the gasoline fueled fleet in Asia:

- It is the fastest growing in the world by far (see figure 2.3), and
- It dominates the global market for two and three wheeled motorcycles and scooters.

2. General Description of gasoline fuel parameters

89. Gasoline is a complex mixture of volatile hydrocarbons used as a fuel in internal combustion engines. The pollutants of greatest concern from gasoline-fuelled vehicles are CO, HC, NO_x, lead and certain toxic hydrocarbons such as benzene. Each of these can be influenced by the composition of the gasoline used by the vehicle. The most important characteristics of gasoline with regard to its impact on emissions are – lead content, sulfur concentration, volatility, aromatics, olefins, oxygenates, and benzene level.

Figure 2.3: Gasoline Consumption Trends in Asia

Source: IEA

Source: IEA

a. Impact of Gasoline Composition on Asian Vehicle Emissions

90. The following tables summarize the impacts of various gasoline fuel qualities on emissions from light duty gasoline vehicles.

Table 2.5: Impact of Gasoline Composition on Emissions from Light Duty Vehicles²⁵

Gasoline	No Catalyst	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 ^a	Comments
Lead	Pb, HC	CO, HC, NO _x all increase dramatically as catalyst destroyed					
Sulfur (50 to 450 ppm)	SO ₂	CO, HC, NO _x all increase ~15-20% SO ₂ and SO ₃ increase					Onboard Diagnostic light may come on incorrectly
Olefins	Increased 1,3 butadiene, increased HC reactivity, NO _x , small increases in HC for Euro 3 and cleaner						Potential deposit buildup
Aromatics	Increased benzene in exhaust						Deposits on intake valves and combustion chamber tend to increase
	potential increases in HC, NO _x	HC , NO _x , CO		HC, NO _x , CO			
Benzene	Increased benzene exhaust and evaporative emissions						
Distillation Characteristics T50, T90	Probably HC	HC					
RVP	Increased evaporative HC Emissions						Most critical parameter for Asian countries because of high ambient Temperatures

²⁵ The impacts of additives which increase the octane rating of gasoline are described in Chapter 4.

Gasoline	No Catalyst	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 ^a	Comments
Deposit control additives		Potential HC, NO _x emissions benefits					Help to reduce deposits on fuel injectors, carburetors, intake valves, combustion chamber

^a Euro 5 emissions standards were recently adopted for implementation in 2010; Euro 6 was also adopted for 2015 implementation

Notes: CO = carbon monoxide; HC = hydrocarbon; Pb = lead; RVP = Reid vapor pressure; NO_x = oxides of nitrogen; O₂ = oxygen; SO₂ = sulfur dioxide; T50 = temperature at which 50% of the gasoline distills; T90 = temperature at which 90% of the gasoline distills

b. Two and Three Wheeled Vehicles

91. Many countries and cities throughout Asia have much higher proportions of two and three wheeled vehicles than anywhere else in the world. While emissions from these vehicles are expected to be influenced by fuel characteristics, there has been very little study focused on the impacts of specific fuel parameters on these vehicles. However, based on the limited available data and the combustion similarities between these and other internal combustion engines, these impacts are estimated to be as shown in the table below.

Table 2.6: Impact of Gasoline Composition on Emissions from Motorcycles²⁶

Gasoline	No Catalyst	India 2005	Euro 3	India 2008	Taipei,China Stage 4	Comments
Lead	Pb, HC	CO, HC, NO _x all increase dramatically as catalyst destroyed				
Sulfur (50 to 450 ppm)	SO ₂	CO, HC, NO _x all increase SO ₂ and SO ₃ increase				
Olefins	Increased 1,3 butadiene, HC reactivity and NO _x					Potential deposit buildup
Aromatics	Increased benzene exhaust					
Benzene	Increased benzene exhaust and evaporative emissions					
Distillation characteristics T50, T90	Probably HC	HC				Not as quantifiable as in passenger cars
RVP	Increased evaporative HC Emissions					
Deposit control additives		potential emissions benefits				Help to reduce deposits on fuel injectors, carburetors

Notes: CO = carbon monoxide; HC = hydrocarbon; Pb = lead; RVP = Reid vapor pressure; NO_x = oxides of nitrogen; O₂ = oxygen; SO₂ = sulfur dioxide; T50 = temperature at which 50% of the gasoline distills; T90 = temperature at which 90% of the gasoline distills

92. Most two- and three-wheeled vehicles currently used throughout the region are not equipped with catalytic converters to control emissions. Therefore it would seem that the impact of the various fuels parameters will be similar to those from pre Euro 1 cars. Some catalysts are starting to enter the fleet as emissions standards are being tightened, especially in India, Taipei,China and Europe. These vehicles are anticipated to be impacted by sulfur and lead in a manner similar to Euro 1 and 2 gasoline fueled cars. For two- and three-wheeled vehicles

²⁶ The impacts of additives which increase the octane rating of gasoline are described in Chapter 4.

equipped with 2-stroke engines, the amount and quality of the lubricating oil is probably more important for emissions than fuel quality.

3. Required Changes in Gasoline Fuel Parameters in Asia to Achieve Lower Emissions

93. The use of catalyst exhaust gas treatment required the elimination of lead from gasoline. This change, which has occurred throughout most of the Asia region, has resulted in a dramatic reduction of ambient lead levels. Other gasoline properties that can be adjusted to reduce emissions include, roughly in order of effectiveness, sulfur level, vapor pressure, distillation characteristics, light olefin content, and aromatic content.²⁷

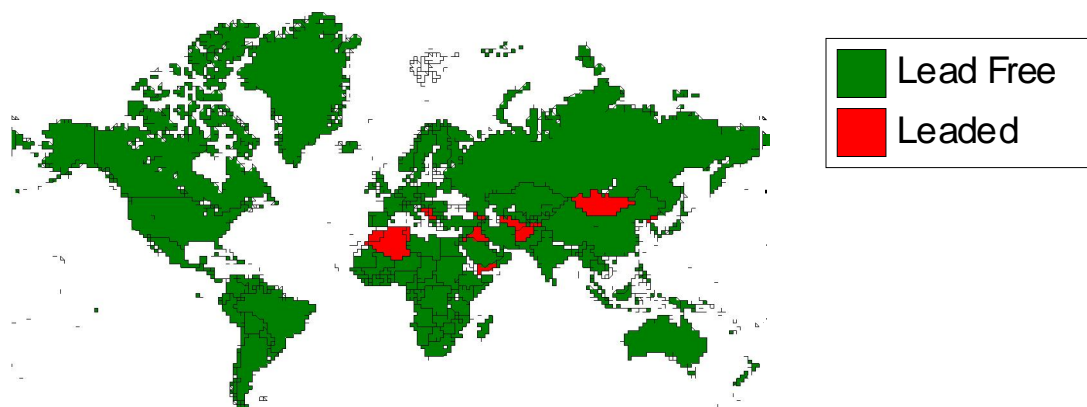
94. As a general rule, countries following European vehicle emissions standards should be guided by the equivalent fuel quality standards. This is especially true for lead and sulfur as these fuel parameters are closely linked to the technologies used to comply with the vehicle emissions standards.

a. Lead

95. Lead additives have been blended with gasoline, primarily to boost octane levels, since the 1920s. Lead is not a natural constituent of gasoline, and is added during the refining process as either tetramethyl lead or tetraethyl lead. In addition to increasing the octane level of gasoline, lead also lubricates the engine valves/valve seat interface of vehicles that have soft valve seats, thereby minimizing wear.

96. Vehicles using leaded gasoline cannot use a catalytic converter and therefore have much higher levels of CO, HC and NO_x emissions. In addition, lead itself is toxic. Lead has long been recognized as posing a serious health risk. It is absorbed after being inhaled or ingested, and can result in a wide range of biological effects depending on the level and duration of exposure. Children, especially under the age of 4, are more susceptible to the adverse effects of lead exposure than adults.

Figure 2.4: Lead Free Gasoline Worldwide, 2007



Source: Michael P. Walsh. 2007. Figure 4 Remaining Use of Leaded Gasoline, 2007

²⁷ R.F. Sawyer. 1993. Reformulated gasoline for automotive emissions reduction. In *Twenty-Fourth Symposium (International) on Combustion*, 1423-1432. Pittsburgh, Pennsylvania: The Combustion Institute.

97. The figure above (figure 2.4) shows that almost every country in the Asia-Pacific region has eliminated the use of leaded gasoline.

b. Sulfur

98. Sulfur occurs naturally in crude oil. Its level in refined gasoline depends upon the source of the crude oil used and the extent to which the sulfur is removed during the refining process.

99. Sulfur in gasoline reduces the efficiency of catalysts designed to limit vehicle emissions and adversely affects heated exhaust gas oxygen sensors. High sulfur gasoline is a barrier to the introduction of new lean burn technologies using De-NO_x catalysts, while low sulfur gasoline will enable new and future conventional vehicle technologies to realize their full benefits. If sulfur levels are lowered, existing vehicles equipped with catalysts will generally have improved emissions.

100. Laboratory testing of catalysts has demonstrated reductions in efficiency resulting from higher sulfur levels across a full range of air/fuel ratios. The effect is greater in percentage for low-emission vehicles than for traditional vehicles. Studies have also shown that sulfur adversely affects heated exhaust gas oxygen sensors; slows the lean-to-rich transition, thereby introducing an unintended rich bias into the emission calibration; and may affect the durability of advanced on-board diagnostic (OBD) systems.

101. The EPEFE study demonstrated the relationship between reduced gasoline sulfur levels and reductions in vehicle emissions. It found that reducing sulfur reduced exhaust emissions of HC, CO and NO_x (the effects were generally linear at around 8-10% reductions as fuel sulfur is reduced from 382 ppm to 18 ppm)²⁸. The study results confirmed that fuel sulfur affects catalyst efficiency with the greatest effect being in the warmed up mode. In the case of air toxins, benzene and C3-12 alkanes were in line with overall hydrocarbon reductions, with larger reductions (around 18%) for methane and ethane.

102. The combustion of sulfur produces sulfur dioxide (SO₂), an acidic irritant that also leads to acid rain and the formation of sulfate particulate matter.

103. In the European Union, the Euro 3 and 4 gasoline specifications set maximum sulfur content limits of 150 ppm and 50 ppm respectively (Euro 2 limits were 500 ppm). Subsequently, these limits were tightened to require 10 ppm sulfur fuel to be widely available in each member state in 2005 and for all gasoline to meet these limits by 2009. Several EU countries such as Sweden and Germany already provide fuels meeting these limits.

c. Vapor Pressure

104. Gasoline volatility is an indication of how readily a fuel evaporates. It is characterized by two measurements – vapor pressure and distillation.

105. Reid vapor pressure (RVP) is a measure of the volatility of gasoline at 100°F (37.8°C) in kilopascals (kPa). The RVP is largely governed by the fuel's butane content, whose average RVP is around 350 kPa. Pentanes, with an RVP of about 17 kPa, add volatility to a lesser extent. Butane content is partly a function of the nature of the crude, but occurs mostly as a result of the refining process.

²⁸ The study found that the effects tended to be larger over higher speed driving than in low speed driving.

106. Sufficient volatility of gasoline is critical to the operation and performance of spark ignition engines. At lower temperatures, higher vapor pressure is needed to allow easier start and warm up performance. Control of vapor pressure at high temperatures reduces the possibility of hot fuel handling problems such as vapor lock and carbon canister overloading. Vapor lock occurs when too much vapor forms in the fuel lines and fuel flow decreases to the engine. This can result in loss of power, rough engine operation or engine stalls.

107. High gasoline vapor pressure causes high evaporative emissions from motor vehicles and is therefore a priority fuel quality issue. Evaporative emissions can comprise a large part of total hydrocarbon emissions. Their release may occur during the delivery and transfer of gasoline to storage, vehicle refueling, the diurnal breathing of vehicle fuel tanks (as they heat up and cool down with normal daily temperature variations), and the fugitive losses that occur from carburetor and other equipment during normal vehicle operation. Reductions in fuel volatility will significantly reduce evaporative emissions from vehicles. A reduction in vapor pressure is one of the more cost effective of the fuel-related approaches available to reduce hydrocarbon emissions.

108. Vapor pressure is most effectively managed on a regional and seasonal basis to allow for the different volatility needs of gasoline at different temperatures. The reduction of evaporative emissions is most effectively achieved when RVP is controlled when ambient temperatures are high – i.e. the summer period.

109. In the European Union, the Euro 3 gasoline specifications identify eight volatility classes. Each class is based on seasonal temperature variations and specifies a range of RVP values. Class 1 is the most stringent situation, with the lowest RVP values, for the warmest climates; with classes 7 and 8 applicable in very cold conditions where more volatile gasoline blends are required. The specifications also set a maximum summer (May to September) limit of 60 kPa. For member states with arctic conditions, summer is from 1 June to 31 August and the RVP is set higher at 70 kPa. In the USA and more especially in California where hot ambient conditions are prevalent, the levels of RVP set by the US EPA and California Air Resources Board are close to 50 kPa. In Asian countries where summer conditions are experienced throughout the year, the RVP limits at low levels are very critical. In one study for Thailand, reducing the RVP by 6.89 kPa was estimated to result in reductions in HC emissions of more than 100 tons per day.

d. Distillation

110. Distillation is a second method for measuring the volatility of gasoline. Distillation can be assessed in terms of 'T' points or 'E' points. For instance, T50 is the temperature at which 50% of the gasoline distils, while E100 is the percentage of gasoline distilled ('E' – evaporated) at 100°C.

111. Excessively high T50 point (low volatility) can lead to poor starting performance at moderate ambient temperatures. The measure of the driveability index (DI), which is derived from T10, T50, and T90 and oxygenate content, can be used as a control to facilitate cold start and warm-up performance. Use of a DI also helps to avoid inclusion of a high proportion of high density poor burning compounds which contribute to carbon monoxide and NO_x emissions.

112. The EPEFE study found that increasing E100 in gasoline reduces emissions of hydrocarbons but increases NO_x emissions. At E100, carbon monoxide emissions were at their lowest value of 50% by volume, for constant aromatics. Increasing E100 from 35% to 50% by volume showed a decrease in mass emissions of both formaldehyde and acetaldehyde. But increasing E100 from 50 % to 65 % by volume showed no clear effect.

113. Limiting distillation temperatures and aromatic content appear to be the most important parameters for controlling emissions during the vehicle's 'cold cycle'.

114. Heavy end limits (and total aromatic limits) provide the best means to limit heavy aromatics, important in managing hydrocarbon and benzene emissions.

115. Research shows that combustion chamber deposits formation can relate to the heavy hydrocarbon molecules found, inter alia, in the T90-FBP portion of the gasoline. A major benefit of reduced combustion chamber deposits is a reduction in NO_x emissions.

116. In the European Union, the Euro 3 gasoline specification addresses distillation in terms of two E points: E100 – 46 % vol min, and E150 – 75 % vol min, and final boiling point (FBP) – 210°C max.

e. Olefins

117. Attention has been given in recent years to the specific make-up of the hydrocarbon content of gasoline. This is due both to the significant role hydrocarbon based vehicle emissions play in urban ozone (or photochemical smog) formation, and to the fact that there are significant adverse public health impacts from exposure to certain hydrocarbons. As a result, there has been a move towards setting content limits on the different hydrocarbon fractions within gasoline especially the aromatics and the olefins.

118. An olefin is a family of chemicals containing carbon-to carbon double bonds. Olefins are unsaturated hydrocarbons (such as propylene and butylenes) and, in many cases, are also good octane components of gasoline. They can, however, lead to engine deposit formations and increased emissions of highly reactive ozone-forming hydrocarbons and toxic compounds. They tend to be chemically more reactive than other hydrocarbon types.

119. Olefins are easily oxidized and thermally unstable and may lead to gum formation and deposits on the fuel injectors and in the engine's intake system. Combustion chamber deposits form from the heavy hydrocarbon molecules found, inter alia, in the olefin portion of gasoline. Combustion chamber deposits can increase tailpipe emissions, including carbon monoxide, hydrocarbons and NO_x.

120. Emission of olefins into the atmosphere as chemically reactive species contributes to ozone formation and toxic dienes. The US Auto/Oil program concluded that reducing total olefins from 20% to 5% would significantly decrease ozone-forming potential.

121. Reduction of low molecular weight olefins accounts for about 70% of the ozone reduction effect. Not only does the ozone formation potential of olefins predominantly derive from the lighter volatile olefin fractions, but also these fractions are typically removed where reductions in low levels of RVP at 48-50 kPa are required. In addition, 1,3-butadiene, a known carcinogen, is formed during the combustion of olefin compounds in gasoline.

122. The European Union fuel specifications for Euro 3 set a maximum olefin content of 18% by volume.

123. Under both phases of the US reformulated gasoline (RFG) program, the olefin specification is a maximum 8.5% by volume. The Californian RFG program (effective since 1996) provides several compliance options for meeting the refiner limits for olefins, one option being

the utilization of a maximum (flat) limit of 6% by volume or an averaging limit of 4% by volume coupled with a cap of 10% by volume.

f. Aromatics

124. Aromatics are hydrocarbon fuel molecules based on the ringed six-carbon benzene series or related organic groups. They contain at least one benzene ring. Benzene (discussed separately below), toluene, ethylbenzene and xylene are the principal aromatics. They represent one of the heaviest fractions in gasoline.

125. Lower levels of aromatics enable a reduction in earlier catalyst light-off time for all vehicles.

126. Research indicates that combustion chamber deposits can form from the heavier hydrocarbon molecules found in the aromatic hydrocarbon portion of the gasoline. These deposits can increase tailpipe emissions, including carbon dioxide, hydrocarbons and NO_x.

127. The aromatic content of gasoline has a direct effect on tailpipe carbon dioxide (CO₂) emissions. The EPEFE study demonstrated a linear relationship between CO₂ emissions and aromatic content. A reduction of aromatics from 50 to 20% was found to decrease CO₂ emissions by 5%. This was considered to be due to their effect on the hydrocarbon ratio and hence carbon content of the gasoline - no clear effect of aromatics was found on calculated fuel consumption.

128. Combustion of aromatics can lead to the formation of toxic benzene in exhaust gas. Benzene is a proven human carcinogen that can cause leukemia in exposed persons. It is estimated that about 50% of the benzene produced in the exhaust is the result of decomposition of aromatic hydrocarbons in the fuel. Both the AQIRP and the EPEFE studies showed that lowering aromatic levels in gasoline significantly reduces toxic benzene emissions from vehicle exhausts. In the EPEFE study, benzene emissions were found to vary between 3.6% and 7.65 % of total volatile organic compounds for fuel aromatic contents ranging from 19.5% to 51.1% by volume. This is consistent with previous studies and can be explained by the de-alkylation of substituted aromatics.

129. The EPEFE study also found that emissions changes from changes to the aromatic content of fuel were influenced by other parameters such as distillation. Reducing the aromatic content of gasoline also contributes to the reduction of NO_x.

130. The European Union fuel specifications for Euro 3 and Euro 4 set maximum aromatic content limits of 42% and 35% by volume respectively.

131. The US specifications under the reformulated gasoline (RFG) program are maximum limits by volume as follows: Phase 1 (January 1995): 27%; and Phase 2 (January 2000): 25%.

132. The California specifications under the RFG program are also maximum limits by volume as follows: Phase 1 (January 1992) 32%; and Phase 2 (January 1996) 22%.

133. In Japan, the specifications for regular and premium grades set maximum aromatic content levels at 42% by volume. In South Korea they were set as maximum limits by volume at 45% in 1998, reducing to 35% in January 2000.

g. Benzene

134. Benzene is a six-carbon, colorless, clear liquid aromatic that occurs naturally in gasoline and is also a product of catalytic reforming used to boost octane levels. It is fairly stable chemically but highly volatile. It has a high octane rating – research octane number (RON) 106, motor octane number (MON) 103.

135. Benzene in gasoline leads to both evaporative and exhaust emissions of benzene. The EPEFE study found that benzene exhaust emissions varied between 3.6% and 7.65% of total volatile organic compounds from gasoline containing benzene of 1.7% to 2.8% by volume.

136. As noted in the preceding section, the key health concern related to benzene exposure is leukemia.

137. The control of benzene levels in gasoline is recognized by regulators as the most direct way to limit benzene evaporative and exhaust emissions and therefore human exposure to benzene. As a result, over the last decade there has been a steady move by regulators to lower the benzene content of gasoline.

138. In the European Union, the Euro 3 and 4 gasoline specifications set maximum benzene limits of 1% by volume (the Euro 2 limit was 5%).

139. The US set a flat limit of 0.8% benzene by volume from January 1995 and has continued with this limit under Phase 2 of the reformulated gasoline (RFG) program, effective from January 2000. It has recently adopted a national cap on benzene limits similar to those on reformulated gasoline.

140. Japan introduced a maximum limit of 5% benzene by volume in 1996, which was reduced to 1% in 2000. In Singapore the current limit is 4%, and in Thailand it is 3.5% for all gasoline grades with a future target of 1%.

4. Engine Technology and Emission Control Technologies for 4-Wheeled Gasoline Vehicles

141. Modern gasoline engines use computer controlled intake port fuel injection with feedback control based on an oxygen sensor to meter precisely the quantity and timing of fuel delivered to the engine. Control of in-cylinder mixing and use of high-energy ignition promote nearly complete combustion. The three-way catalyst provides greater than 90% reduction of carbon monoxide, hydrocarbons, and oxides of nitrogen. Designs for rapid warm-up minimize cold-start emissions. On-board diagnostic (OBD) systems sense emissions systems performance and identify component failures. Durability in excess of 160,000 km, with minimal maintenance, is now common.

142. The use of catalyst exhaust gas treatment required the elimination of lead from gasoline. Other gasoline properties that can be adjusted to reduce emissions include, roughly in order of effectiveness, sulfur level, vapor pressure, distillation characteristics, light olefin content, and aromatic content.²⁹ Of these, sulfur is the most important in terms of the impact on advanced pollution control technology so its impacts on different technologies will be summarized below.

h. No Controls/Pre Catalyst Controls

143. The amount of sulfur in the fuel is directly related to SO₂ emissions; some SO₂ emissions are converted in the atmosphere to sulfate PM.

144. For gasoline fueled vehicles with no catalytic converters, reducing sulfur will have no effect on the principal pollutants of concern, CO, HC or NO_x. While the amount of SO₂ emitted is in direct proportion to the amount of sulfur in the fuel, gasoline vehicles are not usually a significant source of SO₂. Since SO₂ can be converted in the atmosphere to sulfates, however, these emissions will also contribute to ambient levels of particulate matter (PM₁₀ and PM_{2.5}) which is frequently a serious concern.³⁰

i. Catalyst Based Controls

145. All catalyst technology is adversely impacted by sulfur with resulting increases in CO, HC and NO_x.

146. Worldwide, approximately 90% of new gasoline vehicles are equipped with a three-way catalyst (TWC), which simultaneously controls emissions of CO, HC, and NO_x. Sulfur in fuel impacts TWC functioning in several ways:

i. Fuel sulfur reduces conversion efficiency for CO, HC and NO_x.

147. Sulfur competes with these gaseous emissions for reaction space on the catalyst. It is stored by the TWC during normal driving conditions and released as SO₂ during periods of fuel-rich, high-temperature operation, such as high acceleration. Reductions in sulfur levels in gasoline—from highs of 200–600 ppm to lows of 18–50 ppm—have resulted in 9–55% reductions in HC and CO emissions and 8–77% reductions in NO_x emissions, depending on vehicle technologies and driving conditions. Greater percentage reductions have been demonstrated for low emission vehicles and high-speed driving conditions.

ii. Sulfur inhibition in catalysts is not completely reversible.

148. Although conversion efficiency will always improve with return to reduced sulfur levels, the efficiency of the catalyst does not usually fully return to its original state after desulfurization. In tests using 60 ppm sulfur fuel followed by a single use of 930 ppm sulfur fuel, HC emissions tripled from 0.04 g/mile to 0.12 g/mile. With a return to low sulfur fuel, emissions dropped again to 0.07 g/mile but fuel-rich operation (resulting in high exhaust temperatures) was required to regenerate the catalyst fully and return to original emissions levels.

iii. Sulfur content in fuel contributes to catalyst aging.

149. Higher sulfur levels cause more serious degradation over time and, even with elevated exhaust temperatures, less complete recovery of catalyst functioning. The high temperatures necessary to remove sulfur from the catalyst also contribute to thermal aging of the catalyst. Sulfur raises the light-off temperature—the temperature at which catalytic conversion can take place—resulting in increased cold-start emissions.

³⁰As noted earlier, US EPA models predict that over 12% of the SO₂ emitted in urban areas is converted in the atmosphere to sulfate PM.

iv. Regeneration requirements add to overall emissions and reduce fuel efficiency.

150. Fuel-rich operation required to reach regeneration temperatures, results in significant increases in CO and HC emissions; PM emissions under these circumstances can actually rival diesel emissions. In addition, fuel-rich combustion requires increased fuel use. Vehicles that tend to operate at low speed and low load will have lower exhaust temperatures and fewer opportunities for desulfurization and catalyst regeneration.

j. More Advanced Catalyst Controls

151. All catalyst technology is adversely impacted by sulfur with resulting increases in CO, HC and NO_x. Some advanced catalyst technologies such as NO_x adsorbers which may enter the market later this decade are precluded by high levels of sulfur.

152. The percentage benefits of reducing sulfur levels in fuels increase as vehicles are designed to meet stricter standards. Increasingly strict emissions standards require extremely efficient catalysts over a long lifetime. Recent regulations in Europe and the US require warmed-up catalysts to have over 98% HC control, even towards the end of the vehicle's lifetime (100,000 km in Europe and over 100,000 miles in the US).

D. Fuel Quality Monitoring

153. Whatever fuel specifications are adopted it is important to have routine monitoring at the pump and along the distribution chain to assure that the actual in use fuels meet the specification. Penalties should be imposed if the limits are not achieved.

154. Because many countries have differential fuel taxes, and in some cases subsidies, special care must be taken to minimize or eliminate adulteration of high quality fuels with lower quality, but cheaper alternatives (e.g. kerosene).

155. A very comprehensive study of fuel adulteration has been carried out in India.³¹ It showed that the current product quality monitoring system is extremely weak and stems largely from weak regulations and enforcement, skewed market prices of the petroleum products and lack of accountability in the petroleum sector. Unless this is corrected, the authors concluded that the root cause of the problem cannot be eliminated. While there was unanimous agreement that skewed prices are largely responsible for adulteration so far no solutions have been possible for political reasons.

156. This study clearly shows that unless serious steps are taken to improve the system to prevent and check adulteration, it will not be possible to even begin to touch the profitable business of adulteration. The current system is compromised from testing methods that are not adequate to detect adulteration to penalty systems too weak to be an effective deterrent.

³¹ Centre for Science and Environment. February 5, 2002. A Report on The Independent Inspection Of Fuel Quality At The Fuel Dispensing Stations, Oil Depots And Tank Lorries. Submitted to the Environmental Pollution (Prevention and Control) Authority. New Delhi

E. Concluding Remarks on Vehicles and Fuels

157. One of the most important lessons learned in the approximately 50 year history of vehicle pollution control worldwide is that vehicles and fuels must be treated as a system. Improvements in vehicles and fuels must proceed in parallel if significant improvements in vehicle related air pollution are to occur. A program that focuses on vehicles alone is doomed to failure; conversely, a program designed to improve fuel quality alone also will not be successful.

158. A second important lesson is that a program that focuses on cleaning up vehicles and fuels as a system can be successful. Countries in Asia tend to be following the EU system for cleaning up vehicles and fuels and this system has laid out a clear roadmap which carefully links vehicle emissions standards and the associated technologies with appropriate fuel parameters and specifications needed to optimize emissions performance. Deviations from some of the fuel parameters are possible and may even be necessary to account for differences in climate and refinery configurations but this should not include deviations from the specifications for lead or sulfur without very careful study and analysis.

159. Reformulated diesel fuels can effectively reduce oxides of nitrogen and particulate emissions from all diesel vehicles. These fuels have reduced sulfur, reduced aromatics, and increased cetane number. However, certain technologies are especially sensitive to the sulfur content of the fuel. Pre Euro 2, lowering sulfur will tend to lower SO₂ and PM emissions but is not linked directly to diesel technology. Euro 2 vehicles, however, should have fuel with a maximum of 500 ppm sulfur; Euro 3 with a maximum of 350 ppm and Euro 4 with a maximum of 50 ppm. Therefore if stringent control of NO_x and PM was needed, sulfur levels will need to be reduced to 50 ppm or less and Euro 4 vehicle standards introduced. Technologies to achieve these levels already exist and even more advanced technologies are being introduced for new vehicles.

160. Experience has also shown that the availability of clean, low sulfur (50 ppm or less) can open up opportunities to substantially reduce emissions from certain fleets of existing vehicles such as urban buses.

161. Although fuel quality improvements will in most cases be driven by the desire to have cleaner new vehicles entering the fleet, experience has demonstrated the feasibility of aggressively reducing in-use emissions from specific categories of gross polluting vehicles such as city buses.

162. With regard to gasoline fueled vehicles, the use of catalyst exhaust gas treatment requires the elimination of lead from gasoline. This change, which has occurred throughout most of the Asia region, has resulted in a dramatic reduction of ambient lead levels. Other gasoline properties that can be adjusted to reduce emissions include, roughly in order of effectiveness, sulfur level, vapor pressure, distillation characteristics, light olefin content, and aromatic content.³² Catalyst technology is emerging for 2-3 wheeled vehicles and therefore lead free and lower sulfur gasoline will be important for these vehicles as well.

163. While certain types of retrofit strategies are technically feasible for gasoline fueled vehicles, they have not been as widespread or successful as diesel retrofits and should not likely be a priority in the region.

³² R.F. Sawyer. 1993. Reformulated gasoline for automotive emissions reduction. In *Twenty-Fourth Symposium (International) on Combustion*, 1423-1432. Pittsburgh, Pennsylvania: The Combustion Institute.,

164. Unlike in the case of diesel vehicles it is not expected that retrofit programs will be undertaken for gasoline fuelled vehicles in the years to come in Asian cities.

165. It is worth noting that the Japanese oil industry accelerated the introduction of near zero sulfur levels in both gasoline and diesel at a faster rate than the government required not only to facilitate the introduction of advanced NO_x and PM controls on vehicles but also to increase the opportunities for more fuel efficient technologies and lower CO₂ emitting technologies to enter the marketplace.³³

³³ E-mail from Ms. Mikami of JPEC to Ms. Ables, CAI-Asia Secretariat, April 21, 2006.

III. PRODUCING CLEAN FUELS IN ASIA

A. Introduction

166. In general cleaner gasoline and diesel cleaner fuels are defined as fuels with properties that produce less evaporative emissions and contribute to lower tailpipe emissions from motor vehicles. The European and US regulations define clean gasoline and clean diesel as fuels that meet specific levels of standards on eight properties for gasoline and five properties for diesel fuel. Extensive testing programs performed both in the USA and in Europe have identified these properties as influencing emissions from the fuels and from motor vehicles. Over the years the severity of the air pollution problems in EU and the USA have required that regulations specify the acceptable levels for each of these properties in order for the emissions from fuels and motor vehicles to be optimized. Table 3.1 and 3.2 shows a comparison of EU standards with the US EPA, California and Japan standards for gasoline and diesel respectively.

Table 3.1: Comparison of Gasoline Standards for EU, US EPA, CA, and Japan

Fuel Property	EU Euro 3	EU Euro 4	US EPA	CA	Japan
RVP, kPa		60.0	49.6	48.2	62
S, ppm	150	50	30	20	50/10
Aro. Vol%	42	35	25	25	No spec
Benz. Vol%	1.0	1.0	1.0	0.8	1.0
Ole. Vol%	21/18	18	8.5	6.0	No spec
Ox. wt%	2.7	---	2.0	2.0	1.2
T90, deg C	---	---	160	152	190
T50, deg C	---	---	99	100	110
E150	75	75	----	-----	-----
E100	46	46	----	-----	-----

Note: * EU has defined E100, E150 standards; Aro. = aromatics; Benz. = benzene; Deg C = degrees Celcius; Ole. = olefins; Ox. = oxygen; RVP = Reid vapor pressure; S = sulfur; T90 = temperature at which 90% of the gasoline distills; T50 = temperature at which 50% of the gasoline distills; vol% = percent by volume; wt% = percent by weight.

Source: J. Courtis

Table 3.2: Comparison of Diesel EU Standards with US EPA , California, and Japan

Property	Euro 3	Euro 4 (2005)	US EPA	California	Japan
S, ppm	350	50	15	15	50/10
Cetane No.	51	51	50+	50+*	45
Cetane Index	46	52	-	-	45
Density, kg/m ³	845	845	-	-	860
Distillation			-	-	
T95 °C	360	360	-	-	360
PAH, vol %	11	4(?)	-	-	---
Total Aro. Vol%	-	-	-	10-20+*	---

Notes: Cetane and aromatics are defined through alternative formulation provisions; aro. = aromatic; °C = degrees Celsius; kg/m³ = kilograms per cubic meter; PAH = polycyclic aromatic hydrocarbon; ppm = parts per million; S = sulfur; T95 = temperature at which 95% of the Diesel distills; vol% = percent by volume

Source: J. Courtis, 2006

167. The comparisons shown in the above tables indicate that there are significant similarities but also some differences between the Euro 4 standards for both gasoline and diesel fuels and the standards adopted by the US EPA or by California. However, the implementation of the Euro 5 fuel standards at EU followed by Euro 6 would reduce these differences. It should be noted that some refineries in other parts of the world, especially the Middle East, are gearing up to provide refined products to the Asian region and the specifications of those products will depend on the specifications required by countries in Asia.

168. Table 3.3 shows the standards for selected Asian countries.

Table 3.3: Fuel Standards for Selected Asian Countries

Fuel Properties	Japan	PRC	Taipei, China	Hong Kong, China	Thailand	Malaysia	Indonesia	Philippines	South Korea	India
Gasoline										
RVP kPa	50-70	60	70	70	60	70	70	70	70	60
S ppm	30	500 (150 ^a)	50	50	150	500	1000	500	100	150
Aromatics vol %	35	40	35	35	40	-	-	35	35	42
Benzene vol%	1.0	3.5	5.0	1.0	1.0	5.0	---	---	3.5	1.0
Olefins vol%	18	35	18	18	18	-----	-----	-----	-----	---
Diesel										
S ppm	10 (50 ^b)	2000 (350 ^a)	100	50	150	500	----	500	10 (50 ^b)	500 (350 ^b)
Cetane No. minimum	51	--	51	51	--	---	---	---	---	45

Note: kPa = kilopascal; ppm = parts per million; RVP = Reid vapor pressure; S = sulfur; vol% = percent by volume; a = standard for Beijing only; b = various fuel quality available

Source: J. Courtis;

State Environment Protection Administration, PR China. 2000. GB 252-2000 "Light Diesel Fuels" national mandatory standard. In Li Shuang. 2007. E-mail to Ms. Aurora Ables re: Fuel and Vehicle Standards in China. 09 Nov.

169. As Table 3.3 shows there is large variability in the types of fuels that are currently produced in Asia. In some countries, the fuels produced comply with standards similar to Euro 1. In contrast in some other countries, the fuels produced have properties very close to the Euro 4 standards. For some countries governmental agencies have announced roadmaps for the implementation of fuel and motor vehicle standards that identify the implementation of Euro 4 and even Euro 5 standards as the final goals. For all areas that are experiencing severe air quality problems the Euro 4 standards appear to be the long-term optimum fuels' strategy to be followed by the implementation of Euro 5. A clear roadmap approach is needed that will carefully link the vehicle emission standards and the associated technologies with appropriate fuel parameters and specifications needed to optimize emissions performance.

B. Implementation of Fuel Standards

170. In Europe and the USA the clean fuel standards were implemented in phases over a thirty-year time period. This slow implementation was due to the lack of understanding of the effects of some of the fuel properties on motor vehicle emissions, a lack of understanding of the severity of the air pollution, as well as lack of understanding of the health effects of air pollutants. The phased-in implementation has resulted in additional and unnecessary expenses for the refining industry. In some cases severe reforming was implemented that resulted in higher levels of aromatics and benzene content and both aromatics and benzene had, later, to be severely reduced. In other cases initial moderate reductions in sulfur content resulted in refinery modifications that later had to be changed again in order to accommodate more severe reductions in sulfur content. However, the phased implementation did give ample time for the refining industry, which helped in the planning and recovering of the capital expenditures, which has been a vital feature of EU and US approaches. During the intervening time, new developments in fuel processing technology as well as improvements in the understanding of the production of cleaner fuels helped to reduce both the refinery capital investments and the operating expenditures.

171. The knowledge gained by the experiences in the U.S. and Europe -- both on the impacts of fuel properties on emissions and on the refinery strategies for implementing cleaner fuel standards -- will allow Asian countries to proceed with implementation of cleaner fuel standards, without the need for a phase-in period. At a minimum, a clearly defined roadmap can be developed to identify the fuel targets and the associated time schedule. The oil industry needs a clear understanding of the ultimate targets so that an integrated strategy for the implementation of fuel standards could be developed. For some Asian countries, there may be a need to include fuel quality targets beyond Euro 4 resulting in lowering sulfur standards to 10-15 ppm. It would be to the benefit of the refineries to be informed early of these regulatory intentions as it may help to reduce their overall investment in the longer run.

172. There are no technical or scientific obstacles to the implementation of such a roadmap.

173. There are no refining issues that would present an obstacle in implementing fuel standards:

- § The refining technology needed to produce cleaner fuels that meet the Euro 4 and Euro 5 or equivalent standards is well understood and has been implemented in the USA and the EU.
- § Although the Asian marketing and distribution system poses significant challenges, the fuel blending, fuel distribution, fuel monitoring and other issues associated with cleaner fuels are well defined, and there is an extensive experience with the marketing of cleaner fuels.
- § The costs of the refining technology are well defined and there are a variety of engineering and construction services available with experience that could be employed for refinery modifications.
- § There have been developments in refining technology during the last ten years that would significantly reduce capital costs.
- § There are tools available that could help optimize the refining operations and reduce operating and other costs.

C. The Current Status of Refineries and Refining Industry in Asia

174. It is estimated that there are about 264 refineries operated in 16 Asian countries. These refineries vary in size as well as in complexity. Table 3.4 lists a summary of the number of refineries operated in each country in Asia as well as some of their process capacities.

Table 3.4: Summary of Asian Refiners by Country and Process Capacity

Country	Number of refineries	Crude Distillation Capacity (MBPD)	Light Oil Processing (MBPD)	Conversion (MBPD)	Hydro-Treating (MBPD)
Japan	35	4,786	858	1,093	4,232
Singapore	3	1,259	157	164	592
Thailand	7	782	82	115	382
Korea	6	2,560	237	307	1,017
Malaysia	6	516	94	91	154
Philippines	5	428	67	47	193
Indonesia	8	993	109	293	116
Taipei, China	4	975	151	155	511
PRC	155	5,400	247	1,784	433
Australia	9	954	296	280	434
New Zealand	1	106	28	29	62
Myanmar	2	57	-	-	-
Viet Nam	-	-	-	-	-
India	17	2,135	51	222	228
Pakistan	7	285	4	80	90
Sri Lanka	1	48	5	-	18
Bangladesh	1	33	2	1	2

Notes: MBPD = thousands of barrels per day; PRC = People's Republic of China

Sources: (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services. Hart, APEC Study

(2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.

175. Refineries are classified into three general categories according to their level of complexity.

1. Topping Refineries

176. Topping refineries are usually small facilities that rely exclusively on crude oil distillation for the production of various distillate components. The "straight run" streams receive very little processing and the residuum from the distillation process is sold as fuel oil, converted to asphalt; or is sold to other refineries that have additional processing capability. The topping refineries do not have any processes such as catalytic cracking and they may import blending components to meet fuel specifications. The product mix produced by such refineries is strongly dependent upon the crude used.

177. These refineries have very little clean fuels capacity and their flexibility in producing clean fuels is limited. Because of their small size the economies of scale do not favor the installation of grassroots new process units for the production of clean fuels. Under a

competitive market environment it can be expected that these refineries, when under private ownership, will find it unprofitable to produce cleaner fuels; or to invest in capital expenditures in order to modify or expand their refineries. In a controlled price environment, or when under governmental ownership, they could continue their operations if the prices allow the recovery of capital and operating expenditures. There are a number of countries in Asia where topping refineries represent an important part of fuel production. In these countries where the fuels supply relies for a large part on the fuel production from the topping refineries, the issue of clean fuels availability and supply could force the implementation of governmental subsidies or increase dependence on imports.

2. Hydroskimming Refineries

178. The hydroskimming refineries are usually mid-sized facilities that in addition to the distillation processes include processes for catalytic reforming of some of the distillation streams. They may include hydrotreating or hydrofinishing processes that help to improve further the quality of the various distillation fractions as produced. The hydroskimming refineries are less dependent on crude quality to meet product specifications. Some of these refineries may have the capability to produce some clean fuels. Depending upon the types of crude oils that these facilities run, they may be capable of producing gasoline that is very close in meeting Euro 4 standards. However, their clean diesel capacity is more limited. A large capital investment, when required, would significantly reduce the profit margins for these refineries, and they may choose not to maintain their current level of production of motor vehicle fuels. The capital investments needed and the overall costs on per barrel of fuel processed would be higher compared to the costs experienced by complex refineries. It is, however, possible that some of the hydroskimming refineries will be retrofitted to produce cleaner fuels. This will be easier in an environment where prices are controlled and where the price mechanisms allow the recovery of investments. In the USA almost all of the hydroskimming facilities remained operational at the Euro 2 equivalent regulatory standards. When the Euro 3 and Euro 4 equivalent standards took effect, a number of refineries reduced the production of cleaner fuels, while others retrofitted their processes and continued fuels production. This had an impact on the supply of cleaner fuels. In Asia, there are a number of countries where hydroskimming refineries are operated. These facilities are capable of producing some cleaner fuels.

3. Complex Refineries

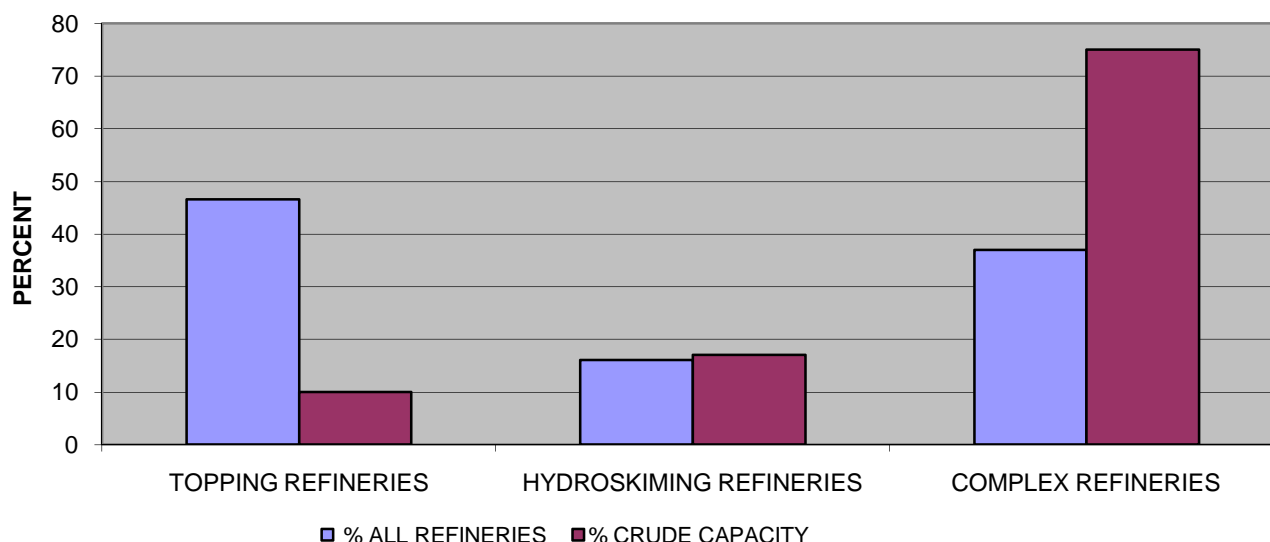
179. The complex refineries are larger facilities that have a wide range of processing capabilities to alter product yields and product quality. In addition to the processes identified for topping and hydroskimming refineries, they include cracking processes and may include some or all of additional processes producing clean gasoline components such as alkylation, isomerization, and polymerization. These processes can convert low-value residual products to higher value gasoline or diesel, or very light streams into gasoline. Complex refineries may already employ processes that would be useful in the production of clean fuels. However, complex refineries in Asia have lower concentration of clean gasoline blendstock plants such as alkylation, isomerization, or hydrotreating than the complex refineries in Europe or in the USA. In the USA such plants are at 15% of crude capacity and in Europe at 10%. In Asia however this only covers 2% of crude capacity in the complex refineries. Therefore, in Asia, the production of clean fuels at the current production levels would require significant additional capital investments and modifications to the refinery operations. For example, even when existing hydrotreating units are in place it may be required to retrofit or to rebuild these in order to be able to produce fuels with sulfur content lower than 50ppm. Additional auxiliary units such as hydrogen (H₂) production units or sulfur treatment units may also be required. Most of the fuels in Asia are produced by complex refineries. Although in number the simple or hydroskimming

refineries are still considerable, it must be noted that these types of refineries produce a relatively small part of all transport fuels in Asia.

180. Figure 3.1 shows in a summary the categories of Asian refineries as classified according to the three main types of refineries.

Figure 3.1: Asian Refineries by Category

FIGURE 3.1: ASIAN REFINERIES BY CATEGORY

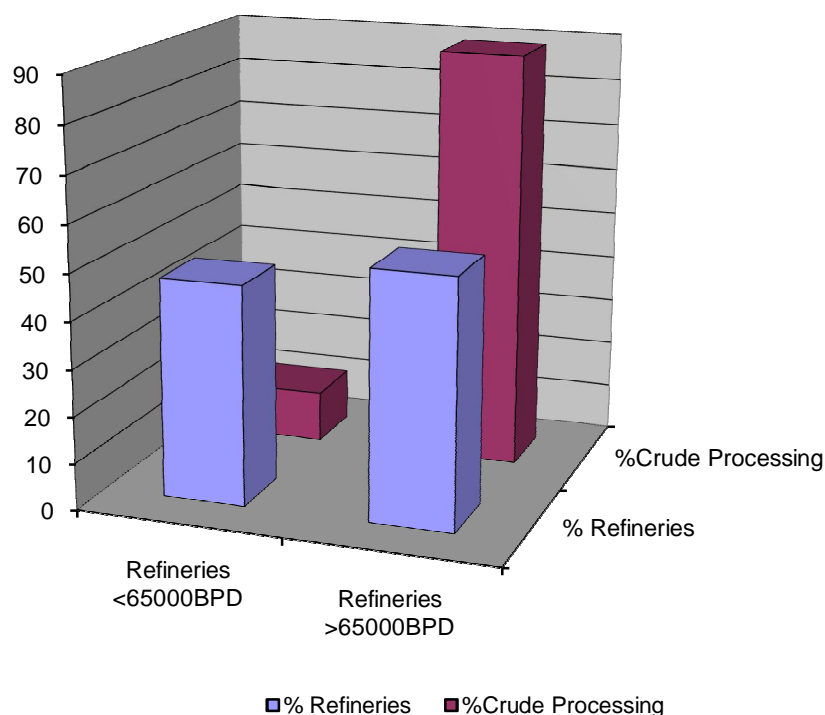


Source: J. Courtis (Data: (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services. Hart, APEC, (2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.)

181. 47 % of Asian refineries can be classified as topping refineries, however, these only process about 10 percent of the crude operational capacity. 15% of the refineries are classified as hydroskimming refineries with about 18% of crude processing capacity. 38% of the refineries can be classified as complex refineries, they do cover however about 75% of crude capacity. This indicates that a significant percentage of Asian refineries are either topping or hydroskimming refineries. Topping and hydroskimming refineries represent together about 28% of crude processing capacity.

182. Another way to look at the Asian refining industry is by comparing refineries' sizes. As a general rule the 65,000 bpd crude throughput is used to separate the small refineries from the medium or large size refineries. Figure 3.2 shows the population of the Asian refineries by size and by percent of crude capacity.

Figure 3.2: Small Refineries vs. Large Refineries by Number and Process Capacity

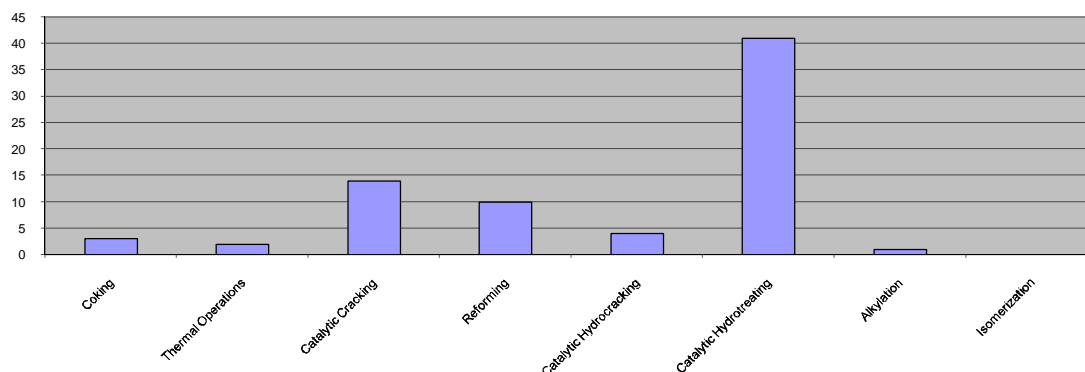


Source: J.Courtis (Data: (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services.HART APEC, (2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.)

183. The figure shows that about 47% of the refineries in Asia can be classified in the small refinery category and these represent only about 11% of refining capacity.

184. Figure 3.3 shows the complexity of refineries in Asia by the type of refinery process and as a percent of crude oil processing capacity. Figure 3.3 shows the refinery processes as a percent of crude capacity for Asia outside Japan.

Figure 3.3: Refinery Complexity as a Percent of Crude Capacity

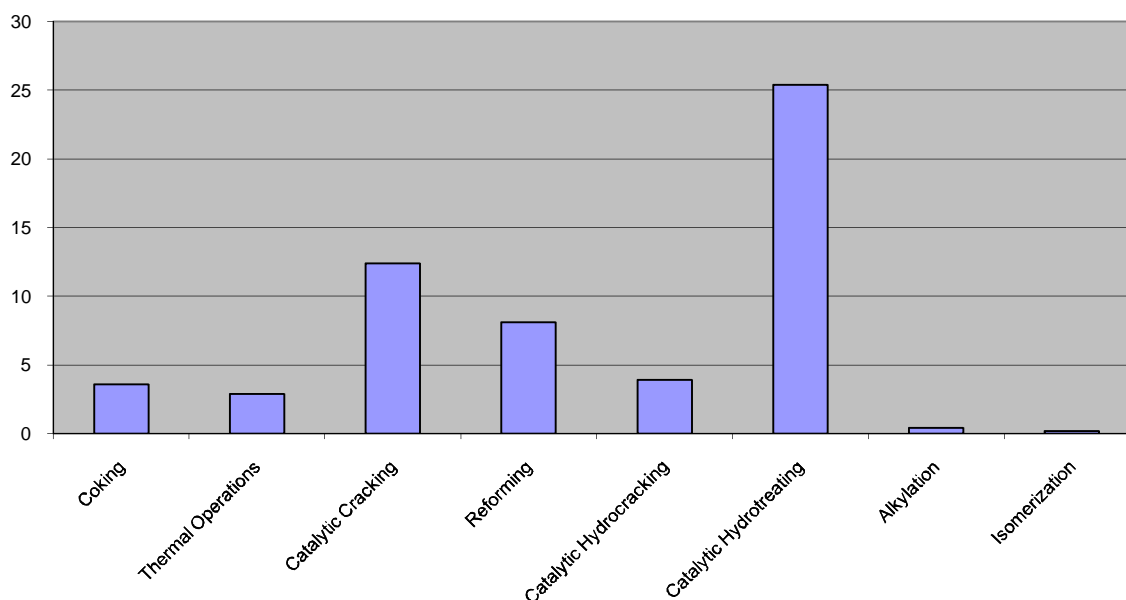


Source: J. Courtis (Data (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services. HART, APEC, (2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.)

185. The figure shows low reforming, low alkylation, and low isomerization capacity. This is an indication that there is less capacity to produce cleaner gasoline. The hydrotreating capacity at about 41 percent of crude capacity is low, an indication that there is low capacity to produce low sulfur products.

186. Figure 3.4 shows the Asian refineries complexity when the Japanese refineries are removed from the pool of Asian refineries. The hydrotreating capacity of Asian refineries is reduced to 25% from 41% of the crude distillate capacity. Everything else being equal, the lower levels of hydrotreating capacity indicate that more capital investments would be required in Asia in order to produce low sulfur content fuels than in Europe and the USA. The weaker initial refining industry capabilities in Asia requires careful planning of clean fuels programs in each country with close cooperation with the respective refining industries.

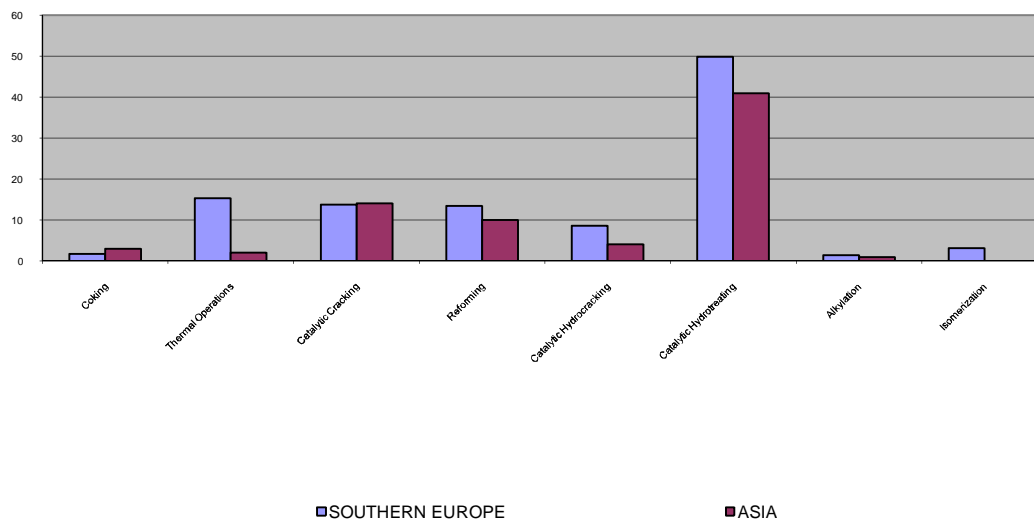
Figure 3.4: (Asia-Japan) Refinery Complexity as a Percent of Crude Capacity



Source: J. Courtis (Data (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services. HART, APEC, (2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.)

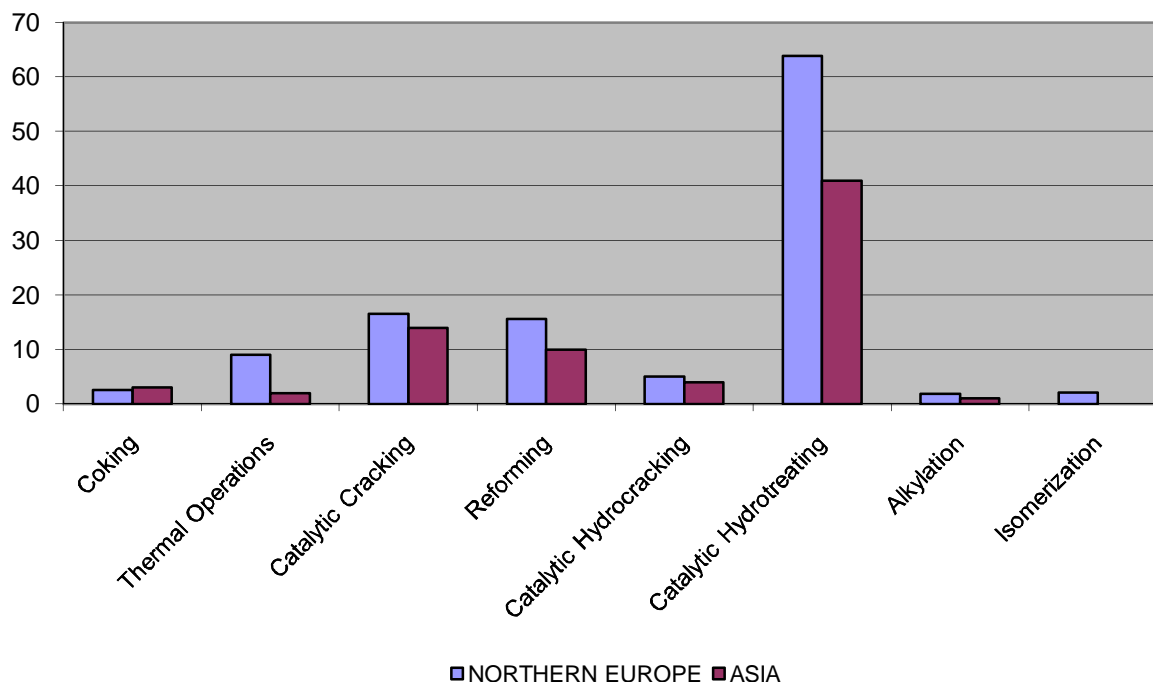
187. Figures 3.5 and 3.6 compare the complexity of Asian refineries to the complexity of refineries in Southern and Northern Europe. The comparison indicates similarities to the effect that both systems seem to put emphasis on distillate production. Asia's catalytic cracking and hydrocracking capacities represent 14% and 41% of crude capacity respectively. This is compared to 14% and 50% for Southern Europe and 17% and 64 % for Northern Europe.

Figure 3.5: Asian vs. Southern European Refineries



Source: J. Curtis (Data: (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services. HART, APEC, (2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.)

Figure 3.6: Refinery Complexity – Northern European vs. Asian Refineries



Source : J. Curtis (Data: (1) Asia-Pacific Economic Cooperation (APEC). 2004. Clean Transportation Fuels Supply Security Study EWG02/2001T, Final Report. Prepared by HART Downstream Energy Services. HART, APEC, (2) Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.)

4. Issues with the Small Refineries in Asia

188. The small refineries in Asia are older inefficient facilities that produce small amounts of fuels. They are mostly topping and a few hydroskimming plants, and they are not equipped with the process units required to produce a whole variety of fuels. (It should be noted that there are also a number of hydroskimming refineries that have a capacity >65,000bpd.) Some of these small refineries are operated by governmental entities, some are independent, and some are a part of a larger and more complex refining system. Considering the system of tariffs and the governmental price controls in a number of Asian countries most of these small refineries are protected from market fluctuations and from price uncertainties. The small refineries that are operated by independent or international oil companies tend to be more at risk and in some cases have closed their doors (i.e., Philippines, Australia). The larger oil companies in order to improve efficiency and refinery margins tend to consolidate operations. This means that inefficient small facilities are closed down first.

189. For similar facilities that were operated in the USA, the implementation of the cleaner fuels regulations forced some regulatory agencies to take a close look at the possibility that some of the small refineries would close down. As a result of concerns about the effects on fuel supply, the governmental organizations encouraged small refineries' participation in the market and provided special provisions that have delayed the implementation schedule of cleaner fuels or have allowed for a less restrictive or for interim standards. However, only a small number of these refineries chose to retrofit and to continue the production of motor vehicle fuels. Some refineries discontinued operations while some others specialized in products for the unregulated markets.

D. What are the Costs of Producing Cleaner Fuels

190. There are both non-process and process options that can be employed for the production of cleaner fuels. The non-process options could achieve some improvements in fuel quality and could supplement or assist in the reduction of costs when additional process options are considered.

1. Non-process options

191. Non-process options can be defined when a refiner makes operational changes to the refinery without investments in new process units. The following is an overview of non-process options:

a. Better Quality Crude Oils

192. To the extent that the refinery design allows it, a refiner could select to purchase and process lower sulfur content or better quality crude oils. The produced intermediary streams have lower sulfur content and would be easier to treat. However, such crude oils are more expensive and the resultant gains in quality are limited. Further, while the crude demand increase in many markets has been for light and sweet crude (lower sulfur levels), the majority of the new production has been heavy and sour crude types (higher sulfur levels).

b. Imports and Exchanges

193. A refiner could import better quality blend stocks such as alkylate, isomate, or other low sulfur content blending components. However, the costs of these products are higher and their availability is very limited. A multi-refiner operator could integrate a multiple refinery system

so that each refinery in the system is optimized and some products are exchanged amongst refineries.

c. Operational Changes

194. A refiner could change the severity and operational characteristics of various processes (cut points, operating pressures, catalysts, etc.) to achieve improvements in the quality of the products. In addition, a refiner may improve the quality by moving products from gasoline to diesel pool or from diesel to the fuel oil pool.

195. All these non-process options would not require significant capital investments but they have design limitations and would have an economic penalty either in the form of additional processing and feedstock costs or as a yield and volume penalty. The refiners may also experience an additional economic penalty due to the downgrading of some products. In general, non-process options are not sufficient by themselves to allow refiners to produce Euro 4 fuels and maintain their fuel production levels.

2. Process Options for Producing Cleaner Fuels

196. Experience from the USA and EU as well as the results of the various studies that we reviewed indicate that the optimum option is building additional processes. This would require capital investments. To reduce the capital and operational expenditures supplemental non-process options, as described above, could be implemented.

197. The following is a discussion of the various process options required for the production of cleaner gasoline and diesel fuels.

a. Gasoline

i. Aromatics

198. The reductions in aromatics content to the Euro 4 levels could be achieved by reductions in reformer severity or by blending in the gasoline pool low aromatics blendstocks (such as alkylates, isomerates, or oxygenates). In most Asian refineries there is low reforming capacity. Therefore, the aromatics are relatively low and the reduction to the Euro 4 aromatics standards would require no significant capital investments. However, if Asia is to increase modest 90-93 RON specifications to the European octane requirements then additional high octane blending or specialized components that increase octane will be required. The availability of these is limited and some have serious health and environmental concerns³⁴. Overall, the reduction in aromatics with a concurrent increase in octane requirements would create another challenge for the refining industry in Asia.

ii. Benzene

199. The reductions in reformer severity discussed for aromatics reduction could achieve small reductions in the benzene content. However, a reduction of benzene to the Euro 4 limit (1% vol.) would require either a benzene extraction unit or a reformat (or a naphtha) fractionation unit combined with a benzene saturation unit. For most Asian refiners benzene improvements would be an issue and would require additional capital investments.

³⁴ The impacts of additives which increase the octane rating of gasoline are described in Chapter 4.

iii. Olefins

200. The reductions in olefins content to the Euro 4 levels (18% vol.) is achieved by the hydrotreating of the high olefins gasoline components (usually fuel catalytic cracking (FCC) gasoline) or by reductions in FCC severity. Preliminary data indicate that in a number of Asian refineries the olefins are quite high and the olefins reduction would be an issue. However, when hydrotreating both the FCC gasoline and the FCC feed in order to reduce the sulfur content, significant reductions in olefins content could be achieved. The reductions in olefins content would also result in some reductions in octane values and further exacerbates the octane challenge discussed above.

iv. Reid Vapor Pressure (RVP)

201. The majority of Asian refineries produce gasoline with RVP higher than the Euro 4 standard. The RVP is reduced to about 50-60 kPa by limiting the blending of light components such as butanes into the gasoline blending pool. This would not require significant capital investment but it would downgrade the monetary value of butane. Additional reductions in RVP would require a fractionation unit that would allow the removal of C4 and C5 streams from the gasoline pool. These compounds could be excluded from the gasoline pool, and could be used for the production of oxygenates, alkylates, or petrochemicals. However, this would require additional capital investments and some portion of the C4/C5s may be reduced in value.

v. Distillation

202. There are not enough data for fuels produced in Asia to evaluate the impact of such a requirement. The reductions in T90 (or E150 in EU standards) would require the building of a fractionation unit to remove the heavier components from the gasoline pool, the use of isomerization, or the blending of oxygenates. Reductions in T50 (or E100 in EU standards) could be achieved by the use of oxygenates that in many cases is sufficient to reduce T50 (or E100) to acceptable levels.

vi. Sulfur

203. Although there are roadmaps in a number of Asian countries to reduce the sulfur content of gasoline there are still countries where the gasoline produced has a high sulfur content and no plans are in place to lower the sulfur content. The hydroskimming refineries in Asia are in good position to meet the Euro 4 sulfur content standards without significant capital investments. However, for most of the remaining complex refineries the reductions in sulfur content would require additional capital investment. In countries where the 500ppm limit is already in place for sulfur, there is hydrotreating capacity that treats either gasoline or gasoline blendstocks. In this case, produced gasoline usually has average sulfur content below the 500ppm. However, a reduction to Euro 4 levels (50ppm or lower) would require the hydrotreating of most of the gasoline blending components such as the straight run, the FCC gasoline, and/or the feed into the FCC unit. New processes and more effective catalysts are available that are sufficient to reduce sulfur content to the 10ppm limit and that require much smaller capital investments. An optimized strategy to meet the 50ppm standard would involve the installation of processes units allowing future modifications in order to produce gasoline at the 10-20ppm limit.

b. Diesel**i. Sulfur**

204. There are a number of countries in Asia which are already producing diesel fuel with a sulfur content of 500ppm. For these countries, the reduction to Euro 4 levels would require the installation of either a new high pressure hydrotreating unit or the conversion of an existing one-stage hydrotreater to a two-stage hydrotreater. In the USA, refiners in the past have used higher-pressure hydrotreating units. New developments in process technology indicate that in some cases lower pressure units with high activity catalysts are capable of producing Euro 4 compliant diesel fuel. The high-pressure units are much more expensive. The ability to use a lower pressure unit is a function of the amount of light cycle oil (LCO) in the diesel blend. The higher the LCO component in the blend the more difficult it is to treat and the more likely require the use of a high-pressure hydrotreating process. In most Asian countries there are low amounts of LCO in diesel thus making the use of lower pressure units feasible.

205. For refiners that are currently producing diesel with sulfur content much higher than 500ppm the installation of a high-pressure hydrotreater could reduce sulfur levels all the way to the 50ppm level. If, however, they choose to first reduce the sulfur content to 500ppm with the use of a medium severity hydrotreater, the further reductions of sulfur content to 50ppm would still require the installation of a high-pressure hydrotreater and possibly a two-stage hydrotreating process with the use of different catalysts. The size of the process units may also need to be increased to allow longer catalyst cycle time. The incremental approach vs a one-step approach is a critical decision for most refineries; fuel quality regulators need to consider the potential cost savings for refiners of the one step approach in setting out their medium term fuel quality roadmaps. It has been reported in some studies that a further reduction to 10ppm in sulfur content may require the installation of new hydrocrackers. However, in most cases it is expected that a high-pressure hydrotreating unit with advanced catalysts would be the norm. Sulfur reduction strategies require a careful optimization in order to implement an approach that would provide for long-term capability and reduce long-term costs. International experience has demonstrated that the one-step approach is to be preferred. However, if a phased-in introduction of the standards is desired, care should be taken to minimize the number of steps. In a two step approach a single large high pressure unit could be installed and operated at the beginning at lower severity to produce 350ppm sulfur. This unit could be modified and operated later at higher severity to produce very low sulfur content diesel fuel.

ii. Distillation

206. There are not enough data available on the distillation properties of Asian fuels. In some countries data indicate that the Euro 4 standards distillation properties can be met without any additional processing. In general, reduction in distillation would require the selective separation and removal of heavier components from the diesel blending pool. The capital costs of such an approach would be small. However, this will result in a reduction in the diesel volume and it will have an economic penalty for the refiner because it would downgrade the value of this component that would find its way into the fuel oil pool.

iii. Cetane improvements

207. Most of Asian refineries would comply with the cetane standards and do not experience cetane shortages. If an increase in cetane is needed, the use of cetane additives could be sufficient to achieve this goal with no additional capital investment.

- **Costs of process options**

208. In all studies, the production of cleaner fuels would involve significant capital investments. The capital investments are needed for both modifying existing refinery and for the installation of new refinery processes. Estimates of the onsite costs for new processes are shown in Table 3.5 below.

Table 3.5: Capital Investments for Refinery Processes Used in the Production of Cleaner Fuels

Process Unit	Capacity (MBBLS/SD)	Onsite Investments (2005) Range of Costs (US\$ million)
Isomerization	6	14 to 26
Naphtha Hydrotreater	20	27 to 33
FCC Gasoline Hydrotreater	20	29 to 32
Gasoil Desulfurization	20	31 to 56
HP Gasoil Desulfurization	20	55 to 77
Benzene Saturation	5	13 to 22
Alkylation	7	40 to 118
Heavy Naptha Splitter	15	9

FCC = fuel catalytic cracking;

Source: J.Courtis, Referenced Studies

209. The table shows a range of capital costs for the various refinery processes as it has been used in the various studies. The data are adjusted by using the Nelson-Farrar inflation index. It is apparent from Table 3.5 that there is a range in reported capital investment costs. This range in costs presented in the table is a reflection of the differences in technology used, or the differences in cost estimates provided by different suppliers for the various processes.

210. In estimating the total costs of production other external factors need to be considered such as off-sites costs and operating costs. Off-site costs include the costs of support equipment (such as pumps, piping, etc.), land cost, or other related costs. Operating costs represent the energy consumption, maintenance and personnel costs, material (such as catalysts, etc.). Whenever we made adjustments to estimates we assume that off-site costs represent 20% of capital costs and that operating costs represent 10% of the annualized capital costs. The capital recovery is assumed to be at 7% interest for 10 years.

- **Costs of production**

211. We have reviewed existing studies for the incremental cost of production of clean fuels in Europe, USA, and Asia.^{35 36 37 38 39 40} There may be a reason to use data from EU because

³⁵ Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf> and http://www.cleanairnet.org/caiasia/1412/articles-40677_EnstratSulphurReport.pdf

³⁶ California Air Resources Board and California Energy Commission. 2003, Sep. Benefits of Reducing Demand for Gasoline and Diesel. Petroleum Displacement Options. Prepared by TIAX LLC. Available: http://www.energy.ca.gov/fuels/petroleum_dependence/documents/2003-10-28_600-03-005A1.PDF

³⁷ National Energy Policy Office. 2002, Mar. Study on Changes in specifications for Gasoline and Diesel Fuels in Thailand. Prepared by Daedalus LLC and ERM-Siam, Co Ltd. Available: <http://www.cleanairnet.org/caiasia/1412/article-58857.html>.

both groups of refineries are designed and operated to satisfy higher demand for distillates rather than for gasoline. However, the EU refineries are more complex when compared to the Asian refineries and the EU studies appear to use cost assumptions for capital investments much higher than the cost assumptions used in all of the other studies. The USA refineries are targeting production of gasoline but the capital cost assumptions for process equipment used in the USA studies are more current and reflect current process technologies. The Asian studies (JAMA, Australia, Thailand, PRC, and Asia) appear to represent more accurately the real costs to Asian refineries. A useful study was the work done by JAMA for estimating the costs for sulfur reductions at two refinery configurations: one small refinery and one more complex refinery plan. We made some adjustments to the costs results estimated by JAMA and incorporated the costs of off-site costs as well as the costs of H₂ production. The California costs are actual costs that were determined when the cleaner fuels have been produced. It should be noted that all studies have used EU or USA labor cost estimates but construction costs for Asia will be lower when compared to cost in the USA or EU.⁴¹

212. In all studies the methodologies tend to underestimate the costs for some refineries and overestimate the cost for others because the modeling methodology was performed on a composite refinery model that does not take into consideration the variability between refineries.

213. Table 3.6 shows the cost estimates from the various studies.

Table 3.6: Costs Estimates from Various Studies

Studies	Region	Fuels Studied	Study's Objectives	Incremental Cost Of Production (US cents/liter)
California (1990-2003)	California	Gasoline	S: 150ppm→30ppm RVP: 9psi→7psi Aro: 35%→22% Ole.:15%→10% Benz.: 2%→1% Distillation ↓	2.64
		Diesel	S: 800ppm→370ppm Aro.:28%→10%	1.6

³⁸ Trans-Energy Research Associates. 2002, Aug. Improving Transport Fuel Quality in China: Implications for the Refining Sector. Available: http://china.lbl.gov/publications/china_refining_study_final.pdf.

³⁹ Environment Australia. 2000, May. Setting National Fuel Quality Standards – Discussion Paper 1. Summary Report of the Review of Fuel Quality Requirements for Australian Transport. Natural Heritage Trust. Available: <http://www.environment.gov.au/atmosphere/fuelquality/publications/paper1.html>.

⁴⁰ Arthur D. Little. 1993, Sep. Modifying European Gasoline Composition to Meet Enhanced Environmental Standards and its Impact on EC Refiners- Document C: Refinery Investment and Operations, Berlin.

⁴¹ The oil industry in their comments indicated that construction costs in Asian countries can be 20% lower when compared to costs in the USA or EU.

Studies	Region	Fuels Studied	Study's Objectives	Incremental Cost Of Production (US cents/liter)
			S: 370ppm→15ppm	0.6-0.7
Arthur D. Little (ADL) (1993)	Europe	Gasoline	S:800ppm→100ppm Aro: 40%→35% Benz.:3.2%→1.0%	2.8-3.0
Daedalus (2002)	Thailand	Gasoline	S:175ppm→50ppm RVP: Benz.:	1.6
		Diesel	S: 500ppm-50ppm	0.6
Enstrat (2003)	All Asia	Diesel	S: 2200ppm→50ppm	2.1-3.3
Australia Gov. (2000)	Australia	Gasoline	S:193ppm→50ppm Benz:2.9%→1.0%	0.7
		Diesel	S:1500ppm→50ppm	1.1
Trans-Energy (2002)	PRC	Gasoline	S: 500ppm→50ppm Ole.:35%→14% Aro.:40%→35% Benz.: 5%→1%	0.5
		Diesel	S: 500ppm→50ppm T95: 370→340	0.8
JAMA (2004)	Asia	Diesel	S:500ppm→50ppm	Small: 1-1.4 Large: 0.7-0.8
		Gasoline	S:500ppm→50ppm	Small: 0.3-0.4 Large: 0.2
USA	USA	Gasoline	S: 270ppm →30ppm	0.4-0.6
USA	USA	Diesel	S:500ppm→15ppm	1.2

Notes: ADL = Arthur D. Little; Aro = aromatic; Benz. = benzene; JAMA = Japan Automobile Manufacturers Association; Ole. = olefin; ppm = parts per million; psi = pounds per square inch; RVP = Reid vapor pressure; S = sulfur; USA = United States of America

Source: J.Courtis, Referenced Studies: Arthur D. Little. 1993, Sep. Modifying European Gasoline Composition to Meet Enhanced Environmental Standards and its Impact on EC Refiners- Document C: Refinery Investment and Operations, Berlin.

Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.

California Air Resources Board and California Energy Commission. 2003, Sep. Benefits of Reducing Demand for Gasoline and Diesel. Petroleum Displacement Options. Prepared by TIAX LLC. Available: http://www.energy.ca.gov/fuels/petroleum_dependence/documents/2003-10-28_600-03-005A1.PDF

Environment Australia. 2000, May. Setting National Fuel Quality Standards – Discussion Paper 1. Summary Report of the Review of Fuel Quality Requirements for Australian Transport. Natural Heritage Trust. Available: <http://www.environment.gov.au/atmosphere/fuelquality/publications/paper1.html>.

National Energy Policy Office. 2002, Mar. Study on Changes in specifications for Gasoline and Diesel Fuels in Thailand. Prepared by Daedalus LLC and ERM-Siam, Co Ltd. Available: <http://www.cleanairnet.org/caiasia/1412/article-58857.html>.

Trans-Energy Research Associates. 2002, Aug. Improving Transport Fuel Quality in China: Implications for the Refining Sector. Available: http://china.lbl.gov/publications/china_refining_study_final.pdf.

214. A careful review of these results shows some internal consistency. For gasoline, the studies show that reduction in sulfur content from 500ppm to 50ppm has a cost that ranges from 0.18 to 0.8 cents per liter. When additional properties are controlled such as benzene, aromatics, and RVP (Thailand case), the costs are increased to about 1.6 US cents per liter, or to 2.6 US cents per liter if the distillation, olefins, RVP, aromatics and benzene are decreased at very low levels (California case). The only cost outside this range is the cost estimated by ADL⁴² for the implementation of the EU Euro 3 standards. The reason for this high(er) cost lies with the high costs assumed for capital investment requirements. In some cases the capital costs were assumed to be two to three times the costs assumed by other studies. It should be noted that this is an older study (1993) and does not reflect current understanding of capital process costs.

215. In regards to diesel, these studies also seem to indicate that the reductions in diesel sulfur content from 500ppm to 50ppm would cost in the range of about 0.53 to about 0.8 cents per liter. The US EPA costs are slightly higher at 1.16 cents per liter and the higher cost is explained because the reduction in sulfur content goes down to 15ppm. The Australian costs are also higher at 1.11 cents per liter but require the reduction in sulfur from 1500ppm to 50ppm. The JAMA study⁴³ indicates that the costs for small refineries would be slightly higher in the range of 0.98 to 1.37 cents per liter than the costs for the large refiners. The California costs derived from actual data after implementation show a higher cost at about 1.59 cents per liter. The California costs are on the high side because they include the cost of hydrodearomatization that would not be required for compliance with Euro 4 standards. The cost estimates by ADL⁴⁴ and Enstrat⁴⁵ are also at the high end of the cost spectrum. Both of these analyses include investments in high-pressure hydrotreating units at significantly higher capital costs.

216. There are a number of studies that evaluated separately the costs of reductions in sulfur content from 50ppm (Euro 4) to 10ppm (Euro 5). For gasoline, the Purvin & Gertz study⁴⁶ estimated this cost to be in the range of 0.11-0.29 cents per liter. The cost for diesel is

⁴² Arthur D. Little. 1993, Sep. Modifying European Gasoline Composition to Meet Enhanced Environmental Standards and its Impact on EC Refiners- Document C: Refinery Investment and Operations, Berlin.

⁴³ Japan Automobile Manufacturers Association (JAMA). 2004, Sep. Fuel Quality in Asean Countries: JAMA Fuel Survey Results 2003/2004, Fuels and Lubricants Committee.

⁴⁴ Arthur D. Little. 1993, Sep. Modifying European Gasoline Composition to Meet Enhanced Environmental Standards and its Impact on EC Refiners- Document C: Refinery Investment and Operations, Berlin.

⁴⁵ Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.

⁴⁶ European Commission (EC) Directorate-General Env.3. 2000, 17 Nov. ULS Gasoline and Diesel Refining Study. Prepared by Purvin & Gertz Inc. Available: <http://ec.europa.eu/environment/sulphur/uls.pdf>.

estimated by the same study at 0.29-0.61 cents per liter, and by the Enstrat⁴⁷ study for Asia to about 0.03 cents per liter. If the assumption is that refiners would design the Euro 4 compliance with the provision that would need to comply with the Euro 5 at a future date, the compliance costs are expected to be at the lower end of the cost spectrum discussed above.

217. All the studies discussed above used much similar technology for the refinery retrofits to improve the RVP, aromatics, olefins, or benzene content. The differences are in the type of technologies used for the sulfur reductions. Some used the assumption that high pressure units, or multistage processes would be required as compared to the use of lower pressure processes. This difference changes the capital and operating costs significantly. Another major difference in the cost results from the capital costs assumed for some of the processes. In some cases the cost assumptions were very (overly) high.

218. Although the average costs estimated above appear consistent, it should be expected that there would be significant variations in clean fuel implementation costs among different refineries. There are differences in local starting fuel specifications, differences in refinery configurations, differences in crudes available in the market place, and the relative balance between motor gasoline and diesel market. Finally, the possibility to dispose of low-value by-products depends on the availability of neighboring industries which would require such by-products.

E. Costs and Benefits of Producing Cleaner Fuels

219. A number of cost-benefit studies on adopting low sulfur fuel and cleaner vehicles have been conducted. These include studies in the United States, China and Mexico. In these studies, the benefits of adopting low sulfur fuels in combination with more stringent vehicle emission standards far outweigh the costs of adopting those programs. For China, a 2006 study (ICCT 2006)⁴⁸ (International Council on Clean transportation (ICCT), 2006) looked at what the costs and benefits of reducing the sulfur content of the fuels to 10 parts per million (ppm) in combination with the adoption of ever more stringent vehicle emission standards would be. It is important to note that lowering the sulfur content of gasoline and diesel, produces important benefits, and air quality should show some improvement immediately. This is because the low sulfur fuel is used by both new and older vehicles. The largest benefits come when low sulfur fuels are combined with stricter vehicle emission standards. The health benefits, for example, increase by a factor of 3-4 when the vehicle emission standards are combined with the low sulfur fuel. Overall, the combination of low sulfur fuels and new vehicle standards showed a benefit to cost ratio of about 20:1, demonstrating that this approach is a very cost-effective tool for reducing the negative impact of vehicle emissions on public health. The health benefits looked at included decreased premature mortality, chronic and acute bronchitis, asthma and restricted activity days.

220. The United States over the past several years has issued various rulemakings which have reduced the sulfur content of gasoline and diesel fuels and set new emission standards for cars, trucks, buses, and construction equipment. Consistently, the benefits of these programs far outweigh the costs. For example, the low sulfur diesel fuel portion of EPA's Heavy-Duty

⁴⁷ Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.

⁴⁸ International Council on Clean Transportation (ICCT). 2006. Cost and Benefits of Reduced Sulfur Fuels in China. Washington, DC. December. Available: http://www.theicct.org/documents/Reduced_Sulfur_China_ICCT_2006.pdf

Highway Diesel rule (the “2007 Highway Rule”)⁴⁹ (EPA 21001)**, finalized in January 2001, took effect in June 2006. Refiners are producing cleaner-burning diesel fuel, called Ultra-Low Sulfur Diesel (ULSD), for use in highway vehicles. This new diesel fuel costs between 4 and 5 cents more per gallon to produce and distribute. ULSD enables advanced pollution control technology for heavy-duty trucks and buses so that engine and vehicle manufacturers can meet the 2007 emission standards. As a result, each new truck and bus will be more than 90 percent cleaner than current models. The introduction of ULSD will also enable light-duty passenger vehicle manufacturers to make use of similar technologies on diesel-powered cars, SUVs and light-trucks.

221. EPA’s Clean Air Highway Diesel final rule required a 97 percent reduction in the sulfur content of highway diesel fuel, from a level of 500 parts per million (ppm), to 15 ppm. ULSD became available at retail stations beginning in the summer of 2006. On October 15, 2006, refiners were required to produce 80% of their diesel fuel at the 15 ppm standard. Cars, trucks and buses with advanced pollution control will be available beginning in the autumn of 2006 (2007 model year vehicles).

222. By addressing diesel fuel and engines together as a single system, this program will provide annual emission reductions equivalent to removing the pollution from more than 90 percent of today’s trucks and buses, or about 13 million trucks and buses, when the current heavy-duty vehicle fleet has been completely replaced in 2030. This is the greatest reduction in harmful emissions of soot, or particulate matter (PM), ever achieved from cars and trucks.

223. Once this action is fully implemented, environmental benefits include annual reductions of 2.6 million tons of smog-causing nitrogen oxide (NOx) emissions and 110,000 tons of PM.

224. In the long term, this program will result in more than \$70 billion annually in environmental and public health benefits at a cost of approximately \$5 billion per year.

225. Health benefits will include the annual prevention of:

- 8,300 premature deaths
- 5,500 cases of chronic bronchitis
- 17,600 cases of acute bronchitis in children
- 360,000 cases of respiratory symptoms in asthmatic children
- 1.5 million lost work days

226. A 2006 study⁵⁰ in Mexico looked at the costs and benefits of an integrated clean fuels and vehicles program. Its conclusion was that the benefits outweighed the costs by a ratio of 2.4:1. In other words, the benefits outweighed the costs by more than 2:1. In the period 2006-2030 the estimated health benefits cited in the study included avoidances of approximately:

- 56,000 premature deaths;
- 166, 000 cases of chronic bronchitis;
- 5.6 million lost work days; and
- 78 million restricted activity days due to respiratory illnesses.

⁴⁹ EPA. 2001. United States Environmental Protection Agency Final Rulemaking, US Federal Register Volume 66. 18 January.

⁵⁰ Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), Instituto Nacional de Ecología, and Pemex Refinación. 2006. Estudio de Evaluación Socioeconómica del Proyecto Integral de Calidad de Combustibles: Reducción de Azufre en Gasolin y Diesel. Mexico City, MX. 26 June.

227. While these studies involve different countries, the results demonstrate that in all three cases the benefits of clean fuel and vehicle programs outweigh the costs, and thus represent sound public policy choices.

F. Phasing of Introduction of Cleaner Fuels

228. The regulatory agencies in Europe, the United States, and Asia have taken different approaches on the introduction of both fuels and motor vehicle standards. The approaches taken are a reflection of: (a) the magnitude of the air quality problem in the region and the contribution of fuels and motor vehicles to the problem, (b) the technical understanding of the fuel emissions and the impacts of fuel properties on motor vehicle emissions, (c) the advances in the developments of vehicle emissions control technology, (d) the political will to implement fuel standards that would have a significant economic impact on the regulated industry, and (e) the economic impacts on the consumers and the region's economy.

229. These approaches can be qualified into three general categories:

1. Gradual Approach

230. A gradual strategy would allow the phased and concurrent introduction of fuels and motor vehicle standards with a defined and clear roadmap for implementation. A gradual approach was followed previously in the USA and Europe because of three main reasons:

1. The gradual advances in vehicle technology required improved fuel quality,
2. The implementation of initial small improvements in fuel quality were not sufficient to reduce emissions to satisfactory levels, and
3. The detailed impacts of fuels and motor vehicles on ambient air quality and on public health were initially not well understood.

231. The gradual approach was adopted by the EU and by the USA. The fuel standards became progressively stricter and roadmaps were implemented over a number of years. Other countries have also followed the same approach and have established different roadmaps and implementation timeframes. As an example, in Thailand a roadmap for lead phase out and a roadmap for progressively tighter Euro 2, 3, and 4 standards for both fuels and motor vehicles have been established. A similar approach was followed by India, PRC, Taipei, China, and other Asian countries. Gradual product quality phasing is currently considered especially by developing countries with a regulated fuels market when there are constraints such as the ability to raise capital and the possibility to pass on the cost of refinery modification to the consumers.

232. Both the refining technology to produce Euro 2, 3 and 4 fuels and the technology to produce Euro 4 vehicles are well understood. The technology to produce Euro 5 fuels and vehicles is also well understood now. In most Asian metropolitan areas the severity of the air quality problem combined with the expected growth in both fuel consumption and vehicle use requires a reduction in motor vehicle emissions to the lowest possible level as soon as possible. This will require the cleanest fuels possible. In all cases the gradual approach would delay implementation of improvements in air quality.

233. The gradual approach will increase the cost of compliance. For example, reductions in sulfur content to 50ppm can be achieved gradually by the use of a medium pressure hydrotreater to first reduce sulfur to 500ppm and then at a later time adding a high pressure hydrotreater to further reduce sulfur to 50ppm. The combination of medium and high-pressure

hydrotreating is more expensive than the building of a high-pressure unit at the beginning to produce 50ppm sulfur content fuel. An analysis done by Enstrat⁵¹ for Singapore, Malaysia, and Indonesia found an increase in cost by about 10%-20% when the gradual approach is followed versus the one-step approach.

2. Implement Some Fuel Quality Standards First and Follow Later with More Comprehensive Standards

234. In most Asian countries the emphasis on cleaner fuels has been on improving of specific fuel properties rather than on implementing an integrated strategy for all fuel properties. The properties are to enable the efficient operation of motor vehicle emissions control technologies such as catalytic converters.

235. An example of this is the removal of lead from gasoline and most recently the emphasis on the reductions of sulfur content for both gasoline and diesel fuels. There is no doubt that both of these strategies will reduce emissions. The lead reductions allowed reductions in ambient lead concentration and the introduction of catalytic systems. The implementation of sulfur content standards would allow the efficient operation of new vehicles equipped with catalytic systems. An important disadvantage of only concentrating on the sulfur content is, however, that some fuel properties such as olefins and aromatics content have an adverse impact on the performance of engine components. Although there is an argument that the use of deposit control additives would minimize the adverse impacts of aromatics and olefins on engine components at this time there is no effective program that would ensure the use of effective and appropriate deposit control additives in Asia. The reductions in benzene and aromatics have also an impact on ambient toxic levels. The reductions in RVP have a significant effect on ozone formation that is very important in hot ambient environments experienced in Asia. The shortcomings of concentrating on just one property have been recognized by regulatory agencies in the EU, and the USA, thus requiring the implementation of multiple fuel property standards. A balanced set of specifications is required.

236. A systemic approach of looking at all fuel properties together also offers long term cost benefits to the refiners. It would be much more costly and problematic for the refiners to implement additional improvements in fuel quality in the future. While the advantage of concentrating on one or two priority properties is that it reduces the short-term cost of compliance and delays capital investments needed to improve the other properties for future times, the disadvantage is that the implementation of improvements in other properties would be delayed and overall air quality improvements may be delayed.

3. Introduction of Fuel Quality Standards in Cities and Regions Where Air Quality is an Issue. Implement Different Lower Standards for the Rest of the Country.

237. Another option that has been discussed is the limited introduction of clean gasoline and diesel fuel standards. The limited introduction may be only for control areas or cities where the air quality problem is a major issue. Different fuels may be marketed for the remainder of the country.

⁵¹ Asian Development Bank (ADB). 2003, 10 Jan. Cost of Diesel Fuel Desulfurization for Different Refinery Structures Typical of the Asian Refining Industry. Prepared by Enstrat International Ltd. Available: <http://www.adb.org/vehicle-emissions/ASIA/docs/EnstratSulphurReport.pdf>.

238. This approach was implemented in the United States. In the United States, California was allowed to implement stricter fuel and motor vehicle standards than the rest of the country because of the severity of the California air quality problem. The same approach was also implemented in other areas of the USA. There are strict fuel standards for so called non-attainment areas (areas where there is severe air quality problem) and less restrictive standards in areas where the air quality is acceptable, and there are also requirements for the use of oxygenates in the fuel for areas where CO is an air quality issue. The same approach was followed in Sweden where very strict standards were implemented for diesel fuel used for certain classes of vehicles and different standards would apply to the rest of the country.

239. In all cases, when less restrictive standards outside of a control area were allowed, there were restrictive market and enforcement mechanisms in order to minimize the use of out of compliance fuels in the control areas. In addition, it was determined that the fuel production, marketing, and distribution systems were capable of handling the marketing and distribution of multiple products. Different storage tanks were employed at refineries and at terminal facilities for the storage and distribution of different products. The governmental fuel quality monitoring was extensive, and heavy monetary penalties were assessed for the cases of violation of the standards. It should be noted that the limited introduction has significant environmental implications when it is used for properties such as lead or sulfur content. Contamination of fuels in the control areas could result either in damage of emission control systems or in permanent reductions in their emissions control efficiency.

240. Such an approach, in order to be effective, must be carefully designed and a number of factors must be considered:

1. The status of the fuel production, marketing and distribution system. More specifically, the ability of the system to produce, segregate, and market two different grades of fuel would need to be evaluated.
2. The quality of fuels in the uncontrolled areas should be carefully monitored to avoid backsliding. It is possible when the clean fuels are introduced that refiners will reject from the fuel pool used in the controlled area blendstocks that have undesirable properties. Some of these unwanted blendstocks might be marketed or used as blendstocks for fuels sold in the uncontrolled areas. Such strategy may result in the deterioration of fuel quality in the uncontrolled areas.
3. Additional resources are needed in order to avoid the penetration of lower quality fuels from the uncontrolled to the controlled areas and to avoid fuel adulteration in areas under control.

G. Demand and Supply Development

241. The supply and demand of cleaner fuels need to be considered within the broader context of supply and demand for fuels. Although the bulk of the produced gasoline finds its way into the motor vehicle market, a significant portion of the distillate pool is used for the unregulated markets (kerosene, fuel for power generation, etc).

242. Available data indicates that in a number of countries there is an excess capacity or a potential for capacity expansion. The refineries in Thailand, Malaysia, Indonesia, Pakistan, Taipei, China, South Korea, and Singapore have already made limited modifications and appear to have the capacity to meet current demand for fuels and have established some capacity to satisfy the short-term demand for Euro 3 and 4 type fuels. For India, the existing refining system appears to be capable of satisfying the current demand and there is some capacity for exports. In addition, there are plans announced in India for refinery expansions and building another

major refinery in the country that would provide additional exporting capacity. In PRC currently the demand is satisfied, although there are some imports from Korea and Japan and a small amount of exports. The existing Chinese refineries do not run at maximum utilization capacity, and there is a capacity for expansion.

243. Overall there are three structural issues that may have a negative effect on the supply of cleaner fuels:

1. The potential that some refineries will chose not to invest in capital expenditures in order to produce cleaner fuels. This is more likely in the case of smaller refiners (including some hydroskimming facilities).
2. The potential that some refineries would choose to reduce capital investments and reduce fuels production capacity.
3. The potential loss in yields from operational changes

244. However, there are a number of factors that may have a positive effect on supply:

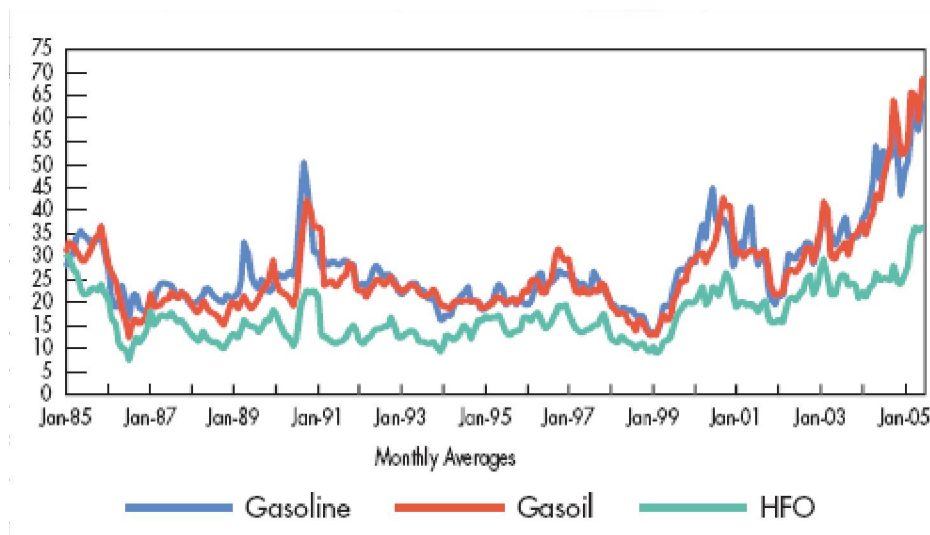
1. Healthy refinery margins during the last few years and the ability to adjust prices to recover the capital investments will support additional capital investments for refinery expansions and process modifications.
2. The production of biofuels (ethanol and biodiesel) is increasing throughout the region. A number of countries in Asia actively pursue the production of biofuels to support the agricultural sector and to meet GHG reductions needs.
3. Refinery expansions are in the planning stages for a number of countries. The building of new refineries is ongoing or planned for India and PRC.
4. There are activities at the major merchant oil processing centers that may help increase the supply for cleaner fuels or the supply of better quality blendstocks. Refiners in Singapore, and in the Middle East are in the process of building additional process units in order to increase their capacity to produce cleaner fuels or cleaner blendstocks. Considering that the demand for cleaner fuels and blendstocks is increasing in many developing countries and that the prices in USA, EU are increasing, these better quality products would only find their way to Asian markets if prices are adequate.

H. Availability of Capital and Trained Labor

245. The availability and cost of capital are important considerations that would significantly impact both the costs of production of cleaner fuels and the ability of refiners to modify their refineries. The availability and the cost of capital would be different amongst refiners, would be a function of the financial strength of the refiner, and the industry, and of the refiner's ability to recover capital and operating expenditures. A market system enhances the ability to recover expenditures, assuming that all producers experience similar expenditures. In markets where the prices are controlled, the potential difficulty to recover the costs through a price adjustment mechanism makes the refiners' ability to raise capital an issue. Unless a price adjustment is implemented the ability to raise the capital is reduced.

246. Considering current fuel and product prices, it appears that the raising of capital may not be a major issue. Figure 3.7 shows the historical evolution of prices of fuels from 1985 to 2005⁵². The availability of capital may be a factor in countries with refineries but no income from oil exploration and with a regulated fuel market without the possibility to pass on costs for refinery upgrades to the consumers.

Figure 3.7: Rotterdam Oil Product Spot Prices in US Dollars/barrel



Note: HFO = heavy fuel oil

Source: Bloomberg

247. However, small privately owned refineries may still be facing a difficulty or the cost of capital for them may be higher. For small refineries owned by governmental entities the decision may be one of governmental policy and security of fuel supply.

248. The availability and costs of trained personnel would differ from refinery to refinery and from country to country. Availability and cost of labor may be a major issue in a number of Asian countries. Well-trained labor as well as experienced engineering and construction services would be required for the revamping of the refineries. In the past in some Asian countries the availability of these services was limited and had to be imported. However, since the late 1990's the continuous upgrades and modifications of refineries in Asia have created an experienced labor force that would be helpful in future activities. It should be noted that the costs of labor are much lower in Asia when compared to the USA and EU. If all refinery modifications are done at the same time across Asia the availability of sufficient trained labor as well as of engineering and construction services may become an issue.

I. Conclusions on the Production of Cleaner Fuels

249. The current ability of Asian refineries to produce cleaner fuels that would comply with the Euro 4 standards is limited. There are a small number of refineries that has the capacity to produce limited amounts of Euro 4 equivalent fuels in India, PRC, Taipei, China, Thailand, and Singapore and a number of countries where marketed fuels have properties similar to Euro 3 or Euro 4. For countries where there is a roadmap for implementing Euro 3 or Euro 4 standards,

⁵² At a Rand Corporation survey of US refining executives many discussants did not consider capital availability a critical issue.

some refiners have announced investments for the production of clean fuels. An expansion of refining capacity which is now becoming more likely after a long period of stable refining capacity in Asia will most likely result in an increase in volume of cleaner fuels.

250. Refinery retrofits for the production of Euro 4 fuels would require significant investments for the installation of new process units. The size of capital investments required and the ability to finance may be the most critical obstacles. However, under current high fuel price environment and high refinery profits the ability to raise capital is expected to be much enhanced.

251. The willingness of refiners to invest in the production of cleaner fuels is a function of their ability to recover expenditures through price adjustments.

252. The various studies indicate that the incremental costs of compliance with the sulfur content limits are on the average at about 0.2-0.8 US cents/liter for gasoline and 0.5-0.8 US cents/liter for diesel. Further reductions to the Euro 5 level would add about 0.6 US cent/liter to the cost of compliance. The improvements in other Euro 4 properties for gasoline such as olefins, RVP, benzene, and aromatics could increase the cost to about 1.6 US cents/liter. The cost associated with producing low sulfur fuels is relatively small compared to the price changes in world price of oil, and the public health benefits are worth the investment.

253. A careful evaluation of each country's refining industry, together with the impacts on fuel supply for the countries in the region, is required.

254. For the large refineries in Asia which produce the bulk of transport fuels in Asia, if enough time is allowed, the implementation of cleaner fuel standards is not expected to significantly affect fuel production. It is expected that the short-term demand regional needs will be met with planned increases in supply through the new refineries that are scheduled to come on line, with planned expansions, or with increases in utilization rates.

255. Small refineries in Asia, which are still relatively large in number but small in production capacity, would experience higher costs of compliance. Capital investments required to produce Euro 4 fuels may be uneconomical for these small refineries. However, for some refineries, protective mechanisms at the country level could allow them to continue their contribution to the motor vehicle fuels market. It is questionable that such an approach is sustainable in the long term and under a free market environment. One of the approaches that could be considered for small refineries is the possibility of temporary less restrictive standards, or a different compliance schedule when the need requires it. However, care should be taken so that the benefits of the standards would not be affected.

256. The full implementation of local programs targeting the increase of production of biofuels, as well as the implementation of fuel economy standards would have a significant impact on supply and demand for motor vehicle fuels in the region.

257. Compliance flexibility or flexibility in standards is a major issue that may provide significant reductions in operating costs and reduce market volatility. There are a number of flexibility mechanisms that could be employed. However, care should be taken to avoid significant reductions in benefits.

IV. ENHANCING OCTANE IN GASOLINE

A. Introduction

258. This chapter reviews relevant public-domain information sources documenting the direct and indirect impacts of the use of octane enhancing additives and oxygenates on health; vehicle emissions and performance; and the refining process.

259. Octane is a measure of a fuel's ability to resist premature detonation⁵³ when used in an internal-combustion engine. This premature detonation, if allowed to happen, wastes energy in the fuel and can potentially permanently damage the engine. In older engines, it can often be recognized by knocking or "pinging" noises and is eliminated by using a gasoline with an adequate (higher) octane number.

260. Vehicles are designed and calibrated by their manufacturers for gasoline with a certain minimum octane rating. Many modern engines are equipped with knock sensors and can handle lower octane levels by automatically retarding the spark timing; however, fuel consumption, drivability and power will suffer and at very low octane levels, knock may still occur.

261. Using gasoline with an octane rating that is higher than that recommended usually does not improve the vehicle's performance⁵⁴. It does not make the vehicle run any better, go faster, get better mileage, or run cleaner. Many countries – and vehicle owners – erroneously feel that it is beneficial to use higher octane levels than are really necessary.. Motorists are to be discouraged from using octane higher than that required by the vehicle manufacturers⁵⁵.

262. The ability of a refinery to produce gasoline at the specified octane value for each grade is variable and it is a function of the refinery's complexity and configuration. As the demand for different fuels shifts, refineries in Asia may not always continue to have the processing capability in place to meet the volume of fuel demanded by their consumers at the required (minimum) octane rating. As indicated in the previous chapter the bulk of transportation fuels in Asia already come from large complex refineries and a relatively small amount comes from small, mostly topping or hydroskimming refineries.

263. The technical options that are available to refiners for octane enhancement include.⁵⁶

1. Refinery modifications or redesign and the import of selected crude oils or high octane blend-stocks (as described in detail in Chapter 3)
2. The use of metallic octane-enhancing additives and/or oxygenates

B. An overview of metallic octane-enhancing additives and/or oxygenates

⁵³ Also known as "auto-ignition", "pinging" or "knock"

⁵⁴ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006. Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>

⁵⁵ See for a further discussion on octane also the World-Wide Fuel Charter, a document developed by the world's automobile manufacturers.

⁵⁶ Australian Institute of Petroleum. 24 June 2005. Submission to the Australian Government Biofuels Taskforce.,. Available: <http://www.pmc.gov.au/biofuels/submissions/submission27.pdf>

1. Metallic octane-enhancing additives

264. The principal compounds used as metallic-based additives include:

a. Lead alkyls – Tetraethyl lead (TEL) and Tetramethyl lead (TML)

265. Lead alkyl additives were first used as inexpensive octane enhancers for gasoline in 1923. Most countries have since moved to ban lead in gasoline. This is due principally to an increased public awareness of the negative health effects associated with its use and a steady growth in the worldwide population of vehicles requiring unleaded gasoline to permit the use of vehicle emission control technologies such as catalytic converters and oxygen sensors.

266. The US banned the use of lead as a motor vehicle fuel additive completely in 1995. Most countries in Asia have since moved to ban lead in gasoline. In the near future, transport will no longer be a source of lead emissions. According to the Partnership for Clean Fuels and Vehicles, leaded gasoline is now found in only 20 Asian countries (Afghanistan, Algeria, Bosnia-Herzegovina, Former Yugoslav Republic of Macedonia, Fiji, Georgia, Iraq, Jordan, Laos, Mongolia, Montenegro, Morocco, Myanmar, North Korea, Palestine, Serbia, Tajikistan, Tunisia, Turkmenistan and Yemen).^{57 58 59}

b. Manganese compounds – Methylcyclopentadienyl manganese tricarbonyl (MMT)

267. MMT is a manganese-based compound marketed as an octane-enhancing fuel additive for gasoline. It has also been suggested for use in diesel fuel as a smoke reducing additive.⁶⁰

c. Iron compounds – Ferrocene

268. Ferrocene (Dicyclopentadienyl iron) is a coordination compound of iron and two molecules of cyclopentadiene. It is a metal-organic complex orange crystal with the smell of camphor which has a potential use as an additive to gasoline to prevent engine knock and as an additive to diesel fuel to facilitate trap regeneration.

2. Oxygenates:

269. Oxygenated compounds are often added to gasoline to increase octane or extend gasoline supplies and to reduce the emission of certain air pollutants such as CO. Oxygenating the fuel also may modify vehicle performance and/or durability. The most widely used oxygenates are all organic based:

⁵⁷ Partnership for Clean Fuels and Vehicles (PCFV) and United Nations Environment Programme (UNEP). 2007. Asia Pacific Lead Matrix. Last updated: 14 August. Available: <http://www.unep.org/pcf/PDF/LeadMatrix-Asia-PacificAug07.pdf>

⁵⁸ Partnership for Clean Fuels and Vehicles (PCFV) and United Nations Environment Programme (UNEP). 2007. West Asia, Middle East and North Africa Lead Matrix. Last updated: 22 January. Available: <http://www.unep.org/pcf/PDF/MatrixMENAWAJan07.pdf>

⁵⁹ Partnership for Clean Fuels and Vehicles (PCFV) and United Nations Environment Programme (UNEP). 2007. Central and Eastern Europe + EECCA Leaded Gasoline Use. Last updated: May. Available: <http://www.unep.org/pcf/PDF/MatrixCEELeadMay07-1.pdf>

⁶⁰ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006. Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>

a. Ethanol

270. Ethanol is a high-octane oxygenate that today is being produced principally in the United States and Brazil from renewable sources such as corn or sugar crops. Ethanol is completely soluble in gasoline and will be readily absorbed by any water present. As it is also a solvent, it does not transport well by pipeline since it collects all the water and contaminants in the system; it has to be transported separately from gasoline and mixed at the tanker prior to dispatch.

b. Methanol

271. Methanol is produced mainly from natural gas and is a traded chemical in the fuels market. It is used for the production of MTBE and formaldehyde. It has very high octane value, high affinity to water, and it is very corrosive. Engine manufacturers do not recommend its use in gasoline fuels.¹²

c. Methyl tertiary-butyl ether (MTBE)

272. MTBE was once the most widely used fuel oxygenate, due to its combination of high octane value, compatibility with gasoline and fuel system components, favorable effects on fuel properties (effects on distillation, dilution) and supply availability. It can be mixed with the fuel at the refinery and transported through pipelines. However MTBE has a major disadvantage in that it travels well in ground water and presents a major risk of contamination of ground water supplies from leaking fuel tanks because tiny amounts of MTBE affect the taste and odor of drinking water.

d. Ethyl tertiary-butyl ether (ETBE)

273. Ethanol can also be utilized for the production of ETBE which is about 42% ethanol and is produced by processing ethanol with isobutylene, which is usually made from natural gas. Global auto manufacturers and refiners prefer to use ETBE in case they are required to utilize renewable fuels.⁶¹

e. Tertiary-amyl methyl ether (TAME)

274. TAME is produced by a similar process to ETBE but from methanol and isoamylenes. It shares MTBE's excellent tolerance to water, and requires no changes to the refining, pipeline and distribution operation or automotive technology.

C. The Regulation and use of metallic based octane-enhancing additives and oxygenates in Asia

275. The current known status of standards in Asia for octane-enhancing additives and oxygenates is shown in Table 4.1. The only country in Asia that has regulations that permit the use of ferrocene is Viet Nam. Through regulations, India and Indonesia have banned the addition of manganese to gasoline. In some countries the use of MMT is allowed such as PRC and Viet Nam. It should be noted however that MMT is currently used only sparsely in the developed world. According to information by the manufacturer of MMT it was being sold world-

⁶¹ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006. Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>.

wide in about 30 countries in 2003.⁶² MMT had been most widely used in Canada, where it was used in roughly 90% of gasoline after the phase-out of lead was completed (Environment Canada 2003) but currently around 95% of Canadian gasoline is MMT-free (Inside Fuels 2004). MMT is not allowed in California (Lloyd 2004) or in reformulated gasoline (RFG) in the U.S and it is used in less than 1% of all gasoline in the U.S. It is not used in Japan, (Menkes and Fawcett 1997; UNEP 1999) or Germany (Friedrich 2004). New Zealand since 2002 has restricted manganese levels in gasoline to a maximum of 2.0 mg Mn/L (New Zealand 2002). MMT is used in a few Eastern European countries.

276. Overall it must be concluded that compared to other fuel parameters, the use of additives is not well regulated in many of the Asian countries.

Table 4.1: Overview of the regulation of octane-enhancing additives and oxygenates in Asia

Country	Government Regulation				Remarks
	Ferrocene	MMT	MTBE	ETBE	
Afghanistan	No specific regulations				
Bangladesh	No specific regulations				Importer is allowed to use octane-enhancing additives
Cambodia	No specific regulations				
Hong Kong SAR	No specific regulations				Gasoline specifications at EU 4 level No additives are being used
India	Not used	not allowed	Max 15% vol	Max 15% vol	Only the Numaligarh Refinery was found to have been using MMT, but its use has been discontinued since Mar 2006
Indonesia	Not allowed as per MOE Decree No 141/2003		No specific regulation	No specific regulation	MTBE used from 1995 but discontinued in 1997. Pertamina has requested MoE to allow the use of MMT and Ferrocene following the complete phase out of leaded gasoline in 2006. MoE turned down the request of Pertamina to use MMT but allowed the use of Ferrocene in the case of supply problems for high octane blendstock with a provision that a permit is issued which will have a maximum validity of 6 months and which will be monitored by MoE
Lao PDR	No specific regulations				
Malaysia	No specific regulations				
Mongolia	No specific regulations				
Nepal	No specific regulations				
Pakistan	No specific regulations				No additives being used
Philippines	No specific regulations		Max 2% vol	Max 2% vol	A number of the smaller fuel importers use MMT while Ferrocene is reportedly used by one of the major refiners in the country.
PRC	Banned (GB17930-1999)	max 18 mg/L (16mg/L in the new gasoline standards)	Max 15% vol.		Beijing is considering to limit MMT to 6 mg/L starting on January 1, 2008.
Singapore	No specific regulations				
Sri Lanka	No specific regulations				No additives being used

⁶² Afton' 2003 Annual Report,

Country	Government Regulation				Remarks
	Ferrocene	MMT	MTBE	ETBE	
Thailand	Not allowed				MTBE is still being used but its use is expected to be reduced considerably once Thailand introduces gasohol on a large scale
Viet Nam	max 5 mg/L (TCVN 6776 – 2005)				

ETBE = Ethyl tertiary-butyl ether; mg/L = milligram per liter; MMT = Methylcyclopentadienyl manganese tricarbonyl; MTBE = Methyl tertiary-butyl ether; PDR = People's Democratic Republic; PRC = People's Republic of China; SAR = special administrative region;

Source: data obtained by CAI-Asia from member countries

D. The health effects of octane-enhancing additives for gasoline

277. The evaluation of the health effects of different fuel additives requires consideration of several factors:

- The degree to which use of the additive increases exposure to components of the additive itself or to combustion byproducts of the additive (e.g. the metal based additives or MTBE) and the toxicity of those substances at ambient levels.
- The degree to which use of the additive decreases or increases vehicle emissions which can improve or worsen ambient air pollution (e.g. a change in the emission of precursors of ozone, or a change in certain air toxics, and
- The degree to which the use of the additive reduces the content of other components of gasoline that are known to have adverse health effects.

278. This section focuses on what is known or not known about the health effects of the additives themselves, and of any significant expected emissions as a result of combustion of the additives. In assessing these effects, however, there is some attempt to place what is known about the additives in the context of the effects of emissions from the broader fuel to which they are added.

1. The Health Impacts of Metallic Octane-enhancing additives

a. Lead: Tetraethyl lead (TEL) and Tetramethyl lead (TML)

279. Lead was widely used as an octane-enhancing additive for gasoline but is now almost entirely phased out due to its health impacts. A number of metallic additives have been proposed and/or are in use in gasoline to fill the void left by the elimination of lead. Two prominent gasoline additives are Ferrocene and MMT.

280. The growing body of research showing the adverse health effects of low-level concentrations of lead caused the US EPA in 1985 to reduce the maximum allowable lead content in leaded gasoline to 0.1 grams per gallon. Subsequent studies, such as one in which 249 children were monitored from birth to two years of age, found that those with prenatal umbilical-cord blood lead levels at or above 10 micrograms per deciliter consistently scored lower on standard intelligence tests than those with lower concentrations. In multiple, more recent studies such as a 5-year study of 172 children, a team of U.S. National Institute of Environmental Health Sciences (NIEHS)-supported researchers from the University of Rochester, Cincinnati Children's Hospital Medical Center, and Cornell University demonstrated

without a doubt that lead does cause intellectual impairment at low levels. Further data emphasized that there is indeed no threshold value, or safe level of lead exposure.⁶³

281. On the basis of multiple analyses performed by Schwartz et al,⁶⁴ it is now considered that each microgram per deciliter of blood lead concentration to be associated with a reduction in intelligence quotient (IQ) of 0.25 points at these levels of exposure. These and other studies show that there is no threshold blood lead level below which cognitive effects are not seen and the effects of losing IQ points are greater in children with low IQ scores than in children with a higher IQ.⁶⁵

b. Ferrocene (Dicyclopentadienyl iron)

282. There is an extensive literature on the occupational effects of exposure to ferrocene at levels much higher than ambient levels expected from use of the substance as a fuel additive. There have, however, been several research investigations and assessments of the substance as a fuel additive and its potential effects, most notably:

- A 13-week inhalation study in which rats and mice were exposed to ferrocene vapor concentrations of 3, 10, and 30 mg/m³ (0.39, 1.3, and 3.9 ppm). No changes in respiratory function, lung biochemistry, inflammation markers, or blood parameters were observed. The most prominent findings were epithelial lesions in the nasal cavity which were seen in all animals and which showed a dose-dependent severity and which suggested that ferrous iron is released inside the cells and causes a form of oxidative stress (i.e. lipid peroxidation of cellular membranes or formation of hydroxide (OH) radicals that react with cellular components (deoxyribonucleic acid (DNA) and protein)⁶⁶.
- The Health Council of the Netherlands, in reviewing the literature to make a recommendation for occupational limits, concluded that ferrocene did not induce mutations in several mutagenicity assays such as *S. typhimurium*, *D. melanogaster* after feeding (sex-linked recessive lethal assay), and mouse lymphoma cells (with metabolic activation) or chromosome aberrations, but was positive in a mutation assay in mouse lymphoma cells in the absence of a metabolic activating system, and, after injection, in a sex-linked recessive lethal assay and a heritable translocation assay in *D. melanogaster*.⁶⁷

⁶³ Canfield RL, Henderson CR Jr, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. 2003. Intellectual impairment in children with blood lead concentrations below 10 micrograms per deciliter. *N Engl J Med*. 2003 Apr 17;348(16):1517-26.

⁶⁴ Schwartz, Joel, Philip J. Landrigan, Clyde B. Schechter, Jeffrey M. Lipton, and Marianne C. Fahs. 2002. Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. (Children's Health Articles). In *Environ Health Perspect* 110:721-728 (2002). Available: <http://www.ehponline.org/docs/2002/110p721-728landrigan/abstract.html>

⁶⁵ Fewtrell, Lorna, Rachel Kaufmann, and Annette Prüss-Ustün. 2003. Lead: Assessing the environmental burden of disease at national and local levels. Environmental Burden of Disease Series, No. 2. WHO Quantifying environmental health impacts. Geneva: World Health Organization. Available http://www.who.int/quantifying_ehimpacts/publications/9241546107/en/

⁶⁶ Nikula KJ, Sun JD, Barr EB, et al. 1993. Thirteen-week repeated Inhalation Exposure of F344/N Rats and B6C3F1 Mice to Ferrocene. *Fundam Appl Toxicol* 21: 127-39. Available: <http://toxsci.oxfordjournals.org/cgi/content/abstract/21/2/127>

⁶⁷ Health Council of the Netherlands: Committee on Updating of Occupational Exposure Limits. 2002. Dicyclopentadienyl iron (ferrocene); Health-based reassessment of current administrative occupational exposure limits in the Netherlands. The Hague: Health Council of the Netherlands, 2002; 2000/15OSH/047.

- A longer-term exposure study done at the Fraunhofer Institute (in Hannover, Germany) compared emissions from a commercial diesel fuel containing 30 ppm ferrocene with a fuel not containing ferrocene. This work involved chemical and physical characterization of exhaust, studies of exhaust fractions in in-vitro mutagenicity and cytotoxicity assays, and animal inhalation studies of chronic toxicity and carcinogenicity. Both mammalian (hamster lung cell line) and bacterial test systems (Ames test for mutagenicity) were used, and under the testing conditions used, ferrocene did not affect the cytotoxicity or mutagenicity (in four tester strains of Salmonella) of exhaust. Whole animal testing involved exposure of rats to the highest technically feasible exhaust concentrations (a 1:20 dilution of exhaust), a 1:40 dilution, and a clean air control. Animals exposed to exhaust from ferrocene-containing fuel did not respond differently than those exposed to fuels not containing ferrocene. No toxic effects were observed after 24-30 months.⁶⁸

283. Based on its own review of this data, the California Air Resources Board in 2003 concluded that "Ferrocene has relatively low toxicity. Based on EU requirements, it is listed in the lowest toxicity class. There is no evidence of carcinogenicity or neurotoxic effects. Emission testing showed no general trends save an increase in iron in the exhaust. Chronic exposure studies showed no significant effect on the subjects."⁶⁹

284. The investigation and analysis of the health effects associated with ferrocene has, however, been less stringent than other, more widely used additives. Ferrocene is not approved by US EPA for use in the US because it has not been subjected to the US EPA's Tier 2 additive health effects evaluation as is required for gasoline additives. MTBE, Ethanol, and MMT have been evaluated (or are in the process of being evaluated) through this approach.

c. **Methylcyclopentadienyl manganese tricarbonyl (MMT)**

285. Manganese is well understood to be a serious toxicant at very high levels of exposure (e.g. in certain occupations) where it can cause a neurologic disease known as manganism (a relative of Parkinson's disease) if inhaled.

286. For exposure of populations to natural, industrial, and mobile sources at ambient levels there is a growing body of literature on the health effects of manganese, and of MMT specifically, as well as an emerging literature of population studies of potential effects.^{70 71 72 73 74 75 76 77}

⁶⁸ Fraunhofer Institut für Toxikologie und Aerosolforschung. 1996. *Investigation of Otto Engine Exhaust Resulting from the Combustion of Fuel with Added Ferrocene*

⁶⁹ California Air Resources Board. 2003. *Proposed Control Measure for Diesel Particulate Matter from On-Road Heavy-Duty Diesel-Fueled Residential and Commercial Solid Waste Collection Vehicle Diesel Engines*

⁷⁰ Dobson AW, Erikson KM, Aschner M. 2004. Manganese neurotoxicity. *Annals of the New York Academy of Sciences* 1012: 115–128;

⁷¹ Tjälve H., Henriksson J., Tallkvist J., Larsson B. S., and Lindquist N. G. 1996. Uptake of manganese and cadmium from the nasal mucosa into the central nervous system via the olfactory pathways in rats. *Pharmacology & Toxicology* 79:347-356.

⁷² Elder A, Gelein R, Silva V, Feikert T, Opanashuk L, Carter J, Potter R, Maynard A, Ito Y, Finkelstein J, Oberdörster G. 2006. Translocation of Inhaled Ultrafine Manganese Oxide Particles to the Central Nervous System. *Environ Health Perspect* 114:1172–1178.

⁷³ Mena I, Horiuchi K, Burke K, Cotzias GC. 1969. Chronic manganese poisoning. Individual susceptibility and absorption of iron. *Neurology*. 19(10):1000-1006.

⁷⁴ Zayed J. 2001. Use of MMT in Canadian gasoline: Health and environmental issues. *American Journal of Industrial Medicine* 39:425–433.

⁷⁸This literature ⁷⁹ indicates that there are potential health risks of lower level exposure and is currently the subject of continuing requirements for health research. Based on the health concerns already identified, the Scientific Committees on Neurotoxicology and Psychophysiology and Toxicology of Metals of the International Commission on Occupational Health (ICOH) recently published their conclusion that “The addition of organic manganese compounds to gasoline should be halted immediately in all nations.”⁸⁰

287. The Health Effects Institute recently summarized some of this science – in the context of its recent study by Yokel and Crossgrove (2004)⁸¹ - when it noted that “There is a large body of evidence that (1) under certain circumstances, manganese can accumulate in the brain,^{82 83} (2) chronic exposure can cause irreversible neurotoxic damage over a lifetime of exposure, (3) manganese may cause neurobehavioral effects at relatively low doses,⁸⁴ and (4) these effects follow inhalation of manganese-containing particles (neurotoxic effect of dietary manganese are much more rare) (ATSDR 2000).”

288. In the US, the Clean Air Act requires testing of motor fuels and additives. The US EPA has required the manufacturer of MMT to perform testing to help fill data gaps and potentially provide information that would result in a more definitive risk evaluation of MMT. This testing included three health pharmacokinetic (PK) studies and one emission characterization study. Completed final reports for all of these studies have been submitted to EPA. They can be found in the Federal Docket Management System (FDMS) at www.regulations.gov, identified by docket number EPA-HQ-OAR-2004-0074. In addition to the already completed tests, the manufacturer is now in the process of developing physiologically-based pharmacokinetic (PBPK) models for manganese which are being derived from data generated from the completed testing. The manufacturer anticipates that these PBPK models will be completed in 2008. After submission of this additional information, US EPA will study the results. US EPA may then be able to refine its risk evaluation or may ask for further testing based upon the results of the submitted testing and resulting model now being developed, as well as any other available data. With funding from the manufacturer the Research Triangle Institute (RTI) also completed a

⁷⁵ Bouchard, M., D. Mergler, M. Baldwin, M. Panisset, R. Bowler, and H.A. Roels, 2007. Neurobehavioral functioning after cessation of manganese exposure: A follow-up after 14 years. *American Journal of Industrial Medicine* 50(11):831-840.

⁷⁶ Lucchini, Roberto G., Elisa Albini, Laura Benedetti, Stefano Borghesi, Romana Coccaglio, Eros C. Malara, Giovanni Parrinello, Siria Garattini, Sergio Resola, and Lorenzo Alessio, 2007. High prevalence of parkinsonian disorders associated to manganese exposure in the vicinities of ferroalloy industries. *American Journal of Industrial Medicine* 50(11):788-800.

⁷⁷ Smith, Donald, Roberto Gwiazda, Rosemarie Bowler, Harry Roels, Robert Park, Christopher Taicher, and Roberto Lucchini, 2007. Biomarkers of Mn exposure in humans, *American Journal of Industrial Medicine* 50(11):801-811.

⁷⁸ Vezér, T., A. Kurunczi, M. Náray, A. Papp, and L. Nagymajtényi, 2007. Behavioral effects of subchronic inorganic manganese exposure in rats, *American Journal of Industrial Medicine* 50(11):841 – 852.

⁷⁹ US EPA Comments on the Gasoline Additive MMT (Methylcyclopentadienyl manganese tricarbonyl). Available: http://www.epa.gov/otaq/regs/fuels/additive/mmt_cmts.htm

⁸⁰ Landrigan, Philip, Monica Nordberg, Roberto Lucchini, Gunnar Nordberg, Philippe Grandjean, Anders Iregren, and Lorenzo Alessio. 2006. The Declaration of Brescia on Prevention of the Neurotoxicity of Metals. *American Journal of Industrial Medicine*. 50(10):709-711. Available: <http://dx.doi.org/10.1002/ajim.20404> and http://www.collegiumramazzini.org/download/Declaration_of_Brescia_August_2006.pdf

⁸¹ Yokel RA, Crossgrove JS. January 2004. Manganese Toxicokinetics at the Blood–Brain Barrier. Research Report 119. Health Effects Institute, Boston MA.

⁸² Hauser RA, Zesiewicz TA, Martinez C, Rosemurgy AS, Olanow CW. 1996.

Blood manganese correlates with brain magnetic resonance imaging changes in patients with liver disease. *Can J Neurol Sci*. 23(2):95-98.

⁸³ Lucchini R, Albini E, Placidi D, Gasparotti R, Pigozzi MG, Montani G, Alessio L. 2000. Brain magnetic resonance imaging and manganese exposure. *Neurotoxicology*. 21(5):769-775.

⁸⁴ Roels HA, Ghyselen P, Buchet JP, Ceulemans E, Lauwerys RR. 1992. Assessment of the permissible exposure level to manganese in workers exposed to manganese dioxide dust. *Br J Ind Med*. 49(1):25-34

study of manganese exposures in Toronto, Canada where MMT was used. US EPA is also evaluating this study to determine what impact it might have on any evaluation of risk associated with use of MMT. In the meantime, more than 99% gasoline sold in the US is MMT free.

289. The Committee on the Environment, Public Health and Food Safety of the European Parliament in its draft report on the proposal for a directive of the European Parliament and of the Council amending Directive 98/70/EC as regards the specification of petrol, diesel and gasoil proposed to amend Article 8a (Directive 98/70/EC). While old text stated: "The Commission shall continue to develop a suitable test methodology concerning the use of metallic additives in fuel," the proposed new text reads: "Use of the metallic additive MMT in fuel shall be prohibited from 1 January 2010 onwards. The Commission shall develop a test methodology concerning the metallic additives other than MMT."⁸⁵

290. Due to the importance of this potential health risk at lower level exposures, literature on health impacts of manganese is currently also the subject of an extensive risk assessment of manganese at ambient levels that is being finalized by Health Canada and which is an update of a 1994 assessment.⁸⁶ This study is expected to be completed in the coming months. This assessment will likely be the most comprehensive health assessment to date of the latest literature on potential effects of exposure to manganese at ambient levels from a variety of sources as well as identification of gaps in current understanding and will serve as an important reference on this literature.

2. Health Impacts of Oxygenates Octane-enhancing additives

291. The primary motor vehicle emissions that are potentially affected by adding oxygenates are carbon monoxide (CO) and certain air toxics.

292. In addition to helping to reduce CO, which is known to have effects on the blood and heart, adding oxygenates also appears to cause a reduction in benzene and toluene emissions and an increase in formaldehyde and acetaldehyde emissions although the final effect depends on the operation of the exhaust gas catalyst;⁸⁷ in which different air toxics are affected differently. Additionally, there are uncertainties in estimating personal exposure to each of the air toxics, and in projecting the carcinogenic risk from each for humans.

a. Methyl tertiary-butyl ether (MTBE)

293. In terms of effects on the nervous and immune systems, and on reproduction, animal inhalation toxicity testing to date generally has not shown MTBE to have significant effects, or to be any more toxic than other components of gasoline. Most recently, this has included extensive testing of MTBE alone and in combination with gasoline, in response to requirements of the US Clean Air Act section 211.^{88 89 90}

⁸⁵ European Parliament, Committee on the Environment, Public Health and Food Safety, 2007/0019(COD)

⁸⁶ Wood, Grace and Marika Egyed. 1994. *Risk Assessment for the Combustion Products of Methylcyclopentadienyl Manganese Tricarbonyl (MMT) in Gasoline*. Environmental Health Directorate. Health Canada

⁸⁷ Pouloupoulos, SG, DP Samaras, and CJ Philippopoulos. 2001. Regulated and unregulated emissions from an internal combustion engine operating on ethanol-containing fuels. *Atmospheric Environment*. 35 (2001) 4399-4406. Available: [http://dx.doi.org/10.1016/S1352-2310\(01\)00248-5](http://dx.doi.org/10.1016/S1352-2310(01)00248-5)

⁸⁸ Gray TM; Hazelden KP; Steup DR; O'Callaghan JP; Hoffman GM and Roberts LG. 2004. Inhalation Toxicity Of Gasoline & Fuel Oxygenates - Reproductive Toxicity Assessment. *Toxicologist* 78(1-S):146

⁸⁹ O'Callaghan JP; Felton CM; Mutnansky BK and Daughtrey WC. 2004. Inhalation Toxicity Of Gasoline & Fuel Oxygenates: Neurotoxicity. *Toxicologist* 78 (1-S):146

294. There are limited data on human populations that may be sensitive to MTBE and effects attributed to MTBE alone have yet to be proven. Limited epidemiological data suggest greater attention should be given to the potential for increased symptom reporting among highly exposed workers.⁹¹

295. The International Agency for Research on Cancer (IARC) and the National Institute of Environmental Health Sciences (NIEHS) have indicated that at this time there are not adequate data to consider MTBE either a probable or known human carcinogen^{92 93 94}.

296. MTBE is highly soluble in water and has contaminated drinking water supplies in some parts of the US. Drinking water containing MTBE at or below the taste and odor levels identified in the EPA's Drinking Water Advisory (20 to 40 micrograms per liter) is not expected to cause adverse health concerns for the majority of the population.⁹⁵ (US EPA 1997) The turpentine-like taste and odor of MTBE, however, can make such drinking water unacceptable to consumers.

297. Overall, it would not appear that the addition of MTBE to fuel adds significantly to the risk already present from existing components of gasoline.⁹⁶ (HEI 1996) In addition, to the extent that it reaches water supplies, the odor and taste of any significant contamination is likely to alert users before they have ingested large quantities.

b. Ethanol

298. The health effects of ingested ethanol have been extensively investigated. Given that ethanol is formed naturally in the body at low levels, inhalation exposure to ethanol at the low levels that humans are likely to be exposed are generally not expected to result in adverse health effects. Health effects questions have been raised, however, about potentially sensitive subpopulations.⁹⁷ (HEI 1996)

299. Increased use of ethanol will result in increases of certain atmospheric transformation products, such as peroxyacetyl nitrate (PAN) and acetaldehyde, although the extent of such increase will vary depending on the vehicle and fleet characteristics and the percentage of ethanol in the fuel. PAN, which has been shown to be mutagenic in cellular research, is a known toxin to plant life and a respiratory irritant to humans.⁹⁸ (Froines 1998) Acetaldehyde is a respiratory irritant at high levels of human exposure and is currently classified by US EPA as a probable human carcinogen.

⁹⁰ White KL; Peachee VL; Armstrong SR and Twerdok LE. 2004. Inhalation Toxicity of Gasoline & Fuel Oxygenate: Immunotoxicity. *Toxicologist* 78 (1-S):148

⁹¹ Health Effects Institute. 1996. The Potential Health Effects of Oxygenates Added to Gasoline. A Review of the Current Literature. Special Report. Boston, MA: Health Effects Institute.

⁹² Office of Science and Technology Policy, National Science and Technology Council. 1997. *Interagency Assessment of Oxygenated Fuels*

⁹³ US Environmental Protection Agency, Office of Water. 1997. *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl Ether (MTBE)*.

⁹⁴ National Research Council. 1996. *Toxicological and Performance Aspects of Oxygenated Motor Vehicle Fuels*. Washington, DC 115

⁹⁵ US Environmental Protection Agency, Office of Water. 1997. *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl Ether (MTBE)*.

⁹⁶ Health Effects Institute. 1996. The Potential Health Effects of Oxygenates Added to Gasoline. A Review of the Current Literature. Special Report. Boston, MA: Health Effects Institute.

⁹⁷ Health Effects Institute. 1996. The Potential Health Effects of Oxygenates Added to Gasoline. A Review of the Current Literature. Special Report. Boston, MA: Health Effects Institute.

⁹⁸ Altshuler AP. 1993. PANs in the Atmosphere. *Journal of the Air and Waste Management Association*. 43(9): 1221-1230

300. Ethanol is far less likely itself to travel far in groundwater than the ethers because it appears to be rapidly biodegraded in soil. However, there is some evidence that the preferential degradation of the ethanol may retard degradation of other components in gasoline (e.g. toluene) causing them to spread further than they otherwise would.⁹⁹

301. Finally, the addition of relatively small quantities of ethanol to traditional gasoline can cause an increase in the volatility of the fuel and the likelihood of increased evaporative emissions particularly in the higher ambient temperatures prevalent in Asia. This increases the concentration of precursors of ozone, which is known to cause exacerbation of asthma and other respiratory symptoms, and has recently been associated with increased premature mortality.¹⁰⁰

c. Methanol

302. Methanol occurs naturally in plants and animals and people regularly consume low doses of it in their diet. Despite its ubiquitous presence, it is well known that methanol is toxic when ingested in sufficiently high amounts. Ingestion of methanol (usually in the form of wood alcohol or tainted alcoholic beverages) can result in metabolic acidosis, blindness, and even death.¹⁰¹ The lethal methanol dose for humans is uncertain but appears to vary over a wide range (0.3 to 1 gram per kilogram (g/kg) body weight)¹⁰². Although it would not be the common route of exposure, increased use of methanol may increase risks of accidental poisoning from fuel cans and other sources.

303. If methanol was to be widely adopted as a fuel, environmental exposures would increase through ingestion of contaminated drinking water, inhalation of vapors from evaporative and other emissions, and dermal contact. Current concentrations of methanol in ambient air are very low, 1 to 30 parts per billion (ppb) and even inhaling substantially increased concentrations of methanol that might result from increased fuel use for short periods of time should not present a risk of direct methanol toxicity and poisoning. At the same time, little is known about the consequences of long-term inhalation of methanol vapors, especially in susceptible populations of pregnant women and developing fetuses, where there is some evidence of effects, even at lower levels of exposure for pregnant mothers. However, one of the most extensive investigations of such possible effects did not find evidence of effects in either mothers or newborns, although there was some evidence of wasting disease in the mothers¹⁰³.

⁹⁹ US Environmental Protection Agency, 1999. *Achieving Clean Air and Clean Water: the Report of the Blue Ribbon Panel on Oxygenates in Gasoline*

¹⁰⁰ US Environmental Protection Agency, Office of Air Quality Planning and Standards. 2007. *Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information*, OAQPS Staff Paper. Research Triangle Park, North Carolina. EPA-452/R-07-003

¹⁰¹ Health Effects Institute. 1987. *Automotive Methanol Vapors and Human Health: An Evaluation of Existing Scientific Information and Issues for Future Research. A Special Report of the Institute's Health Research Committee.*

¹⁰² International Programme on Chemical Safety. 1997. *Environmental Health Criteria 196: Methanol*. World Health Organization, Geneva, Switzerland.

¹⁰³ Health Effects Institute 1999 Reproductive and Offspring Developmental Effects Following Maternal Inhalation Exposure to Methanol in Nonhuman Primates Research Report No. 89 Part I: Methanol Disposition and Reproductive Toxicity in Adult Females. Thomas Burbacher, et al. Part II: Developmental Effects in Infants Exposed Prenatally to Methanol. Thomas Burbacher, et al.

d. Other Ethers (ETBE, TAME)

304. Although toxicity testing of these substances – ethyl tertiary-butyl ether (ETBE) and tertiary-amyl methyl ether (TAME) has not been as extensive as that for MTBE, recent expanded testing of these substances, both alone, and in concert with gasoline, performed in response to requirements of the US Clean Air Act Section 211,^{104 105 106} have found few effects, and those found appear to be similar to those found for MTBE.

E. The effects of octane-enhancing additives on vehicle performance and emissions

1. The Effects of Metallic Octane-enhancing additives on vehicle performance and emissions

305. The Automotive Industry in its Worldwide Fuel charter¹⁰⁷ states that: *“Today’s vehicles employ sophisticated emission control equipment such as three-way catalysts and exhaust gas oxygen sensors to provide precise closed-loop control. These systems must be kept in optimal condition to maintain low emissions for the lifetime of the vehicle. Ash-forming (metal-containing) additives can adversely affect the operation of catalysts and other components, such as oxygen sensors, in an irreversible way that increases emissions. Thus, high-quality gasoline should be used and ash-forming additives must be avoided.”*

306. The automotive industry’s concern about metal additives is principally to protect the long-term, in-use, effectiveness of exhaust gas post-treatment systems, OBD sensors and engine components that are essential to maintain low emissions from the vehicle. To this end, the European Automobile Manufacturers Association (ACEA), amongst others, has recommended that the use of metallic fuel additives in commercial fuel should be forbidden.¹⁰⁸

a. Lead: Tetraethyl lead (TEL) and Tetramethyl lead (TML)

307. Even slight lead contamination can permanently and drastically reduce the effectiveness of catalytic converters and oxygen sensors, causing a substantial increase in vehicle emissions. However, it was the growing body of research showing the adverse health effects of low-level concentrations of lead that caused a complete ban on the addition of lead additives to on-road gasoline in most countries.

b. Ferrocene (dicyclopentadienyl iron)

308. When combusted, ferrocene forms ferric oxides, also known as jeweler’s rouge, which is a fine abrasive. Early studies of ferrocene showed excessive piston ring, cylinder bore, and camshaft engine wear at the concentrations investigated. Recent studies by the auto industry at lower iron concentrations have shown premature spark plug failures at the current

¹⁰⁴ Gray TM; Hazelden KP; Steup DR; O’Callaghan JP; Hoffman GM and Roberts LG. 2004. Inhalation Toxicity Of Gasoline & Fuel Oxygenates - Reproductive Toxicity Assessment. *Toxicologist* 78(1-S):146

¹⁰⁵ O’Callaghan JP; Felton CM; Muthansky BK and Daughtrey WC. 2004. Inhalation Toxicity Of Gasoline & Fuel Oxygenates: Neurotoxicity. *Toxicologist* 78 (1-S):146

¹⁰⁶ White KL; Peachee VL; Armstrong SR and Twerdok LE. 2004. Inhalation Toxicity of Gasoline & Fuel Oxygenate: Immunotoxicity. *Toxicologist* 78 (1-S):148

¹⁰⁷ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006.

Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>

¹⁰⁸ ACEA. May 30, 2005. ACEA response to the fuel directive proposed changes. Available: http://forum.europa.eu.int/Public/irc/env/fuel_quality/library?l=/stakeholder_2005/stakeholder_comments/acea_responsepdf/_EN_1.0_&a=d

recommended concentration of 30 ppm (9 ppm iron (Fe)). Concern also has been expressed that the ferric oxide (Fe_2O_3) or rust will act as a physical barrier on oxygen sensors and exhaust catalyst surfaces, and possibly cause catalyst plugging in modern vehicles.¹⁰⁹

309. Limited testing has shown that the use of ferrocene as a fuel additive causes deposits, which contain iron oxides, to adhere to the combustion chamber, spark plugs, and exhaust pipe and that an abnormal electrical discharge pattern is provoked in spark plugs operating at high temperatures. Iron oxide of iron (II, III) oxide or magnetite (Fe_3O_4) is changed into Fe_2O_3 under high temperatures. Discharge current flows in iron oxides including Fe_2O_3 because the conductivity of Fe_2O_3 increases at high temperatures. These results indicate that adding ferrocene decreases the insulation resistance of spark plugs and causes increase in fuel consumption, exhaust emissions, exhaust gas temperature, and irregular electrical discharge.¹¹⁰

310. There is also concern that iron oxide acts as a physical barrier between the catalyst/oxygen sensor and the exhaust gases, and also leads to erosion and plugging of the catalyst which negates its ability to treat the engines exhaust emissions.¹¹¹ These deposits can physically block channels of the catalyst. This reduces the active surface area and increases the velocity of the exhaust gas through the catalyst, consequently reducing NOx conversion which is very sensitive to this parameter.

c. Methylcyclopentadienyl manganese tricarbonyl (MMT)

i. Performance and emissions issues for vehicles equipped with emission control systems

311. MMT was first commercialized in 1959 and has been used in gasoline by itself and in combination with lead alkyls. In 1977, the US Clean Air Act Amendments banned the use of manganese antiknock additives in unleaded gasoline unless the EPA granted a waiver. In 1996, after several waiver requests and court actions by the manufacturer, the courts ordered the EPA to grant a waiver for MMT¹¹². Its use is limited to a maximum of 0.031 g/gal (8.2 mg/L)¹¹³ but less than 1% of the gasoline in the U.S. currently contains MMT.

312. Gasoline containing MMT can leave significant red-orange deposits on spark plugs, catalytic converters, oxygen sensors and combustion chamber walls. From a discussion with the Association of European catalyst manufacturers (AECC),¹¹⁴ it is apparent that the main mechanism of interaction between MMT and the catalyst is a physical one related to the formation of deposits of oxidized manganese. These deposits can physically block channels of the catalyst reducing the active surface area and increasing the velocity of the exhaust gas

¹⁰⁹ Chevron. No date. Motor Gasolines Technical Review. Available: <http://www.chevron.com/products/prodserv/fuels/bulletin/motorgas/>

¹¹⁰ Atsushi Kameoka - Japan Automobile Research Institute: Influence of Ferrocene on Engine and Vehicle Performance, SAE Technical Papers Document Number: 2006-01-3448 <http://www.sae.org/technical/papers/2006-01-3448>

¹¹¹ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006. Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>

¹¹² The court ruling was influenced by an argument that EPA was not allowed to consider health risks in considering the request for a waiver.

¹¹³ Chevron. No date. Motor Gasolines Technical Review. Available: <http://www.chevron.com/products/prodserv/fuels/bulletin/motorgas/>

¹¹⁴ Durability Testing:- EUROPEAN COMMISSION Directorate General JRC JOINT RESEARCH CENTRE Working Group on Metallic Additives Draft minutes of the meeting held at the DG ENV office Brussels, 6th May 2004

through the catalyst and consequently reducing NO_x conversion which is very sensitive to this parameter. CO and HC conversion rates over the catalyst are in general much less affected by this phenomenon. The MMT can have other effects on the engine but the mechanism is always the same: formation of deposits.

313. In 2002, automobile manufacturers jointly completed a multi-year study of the impact of MMT on Low Emission Vehicles (LEVs). They found that after 100,000 miles, the use of MMT significantly increased non-methane organic gases (NMOG), CO and NO_x emissions from the fleet. MMT also decreased the fuel economy through 100,000 miles by, on average, about 0.5 miles per gallon (0.22 km/L). In another part of the study with earlier model vehicles equipped with Tier 1 emission control technology, HC emissions also increased through 50,000 miles. There were also reports of plugging in high-density honeycomb (brick) catalyst systems with MMT.^{115 116}

ii. Performance and emissions issues for vehicles without emission control systems

314. MMT has been used without problems in vehicles *not* equipped with modern three-way catalytic converters (such as pre-1981 federally certified cars in the USA). The possible detrimental effect on engines has not been an issue in those vehicles; however the automobile manufacturers oppose the use of MMT in all gasoline because of concerns that in practice it will be used detrimentally in vehicles equipped with three-way catalysts and oxygen sensors. Maintaining separate fuel supplies is difficult and expensive. Steps would need to be taken to reduce the risk of mis-fueling such as by legislating larger-diameter dispensing nozzles in the gas-stations that cannot enter narrow filler-necks that could be legislated for modern emission-controlled vehicles. This technique was used in the United States during the period when both leaded- and unleaded- gasoline was available. However, during that time, a large number of vehicles were mis-fueled and a large number of catalysts were destroyed resulting in substantial increases in emissions.

315. Many of the Asian countries will adopt cleaner vehicle emission standards in the next years which will require that vehicles are equipped with catalytic converters and also oxygen sensors. At the same time there will be many old vehicles on the road that do not have catalytic converters or oxygen sensors. It is not realistic to expect that Asian countries will be able to have separated fuel supply systems and it is important therefore to opt for the fuel specifications which will ensure that the air quality benefits of the advanced emission control devices are optimized. In the same manner that this will require ultra low sulfur fuels this will also require avoiding the use of metallic additives that can harm catalysts and oxygen sensors.

2. The Effects of Oxygenates Octane-enhancing additives on vehicle performance and emissions

316. In the US, the Clean Air Act amendments of 1977 specified and controlled the use of oxygenates to ensure that they would not adversely affect vehicle emission control systems and lead to failures that could increase emissions.

¹¹⁵ A systematic study involving swapping of parts between a pair of Ford from the Alliance study, one run on clear fuel and the other on MMT containing fuel has been carried out and the results have been presented in the SAE paper no. 2004-01-1084 and 2005-01-1108

¹¹⁶ The manufacturer of MMT has argued that no ill effects occur of the use of MMT in terms of vehicle performance and vehicle emissions.

317. The US EPA, through its “substantially similar” provisions, allows MTBE, Ethanol, TAME, ETBE (but not methanol) to be blended into gasoline up to a concentration that would result in 2.7 mass % oxygen in the blend which equates to respectively 15%, 10% 17.1% and 16.6% by volume respectively. The EPA regulations also created a process by which a waiver could be granted for an oxygenate recipe that the applicant had demonstrated would not cause or contribute to the failure of any emission control device or system.

318. Methanol is an oxygenate that can cause corrosion of metallic components of fuel systems and the degradation of plastics and elastomers.¹¹⁷ It is not permitted in the US other than at low concentration with cosolvents (up to 0.3% by volume as a de-icer and in special circumstances is allowed to be used with other aliphatic alcohols).

319. The oxygenated gasoline is needed, during wintertime, to reduce vehicle carbon monoxide emissions in some parts of the US; and the use of oxygenates in reformulated gasoline for the rest of the year is required to reduce ozone formation and toxics air contaminants. By 2001 some 10 percent of all the gasoline sold in the U.S contained ethanol and over half of the blends contained 10% ethanol by volume, known as E10.¹¹⁸ It is important to note that there is a growing market for E85 (85% ethanol) in the US as more flexible fueled vehicles become available. There are now over 1000 fuel stations that dispense E85 in the US.

320. Oxygenates may be used in other areas of the U.S where they are not required as long as EPA’s maximum concentration limits are observed, however since oxygenates are generally more expensive than the gasoline they displace, it is only through regulation that ethanol was likely to be used near its concentration limit. The other oxygenates will be used at the lowest concentrations possible (1–7% by volume (v/v)) to achieve the desired octane rating and only when adding oxygenates is the most economical solution.

321. In the European Union, oxygenates are allowed¹¹⁹ to be used at a maximum 15%(v/v) for ethers, 5%(v/v) for ethanol, and 3%(v/v) for methanol. In addition, the European Committee for Standardization EN 228 unleaded gasoline specification has set targets for each member state for the market share of biofuels. These targets will be based on the challenging benchmarks set by Directive 2003/ 30/EC: 2% market share by December 2005; 5.75% market share by December 2010.

322. The Japanese JIS K 2202 standard allows MTBE only up to 7%(v/v) maximum. Canada limits methanol to 0.3%(v/v), other oxygenates to 2.7 mass % oxygen, and ethanol specifically to 3.7% mass oxygen (nominally 10% volume ethanol). Brazil allows up to 24 volume % ethanol, but the vehicles are calibrated to use this high level.

a. Impact of Oxygenates on Vehicle Exhaust Emissions

323. In general, adding oxygenates to gasoline influences vehicle emissions primarily by their effect on the balance of fuel and air in the engine. If a vehicle, tuned to run on gasoline, is run on fuel containing an oxygenate without readjustment, the engine will receive a leaner mix as a

¹¹⁷ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006. Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>

¹¹⁸ Chevron. No date. Motor Gasolines Technical Review. Available:

<http://www.chevron.com/products/prodserv/fuels/bulletin/motorgas/>

¹¹⁹ European Parliament and Council. 1998. Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Directive 93/12/EEC. Available: <http://eur-lex.europa.eu/LexUriServ/site/en/consleg/1998/L/01998L0070-20031120-en.pdf>

result of the oxygen contained in the fuel, at least for non-catalyst equipped vehicles without electronic feedback controlled fuel systems such as carbureted cars and most 2- and 3-wheelers.

324. The leaner oxygen-fuel ratio will tend to reduce CO and HC emissions, but in some cases at the expense of an increase in NO_x.

325. The effects of a change in fuel may not be so large for modern catalyst equipped vehicles with electronic feedback controlled fuel systems¹²⁰ since these will compensate to some extent except during the start and warm up periods and at full engine loads when the vehicle's electronic control system may work in "open loop" mode without lambda regulation.

326. Table 4.2 below¹²¹ summarizes the effect of oxygenates-gasoline blends in regulated emissions from modern cars.

Table 4.2: Effect of Oxygenates on vehicle emissions, when RVP is controlled and no RVP increases are allowed

Compound	Effect of Oxygenates
CO	Significant decrease
HC	No effect or slight decrease
NO _x	No effect or small increase
CO ₂	No effect or slight increase

327. Some tests^{122 123} have shown that the addition of alcohols to gasoline at 10% or higher blend ratios can reduce all three regulated emissions in vehicle fleets not equipped with closed loop engine management systems where engines are typically operated lean, depending on the calibration of the engine. The extent of the reduction in emissions is expected to vary on the basis of the engines' air/fuel ratio control strategy. If a carburetor is set to provide a very fuel-rich mixture, fuel leaning might improve performance. Otherwise, fuel leaning can degrade driveability; depending on the engine's calibration.

b. Other oxygenates' air quality impacts¹²⁴

328. In non-catalytic-converter equipped vehicles, the use of oxygenates in gasoline would be expected to produce additional emissions of formaldehydes and acetaldehydes when compared to non-oxygenated gasoline. MTBE and TAME would increase formaldehyde emissions, while ETBE and ethanol would increase emissions of acetaldehyde. In catalytic-converter equipped

²⁹ European Parliament and Council. 1998. Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Directive 93/12/EEC. Available: <http://eur-lex.europa.eu/LexUriServ/site/en/consleg/1998/L/01998L0070-20031120-en.pdf>

¹²⁰ Where an oxygen sensor in the exhaust stream together with other engine management sensors optimize the air-fuel mixture into the engine and the ignition timing

¹²¹ European Fuel Oxygenates Association. Available: <http://www.efoa.org>

¹²² Society of Automotive Engineers. SAE 961988 – Gasoline/Alcohol Blends: Exhaust Emissions, Performance and Burn-Rate in a Multi-Valve Production Engine

¹²³ Society of Automotive Engineers. SAE 961092 – Federal Test Procedure Emissions Test Results from Ethanol Variable-Fuel Vehicle Chevrolet Lumina

¹²⁴ California Environmental Protection Agency. 1999. Air Quality Impacts of the Use of Ethanol in California Reformulated Gasoline

vehicles however, the magnitude of the increase would depend upon the effectiveness of catalytic systems.

329. Extensive emission tests¹²⁵ carried out with reformulated gasoline (RFG) containing MTBE and TAME, ETBE-containing gasoline and ethanol-containing gasoline have shown that the differences in regulated emissions, speciated hydrocarbons, formaldehyde and total particulates were generally insignificant when fuels containing biocomponents were compared to the RFG. The acetaldehyde emissions were higher for the fuels containing ETBE and/or ethanol than for the RFG. The differences in the particulate and semivolatile PAH emissions were low for these fuels.

330. Oxygenated gasoline gives lower fuel economy than conventional gasoline because the heating values of the oxygenate components are lower than those of the hydrocarbons they displace and the percentage change in fuel economy is similar to the mass percent oxygen in the gasoline.

i. Specific Emission Impact due to MTBE

331. The presence of oxygen within MTBE helps gasoline burn more completely, reducing tailpipe emissions from vehicles, especially beneficial in older cars and 2- and 3-wheelers.

332. MTBE's low vapor pressure is attractive because of its ability to contribute low-boiling quality to gasoline – a particularly desirable quality for low-speed performance in manual transmission vehicles – and this characteristic also helps maintain the T50 standards which are an important consideration for modern higher performance engines.

333. Because tiny amounts of MTBE affect the taste and odor of drinking water – less than one ounce of MTBE per ton of water (which equates to levels on the order of 5 ppb) affects taste and odor -- it has been effectively banned in Australia and California, and is being generally phased out in the rest of the US. The aftermath of using MTBE in the US involved stringent regulations for underground storage tanks, and leakage detection requirements together with the need to determine the liability and financial responsibility for cleaning up contaminated ground water and leakages.

ii. Specific Emission Impact due to Ethanol

334. The main advantage of the use of Ethanol as an additive to gasoline is its very high octane number.¹²⁶ Ethanol is soluble in gasoline, however water contamination may lead to phase separation. The actual phase separation conditions are a function of ethanol content, temperature and properties of the gasoline phase, but the effect is particularly marked at low ethanol concentrations. As there typically is a small amount of water in finished gasoline, the ethanol has to be transported separately from gasoline, and mixed at the tanker prior to dispatch.

¹²⁵ Aakko, P., A. Jäntti, J. Pentikäinen, T. Honkanen, and L. Rantanen. 2002. An extensive analysis of the exhaust emissions from spark-ignition vehicles using fuels with biocomponents. Fisita World Congress 2002. Paper F02E027.

¹²⁶ A Technical Study on Fuels Technology related to the Auto/Oil II Programme – Volume II – Alternative Fuels, December 2000 – Prepared for the European Commission Directorate General for Energy

335. Ethanol has a higher heat of vaporization than ethers. Some of the degradation in drivability of gasoline oxygenated with ethanol can be attributed to the additional heat needed to vaporize the fuel.¹²⁷

336. There is a concern that the use of gasoline-ethanol blends increases the vehicle's evaporative emissions because blends of ethanol and gasoline can result in a disproportionate increase in the vapor pressure of the finished product.^{128 129 130} The evaporative emissions are a function of RVP and ambient temperature. As a result, Asian countries where ambient temperatures are generally high should expect the effects of ethanol blending into gasoline to be much higher.

337. Even in the case when only part of the gasoline contains ethanol, the mixing of fuel in the vehicle during refueling (e.g: a gasoline with a 10% ethanol-blend at a given RVP and a non-ethanol blend of the same RVP) – the so called commingling effect – can increase the average RVP of all the fuel consumed by about 0.5 psi¹³¹ and increase evaporative emissions from the whole fleet.

338. In a 1998 report by the California Air Resources Board, based on the then average US vehicle fleet composition, the US EPA complex model estimates that high RVP gasoline containing 10% ethanol will result 3% increase in total hydrocarbons for exhaust emissions and about 40% increase in evaporative emissions.¹³²

339. Permeation with ethanol is also of concern. In a study conducted from January 2003 to June 2004, the CRC in cooperation with California's ARB found higher permeation emissions when ethanol replaced MTBE as the test fuel oxygenate (both oxygenated fuels contained 2% oxygen by weight). The ethanol-blended fuel increased the average diurnal permeation emissions by 1.4 g/day compared to the MTBE fuel and by 1.1 g/day compared to the non-oxygenated fuel. The study also confirmed previous estimates that permeation of these gasoline-ethanol blends doubles for each 10°C rise in temperature¹³³. However the California ARB study indicated that when a higher ethanol blend is used in flexible fuel vehicle (FFV) fuel systems (85% ethanol)-permeation emissions are lower.

340. Since the mid-1980s automobile manufacturers have upgraded the material specifications used in their fuel system components at different times in different countries. Elastomers in older vehicles and low cost replacement parts may be sensitive to ethanol and high-aromatic gasoline causing unintended leakages. Fuel-system components used in other parts of the world may not be designed for use with oxygenated fuels.

iii. Specific Emission Impact due to Other Ethers (ETBE, TAME)

¹²⁷ Chevron. No date. Motor Gasolines Technical Review. Available:

<http://www.chevron.com/products/prodserv/fuels/bulletin/motorgas/>

¹²⁸ Sierra Research, Inc., January 11, 2000. Report No. SR00-01-01 "Potential Evaporative Emission Impacts Associated with the Introduction of Ethanol-Gasoline Blends in California"

¹²⁹ National Renewable Energy Laboratory (NREL), October 2002. Issues Associated with the Use of Higher Ethanol Blends (E17-E24).

¹³⁰ CONCAWE. Gasoline volatility and ethanol effects on hot and cold weather driveability of modern European vehicles", CONCAWE Report No. 3/04

¹³¹ California Air Resources Board. 1998. Comparison of the Effects of a Fully-Complying Gasoline Blend and a High RVP Ethanol Gasoline Blend on Exhaust and Evaporative Emissions

¹³² California Air Resources Board. 1998. Proposed Determination Pursuant to Health and Safety Code Section 48830(g) of the Ozone Forming Potential of Elevated RVP Gasoline Containing 10 Percent Ethanol

¹³³ IDIADA. 2003, September. Comparison of vehicle emissions at European Union annual average temperatures from E0 and E5 petrol. IDIADA Report LM030411 (oppdragsgiver Abengoa Bioenergia), September 2003

341. Ethanol can also be utilized for the production of ethyl tertiary butyl ether (ETBE). ETBE is about 42% ethanol and is produced by processing renewable ethanol with isobutylene, a refinery byproduct. Global auto manufacturers and refiners prefer this route if or when they are required to utilize renewable fuels.¹³⁴

342. ETBE, like MTBE, can be used immediately and no changes to the refining, pipeline and distribution operation or automotive technology are required. Unlike ethanol, ETBE can be blended into the final gasoline right in the refinery and then be shipped to its point of sale through the traditional transportation pipeline. Blend volatility is not increased by ETBE.

343. In Europe, ETBE is becoming the preferred way by both refiners and vehicle manufacturers to use ethanol. Bio-ethers are key tools to enable bio-ethanol market penetration and to meet the EU bio-fuel directive. Many MTBE units have today been converted to allow the use of either MTBE or ETBE dependent on their tax situation and raw material availability.¹³⁵

344. Japan's Biomass Strategy incorporates a 2003 decision to allow up to 3% blending of ethanol (E3) and for ETBE blending up to 8%. The government of Japan supports the switch from MTBE to ETBE over widespread ethanol use mainly due to the cost and logistical implications. There are currently four unused MTBE facilities in Japan that would be able to get back into production making ETBE. In addition, ETBE could relatively easily be used on a national scale while ethanol blends would only be feasible locally or regionally. ETBE however is still seen to present possible environmental hazards and the oil industry must show they are taking countermeasures to reduce those potential impacts within about two years' time.¹³⁶

345. TAME is produced by a similar process to ETBE but from methanol and isoamylenes. It shares MTBE's excellent tolerance to water and requires no changes to the refining, pipeline and distribution operation or automotive technology.

346. TAME's octane rating is approximately 6 points lower than MTBE and ETBE and has the lowest Reid Vapor Pressure and highest Boiling point of the three (10 kPa and 86°C respectively). Blend volatility is not increased at all by TAME.

347. TAME's oxygen content is the same as ETBE (15.66% by mass) and has similar effects on improving combustion and enhancing vehicle performance.

c. Comparative characteristics of principal oxygenates

348. The properties of oxygenates discussed above together with the estimated values of RVP and boiling point are shown in Table 4.3.

Table 4.3: Characteristics of Principal Oxygenates

Oxygenate	(R+M)/2*	Blending RVP (psi)	Boiling Point (°F)	Oxygen Content (%)	Energy Content (MBTU/gal)	Max Allowed by US EPA	Max Allowed By EU
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¹³⁴ European Automotive Manufacturers Association (ACEA), Alliance of Automobile Manufacturers (Alliance), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA). September 2006. Worldwide Fuel Charter Fourth Edition. Available: <http://www.autoalliance.org/archives/wwfcbrochure.pdf>

¹³⁵ Asian Clean Fuels Association (ACFA). 2006. ACFA News Vol 4 Issue 8 Nov/Dec 2006. Available: <http://www.acfa.org.sg/newsletter.php?year=2006#>

¹³⁶ Fukuda, Hisao, Aaron Kingsbury, and Kakayu Obara. 2006. Japan Bio-fuels Production report 2006, USDA Foreign Agricultural Service Global Agriculture Information Network (GAIN) Report number JA6024 5/5/2006. Available: <http://www.fas.usda.gov/gainfiles/200605/146197881.pdf>

Oxygenate	(R+M)/2*	Blending RVP (psi)	Boiling Point (°F)	Oxygen Content (%)	Energy Content (MBTU/gal)	Max Allowed by US EPA	Max Allowed By EU
MTBE	114	8.0	131	18.2	93.5	15%	15%
Ethanol	120	18.0	173	34.8	76.0	10%	5%
TAME	105	2.5	187	15.7	101	2.7%**	15%
ETBE	112	4.0	161	15.7	96.9	2.7%**	15%
Methanol	116	50-60	149	49.9	57.0	2.75%***	3.0%

ETBE = Ethyl tertiary-butyl ether; EU = European Union; MTBE = Methyl tertiary-butyl ether; psi = pounds per square inch; RVP = Reid vapor pressure; MBTU/gal = mega (or 10⁶) British thermal units per gallon; TAME = Tertiary amyl methyl ether; US EPA = US Environment Protection Agency; °F = degrees Fahrenheit

* Octane values of oxygenates vary depending on the composition of the base gasoline

** Weight % as oxygen

*** With equal volume of butanol

Source: American Petroleum Institute, Alcohols and Ethers: A Technical Assessment of their Applications as Fuels and Fuel Components; Hart Publications: 21st Century Refinery; John Courtis

3. Summary of emission impacts of octane-enhancing additives and oxygenates

349. The following tables (4.4 and 4.5) summarize the impacts of gasoline octane enhancing additives and oxygenates on emissions from light duty gasoline vehicles and 2- and 3-wheelers as described in this chapter. The sources used in the elaboration of this summary are cited in the relevant sections in the main text of this chapter.

Table 4.4: Impact of Octane Enhancing Additives and Oxygenates on Emissions from Light Duty Vehicles

Eight Duty Vehicles							
Additive	No Catalyst	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Comments
Lead	HC increase, Lead emissions	CO, HC, NOX all increase dramatically as catalyst destroyed plus Lead emissions					
MMT	Manganese oxide Emissions			Possible Catalyst Plugging plus Manganese Emissions	Likely Catalyst Plugging plus Manganese Emissions		O2 sensor and OBD may be damaged
Ferrocene				Possible Catalyst Plugging	Likely Catalyst Plugging		
	Deposits of iron oxides on combustion chamber, spark plugs. Can cause misfire in spark plugs operating at high temperatures. HC and Fuel consumption increase plus Iron oxide Emissions. Possible catalyst plugging						O2 sensor and Spark Plugs may be damaged
MTBE up to 15.0% Vol (2.74% mass O2)	Lower CO, HC, higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems					Serious concerns over Water Contamination
ETBE up to 17.1% Vol (2.7% mass O2)	Lower CO, HC, higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems					Concerns over Water Contamination
TAME up to 16.6% Vol (2.7% mass O2)	Lower CO, HC, higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems					Concerns over Water Contamination

Additive	No Catalyst	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Comments
Ethanol up to 10.0% Vol (3.7% mass O ₂)	Lower CO, HC, slight NOX increase (when above 2% oxygen content), Higher aldehydes Potential effects on fuel system components, particularly for older vehicles	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems					Increased evaporative emissions unless RVP adjusted, small fuel economy penalty.

CO = Carbon monoxide; ETBE = Ethyl tertiary-butyl ether; HC = hydrocarbons; mg/L = milligram per liter; MMT = Methylcyclopentadienyl manganese tricarbonyl; MTBE = Methyl tertiary-butyl ether; NOX = Nitrogen oxides; O₂ = Oxygen; OBD = on-board diagnostics; % vol = percent by volume

Table 4.5: Impact of Octane Enhancing Additives and Oxygenates on Emissions from 2- and 3-wheelers

Additive	No Catalyst	India 2005	Euro 3	India 2008	Taipei, China Stage 4	Comments
Lead	HC increase, Lead emissions	CO, HC, NOX all increase dramatically as catalyst destroyed plus Lead emissions				
MMT	Manganese Emissions	Possible Catalyst Plugging plus Manganese Emissions				O ₂ sensor and OBD may be damaged
Ferrocene		Possible Catalyst Plugging				
		Deposits of iron oxides on combustion chamber, spark plugs. Can cause misfire in spark plugs operating at high temperatures. HC and Fuel consumption increase plus Iron Emissions. Possible catalyst plugging.				O ₂ sensor and Spark Plugs may be damaged
MTBE up to 15.0% Vol (2.74% mass O ₂)	Lower CO, HC, higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems				Serious concerns over Water Contamination
ETBE up to 17.1% Vol (2.7% mass O ₂)	Lower CO, HC, higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems				Concerns over Water Contamination
TAME up to 16.6% Vol (2.7% mass O ₂)	Lower CO, HC, higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems				Concerns over Water Contamination
Ethanol up to 10.0% Vol (3.7% mass O ₂)	Lower CO, HC, slight NOX increase (when above 2% oxygen content), Higher aldehydes	Minimal effect with new vehicles equipped with oxygen sensors, adaptive learning systems				Increased evaporative emissions unless RVP adjusted, small fuel economy penalty. Potential effects on fuel system components, particularly for older vehicles, potential deposit issues

CO = Carbon monoxide; ETBE = Ethyl tertiary-butyl ether; HC = hydrocarbons; mg/L = milligram per liter; MMT = Methylcyclopentadienyl manganese tricarbonyl; MTBE = Methyl tertiary-butyl ether; NOX = Nitrogen oxides; O₂ = Oxygen; OBD = on-board diagnostics; % vol = percent by volume

F. The effects of octane-enhancing additives on refinery processes

350. In general the ability of a refinery to produce gasoline at the specified octane value for each grade is variable and it is a function of the refinery's complexity and configuration. As discussed previously gasoline is a blend of various refinery streams with different properties and

different octane values. Example of blendstocks, simple HC, and oxygenates and their main properties as used for gasoline production is shown in Table 4.6.

Table 4.6: Example of Blendstocks Used for Gasoline Production

	% Gasoline Pool What does this mean?	Research Octane (RON)	(R+M)/2	Sulfur (PPM)	Aromatics (% vol)	Olefins (% vol)
FCC Light	Med	91	85	60	7	42
FCC Heavy	Low	89	84	300	40	13
Reformate	High	98	93	low	71	0
Alkylate	Low	91	90	low	0	0
Isomerate	Low	86	86	low	0	0
Benzene	low	99	95	0	100	0
Toluene	med	124	118	0	100	0
Xylene	low	133	124	0	100	0
Butane	low	94	92	0	0	0
ETBE	low	117	110	0	0	0
TAME	low	111	105	0	0	0
MTBE	low	114	106	0	0	0
Ethanol	Low	120	110	low	0	0
Methanol	Very low	133	116	0	0	0

ETBE = Ethyl tert-butyl ether; FCC = ; ppm = parts per million; RON = research octane number; TAME = ; MTBE = Methyl tert-butyl ether; % vol = percentage by volume

Source: Hart: 21st Century Refinery, MEETI presentation, US EPA: Implementer's Guide to Phasing out Lead in Gasoline, John Curtis

351. To meet the octane requirements for each grade, refineries historically have been producing gasoline by using the following components:

a. Refinery-produced hydrocarbons or hydrocarbon mixtures

352. As shown in the table, reformate, alkylate, followed by isomerate together with oxygenates have been the traditional components that provide most of the octane needs at the refinery. The refinery's ability in Asia to use some of these blendstocks is mixed based on current refinery configurations in Asia.. In many parts of Asia, as a result of rising demand refinery upgrades are planned or new refineries are also being put in place. Based on the experience from the developed world this provides a good opportunity to design the refining processes to enhance octane without the need for additives.

353. Pure hydrocarbon streams such as benzene, toluene, and mixed xylenes and their blends (BTX), are also produced at the refinery and could also be used for octane enhancement. The BTX streams are also important petrochemical feedstocks and are exported to petrochemical facilities. Their use at the refinery as octane agents downgrades their economic value to the refiner because they are much more highly priced in the petrochemicals market and use of reformates and BTX for octane enhancement is constrained by the aromatics limits.

354. Another compound that is part of the gasoline pool and has high octane value is butane. If higher levels of RVP are allowed, higher quantities of butane would find its way into the gasoline pool.

b. Metallic Octane Enhancement Additives

355. As described above MMT and Ferrocene, has been used by refiners in some countries as an octane enhancement additive. This more so in the past when concerns about health impacts as well as impacts on vehicle performance and emissions of such additives were not as well articulated as now. For refiners the use of metallic based additives is attractive because of the lower cost, the ease of use, and the flexibility it provides refiners in octane adjustment. A small concentration of MMT or Ferrocene when it is added to the gasoline pool can satisfy some of the octane requirements. The use of MMT and Ferrocene does not require special handling equipment and it can be added to gasoline by the use of existing additive injection equipment. It does not affect any other gasoline properties.

c. Oxygenates

356. Since the mandate which required the use of oxygenates in the US sets standards only on the oxygen content and it was oxygenate neutral, the refineries selected the least expensive option which was MTBE. Small amounts of ethanol and TAME were originally used. No ETBE was used. Some of the MTBE used was produced at the refineries from methanol and isobutylene and some of it was purchased and imported for the refineries.

357. The use of MTBE had the advantage that it was priced close to the price of gasoline, blended easily at the refinery, was widely available, and there has been extensive experience with its use. Water contamination issues have led to it being banned in a number of countries.

358. Ethanol competes with MTBE for market position and it is produced from agricultural feedstocks or biomass at agricultural locations. Ethanol's strong affinity to water makes the gasoline-ethanol mixture a difficult blend to transport through the pipeline system. As a result, ethanol is transported separately by rail or by tank truck to various points in the fuel marketing and distribution system where it is blended with gasoline. This need for downstream blending together with the ethanol's effect on RVP makes the logistics and the ability to control the properties of the final blend more problematic for the refinery.

359. TAME, another oxygenate, is also produced at the refinery from isoamylene and methanol. Most of TAME used in the past was produced with MTBE and it was used to supplement the use of MTBE in Europe.

360. ETBE is produced from ethanol and isobutylene and the cost of production is much higher than the costs of either MTBE or ethanol. However, its use is more attractive to refiners because ETBE does not have the disadvantages of ethanol (affinity to water, RVP increases). Some refineries have explored the possibility of converting existing MTBE production plans to ETBE production facilities. Currently, ETBE is not available for purchase in the fuels markets but some quantities are produced and used in the USA and Europe¹³⁷.

361. Methanol is produced from natural gas and it is available in the marketplace. It can provide significant octane increases but a number of auto manufactures recommend against its use as a blend in gasoline.

¹³⁷ Hart: 21st Century Refinery, MEETI presentation, US EPA: Implementer's Guide to Phasing out Lead in Gasoline, John Courtis

1. Impacts of Changes in Gasoline Standards on Octane Number and Resultant Strategies

362. The implementation of stricter gasoline standards in support of stricter vehicle emission standards can result in changes in the refinery processes, changes in the blendstocks and changes in the properties of the blendstocks used in the gasoline pool, which affect the octane balance at the refinery. In this context Asia countries can benefit from the experience of two major regulatory programs: (a) the removal of lead and (b) the implementation of the EURO 4 fuel standards, or in the case of the USA the adoption of Tier 2 gasoline standards.

a. Transition from Leaded to Unleaded

363. The removal of lead and the transition to unleaded gasoline has been successful in most countries, but the lead removal created an octane deficit in the range of 2-8 octane numbers. To increase octane, in general, refineries increased the utilization of their reforming capacity, some added new reforming capacity, expanded and added new hydrotreating capacity, and expanded the blending of some oxygenates. In some cases refineries used octane enhancing additives. MMT was used by some refineries in the USA, Canada,¹³⁸ Australia, Asia, and to a limited extent in Europe for a quick transition from leaded to unleaded gasoline. MMT, in some cases, was used as an integral part of the lead phase out strategy and in some cases to a limited basis to supplement the use of oxygenates and as an octane trimming agent in the blending of gasoline.

364. Although the strategies varied from refinery-to-refinery and were dependent upon the individual refinery configuration, the availability and comparative costs of various high octane blendstocks and oxygenates or additives shaped the timing and ease of transition from leaded to unleaded gasoline. The transition was generally quicker and less costly when assisted by of the use of oxygenates and or the use of MMT. It should be noted that some refiners at a later time discontinued the use of MMT or the use of some oxygenates but were still able to provide unleaded gasoline in required quantities.

b. Transition to Euro 4 or Tier 2 standards

365. The changes to fuel specifications in order to meet Euro 4 or Tier 2 standards represent an additional challenge for the refinery's octane balance. The reduction of the sulfur content to the levels needed to meet the Euro 4 fuel or Tier 2 standards requires deep hydrotreating for part or all of the FCC gasoline which even with current advanced technologies may give a potential octane penalty of 1 to 2 (R+M/2)octane numbers depending on the specifics of the refinery. To be able to reduce the levels of aromatics and benzene to the Euro 4 or Tier 2 standards a refinery would need to reduce the severity of the reformer and possibly extract benzene out of the gasoline pool.

366. RVP reductions will also impact octane. The RVP reductions are achieved by reducing the amount of light compounds such as butanes or pentanes from the gasoline pool. These compounds have high octane values and their removal would reduce the octane of the pool.

367. Smaller hydroskimming refineries that rely heavily on straight run gasoline would have less of a problem with the standards for olefins, aromatics, or sulfur but these refineries(in the absence of a reformer) would have limited capacity for producing high octane components and they would have to rely on imported blendstocks to meet their interim needs. High octane

¹³⁸ CEC: Supply and Cost of Alternatives to MTBE in Gasoline, 1998

blendstocks with desirable properties (low aromatics, low sulfur, and low olefins) are not readily available in the fuels market. The principal low-cost options for them would be to import and use oxygenates (MTBE or Ethanol) or to use octane enhancing additives (MMT or ferrocene).

368. To meet the Euro 4 or Tier 2 fuel standards many refineries would be required to invest in the construction of new processes or in expansions of existing processes. Some supplemental or additional processes or changes in process operations may be needed to satisfy the change in octane requirements this causes. How that would be implemented would be function of various regulatory constraints, economics, availability of capital, and the availability of refinery feedstocks. There are three main approaches that can be taken:

i. Approach A: MTBE or Octane Enhancing Additives – No; Ethanol and ETBE – Yes.

369. Refineries would need to implement an integrated refinery retrofit program where both the Euro 4 or Tier 2 fuel standards and the octane targets are met with process modifications.¹³⁹ Under this scenario, refiners would be required to use high volumes of gasoline blendstocks such as reformate, alkytale or isomerate and ethanol or ETBE to produce gasoline. Some refiners would be required to invest in reforming capacity, although reformate use would be constrained because of the high levels of aromatics. Since alkylates and isomerates are not readily available in the fuels market, it would be required that refineries invest in the construction of alkylation, and isomerization units. Note that the size of these units would be constrained by the availability of feedstocks at the refinery. The in-house production of ETBE is possible with investments as needed to convert existing MTBE facilities to ETBE production. The importation of ethanol would be an integral part of the refineries' strategy under this scenario.

370. This approach is relatively capital intensive and it could rely on the importation of either some feedstocks or some finished products. Notwithstanding concerns frequently expressed by refiners on the costs of this approach it must be noted that in the US, the oil industry has been able to provide very clean, high-quality and low-emission fuel which meets the performance requirements of the vehicle industry– including octane – without the use of MMT. At the same time, the industry is meeting new requirements for the reduction of sulfur, benzene and other air toxics.¹⁴⁰

ii. Approach B: Use of blending Oxygenates and Octane Enhancing Additives - Yes

371. Under this scenario refineries have a choice either to rely on capital investments; to use oxygenates or octane enhancement additives; or a combination of these approachess. This was the case in Europe and Canada. In some EU countries MTBE and Ethanol are used, and in some others oxygenates and to a much lesser extent octane enhancing additives such as MMT are used. The Canadian approach was similar to the European although much more octane enhancing additives (MMT) were used. This was related to the absence of regulation on MMT in Canada. Overall in the EU where MTBE is allowed and widely used capital investments to meet Euro 4 standards were less than investments required in the US to meet Tier 2 investments.¹⁴¹

¹³⁹ No relaxation of Euro 4 or Tier 2 standards would be allowed in this scenario.

¹⁴⁰ Communication from Margo Tsigotis Oge, Director, Office of Transportation and Air Quality of the United States Environmental Protection Agency Mar 5, 2007.

¹⁴¹ Pervin & Gertz, Cost of Compliance with EU Standards; Bechtel, Technical Study on Fuels Technology Related to Auto-Oil II Programme, 1999

372. The absence of regulation limiting the use of oxygenates or of octane enhancing additives allowed some refineries to meet the regulatory standards with less capital expenditures and more flexibility. However, also in this scenario refiners generally did not use octane enhancing additives but relied exclusively on process modifications, investments, or oxygenates to comply with the standards. Both oxygenates and additives are added as components to the gasoline pool and refiners can use them as needed. Refiners are guided in the use of oxygenates and additives firstly by regulations on their use and secondly by their prices and supply.

iii. Approach C: Relaxation in some of Euro 4 or Tier 2 specifications

373. A third hypothetical scenario, which did not occur in Europe or the US would consist of implementing an integrated plan where only some gasoline properties as specified in the Euro 4 or Tier 2 standards would be required and some property standards would be relaxed. The highest priority could be given to maintain a strict compliance with the sulfur content standard since sulfur is the most critical property for the performance of emission control systems.

374. The three most critical properties for maintaining octane balance would be aromatics, olefins, and RVP. Relaxing the Euro 4 or Tier 2 standards for one or all of these properties would help to partially satisfy the octane needs. It would reduce capital investments, but it would also result in important air quality penalties. Increasing of aromatics content would increase the amounts of benzene in the exhaust and potentially increase the overall hydrocarbon emissions. The increasing of olefins content would result in higher levels of 1-3, butadiene in the exhaust and would increase the photochemical reactivity of the HC emissions (olefins are much more photochemically reactive than other HC species). The increases in RVP would result in much higher evaporative HC emissions. The evaporative HC emissions are critically important for Asian cities where the ambient toxics and ozone are important air quality issues.

375. This approach, where some properties could be relaxed, has been a topic of discussion in some countries in Asia. For example, Thailand has considered and has implemented a relaxation of both the RVP and the aromatics content standard. In Indonesia and PRC, where a high olefins content gasoline is produced, there have been concerns regarding their ability to meet the olefins content standard as it is required by Euro 4¹⁴². The implementation of strict RVP standards is being discussed in a number of Asian countries.

376. The relaxing of some or all of the regulatory standards was not allowed in either USA or Europe.

2. Economics of the Various Options

377. The exact cost of octane replacement is difficult to determine. It would vary for each refinery and it would depend upon the refinery configuration and the types of processes that refinery would employ and the availability and costs of critical components in the fuels market.

378. For small topping refineries having to comply with the Euro 4 standards, their ability to meet the octane needs without significant capital investments is limited. These refineries lack reforming capacity and investments in catalytic reforming would be the first choice if it is decided to upgrade such refineries. As noted in Chapter three although large in number small topping refineries process a relatively small part of the overall crude that is refined in Asia. The rapid

¹⁴² Personal Communication between John Courtis and fuel quality regulators in PRC and Indonesia

increase in refining capacity in Asia will further reduce this already low percentage. In the USA the small refineries initially selected the use of octane enhancement additives and oxygenates as the strategy of choice. However, it is important to note that now MMT is used in less than 1% of the gasoline supply in the US¹⁴³ and in none of the gasoline in India, Canada, Japan and Australia and Brazil, some of which also had or still have a number of small refineries.

G. Concluding Remarks on Additives to Enhance Octane of Gasoline

379. Emissions from vehicles are dependent on the combination of engine technology, including exhaust aftertreatment and fuel specifications and as such it is impossible to discuss one without the others. In this context fuel specifications must include all the characteristics of the fuel and its additives. As vehicle emissions standards have tightened over time, changes have been required to the fuel specifications both to allow more advanced emissions control technologies to be effectively implemented and to mitigate health effects as they become evident.

380. Historically, lead was widely used as an octane enhancer in gasoline since it was readily available and the cheapest solution to the refiner. Over time, we learned that the cost to society and especially its children was immense. Almost all countries, including nearly all the Asian countries, have moved to ban lead in gasoline due to its impact on human health and in the near future, it is hoped that transport will no longer be a source of lead emissions. This has caused refineries to identify other means of covering this octane shortfall. Many face the simultaneous need to reduce the amount of sulphur in the fuel.

381. The options open to them include; refinery capital investment; the use of selected crude oils or high octane blend-stocks; the use of metallic based additives (other than lead) and the use of oxygenates.

382. Less than 1% of the gasoline supply in the US uses metallic based additives and also in many other parts of the world very few metallic additives are being used; however the controversy over their use, especially MMT and Ferrocene continues, focusing on the potential health effects, and the effects on the emissions control systems. Concerns have been expressed that the ban on leaded gasoline should not result in new problems due to the use of metallic additives such as MMT and Ferrocene. As described in this chapter studies are currently continuing in the U.S. and Canada on the health effects of MMT.

383. The vehicle manufacturers, responsible for maintaining low emissions for the lifetime of the vehicle through durable and effective operation of their modern emissions control systems are seriously concerned that metallic ash-forming additives can adversely affect the operation of catalysts and other components, such as oxygen sensors, in an irreversible way that increases emissions. Thus they recommend that high-quality gasoline should be used and metallic ash-forming additives be avoided.

384. While older vehicles and 2- and 3-wheelers that are not equipped with catalytic converters, oxygen sensors and similar emissions control systems are less affected by the use of metallic additives the risk of vehicle owners using fuel containing metallic additives in vehicles with modern emissions control systems has led to a consistent recommendation by the automotive manufacturers that the use of ash-forming additives should be avoided altogether.

¹⁴³ Communication from Margo Tsigotis Oge, Director, Office of Transportation and Air Quality of the United States Environmental Protection Agency Mar 5, 2007.

385. The experience described in this chapter shows that the longer term solution applied by refineries to meet the gasoline octane requirements is through capital investment and blend-stock selection and the use of certain oxygenates. Metallic additives were, initially used more widely because of their financial appeal to the refiners. MTBE was widely seen as an effective option to improve octane ratings. The concerns of contamination of water supplies, with an unpalatable taste and odor, have led to its use being banned in the USA and Australia. ETBE is now increasingly seen as a preferred substitute for MTBE, by refiners and vehicle manufacturers rather than ethanol because of the handling and RVP problems associated with ethanol. The fact that in most countries an overwhelming majority of fuel is now free of metallic based octane-enhancing additives is evidence of the cost-effectiveness of this route within the confines of existing regulations.

V. PRICING, TAXATION AND INCENTIVES FOR CLEANER FUELS

A. Introduction

386. Fuel pricing and taxation policies have important implications for cleaner fuels in Asia. On the one hand automotive fuel pricing and taxation regimes, whether more open or more regulated can impact the way in which the production of cleaner fuels is financed and the ease with which financing can be secured, especially concerning the ability of industry to pass higher costs on in pump prices. At the same time, where governments play strong roles or monopolize fuel supply, political will becomes important in financing cleaner fuels. Also incentives such as differentiated fuel pricing are promising tools for accelerating cleaner fuel uptake. Around the world, as well as in Asia, tax differentials between fuels have been used to help establish markets for cleaner fuels and support regulations. These cases offer lessons for approaching similar policies for a new range of higher quality fuels in Asia.

B. Automotive Fuel Industry and Pricing Structure

1. Industry Structure in Asia

387. National oil markets vary according to the number of competitors and degree of public ownership. On one end of the spectrum, national oil sectors can be characterized by unrestricted ownership and investment among a range of domestic and international private companies, while on the other end, national oil sectors can be dominated by one state-owned monopoly. Prior to the 1970s investments in the oil sector around the world were made primarily by major international oil companies which had little difficulty raising capital from international financial markets. The situation changed in the 1970s when producing countries asserted greater control over oil resources. Many countries began to set up national companies due to rising prices and security of supply concerns and subsequently, an increasing part of investments in the oil sector came from government budgets. From the 1980s the global trend has been toward privatization and the introduction of competition, amidst falling oil prices and increasing government debt. Through the 1990s a significant degree of market deregulation took place and project financing has evolved into a mixture of ownership arrangements and joint ventures. In recent years, with high oil prices and the emergence of significant new demand in countries like PRC and India, national oil companies have continued to play major roles in development and finance in the oil and energy sectors. Notably, some of the largest oil companies in Asia maintain a high degree of state ownership. See Table 5.1.

Table 5.1: Public Ownership in Asia's Major Oil Companies

Company	Country	Government Ownership
PetroChina	PRC	90%
Petronas	Malaysia	100%
Sinopec	PRC	55%
Pertamina	Indonesia	100%
Indian Oil Corp.	India	82%
Petroleum Authority of Thailand (International) (PTT)	Thailand	68%
Petron	Philippines	40%
Pakistan State Oil	Pakistan	52%

Source: Energy Intelligence Group, Inc. 2004. Rankings Based on Financial and Other Measures. Petroleum Intelligence Weekly. Available: http://www.energyintel.com/DocumentDetail.asp?document_id=137158; Indian Oil Company

388. Most countries in Asia have some domestic refining capability. Some countries are larger importers notably: Hong Kong, S.A.R China, Viet Nam (despite being a large crude producer) and increasingly the Philippines. South Korea, Taipei, China and Singapore are major regional exporters of refined products. India is a net importer, but has boosted domestic refining capacity in recent years.

389. While the majority of Asian countries are in the process of de-regulating upstream and downstream oil sectors, the pace and approach of these reforms varies throughout the region. In terms of downstream and refining ownership, Asian countries can be categorized as public, private, or transitional (see Table 5.2). Bangladesh's and Indonesia's markets continue to be dominated by state-owned monopolies. The liberalization of Indonesia's downstream oil and gas sector has been under discussion for several years, although liberalization has been slow. The 2001 Oil and Gas Law established BPH MIGAS to regulate downstream activities and Pertamina became a limited liability company in 2003. Due to high international oil prices in recent years the Indonesian government has deferred plans for fully liberalizing the oil and gas sector and abolishing fuel subsidies until 2010. Originally, the Oil and Gas Law passed in 2001 established a target of 2005 for the introduction of privatization.

390. India's and Pakistan's major national companies largely dominate the downstream sector. In the case of India major domestic, private conglomerates such as Reliance are playing greater roles in domestic refining. PRC's state companies play a dominant role in refining and retailing, although import quotas, and foreign ownership restrictions have eased as the country makes liberalization changes in line with its accession to the World Trade Organization. Malaysia, Taipei, China and Thailand have strong national oil companies, but significant private participation. In the case of Taipei, China the two major downstream companies, Chinese Petroleum Corporation and Formosa Petrochemical Corporation are owned by the state, but significant competition exists among private actors in the retail sector. Japan, South Korea, Singapore and increasingly the Philippines are open markets dominated by private firms. In the Philippines Petron (the state controlled company), Shell, and Caltex, dominate refining, although Caltex is replacing its refining capacity with an import terminal.¹⁴⁴

Table 5.2: Ownership in Downstream Oil Markets in Asia

Country	Dominant Enterprises in Downstream/Refining	Ownership
Bangladesh	Bangladesh Petroleum Corporation	public
Hong Kong, SAR	None	-
India	Reliance, Hindustan, Indian Oil Corporation, Shell	public/private
Indonesia	Pertamina, BP, Petronas	public/transitional
Japan	Nippon Mitsubishi Oil, Showa Shell, Tonen, Exxon	private

¹⁴⁴ 62 new firms entered the retail market, since 1998 when oil market deregulation began. The new firms have captured a growing share of the market, increasing from around 10% in 2000 to about 20% in mid-2004 and have put significant downward pressure on retail fuel prices (the lowest of any non oil-exporting Asian country). The 20% figure comes from US DOE, EIA country brief for Philippines/

Country	Dominant Enterprises in Downstream/Refining	Ownership
Malaysia	Petronas, Shell, Esso, Conoco	public/private
Pakistan	Pakistan State Oil, PARCO, OGDCL	public/private
Philippines	Petron, Pilipinas Shell, Caltex	public/private
PRC	CNPC, Sinopec, CNOOC BP, Exxon, Shell	public/ transitional
Singapore	Shell, Exxon, SRC	private
Sri Lanka	Ceylon Petroleum Corp.	public
South Korea	SK Corp., LG-Caltex, Hyundai	private
Taipei, China	Chinese Petroleum Corp., Formosa Petrochemical	public/private
Thailand	PTT, Shell, Esso	public/private
Viet Nam	-	-

Notes: BP = British Petroleum; CNPC = China National Petroleum Corporation; CNOOC = China National Offshore Oil Corp.; Esso = sister company of Exxon Mobil; PRC = People's Republic of China; SAR = special administrative region; SRC = Singapore Refinery Company

Source: Energy Information Administration, 2005 (EIA)

2. Automotive Fuel Pricing in Asia

391. Typically, prices for petroleum products are determined by cost for crude, refinery production costs and margins, taxes, distribution costs and profit margins. As the cost of crude and cost of refining differ marginally from country to country, the primary sources of variation in national fuel prices are tax and pricing practices. Countries that are heavy importers of petroleum products tend to have higher tax rates than those who export petroleum products. However, there are a range of policy goals that come to shape fuel taxation and pricing, including general revenue generation, road and infrastructure finance, price volatility control, redistribution of income, as well as reduction of environmental externalities. Generally, health and environmental concerns are not consistently reflected in fuel taxation regimes in Asian countries.

392. Asian fuel tax practices can be grouped into four categories according price range and tax policy: subsidized, low tax, medium tax and high tax. Higher income and oil dependent economies generally have higher taxation regimes. For example, diesel prices in Japan and Hong Kong were above US\$ 0.90 per liter in 2004, while diesel prices in Indonesia and Malaysia were below \$0.25 and subsidized. See table 5.3.

393. Tax policies are closely related to pricing regimes, which are determined primarily by either the market or the state. Market pricing is the norm in industrialized countries, where demand is typically high and stable and there are a sufficient number of private refineries for a competitive market. In markets dominated by the state, prices are set according to government controls and price formulas. Price controls are often associated with some form of subsidy, where governments absorb the difference between consumer prices and world prices.

Table 5.3: Automotive Fuel Pricing and Taxation Practices in Asia US\$/liter in 2004

Country	Price Gasoline	Price Diesel	Pricing	Taxation (Brent =42\$)	Fuel tax as % of total tax revenue
Bangladesh	\$0.59	\$0.34	controlled/transitional	low taxation/subsidy	1%
Cambodia	\$0.79	\$0.61	controlled	medium taxation	N/A
HK, S.A.R China	\$1.54	\$1.00	market	high taxation	N/A
India	\$0.87	\$0.62	transitional	medium taxation	8%
Indonesia	\$0.27	\$0.18	controlled	subsidies	-6%
Japan	\$1.26	\$0.95	market	high taxation	11%
Malaysia	\$0.37	\$0.22	controlled	subsidies	-2%
Pakistan	\$0.62	\$0.41	transitional	low taxation/subsidy	4%
Philippines	\$0.52	\$0.34	market	low taxation/subsidy	0
PRC	\$0.48	\$0.43	controlled/transitional	low taxation/subsidy	4%
Singapore	\$0.89	\$0.55	market	medium taxation	3%
Sri Lanka	\$0.72	\$0.41	transitional	low taxation/subsidy	7%
South Korea ¹⁴⁵	\$1.35	\$0.95	market	high taxation	19%
Taipei,China	\$0.71	\$0.55	transitional	medium taxation	N/A
Thailand	\$0.54	\$0.37	transitional	low taxation/subsidy	2%
Viet Nam	\$0.48	\$0.32	controlled/transitional	low taxation/subsidy	N/A

Source: Derived from Metschies, Gerhard. 2005. International Fuel Prices 2005, 4rd Edition. GTZ. Available: http://www.gtz.de/de/dokumente/en_International_Fuel_Prices_2005.pdf.

394. In Asia, pricing mechanisms for petroleum products range from market pricing to controlled pricing with transitional variations (see Table 5.3). Japan, Singapore and South Korea, and increasingly the Philippines rely on market pricing. Countries with direct price controls include Bangladesh, Indonesia, Malaysia, and Viet Nam. These countries typically set prices at the local cost of production plus a fixed percentage for different market segments and taxes. The production cost is often set by the government, although an attempt may be made to index the production cost figure to an import parity price. A typical price formula would consist of an import parity price, plus storage cost, domestic distribution, wholesale profit margin, retail margin, value added taxes and other taxes, as practiced in Bangladesh. The government may also employ a price band that allows producers to set prices within a certain range (e.g. plus or minus 10% in Viet Nam). Indonesia has historically administered fuel prices fully, but in recent years has begun to open pricing to world fluctuations. In 2002, the Government announced a new formula that allowed fuel prices to be modified by Pertamina every month based on the Mid Oil Platt Singapore (MOPS) prices, but shortly thereafter set a price band in order to protect

against extreme fluctuations in world prices. In December 2002 the price index was set at MOPS plus 5%. In January 2003 the government suspended the index practice due to high world oil prices and has let prices rise significantly in recent years.¹⁴⁶ (US Embassy Jakarta, 2003).

395. India, Thailand, PRC, Sri Lanka, Pakistan, and Taipei, China could be described as *transitional* in terms of their degree of price liberalization. In these cases, governments have typically implemented measures to move toward market pricing and in particular have opened pricing to international price fluctuations, but tend to maintain certain controls like frequent excise tax adjustments or the continued use of pricing formulas based on import parity-pricing. Pakistan, has maintained a policy of “pan-territorial” energy pricing or uniform pricing across the country for many years. The origins of the policy lie in the political goal of promoting national unity in Pakistan. Ex-refinery prices are set bi-monthly by the Ministry of Petroleum and based on import parity prices- or the ‘free on board’ (FOB) prices of equivalent products. Import parity prices are averaged for the fortnight as quoted in the Arab Gulf Region; on top of which are added elements like bank charges, customs duties and so forth. (Ministry of Petroleum and Natural Resources, 2005).

396. India officially dismantled its Administered Pricing Mechanism from 1997-2002, but still intervenes to keep prices from rising. The administered pricing system was originally set up in the late 1970s, as so-called ‘retention pricing’, where refineries and distributors were compensated on the basis of a cost-plus formula- i.e. operating costs plus a 12% return, and prices were fixed accordingly. In 1997 the government introduced ‘import parity’ pricing on gasoline and diesel but the Ministry of Petroleum and Natural Gas still screens prices for diesel and gasoline on a fortnightly basis. In August 2004, the government developed a price band in which retailers were able to pass higher costs of production onto consumers, but the cap has not been high enough to keep up with rising costs for international crude (TERI, 2005).¹⁴⁷

397. Thailand relies mainly on market prices for production cost prices and has a transparent tax regime, but intervenes in final pricing at times, often with funds from its oil fund tax. From 1998 PRC began to set prices on the basis of international price fluctuations. Sri Lanka sets prices monthly on the basis of an import-parity formula introduced in 2002.

3. Fuel Subsidies in Asia

398. The international energy agency defines an energy subsidy as any government action that concerns primarily the energy sector that lowers the cost of energy production, raises the price received by energy producers or lower the price paid by energy consumers (IEA, 1990). Although energy subsidies are common throughout the world, measuring subsidies can be difficult in practice. Many subsidies also often reflect entrenched industry practice and may not be viewed as subsidies locally. In some Asian countries automotive fuel consumption has been subsidized to keep prices lower for consumers. Many governments in Asia have tended to subsidize diesel fuel to support commercial transport and economic growth, as reflected in the lower diesel prices compared to gasoline in table 5.3. Some countries in Asia also subsidize domestic prices compared to international prices. According to the data in table 5.3 prices in Malaysia and Indonesia were subsidized in this way in 2004. In Malaysia, fuel subsidies cost the

¹⁴⁶ US Embassy Jakarta. 2004, Mar. Petroleum Report Indonesia 2002-2003. Available: <http://www.usembassyjakarta.org/econ/petro2003-toc.html>.

¹⁴⁷ The Energy Research Institute (TERI). 2005. Petroleum pricing in India: balancing efficiency and equity. Prepared by Neha Misra, Ruchika Chawla, Leena Srivastava, and R. K. Pachauri. Available: <http://www.teriin.org/images/petroprice.pdf>.

Government US\$1.3 billion in 2004 (ADB 2005).¹⁴⁸ In addition to direct subsidies on prices and production costs, there may also be indirect subsidies such as preferential rates for shipping for government enterprises and so forth. Subsidies to protect consumers from international prices shocks have been more common in recent years. Other forms of subsidies common in Asian fuel markets include preferential pricing and tax treatment for unleaded gasoline and alternative fuels like natural gas to support public health and energy conservation/diversification programs, as discussed further below.

4. Impact of Rising International Oil Prices in Asia

399. Higher international oil prices in recent years have had a significant impact on Asian fuel markets and pricing practices. Most notably, high international prices have forced some countries which have typically subsidized domestic fuel consumption to reduce controls to ease the strain on government budgets. Initially, several countries attempted to absorb the international fluctuations by increasing subsidies. At the beginning of 2004, the Thai government introduced a subsidy on diesel to mitigate rising prices, which by June of 2005 had reportedly cost the government 88.37 billion baht (US\$2.2 billion) (International Oil Daily, 2005).¹⁴⁹ In 2004 Indonesia spent four times the 14 trillion rupiah (US\$1.5 billion) that it had planned to spend on fuel subsidies (The Economist, 2004).¹⁵⁰ To keep prices low, in Malaysia, the government forewent a fuel sales tax, which amounted to RM7.9 billion (US\$2.2 billion) in 2005 (Morgan Stanley, 2005).¹⁵¹

Table 5.4: Regular Unleaded Gasoline Prices in Asia 1996-2004 in US dollars/liter

	1996	1997	1998	1999	2000	2001	2002	2003	2004
PRC	0.272	0.282	0.250	0.251	0.281	-	-	-	-
Taipei, China	0.568	0.599	0.492	0.491	0.569	0.532	0.510	0.571	0.650
India ¹⁵²	0.611	0.690	0.634	0.655	0.648	0.674	0.622	0.626	-
Indonesia	0.360	0.290	0.130	-	-	0.16	0.176	0.211	0.203
Japan	0.963	0.863	0.746	0.863	0.964	0.863	0.831	0.917	1.039
Korea	0.840	0.882	0.802	1.004	1.104	0.992	1.014	1.087	1.192
Thailand	-	0.322	0.271	0.300	0.365	0.328	0.333	0.378	-

Source: International Energy Agency (IEA). 2005. International Prices and Taxes: Quarterly Statistics. OECD/IEA: Paris.

Table 5.5: Commercial Diesel Prices in Asia 1996-2004 in US dollars/liter

	1996	1997	1998	1999	2000	2001	2002	2003	2004
PRC	0.235	0.261	0.242	0.252	0.330	0.317	0.317	0.352	0.393
Taipei, China	0.434	0.452	0.377	0.380	0.447	0.410	0.398	0.443	0.503
India	0.238	0.289	0.275	0.289	0.396	0.439	0.455	0.382	-
Indonesia	0.154	0.124	0.045	0.064	0.061	0.063	0.138	0.192	0.185
Japan	0.560	0.521	0.468	0.531	0.578	0.528	0.503	0.562	0.649
Korea	0.370	0.424	0.395	0.440	0.542	0.500	0.542	0.653	0.793
Thailand	0.340	0.302	0.222	0.239	0.322	0.303	0.306	0.399	-

¹⁴⁸ Asian Development Bank (ADB). 2005. The Challenge of Higher Oil Prices – Asian Development Outlook 2005 Update. Available: <http://www.adb.org/Documents/Books/ADO/2005/update/part030000.asp>

¹⁴⁹ International Oil Daily. 2005. Thailand Approves Subsidy Bond. 1 June. Volume 4, No 104. Available: http://www.energyintel.com/DocumentDetail.asp?Try=Yes&document_id=149319&publication_id=31

¹⁵⁰ The Economist. 2004. Pump priming. 30 September.

¹⁵¹ Tan, Deyi and Daniel Lian. 2005, 25 Aug. Malaysia: The Ugly Face of Fuel Subsidies. Morgan Stanley - Global Economic Forum. Available: <http://www.morganstanley.com/views/gef/archive/2005/20050825-Thu.html>.

¹⁵² For leaded gasoline

Source: International Energy Agency (IEA). 2005. International Prices and Taxes: Quarterly Statistics. OECD/IEA: Paris.

Table 5.6: Refined Oil Product Spot Prices (Singapore) in US\$/bbl.

Period	Gasoline	Diesel
2002	28.0	27.45
2003	34.74	32.41
2004	47.19	45.65
2005	61.96	63.79
Jan 2005	47.57	49.23
Feb 2005	54.27	52.53
Mar 2005	59.47	62.58
Apr 2005	61.50	63.91
May 2005	54.46	58.89
Jun 2005	59.65	67.67
Jul 2005	64.70	69.35
Aug 2005	73.20	70.66
Sep 2005	79.40	75.45
Oct 2005	69.10	72.62
Nov 2005	60.87	61.80
Dec 2005	59.30	60.80

Source: International Energy Agency (IEA). 2005. International Prices and Taxes: Quarterly Statistics. OECD/IEA: Paris.

400. However, persistent price rises led to difficulties. Indonesia's policy of subsidizing domestic fuel prices placed large strains on government finances. At one stage the subsidies accounted for around 7% of GDP. In April 2005, the government dispersed only Rupiah 4.1 trillion, rather than the planned 24 trillion in subsidies (US\$2.5 billion) leading to a financial crisis for Pertamina and supply shortages across the country. Subsequently, the Indonesian government raised pump prices by an average 126%, the second hike of 2005 after a relatively modest 29% increase in March. Gasoline prices rose 87%, diesel fuel by 104%, while the price of kerosene almost tripled. With the fuel price rises government aimed to halve its anticipated spending level on subsidies to Rp 39,800 billion (US\$4.3 billion) in 2005. Phasing out fuel subsidies will now be implemented through a series of fuel price increases over the next five years. The government has provided direct cash subsidies to low income groups to ease the burden of price increases (Energy Economist, 2005).

Table 5.7: Indonesian retail fuel prices January, March, and October 2005 (Rp/liter)

Fuel	Jan-05	Mar-05	Oct-05
Premium Gasoline	1,810	2,400	4,500
Diesel	1,650	2,200	4,300

Source: US Embassy Jakarta. 2004, Mar. Petroleum Report Indonesia 2002-2003. Available: <http://www.usembassyjakarta.org/econ/petro2003-toc.html>.

401. Thailand kept the price for diesel at US\$0.36/liter from January 2004 to February 2005, but by the summer of 2005 had ended the subsidy, costing the country an estimated US\$ 2.2 billion (Shrestha et al, 2005).¹⁵³ In 2005 Thailand also ended gasoline subsidies and raised the

¹⁵³ Global Network on Energy for Sustainable Development. 2005. Role of Renewable Energy for Productive Uses in Rural Thailand. Prepared by Ram M. Shrestha, S. Kumar, S. Martin, and N. Limjeearajarus from the Asian Institute of Technology. Available: <http://www.gnesd.org/Downloadables/RETS/AIT%20RETS%20final%20draft.pdf>.

diesel price by 3 baht per liter (US\$0.073/liter). Malaysia has also begun to raise fuel prices. As of March 2006, regulated pump prices rose 40% for gasoline and 100% for diesel since October 2004 (Reuters, 2006).¹⁵⁴ Bangladesh's government has also let prices rise by about 15% in recent years.

402. PRC and India, which have allowed the brunt of prices increases to be carried by state owned oil refiners have also begun to allow domestic prices to rise and to subsidize refiners due to persistent low margins and losses resulting from capped domestic prices and high international crude prices. In India, the Ministry of Petroleum and Natural Gas allowed prices increases in June and September 2005. Also for fiscal year 2005, the government decided to take over a portion (about US\$2.5 billion) of the refinery losses, for which bonds were to be issued to oil companies (ADB 2005).¹⁵⁵ In 2005, the Chinese government gave Sinopec a windfall payment of Rmb9.42 billion (US \$1.18 billion) to compensate for its refining losses and recently introduced a "special revenue charge" on crude oil producers in order to subsidize refiners. The tax, which applies to all Chinese oil producers, varies according to international crude prices between 20% and 40% on amounts exceeding US\$40 per barrel.

403. Increased fuel prices in recent years have also led to lower demand in Asia with impacts for economies and lower income groups in particular. In the first five months of 2005, oil demand fell by 8% in the Philippines (Energy Economist, 2005xx).¹⁵⁶ Many Asian countries are particularly vulnerable to price spikes due to the lower proportional tax rates on fuel. Since most countries place a fixed tax per liter on automotive fuels, high tax regimes tend to be more sheltered from price increases. This explains why high international prices have had a greater impact on domestic prices in low tax regime countries in Asia than in those countries with higher tax regimes like Korea and most European countries.

5. Implications for Cleaner Fuels in Asia

404. Ownership structure and tax and pricing regimes for petroleum fuels have implications for the way cleaner fuels will be introduced in Asia. Over the long-term open markets appear to be more conducive to the penetration of cleaner fuels than heavily regulated and closed markets. In open markets competition among firms helps to encourage investments in new products and fuels, yet, with government policy as the main driving force. A closed market with a state energy supplier, on the other hand, will typically not facilitate the production of cleaner fuels unless mandated by the government.

405. Market ownership and pricing policy affect opportunities for raising capital for investments in cleaner fuels. Highly regulated markets in low income countries for example, are likely to have difficulty raising capital for refinery upgrades if public resources are limited and there are restrictions on foreign ownership and investment. This has been a major problem, for example, faced by Indonesia in financing unleaded gasoline, where proposed solutions that would allow Pertamina, the state-owned oil company, to produce unleaded gasoline have been slow to materialize due to restriction on foreign ownership in refining and price controls combined with limited public financing options.

¹⁵⁴ Reuters. 2006. Malaysian police quash protests. 26 March. Available: <http://english.aljazeera.net/NR/exeres/D4ECE099-0295-47F5-9F30-B41262C464D9.htm>

¹⁵⁵ Asian Development Bank (ADB). 2005. The Challenge of Higher Oil Prices – Asian Development Outlook 2005 Update. Available: <http://www.adb.org/Documents/Books/ADO/2005/update/part030000.asp>

¹⁵⁶ Energy Economist. 2005. Philippines gets efficient. September

406. Also, industry is generally unwilling to invest in refinery upgrades where there is an inadequate guarantee that they can recover costs through price increases. In this case perceived inadequacies in potential demand, inflexible or unpredictable price controls and/ or price caps can discourage market actors (including potential importers and firms with state ownership) from making investments in cleaner fuels in Asia. A number of Indian firms, for example, have recently declined to invest in refinery upgrades for lower sulfur diesel because the government will not allow higher retail prices in the country due to pricing controls. At the same, time some Indian oil refiners are investing in upgrades to meet demand in foreign markets, where the cleaner fuels can fetch higher prices, while turning to imports to meet tighter domestic fuel standards. For 2004-05 fiscal years the Indian Oil Corporation imported 11 billion barrels in transport fuels, including 1.7 million to meet higher fuel specifications, from Singapore, South Korea and Taiwan. In the same year, Indian refiners operated at nearly 100% capacity producing 2.4 million b/d of petroleum products. Of this, state companies exported almost 176,000 b/d and Reliance exported 205,000 b/d, equivalent too nearly 1/3 of capacity at its Jamnagar refinery (Petroleum Intelligence Weekly, 2005).¹⁵⁷

407. While the market can and does provide cleaner fuels in countries that allow imports and flexible fuel pricing, suggesting that open markets are good for cleaner fuels in general, experience also shows that cleaner fuels can be bought or produced if the political will is sufficient, regardless of the market orientation of the downstream sector. Viet Nam Bangladesh, the Philippines and Pakistan, for example, introduced unleaded gasoline rapidly with regulations in the 1990s despite having relatively closed downstream market, demonstrating the importance of political will in introducing cleaner fuels in different economies throughout the region. Viet Nam has recently taken a similar approach to the introduction of lower sulfur fuels, despite the higher costs imposed on importers.

408. Furthermore, state-controlled markets with controls on pricing, while arguably not as efficient as open markets, may be more expedient agents in producing cleaner fuels when the political will exists to mandate cleaner fuels. State-controlled refining firms with large parent companies operating with subsidies and soft budgets may, in fact, have ready access to financing where the political will exists to support investments in cleaner fuels (in a similar way, for example, that Chinese oil producers have been recently taxed to subsidize local refiners) or where controlled prices would otherwise render such investments unattractive. Also, administered pricing may provide greater leverage to governments in pricing cleaner fuels more inexpensively than other fuels.

C. Incentives for Cleaner Fuels and Vehicles: Asian and International Experience

409. From the regulatory perspective, the introduction of higher quality fuels and especially the reduction of specific properties in fuels such as sulfur depend on a range of actions, including fuel specifications and bans, pricing and taxation policies, incentives, and public procurement and education. To improve fuel quality, governments typically issue a regulation or product specification. In order to accelerate investments, support regulations and encourage the market for cleaner fuels, governments can and often do intervene with some form of incentive in addition to regulations. Possible approaches include differentiated consumption and production taxes on fuels, subsidies or other incentives for refiners and similar measures for cleaner vehicles that can indirectly support the market for cleaner fuels as well as vehicles. A common approach among governments around the world has been to differentiate taxes on automotive

¹⁵⁷ Energy Intelligence Group, Inc. 2005. Petroleum Intelligence Weekly. May. Available: http://www.energyintel.com/PublicationHomePage.asp?publication_id=4.

fuel sales, creating a relative advantage for a particular higher quality fuel. This tax difference is often passed onto consumers in differentiated pump prices.

410. This type of policy approach can be viewed as a market-based or economic instrument. Market-based instruments have been utilized mainly in OECD countries in recent decades to support environmental policies. When environmental policies began to be adopted in the 1960s and 1970s authorities relied primarily on the 'regulatory' approach—prescribing objectives, standards and technologies such as ambient standards, emission standards, production process standards, and product standards, based on 'best available technology'. Economic approaches were developed by academic economists and entered into mainstream policy discourse in the 1980s. Economic instruments such as green taxes purportedly offered a more cost-effective and flexible means of environmental control that gave greater decision-making power to competitive markets and incorporated environmental policy into market rules and economic development goals. Economic instruments were intended to be less costly for society overall; to give long term incentives for innovation, to act as a source of tax revenue (that could be used for other social projects or to correct the distributional impacts of the environmental taxes); and to provide learning experience in the pricing of environmental services in general. Importantly, it was argued, economic instruments did not require that regulators have comprehensive and accurate knowledge of workings and capacities of industry, as is the case with regulations.

411. There have been both productive and less productive experiences with economic instruments. With regard to the vehicle and fuels sectors, the experience has been that the command and control approach has been generally effective at pushing the development of advanced technologies; and that economic instruments were effective at accelerating their introduction. In some cases the information requirements for setting tax or incentive rates and prices have been higher than anticipated. More recently, a 'portfolio' approach that includes a role for regulations, economic instruments and other techniques for specific problems is viewed as the most appropriate way forward rather than taking an either/or approach to command and control and market-based approaches. This is also the case in terms of fuel quality improvements. Tax policies and incentives help to lower the overall cost to society of meeting regulations by encouraging those companies with the greatest capacities to take the lead, but these tax policies are nonetheless complemented by regulations, public outreach and other tools. A number of Asia countries have made some use of cleaner fuel or vehicle tax incentives, as illustrated in the following examples and in Table 5.8.

1. Differentiated Taxation and Pricing for Fuels

412. Differentiating tax rates (and/ or prices) between fuels, through adjustments in the excise, import duty or other tax is a powerful instrument for supporting cleaner fuels, by helping level the playing field for more expensive-to-produce cleaner products.¹⁵⁸ Differentiated pump pricing

¹⁵⁸ While differentiated fuel taxes are the most common market-based approach to accelerate cleaner fuels, *direct subsidies* to producers for refinery upgrading can also be used. In 1990-1992 for example, Japan instituted a direct tax incentive to subsidize refinery investments required to lower sulfur content in diesel fuel below 2000ppm. Firms could opt for a 7% deduction in corporate tax or 30% accelerated depreciation on the purchased equipment. In 2004, the Japanese government provided a direct incentive for refiners to produce 10ppm sulfur diesel earlier than the January 2007 regulation. At the time the government acknowledged that raising prices to cover the costs of lower sulfur diesel would be difficult for industry due to the deflated Japanese economy and heavy competition in Japan. The government subsidized a total of US \$90 million over three years (2004-2006) accounting for about 2-4% of the actual investment of the Japanese petroleum industry. The subsidy was allocated on a first come first serve basis for those companies that produced or imported the fuel. The scheme was developed by the Ministry of Industry, the Ministry of Finance and the Ministry of Environment and was funded from the "Oil and Energy

also sends a clear signal to motorists concerning the relative social costs of different fuels. One common concern with adjusting taxes is lost public revenue, however, tax rates can be modified to capture changing fuel demand. These tax incentives have been applied most extensively in the global phase out of leaded gasoline. The European experience in the early 1990s shows the amount of price difference between leaded and unleaded petrol was directly and positively related to the market penetration of unleaded gasoline. Tax differentials have also been used in helping introduce unleaded gasoline in Asian countries (see table 5.8) although not in all instances. There has also been some longstanding pricing support for alternative fuels like LPG in Japan and South Korea or CNG in India for example.

Table 5.8: Fuel Price and Tax Differentials in Asia

Country	Fuel Incentive
Bangladesh	2006 CNG at 8.5 Taka/liter (US\$0.13) ¹⁵⁹ compared to 42 taka/liter (\$US0.64) for gasoline. Price for CNG lower since 1998 (US\$ 1.00 = Taka 70.00) 100% tax exemption on import of CNG conversion kits and dispensing units.
Hong Kong, SAR, China	2000: 50 ppm diesel HK\$ 0.89/liter (US\$0.11) ¹⁶⁰ less than conventional 500ppm 1991: ULG average HK\$ 0.52/ liter (US\$0.07) ¹⁶¹ less tax than LG over 8 years
India	2005: CNG exempted from VAT tax
Japan	2004: Total tax on non-commercial LPG 12.9 yen/liter (US\$0.13) versus total tax on unleaded gasoline at 59.2 yen/liter (\$0.57) ¹⁶² .
Malaysia	2003: CNG RM 0.585/ liter (US\$0.15) compared to RM1.35/liter (US\$0.36) for gasoline (RON 97) and RM 0.761/liter (US\$0.2) for diesel. ¹⁶³ 1991: ULG retail price 2.65% lower than LG
Nepal	LPG incentive
Philippines	1999: ULG 1 peso (US\$0.25) ¹⁶⁴ less than leaded 2003: lower duty rate on natural gas vehicle engines/ CNG price lower than diesel.
PRC	2005: Retail prices on gasoline and diesel in Beijing were raised by a

Conservation Fund", a duty dedicated to oil conservation and stockpiling, which typically generates around 500 billion yen annually.

¹⁵⁹ Converted May 15, 2006 rates

¹⁶⁰ Converted Dec 31, 2000 rate

¹⁶¹ Converted Dec 31, 1998 rate

¹⁶² Converted Dec. 31, 2004 rate

¹⁶³ Converted Dec 31, 2003 rate

¹⁶⁴ Converted Dec 31, 1999 rate

Country	Fuel Incentive
	greater margin than in other cities to compensate refining companies for the increased cost of providing Euro 3 in capital. 2005: the fuel excise tax is 0.28 yuan/liter (US\$0.03) for leaded petrol, 0.20 yuan/liter (US\$0.02) ¹⁶⁵ for unleaded 1999: LG tax increased to make its price no lower than ULG
Singapore	1991: LG raised 0.12 \$S/liter (US\$0.07) ¹⁶⁶ over ULG
South Korea	2004: 277 won /liter (US\$0.27) less on ULSD relative to conventional diesel.
Thailand	Planned: Biodiesel (5%) at least 0.75 (\$US0.02 THB/liter less than diesel 2006 ULG (95)= 27.14(US\$0.72); diesel=25.49 (US\$0.68); CNG=8.5 (US\$0.23); LPG=16.81 THB/liter (\$US0.45) 2005: Gasohol (90% petrol/10% ethanol) THB 0.50 (US\$0.01) cheaper than octane-95 petrol. 1991: ULG 1 THB/liter (\$US0.04) ¹⁶⁷ less excise tax than LG

Notes: CNG = compressed natural gas; LG = leaded gasoline; LPG = liquefied petroleum gas; NO_x = nitrogen oxides; ULG = unleaded gasoline; ULSD = ultra low sulfur diesel; VAT = value added tax

a. Hong Kong: Unleaded Gasoline

413. In 1991 the Hong Kong government instituted a tax differential to stimulate the market for unleaded gasoline that averaged \$HK 0.52 over an 8 year phase out period. The market changed to unleaded gradually and leaded was banned in 1999, when the market share of unleaded was over 90%. Table 5.9 shows the progressive market penetration of unleaded petrol in Hong Kong in accordance with a steady price and tax differential throughout the 1990s. Hung (2004) suggests the slow up take can be attributed to the relatively small price advantage for unleaded that was created by the policy.

Table 5.9: Sales, Prices and Duties for Gasoline in Hong Kong 1991-2001

	Local Sales (kiloliter)		Listed Price (HK\$/liter)		Duties(HK\$/liter)	
	leaded	unleaded	leaded	unleaded	leaded	unleaded
1991	383,026		7.87	7.07	4.17	3.72
1992	173,359	240,515	7.70	7.41	4.59	4.09
1993	160,853	291,019	8.10	7.76	5.03	4.48
1994	136,564	338,863	8.80	8.41	5.46	4.86
1995	113,380	353,792	9.44	9.00	5.90	5.25
1996	92,337	376,791	10.20	9.7	6.43	5.72
1997	73,508	408,010	10.79	10.24	6.82	6.06
1998	45,721	449,091	10.69	9.84	6.82	6.06

¹⁶⁵ Converted Dec 31, 2005 rate

¹⁶⁶ Converted Dec 31 199 rate

¹⁶⁷ Converted Dec 31 1993

	Local Sales (kiloliter)		Listed Price (HK\$/liter)		Duties(HK\$/liter)	
	lead	unlead	lead	unlead	lead	unlead
1999	3,990	507,502	N/A	10.34	N/A	6.06
2000	N/A	553,298	N/A	10.70	N/A	6.06
2001	N/A	575,950	N/A	10.40	N/A	6.06

Source: Hung, Wing-Tat. 2003. Taxation on Vehicle Fuels: Its Impacts on Switching to Cleaner Fuels. Energy Policy 34(16): 2566-2571. Available online October 2004. doi:10.1016/j.enpol.2004.08.018

b. Thailand: Unleaded Gasoline

414. In 1991 the Thai government introduced unleaded gasoline as part of a larger air pollution control strategy. The initiative was led by the National Energy Planning Office (an office of the Prime Minister) and included multiple ministries as well as oil and auto companies. Reformulation was required in order to maintain required octane levels and performance. For the short term, it was possible to import low level lead and unleaded gasoline, however, major modifications to local refineries were required to produce reformulated unleaded gasoline for the longer term.

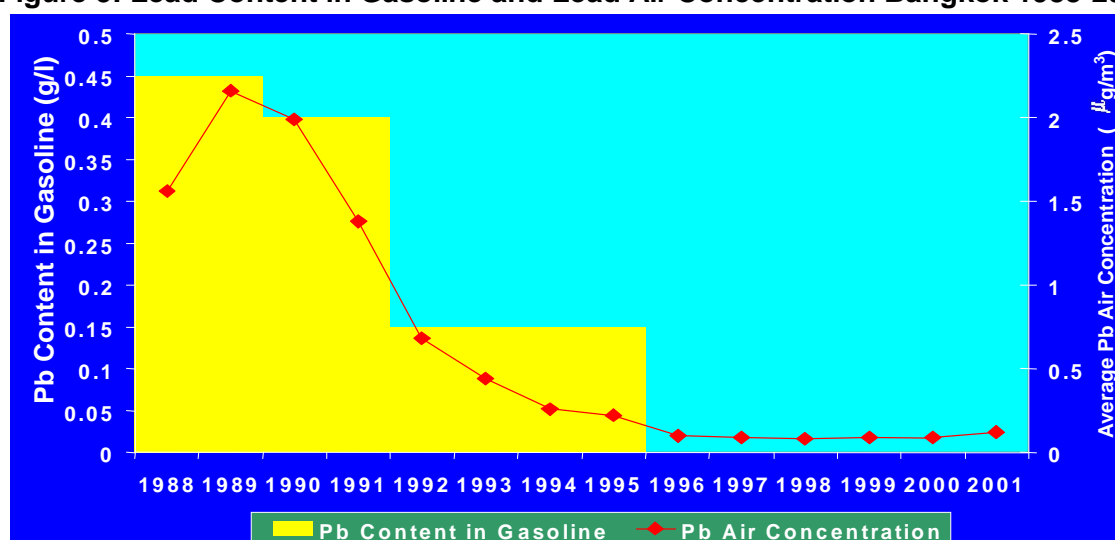
415. Although the costs of producing unleaded gasoline were higher than producing leaded gasoline (the net additional cost was estimated to be 0.5 Baht per liter), the government made the price for unleaded 0.3 Baht per liter less than leaded. To achieve this price, the government collected 1 Baht per liter less in excise tax on unleaded gasoline as indicated in table 4.10 for locally produced and imported products. This cost was financed primarily from the government's Oil Fund, which happened to be in a Baht 6.65 billion surplus in 1991 due to low world oil prices and a simultaneous tax increase on diesel fuel at 0.4 Baht per liter. In addition, the import duty on MTBE was lowered from 30% to 1% to encourage MTBE as a substitute for lead additives.

Table 5.10: Excise Tax on Gasoline in Thailand 1991-1992

Product	March 1991	May 1991	June 1991	Sept 1991	Jan 1992
Unleaded	-	2.9290	2.9290	3.1900	2.5850
Regular	3.9390	3.9390	3.9390	4.2900	3.3550

Source: NEPO, 1996 in Sayeg, Phil. 1998. Successful Conversion to Unleaded Gasoline in Thailand. World Bank Technical Paper 410. Washington, DC: The World Bank.

Figure 5: Lead Content in Gasoline and Lead Air Concentration Bangkok 1988-2001



Source: Wangwongwatana, 2002

416. Unleaded gasoline made a slow and steady penetration into the Thai market. However, it was not until 1995, a year prior to a leaded ban (and after a slowing period in 1994), that penetration reached 100% of the market. According to National Energy Policy Office, lack of consumer awareness played a significant role inhibiting the quicker uptake of premium unleaded fuel. Many drivers perceived unleaded fuel as a lower grade and questioned the safety of using the new fuel. As a response the government launched an awareness-raising and educational campaign for motorists.

c. Philippines: Unleaded Gasoline

417. In the Philippines in 1999 unleaded gasoline was assessed Php1.00 less excise tax than leaded (Php5.35 to Php4.35) through a policy initiative of the Department of Energy and the Department of Environment and Natural Resources. The result was approximately a Php0.5 pump price advantage for unleaded. Unleaded in the initial year of operation expanded its market share from 20 to 34 % in Metro Manila and 7- 15 % in the rest of the country. An attempt was made to recover lost tax revenue on unleaded gasoline with increases on taxes for less price sensitive fuel products.

418. When unleaded gasoline was mandated in 1999, the supply was first met through increased imports and then gradually met by local producers. While the price differential helped to generate the consumer uptake for the fuel, it was not considered an important factor in encouraging local refinery investments for unleaded. Investments that did follow were more likely a response to Asia Development Bank loans to the government, which were conditional on the development of an effective ban on unleaded gasoline in Metro Manila.

d. Sweden: Low and Ultra Low Sulfur Diesel

419. In 1991 the Swedish government introduced 10ppm and 50ppm sulfur diesel to the Swedish market with the assistance of a tax differential. Compared to the tax on standard diesel (350ppm) in 1990, tax on 10ppm diesel was lowered by 20 ECU/ cubic meter in 1991 and by a further 12 ECU in 1992. Tax on 50ppm diesel in 1991 was increased by 4 ECU and then decreased in 1992 by 8 ECU and tax on 350ppm was increased by 21 ECU in 1991 and kept at that level in 1992. Shortly thereafter, 10ppm diesel accounted for 85% of the market share, which was estimated to reduce particulate emissions by 10-30%, SO₂ emissions by 99% and NO_x by 11-15% (Arthur D. Little, 1998).¹⁶⁸

420. The tax differentials in Sweden were significant enough to motivate industry to invest in advance of regulations without increasing prices to consumers. Increased prices per liter for the refiner on higher quality fuel sales helped to cover the extra cost of investment. The total value of tax reductions (on higher quality fuels) equaled 600 million ECU and the total value of tax increases (on lower quality fuels) equaled 500 million ECU between 1991 and 1996, suggesting a revenue loss of 100 million ECU from 1991 to 1996. 18.5 billion ECU in tax revenue was collected from transport fuels in that period and industry invested approximately 540 million ECU in response to the tax differentials (Arthur D. Little, 1998).¹⁶⁹

¹⁶⁸ Arthur D. Little. 1998. Case Study: The Introduction of Improved Transport Fuel Qualities in Finland and Sweden. A Report to the Governments of Finland, Norway and Sweden.

¹⁶⁹ Arthur D. Little. 1998. Case Study: The Introduction of Improved Transport Fuel Qualities in Finland and Sweden. A Report to the Governments of Finland, Norway and Sweden.

e. United Kingdom: Low Sulfur Diesel

421. The United Kingdom (UK) introduced 50ppm diesel in 1997. At the time, the average sulfur content was 200ppm. A preferential tax rate of 1 pence per liter for low sulfur diesel (LSD) over conventional diesel was brought into effect in 1997 in order to offset additional production costs and to encourage diesel retailers to convert the diesel sold at their pumps. To accelerate the conversion, the differential was increased to 2 pence in 1998 and then to 3 pence in 1999. The UK had nine major and three smaller domestic refining units. In 1997 some companies began supplying LSD, including Shell, Total, ELF, Futura and Green Energy. However, there was generally limited access for motorists to the cleaner fuel and producers continued to manufacture conventional diesel. In 1998 a greater number of companies were producing the fuel and by 1999, with the 3 pence per liter advantage, all companies began supplying the higher quality fuel. By August 1999 LSD had achieved 100% share of the market, six years ahead of the EU mandate.

422. This tax differential was introduced by the Department of Environment, Transport and the Regions, but the final decision was taken by the Treasury. The tax differential resulted in some revenue loss for the government. In 1997, when the 1 pence differential was introduced, the cost in tax revenue was calculated at 15 million pounds per year and by 1999, with the increase to 3 pence per liter and the market shift to the lower taxed LSD, the revenue cost was estimated at 400 million pounds per year.

423. These measures were taken in the context of a larger fuel quality strategy in the UK starting in 1993, which consisted of a fuel duty escalator and several differentials to help mitigate local air pollution and reduce greenhouse gas emissions. Although the UK did not have a tradition of using fuel tax for environmental purposes, its commitments under the National Air Quality Strategy and the Kyoto Protocol provided the impetus for these policies. Moreover, the level of public awareness concerning the benefits of low-sulfur diesel was high in the UK, with a number of supporting civil movements. Bus companies also publicized their use of LSD as a form of marketing and public relations (HM Customs and Excise, 2000).¹⁷⁰

f. Hong Kong: Low Sulfur Diesel

424. Hong Kong introduced a tax advantage for LSD in July 2000 (along with tighter vehicle standards and other air improvement measures). The tax differential was HK\$ 0.89 for 50ppm diesel compared to the conventional 500ppm (from \$2.00 to \$1.11).

425. Subsequently, LSD penetrated 100% of the market over the summer of 2000. During the summer, the pump prices of LSD and regular diesel were equal. The government was further able to mandate higher vehicle standards- Euro 3, as well as to undertake an extensive diesel oxidation converters retrofit programme. The measure was seen as instrumental in achieving rapid market penetration for the cleaner diesel prior to the regulation in 2002.

426. A number of groups were involved, including, the Environment Bureau and the Environment Protection Department as well as the oil and vehicle companies. Prior to the instrument's introduction, there were internal studies undertaken on the costs and benefits of the differential. As the tax department was not readily willing to forgo revenue, the decision on the policy needed to come from the top of government. Lost revenue amounted to HK\$ 0.89 cent per liter. Notably, due to economic downturn, local truck unions have waged a successful

¹⁷⁰ HM Customs and Excise. 2000, Nov. Using the Tax System to Encourage Cleaner Fuels: The Experience of Ultra-Low Sulphur Diesel. Norwich. Available: <http://www.hm-treasury.gov.uk/media/8A0/32/89.pdf>.

lobby to retain the tax advantage and the government has not been able to re-instate the original tax rate on diesel.

427. As public support for the higher quality fuel was anticipated and there were no anticipated adverse impacts on vehicle operation, there were no major public outreach campaigns undertaken, as in the case of introducing unleaded gasoline in 1991. Along with other programmes, the measures helped reduce the number of smoky vehicles by more than 80% from 2000-2004. At the same time there was a subsidy put in place for light and heavy duty diesel vehicle for retrofits (diesel oxidation catalysts or particulate traps).

2. Differentiated Taxation and Pricing for Vehicles Incentives

428. Tax incentives for tighter standard and lower emission vehicles that often rely on higher quality/cleaner fuels (see section 2) are an important component of a government's overall strategy to reduce vehicle emissions. In terms of cleaner fuels, tax incentives for tighter standard vehicles send an indirect signal to oil producers that higher quality fuels will be required for new fleets, as has been the case in Singapore where oil producers have begun to supply Euro 4 fuels to incentivized market segments like diesel taxis, before country-wide Euro 4 emissions standards come into effect.

429. Vehicle incentives generally include fee exemptions and tax credits for cleaner or more efficient vehicles. Vehicle taxes for consumers are often assessed as acquisition, registration, or road taxes and can be differentiated between products in the same fashion as fuel products. As with fuel tax incentives, vehicle tax incentives will often be used in conjunction with regulations to accelerate market uptake.

430. Market based approaches targeting manufactures, such as the use of emission standard quotas and targets is another approach aimed at innovation rather than the accelerated implementation of established standards.

Table 5.11: Vehicle Price and Tax Differentials in Asia

Country	Vehicle Incentive
Japan	2004: Hybrid electric vehicles charged 0.8% of retail prices for registration tax- and diesel/petrol vehicles are charged 3%. 2004: 11-year-old diesel vehicles and 13-year-old gasoline vehicles pay 10% additional tax. 2001: 25%-75% tax reduction for gasoline and diesel vehicles meeting higher NO _x emissions standards.
Malaysia	2003: 50% reduction in road tax for CNG vehicle
Nepal	Tax incentive of up to 33% for electric vehicles
PRC	2006: cars with engines exceeding two liters face consumption tax of 20%, up from 8 %, while taxes on smaller cars will remain unchanged or will be reduced. 2005: 30% consumption tax exemption on vehicles with installed Onboard Diagnostics

Country	Vehicle Incentive
	<p>2005: 4000 RMB (US\$495.00) subsidy for scrapped or dismantled buses and trucks used for 8-10 years.</p> <p>2003: 30% consumption tax exemption for automakers meeting Euro 3. 30% excise tax reduction on Euro 2 light duty vehicles in Beijing.</p>
Singapore	<p>2006 Euro 4 taxis get 40% rebate on Additional Registration Fee and Euro 4 buses and commercial vehicles 5%. EURO 4 passenger cars 30% lower rise in Special Tax than non Euro 4 vehicles.</p> <p>2005: "Green" vehicles--those with CNG, electric, or hybrid engines 20% road tax reduction (same as gasoline rate rather than diesel)</p> <p>2003: 100% rebate on basic car price for Euro 4 taxis</p> <p>2003: Additional Registration Fee (usually assessed as 110 % of market value of the vehicle) exemption for Euro 4 buses and commercial vehicles.</p>
South Korea	2004: CNG buses exempted from VAT and acquisition taxes, equivalent to approximately US\$3,000 per bus
Viet Nam	2006: Import duties differentiated for vehicles based on engine size: - US\$ 3000 for cars under 1000 cc, and US\$ 25,000 for cars over 5000 cc

Notes: CNG = compressed natural gas; LG = leaded gasoline; LPG = liquefied petroleum gas; NO_x = nitrogen oxides; ULG = unleaded gasoline; ULSD = ultra low sulfur diesel; VAT = value added tax

a. Singapore

431. Singapore has introduced vehicle incentives to accelerate the introduction of Euro 4 diesel vehicles (that require 50ppm fuel) leading up to its October 2006 Euro 4 vehicle emissions regulation deadline. Taxi fleets and to a lesser extent buses and commercial vehicles have received incentives, mainly in the form of rebates on the Annual Registration Fee. Accordingly, oil companies in Singapore geared up to provide Euro 4 (50ppm) diesel for direct supply to these particular market segments.

432. Passenger cars all pay an Annual Registration Fee of 110% of the Open Market Value¹⁷¹ (OMV). Currently, CNG, Electric and Hybrid vehicles pay only 70%. Euro 2 taxis pay an Annual Registration Fee of 110% but Euro 4 taxis and CNG taxis only pay 30%. Buses and commercial vehicles in general enjoy tax advantages over passenger cars. Euro 2 diesel buses and commercial vehicles have an annual registration fee of 5% of OMV and Euro 4 and CNG are exempt.

433. Euro 4 diesel passenger vehicles pay less fuel/special tax than Euro 2 vehicles. CNG and electric passenger vehicles are exempt from fuel/special tax.

¹⁷¹ OMV (Open Market Value) is the basic price of the vehicle determined by customs on import. The value includes the cost, insurance and freight charges and is used as the basis for calculating taxes such as the Annual Registration Fee

Table 5.12: Vehicle Taxation in Singapore

Tax / Vehicle	Customs	Annual Registration Fee	COE*	Fuel / Special Tax	Road Tax**
Passenger Cars					
Petrol	20%	110% OMV***	Payable	\$0.37 - \$0.44/L	By Formula
Euro II Diesel	20%	110% OMV	Payable	6 times road tax	By Formula
Euro IV Diesel	20%	110% OMV	Payable	4 times road tax	By Formula
CNG and Electric	20%	70% OMV (rebate of 40%)	Payable	\$0	By Formula
Hybrid	20%	70% OMV (rebate of 40%)	Payable	\$0.37 - \$0.44/L	By Formula
Taxis					
Euro II Diesel	20%	110% OMV	Payable	\$5100	By Formula
Euro IV Diesel	20%	30% OMV (rebate of 80%)	Payable	\$5100	By Formula
CNG	20%	30% OMV (rebate of 80%)	Payable	\$0	By Formula
Buses and Commercial Vehicles					
Euro II Diesel	Exempt	5% OMV	Public and school buses are exempt	\$0	By vehicle category
Euro IV Diesel	Exempt	0% OMV ^a (rebate of 5%)	As above	\$0	By vehicle category
Petrol	Exempt	5% OMV	As above	\$0.37 - \$0.44/L	By vehicle category (20% less than diesel road tax)
CNG	Exempt	0% OMV ^a (rebate of 5%)	As above	\$0	By vehicle category (20% less than diesel road tax)
Electric and Hybrid	Exempt	5% OMV ^b	As above	\$0	By vehicle category (20% less than diesel road tax)

Notes: COE = certificate of entitlement; CNG = compressed natural gas; OMV = open market value; L = liter

* Certificate of Entitlement (COE) is the certificate required for newly registered vehicles in Singapore, the price for which is established in an open bidding system in bi-monthly auctions.

** Vehicle road tax in Singapore is assessed on the basis of engine size with formulas for four sizes ranging from less than 600CC to greater than 3000CC.

^a Except Euro IV Goods-cum-Passenger Vehicles for which an ARF of 110% OMV applies (they do not enjoy an ARF rebate under the legislation).

^b Except CNG Goods-cum-Passenger Vehicles which attract an ARF of 110% OMV but enjoy an ARF rebate of 5% OMV, resulting in a net ARF of 105% OMV.

Source: Land and Transport Authority

434. Euro 4 diesel taxis have been the primary targets of incentives, reflecting the fact that higher quality diesel can most effectively be introduced to fleets in early stages of phasing in the fuel. In 2004 and 2005 Euro 4 diesel taxis paid only 10% of OMV in Annual registration fee (ARF) (compared to the standard 110%) and will pay 30% in the first three quarters of 2006 and 70% to the end of 2007 when the rebate will be phased out. EURO 4 passenger cars receive a 30% lower rise in Special Tax than non Euro 4 vehicles. From 1 Oct 2006, Singapore will require Euro 4 emission standard for all new diesel vehicle registrations.

Table 5.13: Euro 4 Vehicle Incentives in Singapore 2004-2008

TAX INCENTIVES / CHANGES FOR VEHICLES				
	1 Jun 04 – 31 Dec 05	1 Jan 06 – 30 Sept 06	1 OCT 06 – 31 DEC 07	1 JAN 08 ONWARDS
<u>Euro IV Diesel Passenger Cars</u>				
Special tax	6 times the road tax	4 times the road tax		
<u>Euro IV Diesel Taxis</u>				
ARF rebate	100% OMV	80% OMV	40% OMV	No ARF rebate
<u>Euro IV Diesel Buses & Commercial Vehicles</u>				
ARF rebate	5% OMV	5% OMV	5% OMV	No ARF rebate

ARF = annual registration fee; OMV = open market value

Source: Land and Transport Authority

b. USA

435. Incentive programme for environmentally friendly vehicles in the USA, mainly California, have typically structured programmes to promote innovation in manufacturing rather than subsidize specific technology. For example, the California Vehicle Emission Standard established a minimum market share for 'low' and 'ultra low' emissions vehicles-where companies were fined \$5000 per vehicle for not meeting the required market share through production or the acquisition of tradable credits from other firms. Also the California Carl Moyer Memorial Air Quality Standards Attainment Program provides incentives for improve vehicle emission standards. Up to US\$140 million a year is available from the state. From 2002 to 2003 the programme helped reduce over 750 tons of NO_x emissions as a result of funding for 453 new engines and vehicles in Southern California. In 2004, this program was expanded to include cars and light-duty trucks.

c. Germany

436. Incentives for higher standard vehicle can also be applied. Since 1985 a large difference has existed in rates on cars on environmental grounds in Germany. In 2002 Euro 4 gasoline cars were exempted up to 250 Euro and 100 Euro in 2003- a 5 year savings of 2500 Euro (Friedrich, 2005).¹⁷² In 2000-2003 diesel vehicles meeting Euro 4 standards were exempted up to 600 Euro, after and 2003 280 Euro. In 2005 Germany imposed a heavy duty vehicle road tax that is differentiated across different Euro standard vehicles.

437. In addition to determining vehicle characteristics to be taxed it is important to determine whether the tax should be an acquisition tax (sales) or on the basis of an annual licensing and registration. Acquisition taxes may reduce turnover in vehicles and thereby, reduce the overall penetration of new lower emission vehicles, whereas annual registration taxes are targeted at costs of continued use of heavier emitting vehicles and may be better of overall air quality.

¹⁷² Friedrich, Axel. 2005. Economic Incentives and the Environment. Presented at Environment 2005: Sustainable Transportation in Developing Countries, Abu Dhabi, 29 January - 2 February.

d. Japan

438. Japan, in addition to offering tax incentives for more fuel efficient vehicles like hybrid electric vehicles, also has a Green Vehicle programme which has helped introduce lower emissions vehicle since 2000. Cars with NO_x emissions equivalent to 25% of 2000 standards are granted a 50% reduction in taxes, those with less than 50% of 2000 standards are granted 25% reduction in taxes and those with less than 75% are granted 13% reduction in taxes. Also, eleven year old diesel vehicles and thirteen year old gasoline vehicles are penalized with a 10% additional tax. Low emissions vehicles (those with either 25%, 50%, 75 % of 2000 standards) increased from 882,049 in 2000 to 2,390,762 in 2001 (Hirota, 2002).¹⁷³

e. PRC

439. PRC has also provided incentives for lower emissions vehicles in the capital as well as incentives for more efficient vehicles. 2006: cars with engines exceeding two liters face consumption tax of 20%, up from 8 %, while taxes on smaller cars will remain unchanged or will be reduced. In 2003 a 30% consumption tax exemption for automakers meeting Euro 3 was instituted along with a 30% excise tax reduction on Euro 2 light duty vehicles in Beijing.

D. Differentiated Fuel Taxes for Cleaner Fuels in Asia and Policy Considerations

440. Differentiated product taxes and prices to support cleaner fuels are likely the most promising form of market-based government support for higher quality fuels in Asia. Other forms of incentives such as direct subsidies for capital improvements may also play a role as they have done, for example, in Japan but regional preferences for market rationalization and the reduction of fuel subsidies as well as the constraints on public budgets in the face of high oil prices make the discussion over direct subsidies for higher quality fuels less attractive. Incentives for clean vehicles play a direct role in reducing vehicle emissions and but only an indirect role in supporting the introduction of cleaner fuels.

441. Many countries in Asia have a history of differentiating fuel prices and taxes to accelerate or sustain the use of cleaner fuels. Many have introduced and retained lower prices for unleaded gasoline and many have introduced and retained lower prices for compressed natural gas, liquefied petroleum gas and more recently gasohol. In the case of lower sulfur fuels and Euro standard fuels, Hong Kong has differentiated prices between lower sulfur and conventional diesel. Japan, Singapore and PRC have differentiated taxes for vehicles that meet different Euro standards. These experiences from Asia and those from different parts of the world discussed above, suggest a potentially important role for further use of prices differences in meeting higher fuel quality standards in Asia over the coming years. Still there are important considerations for each case.

1. Differentiated Taxes and Instrument Performance

442. In theory, market-based approaches, such as product tax differences, function most effectively in market-based, open economies. Adequate performance of economic instruments in general requires functioning markets, defined and enforceable property rights, fiscal structures, controlled inflation, efficient and transparent circulation of information, general acceptance of the polluter pays principle, and non-monopolistic conditions. Tax modifications

¹⁷³ Hirota, Keiko. 2002. Comparison of Vehicle Related Taxes by Cross Section. Better Air Quality in Asian and Pacific Rim Cities 2002, Hong Kong SAR, 16-18 December. Available: http://www.cse.polyu.edu.hk/~activi/BAQ2002/BAQ2002_files/Proceedings/PosterSession/48.pdf.

such as those described above may not perform equally well in non-competitive markets. In the case of Hong Kong, which imports its refined products in an open and competitive market, the HK\$0.86 incentive in 2000 triggered a rapid shift to ultra low sulfur diesel over the short period of one summer. Similarly, the decision to increase the tax advantage for ultra low sulfur diesel in the UK from 2 to 3 pence per liter in 1999 appears it was sufficient to trigger investments among all suppliers, years ahead of regulation deadlines. As indicated in table 5.2 many Asian countries have state-owned oil and refining sectors (although this appears to be changing). In such cases soft budgeting practices, subsidies and lack of competition may make moderate tax modifications ineffective or less efficient in stimulating investments.

443. In Japan, Hong Kong, Sweden and the UK prices are also characterized by open market pricing systems and high tax regimes. One implication here, in addition to the above remarks concerning instrument performance, is whether or not there is a sufficient tax margin to make a differential. Quite simply, countries with very low tax margins or subsidies on fuel may not have sufficient tax margins with which to influence preferences for different products in the same fashion outlined in the above examples. Also, any type of tax modification that leads to revenue loss in low tax countries will potentially constitute a relatively large disruption to tax revenue. This is not so much an issue in countries with large tax margins on fuel products. In Sweden for example, losses in tax revenue due to the tax differential on ULSD were approximately ECU 100 million- a relatively small amount when considered against the ECU 18.5 billion total in taxes collected on fuels in that period.

444. This does not mean that Asian countries with state controlled pricing, low taxes or subsidies are unable to provide some form of pricing incentives to refiners and /or motorists for higher quality fuels. In fact, those countries with price control practices could be seen as having the strong state administered levers necessary to implement price differentials for cleaner fuels - although, the economic performance of such an approach is perhaps less reliable. Similarly, those countries with subsidies on fuel can differentiate/ or increase subsidies in an analogous manner to differentiated taxes in order to support lower sulfur fuels, as Indonesia is beginning to do in support of unleaded gasoline. Similarly, retail prices on gasoline and diesel in Beijing were raised by a greater margin than in other cities to compensate refining companies for the increased cost of providing Euro 3 in the capital.

445. However, over the medium to long term, phasing out distorting subsidies and improving efficiencies can improve the attractiveness of cleaner fuel investments, as discussed out in section one. In principle, open markets and free prices are seen as important precursors to generating capital, generating opportunities for imports and allowing refiners to pass costs of cleaner fuels onto motorists or at least fetch market prices for products. Nevertheless, to help introduce cleaner fuels over the short term governments should take advantage of existing regimes and practices in the country.

2. Differentiated Taxes and Finance

446. In theory tax differentials can be designed to be revenue-neutral across fuel grades if the government adjusts the differential to maintain constant revenues, according to consumption. Hong Kong's phased use of a tax differential to introduce unleaded gasoline from 1991 was apparently revenue neutral, as was the case in some European countries like Denmark with the introduction of lower sulfur diesel. In some cases, such as the raised tax on leaded gasoline in Singapore in 1991 by 12 cents, there may, in fact, have been a revenue gain. Also, administrative costs are generally low, as the fuel duty is collected through established procedures and a few collection points.

447. However, it appears in most instances (at least those reviewed above) that tax differentials do result in missed public revenue, notwithstanding the likely net gains in overall public benefits. In the case of the UK, at 3 pence per liter, the estimated loss in revenue was approximately 400 million pounds per year. In Hong Kong the drop in tax on ULSD (\$HK 0.89 per liter) in 2000 was not replaced by higher taxes on other fuels and continues as a 'loss'. Considering the tight fiscal position of many countries in Asia, tax policies that reduce revenue may not be feasible, especially in a period of high international oil prices. Still, such initiatives can remain viable. Pricing incentives on CNG in Bangladesh are maintained despite the estimated cost of approximately US\$300 million per year as well as high international prices. Notably the successful use of an excise differential for unleaded gasoline in Thailand in the early 1990s was made possible in part due to the surplus status of the Thai Oil fund, and low world oil prices at the time. Conversely, the Thai Oil fund has run a deficit recent years and in 2005 carried an 80 billion baht deficit. Still recent tax breaks for gasohol are planned to be financed from the Thai Oil Fund. Nepal has maintained a subsidy for LPG at a loss to the Nepal Oil Corporation.

3. Differentiated Taxes and Political Acceptability

448. Fuel tax changes require support within government and among the public. Decisions within government to alter taxation in particular, are often met with resistance due to the highly political nature of fuel taxation. Accessing fuel taxation as an instrument for environmental goals may be particularly challenging during high oil price volatility or economic downturn. Importantly, tax and pricing policies in general require close cooperation between ministries of environment and ministries of finance as well as between the government and private oil companies. Ultimately, it is the finance ministry that will be responsible for implementing the tax change, although the political basis will likely come from the environment or health ministry. In the case of ULSD tax in Hong Kong, the finance ministry was initially opposed to the tax incentive and the final decision to implement the tax came from the most senior levels of government. One reason for Japan's use of direct subsidies to refiners to accelerate lower sulfur fuels has been to avoid the political negotiations often required for adjustments to the tax code that would be involved in modifying fuel tax regulations.

449. Among the public, price differences at the pump may be met with resistance. While general price increases are almost always met with resistance (as seen in Indonesia in the past and Malaysia more recently), differential pricing between fuel substitutes is likely to meet with resistance if the lower priced fuels are viewed to benefit groups that drive the newer cars for which the fuels are required or if the lower priced fuel is viewed to be incompatible with certain vehicles. This has been a problem in places where the public believed that unleaded gasoline could not be used safely in older cars due to concerns over valve-seat recession. In South Africa, public resistance over this issue led to the reversal of a tax incentive for unleaded gasoline. As it turns out, this is largely an education issue as there are no major technical problems associated with unleaded gasoline in older vehicles. Proper awareness-raising campaigns can overcome public resistance toward new, higher quality fuels if it exists. In Hong Kong and the UK, citizens and civic groups were well aware of the benefits of lower sulfur fuels and many, in fact, were involved their promotion, especially in the UK.

450. Certainly, the overall political currency of fuel tax adjustments within governments and among the public will depend partially on the accuracy of knowledge on the emissions benefits of cleaner fuels as well the level of awareness in society of the importance of fuel quality for air quality and health issues. Public awareness raising, the presence of local scientific analyses of air quality and health issues and fuel, and a strong role for civil society activity will enhance political feasibility.

E. Concluding Remarks on Pricing, Taxation and Incentives for Cleaner Fuel

1. Regulations are the most important

451. The global experience shows that regulations are instrumental in establishing the market for cleaner fuels. The global phase out of leaded gasoline and the reduction of sulfur levels in gasoline and diesel, for example, highlight the important role for regulations. Tax advantages and incentives have helped accelerate and support cleaner fuels, but have not substituted for the certainty and results associated with fuel specifications and regulations.

452. In countries with refining industries incentives may form part of the public sector stance to force tighter regulations, and this may be particularly important in countries with domestic refining sectors. Experience such as that in Viet Nam shows that incentives are not necessary where the political will exists to implement tighter standards. Also, where controlled pricing regimes make local investments in cleaner fuels unattractive, industry has still been able to meet tighter specifications through imports as the case of India and Philippines shows with lower sulfur fuels.

2. Short term pricing and tax measures can be undertaken to foster cleaner fuels, despite the type of pricing regime in place

453. Market pricing allows refiners to pass higher costs of cleaner fuels on to consumers to recover capital costs. Over the long run, this may well be the most important fuel pricing policy issue concerning the introduction of fuel cleaner fuels. High international prices in recent years have illustrated the non-sustainable nature of subsidized fuel prices in general. Equally, differential pricing for automotive fuel standards and pollution characteristics should factor into longer term fuel pricing policy discussions.

454. Over the short term, however, more immediate tax and pricing measures can be adopted to expedite the introduction of cleaner fuels. Measures that offer incentives for cleaner fuels can follow these larger shifts in pricing regime reform. Subsidies and pricing formulas can be differentiated between fuels in countries with greater state control or an incremental approach can be developed for specific locations. In PRC retail fuel prices have been allowed to increase to a greater degree in 2005 in Beijing to allow refiners greater flexibility in meeting more stringent Euro 3 standards in the capital. In any case, sufficient time should be given to the industry to plan, and carry out the necessary investments to retrofit its entire supply chain to assure a smooth transition.

455. Fuel and vehicle price / tax differentiation are the main instruments to consider. Direct subsidies such as the type introduced in Japan for lower sulfur diesel, may not be appropriate given the levels of efficiency in many countries or the feasibility of subsidies with higher international prices. The design aspects and impact will vary from country to country.

VI. TIMING AND APPROACH IN THE INTRODUCTION OF CLEANER FUELS IN ASIA

456. Cleaner fuels will play an important role in reducing vehicle emissions and improving urban air quality in Asia. Fortunately, most of the Asian countries have already started to plan for the introduction of cleaner fuels in conjunction with more stringent new vehicle standards with the objective to reduce emissions from mobile sources of pollution. The observations and recommendations put forward in this chapter are intended to support the dialogues and discussions already taking place and to help develop a dialogue on fuel roadmaps in those countries where no substantial discussion has been started. It is acknowledged that setting the agenda for cleaner fuels and vehicles will involve consultations and trade-offs between different stakeholders and agendas. This report and the recommendations in this chapter are aimed at strengthening the environmental dimension in such dialogues and thereby promoting environmentally responsible decisions and actions on fuels and vehicles.

457. A very high priority for Asia will be to complete the phase out of leaded gasoline in those countries where leaded gasoline is still available in the market.

458. As mentioned in this report several individual countries in Asia have already largely decided on their future fuel specifications and when these should be in place. Thailand in 2004 confirmed its intention to have Euro 4 similar fuels in 2010 with the possibility to go beyond these requirements and introduce shortly after 2010 ultra low sulfur fuels with less than 15 ppm sulfur¹⁷⁴. Korea, Singapore, Taipei, China and Hong Kong, either already have Euro 4 similar fuels or will shortly have them¹⁷⁵. At the sub-regional level the discussions conducted under the umbrella of ASEAN - Ministry of Economy, Trade, and Industry (Japan) Economic and Industrial Cooperation Committee (AMEICC) Working Group on Cleaner Fuels in Asia by representatives from the Japanese and ASEAN vehicle industry and the ASEAN governments are moving towards the adoption of a flexible non binding framework in which ASEAN member countries commit to introduce Euro 2 equivalent emission standards by 2006 and Euro 4 equivalent emission standards by 2010-2012. This is in line with the objectives for sulfur levels agreed upon by the Partnership for Clean Fuels and Vehicles which set a goal of 50 ppm sulfur or less in gasoline and diesel worldwide.

459. Individual oil companies have already started to develop capacity to produce 50 ppm sulfur diesel even though there is no formal requirement for them to do so. Petron in the Philippines and Reliance in India are either already producing ultra low sulfur diesel or will soon be able to do so.

460. Decision making on the introduction of cleaner fuels should be based on a broad based dialogue among all stakeholders. The main benefits in terms of reduced emissions resulting from the introduction of cleaner fuels will be produced by new vehicles with advanced emission control devices. Considering the rapid motorization in many of the Asian countries, the sooner cleaner fuels and vehicles will become available the fewer relatively "dirty" vehicles there will be in Asian cities. Fuel quality regulators are driven by several considerations. In addition to concerns about poor air quality and related costs to society, energy security, industrial policy and macro economic considerations also influence decision making on fuel quality.

¹⁷⁴ Thailand since then has moved back the introduction of Euro 4 vehicle emission standards with 2 years to 2012.

¹⁷⁵ These fuels are equivalent to EURO 4 in sulfur content but could have higher aromatics, benzene, olefins, or RVP and should not be characterized as equivalent in terms of emissions, drivability, engine wear and fuel efficiency.

461. The fuel mix of the future in Asia will be more diversified, and alternative fuels such as CNG, LPG and biofuels will have a larger market share. Such alternative fuels can play an important role in reducing air pollution caused by the transport sector. The consensus among experts, however, is that the bulk of transportation fuels over the next 10-15 years in Asian cities will remain gasoline and diesel.¹⁷⁶ It is thus important for policy makers to develop and agree upon future standards for gasoline and diesel. Following a period in which no new refining capacity was created in Asia the surging demand for transportation fuels has resulted in additional demand which can no longer be met by existing refining capacity. The need to create new refining capacity or to upgrade and/or expand existing refineries creates a window of opportunity to shape the future refining structure in Asia which fuel regulators should not pass over.

462. If policy makers in Asia intend to continue to promote diesel as the preferred public transport fuel by maintaining incentives, they should ensure that they promote “clean” diesel and not “dirty” diesel. From the viewpoint of climate change mitigation, the preference for diesel might be wise considering the relatively higher combustion efficiency of diesel which will result in lower CO₂ emissions. In addition some countries may be interested in increasing the deployment of more efficient diesel vehicles in order to decrease oil imports as part of an energy security strategy. However, these climate benefits may be lost if the diesel fuels and vehicles are not very clean since black carbon emitted from diesel vehicles is increasingly recognized as a potent greenhouse pollutant. Pursuing such synergies between fuel quality strategies, urban air quality management strategies and climate change mitigation strategies can help to strengthen the support for all three objectives and improve the chances for their successful implementation. Fuel specifications influence emissions but they also influence drivability, engine-wear, as well as fuel efficiency which is important in terms of impact on greenhouse gas emissions.

463. In the development of roadmaps for Asian countries the following factors will need to be considered:

A. Integrated approach

464. Fuels and vehicles are an integrated system and should be dealt with as such. There is a need to consider the fuel-vehicle relationship within an overall, wider, air quality context. The specific air quality context in a country or city can influence detailed formulation and implementation of cleaner fuel regulations. Taking into account the international experience outside Asia and in selected Asian countries, the severity and nature of air pollution in the majority of Asian cities, the absence of detailed emission inventories and source apportionment studies should not prevent Asian countries from deciding on a roadmap for cleaner fuels. In parallel to the implementation of agreed upon fuel roadmaps, Asian countries should continue to strive to improve the frequency and quality of detailed emission inventory and source apportionment studies. This will help to further improve and fine tune the planning and implementation of integrated vehicle emission reduction strategies.

465. For example, PRC has adopted a roadmap for new vehicle standards, laying out a schedule to introduce Euro 3, 4 and (for heavy duty vehicles only) Euro V standards in 2008, 10 and 12, respectively. However, they have not yet adopted a companion roadmap for clean fuels. Failure to do so will either result in the need to delay the vehicle standards or lead to higher in use emissions than would otherwise be the case, perhaps much higher.

¹⁷⁶ ADB. 2006. Consultation draft on Energy Efficiency and Climate Change Considerations for On-road Transport in Asia

B. Fuel specifications

466. What are the fuel parameters that need to be regulated? Is there a model that can be followed so that Asia does not have to start from scratch?

467. Asian countries can benefit from the fact that they lag behind Europe and other parts of the world and can base decision making on fuel quality research and refinery advances implemented in Europe, Japan and the USA. Extensive research has been conducted in support of the development of these standards as summarized in Chapter 2 of this report. The development of vehicle emission and fuel standards is not only based on emission reduction potential but takes into account other factors such as drivability, engine wear and fuel efficiency. Few Asian countries will have the resources to duplicate this supportive research. One country in the Asia-Pacific region which decided to base its fuel standards on Euro specifications but to conduct additional research to set the specific standards is Australia.¹⁷⁷

468. Since Asian countries have indicated a preference for Euro emission standards, they should, where possible, implement all fuel parameters as defined in the fuel specifications linked to the different Euro emission specifications. This to ensure that all objectives related to emissions reduction, drivability, engine wear and fuel efficiency are optimized. One area where Asian countries can apply some variation is RVP taking into account local climatic conditions and requirements to blend biocomponents such as ethanol.

469. For properties where there is potential for deviation from the EURO 4 standards (RVP, Olefins, Aromatics) a detailed evaluation should be performed together with an evaluation of alternatives to determine the emissions increases and the air quality penalties associated with the relaxation of the standards. This will enable the decision makers to decide on the optimum strategy in order to minimize adverse environmental impacts. This is similar to the Australian approach and the approach followed by the USA, where, when industry proposes a relaxation of the standards, an evaluation is performed to determine the optimum path. However, there might be circumstances in which the implementation of such a comprehensive set of fuel properties would delay the introduction of cleaner fuels substantially. In such cases, decision makers will have to make a trade-off and decide whether the benefits of, for example, first reducing the sulfur levels without addressing other fuel properties, outweigh the disadvantages this may cause.

470. The phase out of leaded gasoline, which has been completed in almost all of the Asian countries, has raised the issue of using other octane enhancing additives and oxygenates for the use in gasoline. Consideration of this issue should take place in the context of the global experience in addressing the health impacts of leaded gasoline. Many Asian countries have no regulations in place for major categories of octane enhancing additives such as MMT or other metal based additives and oxygenates such as MTBE, ETBE and Ethanol.

471. In deciding to regulate the use of octane enhancing additives and oxygenates, Asian countries should consider the impact of the use of these additives on (a) vehicles and vehicle

¹⁷⁷ Australian Government Department of the Environment and Water Resources. Setting the Standards. Last updated: Monday, 19-Sep-2005 11:09:47 EST. Available: www.deh.gov.au/atmosphere/fuelquality/standards/setting.html Australia adopted an approach whereby the commitment was made to selectively align with the Euro specifications but each parameter would be subject to a benefit analysis based on a need to regulate and if so the degree (i.e. required specification level to achieve the desired result) of regulation versus air quality. See www.deh.gov.au/atmosphere/fuelquality/standards/setting.html for an overview of the detailed process.

emissions, (b) the health impact of such additives and their combustion by-products and (c) the technical alternatives to produce gasoline with required octane levels.

472. The automobile manufacturers have raised serious concerns about the impact of MMT and ferrocene on vehicle emissions. These concerns stem from the adverse impact these additives may have on the functioning of catalysts, O2 sensors and OBD equipment, and the potential for increased emissions. From a viewpoint of air quality management these are serious concerns.

473. The use of MTBE and related additives such as ETBE and TAME have minimal effect on emission control devices that most of the new vehicles are equipped with. These additives generally reduce CO and HC emissions while leading to higher aldehyde emissions. A concern over ground water contamination by MTBE has however resulted in a ban on the use of MTBE in some countries.

474. Ethanol, when, added to gasoline, in quantities of less than 10% by volume (E10), has minimal effect with new vehicles equipped with oxygen sensors. E10 typically results in lower CO, HC, and when above a 2% oxygen content, a slight NOx increase. E10 can, however, increase evaporative emissions unless RVP is adjusted. Concerns have been raised on potential effects of fuel system components, particularly for older vehicles, as well as deposit issues. Ethanol is primarily used as a strategy to promote biofuels and not to enhance octane.

475. Serious concerns have also been raised on the health impacts of MMT. This has resulted in an ongoing review of the latest research by the U.S. EPA, as well as a comprehensive review of manganese risk by Health Canada. The majority of Asian countries will lack the capacity and resources to replicate such comprehensive health impact studies and are advised to take note of the results of the studies by Health Canada and the US EPA when they emerge, along with other studies, before they authorize refiners to start using MMT. They should also carefully consider the assessment by the Scientific Committee on Neurotoxicology and Psychophysiology and the Scientific Committee on the Toxicology of Metals of the International Commission on Occupational Health (ICOH) which concluded that "The addition of organic manganese compounds to gasoline should be halted immediately in all nations."¹⁷⁸ The Committee on the Environment, Public Health and Food Safety of the European Parliament in its draft report on the proposal for amending Directive 98/70/EC, which deals the specification of petrol, diesel and gasoil called for a ban by 2010 on the use of MMT. Limited testing on the health impacts of ferrocene has been conducted and additional testing is required if it is to be used as an automotive fuel additive. Existing data, however, do show that ferrocene plugs up catalytic converters.

476. There has been relatively little evidence of health effects of MTBE, ETBE, and TAME. Regulators in Europe and the USA have responded in different manners to the risk of ground water contamination by MTBE.

477. Experience from Japan, Europe and the USA teaches that the use of octane enhancing additives was most frequent in case of older refineries and that new refineries and refineries that

¹⁷⁸ Landrigan, Philip, Monica Nordberg, Roberto Lucchini, Gunnar Nordberg, Philippe Grandjean, Anders Iregren, and Lorenzo Alessio. 2006. The Declaration of Brescia on Prevention of the Neurotoxicity of Metals. American Journal of Industrial Medicine. 50(10):709-711. Available: <http://dx.doi.org/10.1002/ajim.20404> and http://www.collegiumramazzini.org/download/Declaration_of_Brescia_August_2006.pdf

are upgraded can be more readily configured in a manner in which the use of octane enhancing additives can be avoided.

478. Asian countries are urged to improve the regulation of octane enhancing additives and oxygenates:

- a. The best manner to meet the gasoline octane requirements is through capital investment and blend-stock selection and the use of certain oxygenates;
- b. Use of MTBE, ETBE and TAME should be limited to maximum allowable concentrations to 2.7% (mass O₂) and respectively 15%, 17.1% and 16.6% by volume. Regulation should include the provision of appropriate storage facilities and handling to avoid ground water contamination;
- c. Ethanol blending should be limited to 10% by volume and 3.7% by mass. This will help assure that the air quality is not significantly impacted and will protect fuel system components;
- d. The use of MMT and Ferrocene should be discouraged because of potential health concerns and potential impacts on vehicle emissions and emissions systems components. Decision makers in Asia should take note of the upcoming results of the studies by Health Canada and the US EPA on health impacts of manganese (including MMT). Due to a lack of conclusive evidence that the use of metallic-based additives do not have a negative health impact, and a growing body of evidence that they do, the environmentally responsible approach for Asian countries to take concerning the use of metallic-based additives is to apply the precautionary principle for these metallic additives until and unless the scientific and health studies show that they are safe.¹⁷⁹
- e. If Asian countries do decide to authorize the use of MMT, ferrocene, or other ash forming metal based additives to raise octane, they should make this decision on a refinery-by-refinery permit basis, with clear deadlines for the phase out of the use of MMT, ferrocene or other ash forming metal based additives while ensuring that they are used in limited concentrations.
- f. As new refineries are built or old ones expanded in Asia, they should be configured in a manner to avoid the use of octane enhancing additives.

479. Asian governments are encouraged to ensure that fuel quality standards reflect at least the quality of fuel as sold in the market. This is especially the case in countries which have not yet adopted Euro 2 equivalent fuel standards but where the fuel marketed is already of an Euro 2 equivalent quality.

480. Some Asian countries have stated their intentions to skip Euro 3 emission standards and leapfrog from Euro 2 to Euro 4 standards. Both Thailand and Malaysia have decided to do so.

¹⁷⁹ United Nations Environment Programme (UNEP). 1992. Rio Declaration on Environment and Development, under the auspices of The United Nations Conference on Environment and Development. Principle 15. Available: <http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=78&ArticleID=1163>. The Precautionary Principle, which was adopted at the Rio Declaration on Environment and Development states: "In order to protect the environment, the precautionary approach shall be widely applied by states according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

The adoption of the AMEICC framework for fuel quality improvement is likely to result in more ASEAN countries skipping the Euro 3 phase.

481. Some Asian countries where the air pollution problem is projected to be severe may want to consider incorporating in their individual roadmaps some indication of the potential to implement Euro 5 standards at a future time. Such an indication may be helpful to refiners for planning purposes.

482. It is assumed and recommended that Asian countries will make use of Euro fuel specifications. Regulators might want to consider, however, applying some flexibility following the example of US regulations. Flexibility provisions could reduce operating expenditures and ensure availability of supply, but should be carefully designed in order to avoid erosion of benefits. All fuel properties should be looked at in an integrated manner to decide costs and benefits. Singling out any individual fuel property when considering a flexibility provision should be avoided until such an integrated analysis has been conducted.

483. The adoption of stricter fuel standards needs to be accompanied by more and better fuel quality monitoring and enforcement of fuel quality standards. Fuel adulteration becomes an increasingly important issue once emission and fuel standards become stricter. Two types of adulteration need to be monitored (a) with kerosene and (b) with lower grades fuel. Fuel quality monitoring is particularly important in cases where different fuel standards exist within the same country.

C. Timing of the introduction of cleaner fuels

484. To meet the requirements outlined above, most of the older refineries in Asia would require the installation of new process units and expansion of existing units. The technologies involved in the production of cleaner fuels are well established, and they can be applied in Asia without any risk. The EU, Japan and USA have extensive experience modifying refineries to produce cleaner fuels. Actual experience indicates that extensive refinery modifications, or the construction of new refineries, for the production of cleaner fuels (Euro 4 or stricter) requires about 4-6 years, with about 1-2 years for financing and engineering, 1-2 years for permitting and about 2 years for construction. An additional 1 year may be required for contingencies. A significant portion of the total time is needed for permitting, financing, and public input. To the extent that this portion is expedited, shorter time for compliance may be sufficient. Refineries that require fewer modifications will, of course, need less time. Installations for limited number of properties such as sulfur content or retrofits of existing equipment would require less construction and the time for compliance could be reduced. Europe allowed a period of 4-6 years, USA of 6-7 years and California 2-5 years – see also example of Singapore which gave lead time of only 2 years¹⁸⁰.

485. Tremendous refinery expansion is underway throughout Asia with PRC and India leading the way. These new or expanded or upgraded refineries can reduce the overall costs or incremental time to meet Euro 4 or better fuel specifications without a need for metallic additives.

486. Fuel regulators in fuel importing countries are well advised to announce their fuel road maps quickly to give refiners in the region the chance to respond and prepare for supplying cleaner fuels.

¹⁸⁰ The domestic market in Singapore represented approximately 10% of refineries' output and this special fuel could be made by reallocation of existing components within the refinery rather than the construction of new plants.

487. Vehicle Technology for the production of Euro 4 compliant vehicles is well established in Asia.

488. There are a number of companies in Asia that already manufacture Euro 4 and Euro 5 compliant vehicles as well as companies outside Asia that manufacture such cars- for exports to Asia. Euro 4 vehicle emission standards for new vehicles can be introduced well within the time required to establish or modify refineries.

489. The technology is now available to retrofit gross polluting diesel vehicles and Asian countries can consider the implementation of retrofit programs in cities with PM problems caused by diesel vehicles. Preference should be given to retrofit of fleet vehicles (e.g., urban buses). Considering the relative long lifetime of vehicles in Asia, retrofitting might be an option for several years to come. Best candidates are high use, well maintained vehicles which are at least Euro 2 compliant. These are mostly public transport and commercial vehicles. Retrofitting of in-use vehicles needs to be balanced against accelerated phase out of old vehicles, especially those which are pre-Euro 2 where retrofits with the most advanced technology can be difficult.

D. Scenarios for Introducing Cleaner Fuel Standards

490. The uniform introduction of cleaner fuel across the entire country has clear advantages in terms of impact on air quality, provided that the specifications are strict enough. This scenario has higher short term costs to the refining industry, but it also avoids mis-fueling and it reduces the resources and complexity needed for monitoring compliance. To allow flexibility, special provisions may be implemented for special markets e.g. off road vehicles, stationary equipment, others.

491. In some cases, especially for large countries such as India and PRC, a system of differentiated (two grades) fuel quality for different parts of the country has already been introduced. Cleaner fuels are required for certain metropolitan areas, with a different quality for the rest of the country. Such an approach requires the availability or the installation of a segregated fuel marketing and distribution system. To avoid mis-fueling and ensure compliance, an extensive fuel monitoring system and an associated enforcement mechanism are also needed. Price differentials could be established to ensure that the cleaner fuel is priced more favorably than the relatively dirty fuel.

492. Harmonized introduction across Asia or sub-regions will have clear advantages for the regional oil companies, and for the vehicle industry. For regulators, a harmonized approach increases the security of supply of cleaner fuels.

E. Ways and means to facilitate the introduction of Cleaner Fuels in Asia

493. Fuel quality regulations, combined with vehicle emission standards need to form the backbone of any policy, strategy, or legislation to promote the introduction and adoption of cleaner fuels.

494. However, experience has shown that governments can accelerate the production of cleaner fuels and their uptake by the market through a combination of tax and pricing policy, public outreach and consensus building. The specific mix to be adopted and its impact will be influenced by: whether the country is refining or importing country; market orientation; and/or whether subsidies are in place. Note: If a harmonized approach is considered, the specific means of implementation will be different in each country.

495. The cost for producing cleaner fuels needs to be passed on to the consumer. Controlled pricing regimes in many Asian countries however, tend to preclude opportunities to pass higher costs of cleaner fuels onto consumers. Still, high international oil prices in recent years have forced the hand of many governments to begin dismantling entrenched fuel subsidies and price controls.

496. Temporary incentives such as fuel product tax differentiation can be used to accelerate fuel uptake ahead of regulations. Incentives for tighter standard vehicles that require cleaner fuels can also be used as measures to stimulate the market for cleaner fuels in the early stages of regulations implementation.

497. There is a need for intensified awareness-raising at the national and sub-national level to make the case for cleaner fuels. Awareness raising campaigns need to be focused on the general public as well as on specific groups of decision makers. The messages should focus on the role of fuels in causing air pollution, the health effects of vehicle emissions and the potential for cleaner fuels to reduce air pollution, and the technologies available to produce cleaner fuels and their financial and economic costs and benefits.

498. The rationale for promoting the adoption of cleaner fuels in this report is the impact on environment and public health. Environment is an integral part of the mandate of bilateral and multilateral development organizations. The health impacts of cleaner fuels and vehicles are obvious and well documented. In a number of countries, the governmental organizational capacity is limited, and there is a lack of administrative and legal expertise as well as limited compliance monitoring capacity. As a result the introduction and implementation of cleaner fuel and vehicle standards is not timely and not performed in an effective way. Based on this development organizations can and should consider assistance to support the introduction of cleaner fuels. This can consist of:

- a. Capacity building for regulators to formulate, implement and monitor fuel quality improvement strategies and legislation Examples of such assistance are: GTZ-Malaysia, WB – Sri-Lanka, ADB/ CAI-Asia – Viet Nam/ Indonesia/ Philippines/ Bangladesh/ Sri-Lanka, USAEP-Viet Nam, and USAEP-Indonesia.
- b. Loans or partial guarantees for refinery upgrading or new construction.

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WHITEPAPER ON MTBE FOR THE GOVERNMENT OF AUSTRALIA

Prepared for and submitted to:
ASIAN CLEAN FUELS ASSOCIATION (ACFA)

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UPSTREAM | MIDSTREAM | DOWNSTREAM | FUEL & TRANSPORT

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EXECUTIVE SUMMARY

Methyl tertiary butyl ether (MTBE) is a clean-burning, high-octane blending component used in gasoline since 1973. Today, it is widely manufactured and used in nearly all major gasoline markets around the world.

MTBE's unique properties of high octane rating, low boiling temperature and moderate vapor pressure make it a versatile gasoline-blending component to help refiners and fuel blenders meet quality requirements and expand production. MTBE allows petroleum refiners to adjust fuel production and product qualities to meet changing markets and achieve environmental specifications. These unique blending properties coupled with MTBE's oxygen content allow refiners to make cleaner-burning reformulated gasoline (RFG) to help reduce vehicle emissions that are precursors to ground-level ozone and particulate matter (PM) pollution. MTBE blending can replace aromatic compounds in gasoline, which largely contribute to air toxics emissions from vehicles. Global auto manufacturers recommend and prefer MTBE (and similar ethers) as the blending component for oxygenate use in gasoline.

Australia presently prohibits the use of MTBE in gasoline. With Australia's continued gasoline demand growth and need for improved quality specifications to improve air quality and fuel efficiency to combat greenhouse gas (GHG) emissions, this whitepaper was commissioned by the Asian Clean Fuels Association (ACFA) to examine the option to use MTBE-containing gasoline in Australia's domestic gasoline pool without adverse environmental impacts. This whitepaper by Stratas Advisors reviewed and analyzed:

- Regional and world trends in the use of MTBE;
- Available practices for safe storage, handling, transfer and blending of MTBE and MTBE-containing gasoline;
- Summaries of health and safety testing of MTBE;
- Summaries of environmental and aesthetic (taste and odor) properties of MTBE;
- Information on contingency needs to address potential environmental events from import, storage and use of MTBE;
- Vehicle compatibility and emissions profiles for MTBE-containing gasoline; and
- Applicable government regulations and specifications.

Based on the long-term experience of other major gasoline markets (e.g., Europe, Asia and the U.S.) that have used oxygenated gasoline for more than three decades, MTBE (or other aliphatic ethers) in any ratio up to a total oxygen content of 2.7 wt% results in fully fungible gasoline. It can be commingled with non-oxygenated gasoline or domestically produced MTBE-gasoline blends in the product distribution system, the fuel storage tanks at refueling stations or fuel tanks of vehicles without loss of performance quality or without environmental degradation or hazard concerns from fuel blends up to 15 vol% MTBE.

MTBE has linear blending properties that are essentially similar to gasoline components with comparable boiling point temperatures. Consequently, MTBE-gasoline blends can be treated as fully fungible with hydrocarbon blends, and intermixed, stored and shipped with conventional gasoline in barges, oceangoing tankers, pipelines, rail tank cars and tank trucks without restrictions or loss of product quality (i.e., specifications). Furthermore, the properties for commingled gasoline, including MTBE blends, will meet quality specifications and existing safety and hazard controls as a final mixture provided the properties of the original gasoline prior to commingling meet requirements for quality specifications, safety and hazard controls.

HISTORY, TRENDS AND KEY POLICIES

In the **United States**, MTBE was approved for use in unleaded gasoline in March 1979 by the Environmental Protection Agency's (EPA) "substantially similar" waiver rule established under authority of the Clean Air Act Amendments (CAAA) of 1977, Section 211(f). Subsequent approvals (in 1981 and 1988) by EPA allowed MTBE blends up to 15 vol% (2.7 wt% oxygen) in gasoline. In 1988, EPA finalized regulations under the Hazardous and Solid Waste Amendments (HSWA) Act of 1984 to require owners of gasoline underground storage tanks (USTs) to upgrade existing systems to monitor, mitigate and report releases. The EPA allowed the industry a 10-year timeframe to implement these regulations. The removal of the oxygen content requirement for RFG with the passage of the Energy Policy Act of 2005, coupled with various states enacting statutes to limit or ban the use of MTBE, resulted in refiners deselecting MTBE as a component in U.S. gasoline. MTBE continues to be made in the U.S. for gasoline exports.

Commercial production of MTBE started in **Europe** in 1973, when it was added to gasoline at levels typically between 2 vol% to 5 vol%, to boost the octane rating of unleaded gasoline or for high-performance gasoline grades. During the 1990s and early 2000s, MTBE was blended at higher levels between 11 vol% and 15 vol%. In 1998, the European Union (EU) adopted Fuel Quality Directive (FQD) 98/70/EC that included an oxygen content limit of 2.7 wt% for gasoline (15 vol% MTBE) along with specifications for other gasoline properties. Directive 2003/30/EC, which promotes the use of biofuels or other renewables in transport, was adopted in 2003. Producers in EU Member States moved to make ETBE (ethyl tertiary butyl ether) rather than MTBE to help them meet the targets for biofuels. By 2010, MTBE was about 40% of the share of ethers blended into gasoline. Under Directive 2009/30/EC and the European gasoline standard, EN 228:2012, the maximum allowable limit for MTBE blended in gasoline is presently 22 vol%.

In **Latin America and Caribbean** countries, MTBE is used mostly as an octane booster based on competitive pricing and emissions benefits. Among countries that have specifications for gasoline oxygen content, most range from 2.0 wt% to 4 wt% limits (the higher limit is reserved for ethanol blends). MTBE demand is appreciably growing in Chile and Venezuela because of growth in gasoline demand. Brazil does not allow MTBE blending because of its ethanol requirements.

The **Asia Pacific** region is extremely diverse, with countries at different stages of economic and sociopolitical development. The majority of the countries in the region adopt fuel specifications similar to those implemented in the EU, although their respective timetables vary considerably. Most countries use a variety of blending components to help replace or enhance octane levels in their gasoline pools, including MTBE, ETBE, methylcyclopentadienyl manganese tricarbonyl (MMT) and alcohols. MTBE is widely produced, imported and blended into the gasoline marketplace. In China, MTBE represents about 6.4% of the total gasoline pool, according to ACFA's sources. The oxygen content limit, when defined, is generally established at 2.7 wt% max. South Korea sets current oxygen content limit based on season (0.5 wt% in summer and 1 wt% during winter), while Singapore currently does not set a limit on oxygen or ethers in its gasoline specifications but plans to set limits for oxygen and ethers at 3.7 wt% and 22 vol% respectively by 2017. Other Pacific islands tend to follow the fuel specifications of Australia and New Zealand e.g. Fiji and New Caledonia which have set a 1 vol% maximum limit on oxygenates, including MTBE and di-isopropyl ether (DIPE). In the

region, only the Philippines sets a 2 vol% maximum limit on ethers because of its ethanol requirements.

In the **Middle East**, the Gulf Cooperative Council (GCC) countries have not established regional quality standards for gasoline, despite having the largest petroleum and petrochemical industries. Each country sets its own gasoline specifications generally determined by refining capabilities or imports. The GCC Standardization Organization (GSO) issues nonbinding fuel standard recommendations for member countries. As lead phase-out took place, regional refineries found MTBE to be the most compatible and available product to serve as an octane replacement. Except for Bahrain, GCC countries use MTBE in their gasoline. However, it is worthwhile to note that Bahrain received conditional approval by the government in 2014 to allow the use of MTBE. Because Bahrain imports gasoline produced by other GCC countries that contains MTBE, the Ministry of Environment issued a waiver for this gasoline to be imported and used in the country. Current maximum allowable levels of MTBE in gasoline range from 10 vol% to 15 vol% (2.7 wt% oxygen) depending on country and fuel grade.

VEHICLE EMISSIONS AND COMPATIBILITY

Vehicle research has been conducted for both exhaust and evaporative emissions with gasoline blends containing up to a nominal 20% MTBE (~3.7 wt% oxygen such as in 10% ethanol). In addition to standard vehicle emissions such as volatile organic compounds (VOCs), nitrogen oxides (NO_x) and carbon monoxide (CO), the effects of oxygenates such as MTBE on vehicle emissions have also been investigated for air toxics (e.g., benzene, formaldehyde, acetaldehyde and butadiene) and also fine PM in the vehicle exhaust.

As part of evaporative emissions, the impact of the various oxygenates on the rate of VOC permeation from the vehicle elastomers has also been investigated. Based on these studies conducted over the past 30 years, vehicles operating on fuels containing up to a nominal 20% MTBE (~3.7 wt% oxygen) will have lower exhaust emissions and also should not experience any degradation in performance as compared to gasoline containing no oxygenates. The various metals used in the vehicle fuel system as well as the fuel storage and distribution systems are not expected to be affected by MTBE in the fuel because of its inert fuel properties.

HEALTH AND ENVIRONMENTAL ASSESSMENTS

MTBE is one of the most tested and evaluated components in gasoline and in commerce today. The first health screening tests were conducted as early as 1969. Further tests to characterize MTBE properties were carried out in the 1970s when approval was granted in the U.S. and Europe for blending with unleaded gasoline. Expanded toxicological and environmental testing was completed during the 1980s as MTBE's commercial importance grew. Industry groups sponsored further extensive research during that time, and the work continued throughout the 1990s and into the 2000s. The results from these testing programs were either published in scientific literature or the final reports submitted to government agencies and generally made publicly available. As this database expanded, different organizations performed assessments of MTBE to determine if concerns about health or environmental effects were warranted. Assessments were conducted by the EU's Existing Chemical Bureau, U.S. National Toxicology Program, International Agency for Research on Cancer (IARC), California Science Advisory Board for Proposition 65, U.S. EPA, World Health

Organization's (WHO) International Programme on Chemical Safety and other recognized authoritative groups. The outcomes of these evaluations collectively demonstrate that MTBE blending into gasoline does not pose increased risks to human health.

In July 2005, the WHO issued a report titled "WHO Guidelines for Drinking Water Quality: Methyl tertiary-Butyl Ether in Drinking Water". This report concluded that the vast majority of MTBE detections in the U.S., Canada and Europe have been at or below 2 parts per billion (ppb). The WHO recommended a guideline for treating MTBE concentrations exceeding 15 ppb – the lowest level eliciting a response in a study of taste- and odor-sensitive participants. This level is generally considered to be well below that which would pose any environmental or human health concern.

The EPA has not established a national drinking water limit for MTBE, either as a health-based primary standard or non-health-based secondary standard. The agency has issued an advisory recommending a protective level of 20 µg/L to 40 µg/L for taste and odor.

CONTAINMENT PRACTICES AND ENVIRONMENTAL PROTECTION

The U.S. Congress enacted legislation under Subtitle I of the HSWA of 1984 to the Resource Conservation and Recovery Act (P.L. 94-580) that directed EPA to promulgate regulations on establishing programs to upgrade and monitor fuel and gasoline USTs. The regulations were finalized in 1988 with a 10-year phase-in period. As UST owners began to upgrade their USTs and install new USTs, MTBE use in the U.S. gasoline pool began to dramatically expand, primarily in response to the oxygenate requirement under the federal RFG program. Detections of MTBE in groundwater resources were being reported, albeit usually under EPA's odor and taste threshold levels of 20 ppb to 40 ppb. From 2000 to 2005, EPA collected MTBE sampling data in finished drinking water from public water systems nationwide. Out of the 34,000 samples, MTBE was detected above 5 ppb (the minimum reporting level for the study) in only 26 samples – or less than 0.1% – and above 20 ppb (the minimum threshold for taste or odor issues) in only five samples – or less than 0.015%.

In many cases where MTBE was found, gasoline USTs had not been upgraded as the regulations required, or there were installation and filling mistakes and/or equipment failures. There were also inadequate compliance and enforcement activities at the state level. This factor was cited as the No. 1 problem that led to issues with gasoline containing MTBE in groundwater supplies. Adequate enforcement remains a problem at the state and federal level, complicated by limits in funding to hire and train qualified UST inspectors.

EPA regulations for USTs are implemented by the states, territories (e.g., Puerto Rico) and tribal lands. States must receive approval of their UST programs from EPA. As of February 2012, 38 states and the District of Columbia as well as Puerto Rico have approved programs. EPA runs the UST enforcement for states without approvals. The UST standards include provisions to prevent gasoline releases:

- Leak detection systems;
- Spill/overfill protection;
- Corrosion protection requirements; and
- Monitoring and record-keeping.

Since the inception of the UST program, more than 1.7 million USTs have been closed. As of December 2012, there are 584,000 active USTs at approximately 214,000 sites. According to EPA, 85.5% of the active USTs are in significant operational compliance with the spill, overfill and corrosion protection requirements, and 78.9% of USTs are in significant operational compliance with the leak detection requirements. Approximately 71% of USTs are in significant operational compliance with both sets of requirements.

There is a large array of well-proven remediation technologies for treating soil and groundwater contaminated by conventional gasoline. In general, these methods are applicable to gasoline containing MTBE, and remediating gasoline containing MTBE is not necessarily more expensive compared to gasoline that does not contain MTBE. The critical determining factor for cost depends largely on how long the release has gone undetected. Because MTBE has a higher vapor pressure and a lower affinity for sorption to soil, it can be effectively remediated by two soil treatment technologies – soil vapor extraction or low-temperature thermal desorption. When groundwater impacted by gasoline containing MTBE needs to be managed, effective remediation methods include pump-and-treat, air stripping, air sparging and enhanced bioremediation.

Best practices are well established for prevention and emergency response; spill and leak procedures; storage and unloading stations; transfer operations and marine transport. These best practices are generally applicable to gasoline as well as to MTBE. MTBE producers have done a great deal over the years to develop, implement and externally promote best practices. As a result, spills, fires and other sorts of safety and environmental emergencies have been kept to a minimum.

RECOMMENDATIONS

Based on our observations of global fuel quality policies, market trends and historical research studies, Stratas Advisors makes the following recommendations on MTBE use in Australia:

- Based on the established safety from its long history of use, and recognizing the assessments carried out by respected authoritative bodies demonstrating MTBE use does not pose increased risks to human health, we recommend that full analysis and consideration be given to the option of allowing MTBE to be imported, stored and blended into gasoline.
- We recommend that Australia reviews its operations for handling, transport, storage, blending and delivery of gasoline to ensure best practices are employed that are readily applicable to MTBE-containing gasoline.
- We recommend that Australia develops educational information about the safety, benefits and cost-effectiveness of MTBE and MTBE-blended gasoline for workers and motorists/consumers.
- We recommend that Australia reviews its prevention control and emergency response plans for gasoline, MTBE and MTBE-blended gasoline to assure up-to-date practices and preparations are established.

Based on the above recommendations, ACFA would like to make the following recommendations on MTBE use in Australia:

- We suggest a country-wide allowance of MTBE use of up to 15 vol%.

- Should a more cautious approach be needed, to use a phased-in approach:
 - First phase of 7 vol% MTBE; and
 - Second phase of 15 vol% MTBE.
- Alternatively, we suggest the following three-staged plan, if an even more vigilant approach is preferred:
 - First phase of 5 vol% MTBE;
 - Second phase of 10 vol% MTBE; and
 - Third phase of 15 vol% MTBE.
- In addition, individual states may set lower limits based on their own concerns.
- Note that the above recommendations have been made based on the New South Wales Environment Protection Authority's (NSW EPA) proactive approach in maintaining its underground petroleum storage systems and their potential readiness to use MTBE.
- With Australian-based CRC CARE taking the lead on setting odor-based and ecological screening threshold criteria for groundwater, and risk-based remediation and management guidance, we expect Australia to be able to safely use MTBE rather than limiting its use.
- We recommend for Australia to use a science-based system to address groundwater issues like what the EU and Japan have done, and avoid stagnating in its role to protect the environment.
- We advise that limiting MTBE could potentially encourage fuel blenders/traders to blend gasoline with illegal or unauthorized chemicals.

The basis for the above sets of recommendations follows in the sections below.

INTRODUCTION

Stratas Advisors is pleased to present this whitepaper to ACFA on MTBE for the government of Australia. With Australia's continued gasoline demand growth and need for improved fuel efficiency and quality specifications, this whitepaper was commissioned to examine the option to use MTBE-containing gasoline in Australia's domestic gasoline pool without adverse environmental impacts. This whitepaper by Stratas Advisors reviewed and analyzed:

- Regional and world trends in the use of MTBE;
- Available practices for safe storage, handling, transfer and blending of MTBE and MTBE-containing gasoline;
- Summaries of health and safety testing of MTBE;
- Summaries of environmental and aesthetic (taste and odor) properties of MTBE;
- Information on contingency needs to address potential environmental events from import, storage and use of MTBE;
- Vehicle compatibility and emissions profiles for MTBE-containing gasoline; and
- Applicable government regulations and specifications.

As research confirmed the serious public health effects posed by tetra-ethyl lead (TEL) in the environment, refiners and gasoline blenders began to evaluate alternative products to provide the anti-knock performance needed for advancing vehicle emissions control technologies. The introduction of the catalytic converter in passenger vehicles in 1974 started the movement to remove lead from gasoline globally to the point that today less than 2% by volume worldwide still contains lead.

As a result of lead removal, followed over the next couple of decades with reductions in gasoline sulfur levels, refiners had to seek replacement of the octane loss caused by these fuel specification changes. The specific needs for refiners to compensate for this octane loss are a function of available refining processing operations, crude oil being processed, refined products being made at the site and the availability of alternative products. The refinery can look to modify existing process units, build additional new units (capital expansion) or seek out supplies of cost-effective, high-octane volumes to blend into its gasoline. The high-octane blending components can come from petrochemical operations, other refinery units (co-products) or new add-on units. The products most readily available to the refiner include ethers (e.g., MTBE or ETBE); alcohols (e.g., ethanol or butanol); aromatics (e.g., benzene, toluene or xylenes) or alkylates (e.g., iso-octane or trimethylpentane).

These high-octane components have various properties that affect how they can be used in gasoline blends. Besides octane level and sulfur content, these components have distinct physical-chemical and blending properties important to how the overall gasoline blend performs. These properties also influence how they behave in the environment (e.g., volatility and water solubility) (see section on "Physical and Chemical Properties").

The octane rating of these gasoline components determines the anti-knock performance of the fuel – its ability to resist knocking caused by premature combustion in the engine cylinder. Prolonged or heavy knocking can result in loss of power, overheated engine parts or even engine damage. Knock is often experienced during high-load conditions on the engine, such as operating in very hot weather or hard acceleration. Knock-free engine performance is as important as good drivability from the gasoline formulation. As the technical sophistication of today's passenger vehicles increases, with complex control systems and higher

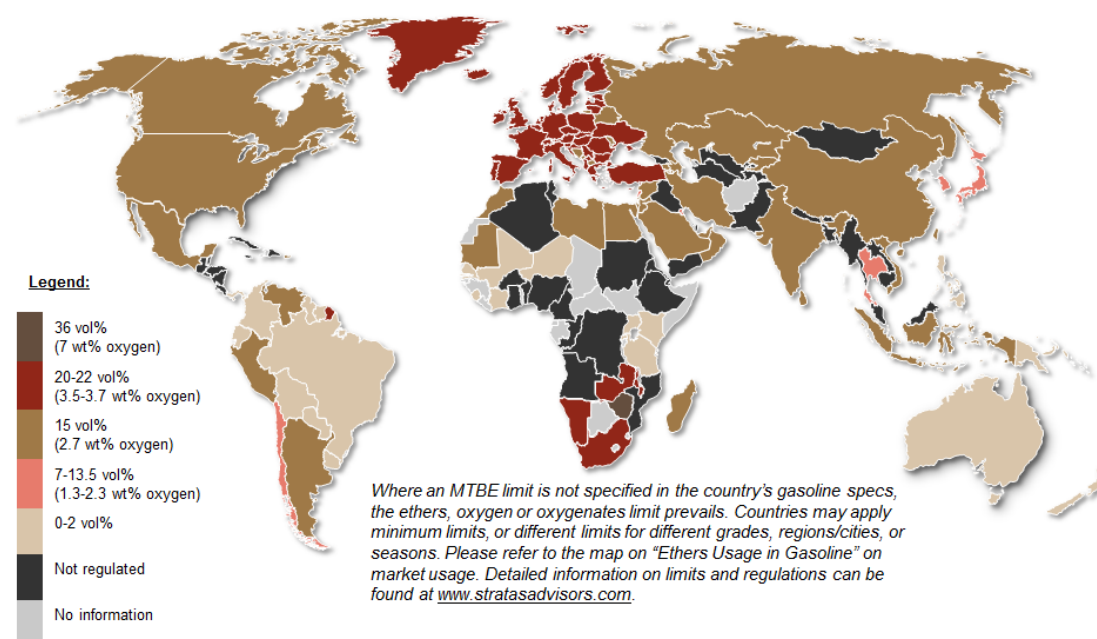
compressions for both power and efficiency, the ability of refiners to maintain and even increase octane rating becomes more important. The need for readily available and cost-competitive high-octane components for gasoline blending is growing worldwide.

GROWTH OF GASOLINE AND MTBE DEMAND

MTBE is growing and in greater demand than ever globally. This is because it is a cost-effective and clean fuel component that reduces capital and blending costs while expanding the gasoline pool, providing needed octane and air quality improvement benefits. It is fungible and auto manufacturers often prefer it as compared to other octane components, according to the World Wide Fuel Charter (WWFC).

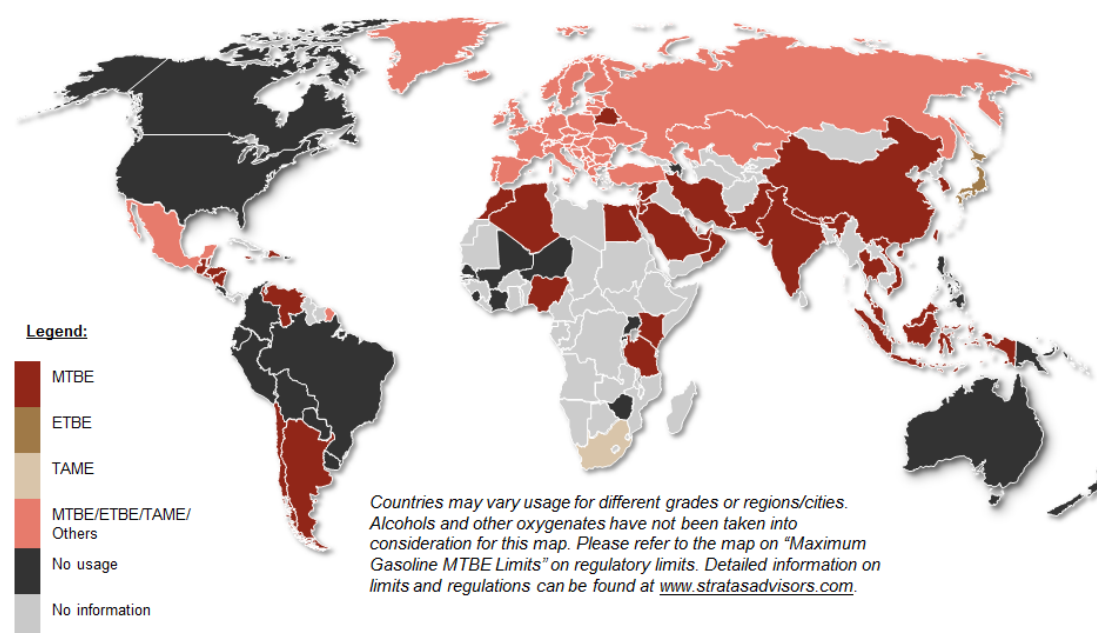
As shown in the first map below, Australia has set a limit of 1 vol% on MTBE in its gasoline specifications. The limit was driven out of concern for the potential for gasoline to leak out of USTs and its potential impact to water quality. However, when looking at the second map below, other countries that are blending MTBE into gasoline are doing so with consideration for the environment by implementing strong responsible care measures to prevent leaking tanks against all fuels and chemicals. Thus, limiting the use of MTBE in gasoline is not the only solution in preventing leaks.

Maximum Gasoline MTBE Limits



Source: Stratas Advisors, March 2015

Ethers Usage in Gasoline

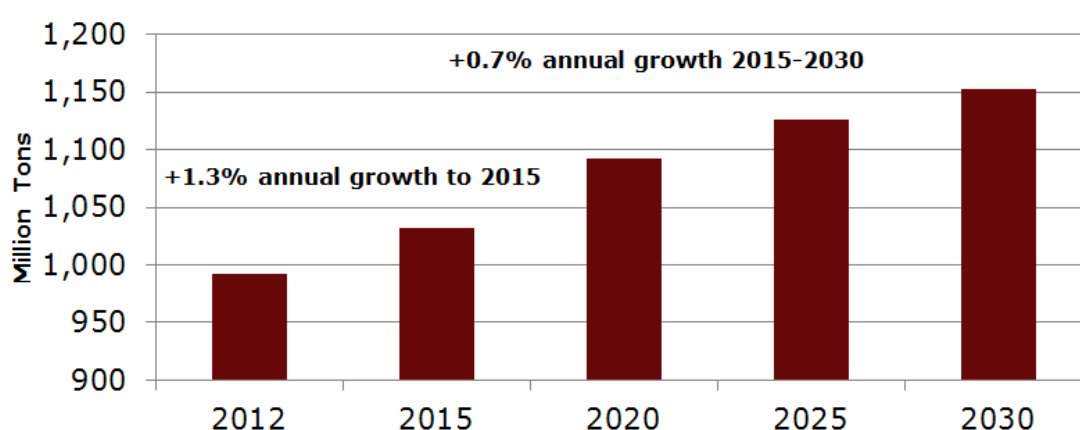


Source: Stratas Advisors, Asian Clean Fuels Association, October 2015

Gasoline and MTBE Market Growth

Gasoline accounts for nearly 26% of world petroleum product demand and Stratas Advisors forecasts that the gasoline market is projected to grow 0.7% annually from 2015 to 2030, primarily in the developing regions (see figure below).

Global Gasoline Market Demand Outlook

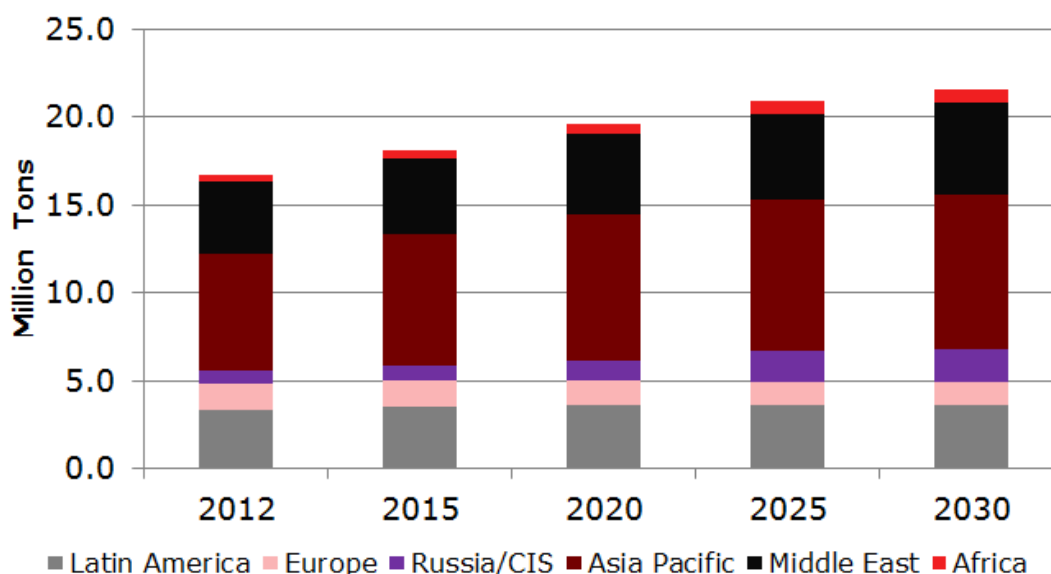


Source: Stratas Advisors, 2014

Demand growth for MTBE is expected in Asia Pacific and the Middle East, as well as CIS and Africa (see figure below), where drivers for demand include sulfur reduction, octane improvement, cost-effective gasoline pool extension and air quality improvement. On the other hand, Europe and Japan are expected to remain the largest markets for ETBE where

octane enhancement is the primary driver; and other important drivers for ETBE continue to be biofuels targets and GHG emissions.

Global MTBE Demand, 2012-2030



Source: Stratas Advisors, 2014

Cleaner Octane

Over the years, Asia Pacific's economy has grown at a tremendous pace, and despite China's economic slowdown in recent years, it is still growing at a pace faster than the rest of the world. However, improving fuel quality and vehicle emissions standards to mitigate urban air pollution and protect public health has lagged behind and is even worsening as vehicle ownership and miles traveled increases. To address these issues, some governments have and will be introducing tightened fuel specifications and emissions standards over the next few years.

However, in some cases this can constrain local refiners. The region is heavily dependent on crude and petroleum product imports and is especially vulnerable to high global oil prices. Securing local fuel supplies is a very high priority in growing economies such as China and Vietnam, and other important Asian gasoline markets such as Malaysia, Singapore, South Korea and Taiwan. Increasing minimum octane at their refineries would decrease gasoline production, thereby reducing supply.

As a result, refiners in the region are increasingly turning to MTBE as a cost-effective octane blending component to fill the gap. MTBE in particular has emerged as a reliable octane blending component in the region with demand expected to increase nearly 30% in 2012-2030, according to Stratas Advisors' analysis. The largest potential markets (in descending order) are China, Malaysia and Vietnam, according to analysis by Stratas Advisors.

Due to stricter fuel quality and vehicle emission requirements, expanding vehicle fleets, growing gasoline demand, countries in the Asia Pacific and the Middle East regions increasingly require cleaner fuel components because they are short of clean octane. As

Australia moves towards cleaner gasoline (10 ppm sulfur) and possibly higher octane grades, MTBE is likely to become an attractive solution.

Use of Illegal Chemicals

In the context of this whitepaper, illegal chemicals are defined as products that blenders and traders use in order to reduce their cost of blending with gasoline. As mentioned in the previous section, since cleaner octane is very much needed in Asia Pacific, the use of these chemicals has become more prevalent in recent years especially in developing countries like China and Vietnam where there is lack of a fuel quality monitoring legislation and system (i.e. fuel quality is not monitored or controlled). These chemicals include:

- Acetone;
- NMA (N-methyl aniline);
- SBAC (Secondary butyl acetate); and
- Methylal (dimethoxymethane).

The primary use of these chemicals is solvents. They are typically corrosive and are generally not compatible with vehicle engines and their parts.

As a result, starting in December 2013, Vietnam restricted the use of ketones in its specifications for 150 ppm sulfur gasoline grades, and will apply this restriction when 50 ppm sulfur gasoline is implemented nationwide starting January 2016. Similarly for China, its existing national specifications for 50 ppm sulfur gasoline include the following note: "Additives or contaminants containing methylal (dimethoxymethane), aniline, halogen, phosphorus and silicon are strictly prohibited."

MTBE BASICS

MTBE is a gasoline blending component introduced into commerce around 1973 in Europe by Hüls AG as a high octane substitute for TEL. Since its introduction and subsequent expansion in the fuel marketplace, it has been successfully used as a gasoline octane enhancer to improve fuel quality and performance. Gasoline and MTBE have a similar density, thus the percentage of MTBE by volume is similar to its weight percentage. MTBE is being used globally at volumes generally ranging between 5 vol% up to 15 vol% (although some countries allow up to 22 vol% blends). When MTBE is blended at these volume levels, the oxygen content in the gasoline represents between 1.0 wt% to 2.7 wt%.

MTBE is principally made by reacting isobutylene with methanol over a catalyst bed. The isobutylene comes from a number of sources, including C4 stream from a steam cracker with butadiene removed (known as raffinate-1); C4 fractions from a catalytic cracker; n-butane from liquefied petroleum gas (LPG) isomerized to isobutane and then dehydrogenated to isobutylene; or dehydration of tertiary-butyl alcohol co-produced from propylene oxide.

Besides its initial use as a lead-additive replacement, MTBE is additionally used to replace higher aromatic levels in gasoline to improve drivability performance and to reduce air toxics emissions that occur with these elevated aromatics content. MTBE blending was demonstrated to significantly reduce tailpipe emissions from spark ignition vehicles. These benefits are accomplished in several ways:

- Higher octane rating enables more efficient engine design and operation;
- Displacement of toxic aromatics from the fuel;
- Maintain vapor pressure (RVP) properties;
- Cold and hot start operations;
- Vapor-liquid ratios; and
- Performance (T50) for combustion process

These combustion benefits help reduce vehicle emissions, thereby reducing air pollution and lowering air toxics levels created from the transport sector. Testing has demonstrated that MTBE blends in gasoline have minimal impacts on vehicle fuel economy – about 1% to 2% depending on the volume used. Likewise, vehicle materials compatibility and engine durability are not affected by the allowable MTBE blend levels.

At the national level in the U.S., MTBE has not been banned or otherwise restricted for use in gasoline at the levels allowed for oxygenates (e.g., alcohols and ethers) (There have been erroneous media reports to the contrary). The removal of the oxygen content requirement for RFG with the passage of the Energy Policy Act of 2005 (Public Law 109-58), coupled with various states enacting statutes to limit or ban the use of MTBE (including, in some cases, other oxygenates) because of concerns about potential impacts to water resources, resulted in refiners deselecting MTBE as a gasoline component in U.S. gasoline. MTBE continues to be made in the U.S. for gasoline exports. In other regions, MTBE blending continues to expand to help improve gasoline performance and reduce vehicle emissions.

PHYSICAL AND CHEMICAL PROPERTIES

The table below provides a summary of some key properties of MTBE.

Select Physical & Chemical Properties of MTBE

Parameter	Unit	MTBE
CAS No.		1634-04-04
Molecular Formula		C ₅ H ₁₂ O
Specific Gravity	g/l @25°C	0.741
Boiling Point	°C	55.2
Flash Point	°C	-10
Auto-ignition	°C	374
Octane Value	RON	112
Water Solubility	mg/l @25°C	48,000
Vapor Pressure	mm Hg @25°C	249
Log K_{ow}	C _{octanol} /C _{water} @25°C	1.6
Heating Value	BTU/l @15°C	24,800
Sulfur Content	ppm	none

Sources: U.S. Environmental Protection Agency; U.S. Energy Information Administration; American Chemical Society (Chemical Abstracts Services); American Petroleum Institute; California Air Resources Board; U.S. National Library of Medicine, 2005-2013

TOXICITY

MTBE continues to play an important role in helping to boost gasoline quality, improve vehicle performance and meet environmental requirements. MTBE's blending properties help the petroleum industry make gasoline that meets these more stringent specifications at lower costs to manufacturing centers and thereby at a lower cost to consumers. As MTBE production and use expanded in the transport sector, extensive health, toxicology and environmental testing was conducted by industry, government and independent researchers to characterize its properties.

Review of Toxicology Studies

MTBE is one of the most tested and evaluated components in gasoline and in commerce today. The first health screening tests were conducted as early as 1969. Further tests to characterize MTBE properties were carried out in the 1970s when approval was granted in the U.S. and Europe for blending with unleaded gasoline. Expanded toxicological and environmental testing was completed during the 1980s as MTBE's commercial importance grew. Industry groups sponsored further extensive research during that time, and the work continued throughout the 1990s and into the 2000s.

The results from these testing programs were either published in scientific literature or the final reports submitted to government agencies and generally made publicly available. As this database expanded, different organizations performed assessments of MTBE to determine if legitimate concerns about health or environmental effects existed. The outcomes of these evaluations collectively demonstrate that MTBE blending into gasoline does not pose increased risks to human health. A summary of relevant expert panel reviews and assessments is given in the table below.

Health Assessments Summary for MTBE

Agency/Institute	Study	Date	Conclusion
European Union – Existing Chemical Bureau	Risk Assessment Report: tert-butyl methyl ether; 3 rd Priority List, Volume 19	2002	Health risk assessment concluded that consumers are not at risk from exposures to MTBE; protective measures being applied are considered sufficient.
U.S. National Toxicology Program	9 th Report on Carcinogens	2000	Scientific weight-of-evidence did not warrant listing under criteria for carcinogenic hazard. MTBE not recommended for listing.
International Agency for Research on Cancer	Vol. 73: Some chemicals that cause tumors of the kidney or urinary bladder in rodents and some other substances	1999	Scientific weight-of-evidence assessment concluded: <ul style="list-style-type: none"> ♦ Group 3 (not classifiable) as carcinogenic hazard; ♦ Inadequate evidence in humans for carcinogenicity; ♦ Limited evidence in experimental animals.
California Science Advisory Board for Proposition 65	Consideration for listing under Prop 65 law	1998	Carcinogen Identification Committee declined to list as known to the state to cause cancer. Reproductive Effects Committee determined MTBE does not cause reproductive toxicity or birth defects.
U.S. Environmental Protection Agency	Achieving Clean Air and Clean Water: The Report of the Blue Ribbon Panel on Oxygenates in Gasoline	1999	Did not conclude that MTBE use in gasoline represented health risks (although the panel did not conduct independent health assessment). MTBE in water supplies primarily causes consumer odor and taste concerns.
WHO International Programme on Chemical Safety	Environmental Health Criteria 206: Methyl Tertiary-Butyl Ether	1998	Unlikely that MTBE alone induces adverse health effects in the general population under common exposure conditions. Data on effects in animal studies at very high exposure are considered inadequate for use in human cancer risk assessment.
Northeast States for Coordinated Air Use Management	Relative Cancer Risk of Reformulated Gasoline and Conventional Gasoline Sold in the Northeast	1998	Reformulated gasoline (RFG) reduced relative cancer risk associated with gasoline vapors and vehicle exhaust compared to conventional gasoline.
European Centre for Ecotoxicology & Toxicology for	Special Report No. 72	1997	Concluded that the risk characterization for MTBE does not indicate concern for human health with regard to current

Agency/Institute	Study	Date	Conclusion
Chemicals			occupations and consumer exposures.
National Science and Technology Council, Committee on Environment and Natural Resources	Interagency Assessment of Oxygenated Fuels	1997	Uncertainty in results from animal studies suggests on weight-of-evidence that MTBE exposure may represent potential hazard of carcinogenicity; however, further study is necessary to assess this likelihood.
National Research Council	Toxicological and Performance Aspects of Oxygenated Motor Vehicle Fuels	1996	Stated that inconsistencies and unresolved questions with results from animal carcinogenicity studies should be resolved (including objective third-party reviews) before these data are used for human health risk assessment.
Health Effects Institute	The Potential Health Effects of Oxygenates Added to Gasoline	1996	Adding oxygenates to fuel is unlikely to substantially increase health risks with fuel used in motor vehicles; oxygenates use reduces the emissions of carbon monoxide and benzene.

Sources: European Union Existing Chemical Bureau (2002); U.S. National Institute for Environmental Health Sciences, National Toxicology Program (2000); World Health Organization, International Agency for Research on Cancer (1999); California Environmental Protection Agency, Science Advisory Board for Prop 65 (1998); Environmental Protection Agency, Blue Ribbon Panel on Oxygenates in Gasoline (1999); WHO International Programme on Chemical Safety (1998); Northeast States for Coordinated Air Use Management (1998); European Centre for Ecotoxicology & Toxicology for Chemicals (2003); National Science and Technology Council (1997); Health Effects Institute (1996)

Numerous government and world-renowned independent health organizations have conducted assessments of MTBE. None of these independent bodies has found sufficiently compelling reasons to classify MTBE as a possible cancer-causing agent for humans. However, California's Office of Environmental Health Hazard Assessment ignored the decision by the state's independent Science Advisory Panel for Proposition 65 not to list MTBE as "known to the state to cause cancer" and instead established protective exposure levels based on cancer-potency factors. This is the only example of a government agency concluding such risk potential.

The critical risk assessments and related studies summarized below help demonstrate that incidental exposure to MTBE due to its use in gasoline does not pose increased risk of either cancer or other adverse chronic effects in humans. An overview of MTBE exposures and human health risk was published in 2002 (Williams and Sheehan, "Contaminated Soil, Sediment and Water." July/August 2002, pp. 93-103). This paper concludes:

"Overall, the available data suggest that current environmental exposure to MTBE in the U.S. and abroad are not acutely toxic to humans and are unlikely to pose chronic health effects from longer-term exposures. That is, MTBE is rarely detected in public drinking water supplies at notable concentrations, estimated exposures from MTBE in air or drinking water are typically very low for the general population, and predicted toxicity levels (for humans or wildlife) are well above those typically encountered in the environment."

1. European Union Risk Assessment/Risk Reduction Strategy for MTBE

In 1997, the European Union Existing Chemicals Bureau evaluated the health and environmental data on MTBE to assess the overall risk potential that it may pose. The full EU risk assessment for MTBE was published December 2001 in the Official Journal of the European Communities. The principle findings of the risk assessment and risk-reduction strategy review are as follows:

- Consumers are NOT expected to be at risk from MTBE exposure; protective measures already being applied are considered sufficient;
- Regarding worker exposure, the findings indicate the use of skin protective equipment already used to guard against exposure to other gasoline components is deemed adequate as a risk-reduction measure; and
- The assessment recognized the need for specific measures to protect the aesthetic quality (i.e., taste and odor) of drinking water, which is primarily sourced from groundwater. To accomplish this, the EU adopted recommendations on MTBE in connection with gasoline UST installation and maintenance in March 2001. In general, the EU concluded that measures being applied to prevent and minimize gasoline and MTBE releases aimed at protection of groundwater will contribute to preventing impacts to drinking water.

Based on the risk assessment and recognition of current risk-reduction strategies, the EU is not limiting the use of MTBE in gasoline or proceeding with additional regulatory actions.

2. IARC Hazard Assessment for MTBE

The IARC, established in 1965 by WHO, coordinates and conducts research on the causes of human cancer and develops scientific strategies for cancer control. IARC conducts objective, scientific reviews of health and toxicological data on chemical substances to evaluate the potential for human cancer hazards. Expert panels convene from around the world; scientists representing research centers, academic institutions, governmental agencies, and environmental and industry groups carry out IARC reviews. IARC uses a classification system to rank cancer hazard to humans:

- Group 1 is known human carcinogen;
- Group 2A is probable;
- Group 2B is possible;
- Group 3 is not classifiable as to its carcinogenicity; and
- Group 4 is probably not carcinogenic to humans.

The IARC Working Group met in October 1998 to examine data on various chemicals, including MTBE. The outcome of the IARC expert panel's deliberations on MTBE is contained in detail in the Volume 73 Monograph, published in 1999. Based on the extensive consideration made by the IARC panel, it concluded:

- There is inadequate evidence in humans for the carcinogenicity of MTBE;
- There is limited evidence in experimental animals for the carcinogenicity of MTBE; and
- MTBE is not classifiable (Group 3) as to its carcinogenicity to humans. This means that the expert panel concluded the available data did NOT warrant a more severe (higher) classification.

3. U.S. National Institute for Environmental Health Sciences, National Toxicology Program

The National Toxicology Program (NTP), administered by the U.S. Department of Health & Human Services' National Institute for Environmental Health Sciences, examined the MTBE data in 1999 and declined to list MTBE as either known or "reasonably anticipated" to be carcinogenic to humans. The NTP is made up of various U.S. federal environmental and health agencies, with an independent advisory board of scientific counselors. The NTP is required to prepare a biennial report to Congress that lists those chemicals, substances or agents either "known to be human carcinogens" or "reasonably anticipated to be human carcinogens." The Ninth Report on Carcinogens, published in 2000, notes in Appendix C that MTBE was formally evaluated by the NTP and scientific review groups, and recommended that it not be listed in the report.

4. California Science Advisory Board for Proposition 65

In December 1998, the California Science Advisory Board's Carcinogen Identification Committee did not list MTBE as "known to the state to cause cancer" under the state's Proposition 65 law. Another committee of the advisory board separately determined that MTBE does not cause reproductive toxicity or birth defects. These assessments were conducted at the request of the state's Office of Environmental Health Hazard Assessment (OEHHA) in response to the governor's decision to phase out MTBE use in the state.

5. NESCAUM Relative Cancer Risk of RFG and Conventional Gasoline

The Northeast States for Coordinated Air Use Management (NESCAUM) sponsored a study in 1998 to examine the potential cancer risk associated with the use of federal RFG and conventional gasoline. As part of the study design, NESCAUM made the unsubstantiated assumption that MTBE could pose a cancer risk to be able to project the maximum possible risk factors in conducting the analysis (i.e., a "worst-case" scenario). Additionally, NESCAUM assumed maximum potential exposure conditions (air and water) would always occur for MTBE. The NESCAUM report concluded the RFG-MTBE blend reduced the relative cancer risk compared to formulations not including MTBE. The NESCAUM study determined that there was a 12% reduction in benzene – a known carcinogen – under Phase I RFG (1995-1999) and estimated a further reduction of 20% under Phase II RFG (2000).

6. European Centre for Ecotoxicology and Toxicology of Chemicals

In 1997, the European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC) conducted an extensive review of exposures to MTBE and available health and toxicology data. The study examined relevant routes and concentrations of exposures and health-risk characterization of MTBE. Based on the potential exposure and the risk characterization for MTBE, ECETOC concluded that MTBE does not indicate a concern for human health with regard to current occupational and consumer exposures.

Acute Responses and Human Exposure Studies

There have been several human exposure studies that evaluated acute responses to MTBE exposures. Self-reported symptoms from inhalation exposure to MTBE include headache, eye irritation, cough, nausea and dizziness (specific exposure levels are unknown in these cases). Available studies of controlled inhalation exposures to MTBE with self-reported sensitive individuals showed no difference in neurobehavioral or psychophysiological responses to vapors from 15 vol% blended gasoline vs. gasoline without MTBE (Fiedler et al. 2000. *Environmental Health Perspectives*, Vol. 108, pp. 753-763).

Another study of acute exposures to low-level MTBE did not establish that symptoms (e.g., nausea, eye irritation, headache, etc.) were caused by exposures (Cain et al. 1996. *Inhalation Toxicology*, Vol. 8, pp. 21-48). Comparative controlled-exposure studies with MTBE could not establish a correlation for acute symptoms to MTBE exposure (Prah et al. 1994. *Inhalation Toxicology*, Vol. 6, pp. 521-538). Overall, these studies demonstrated that symptoms typically reported as associated with MTBE exposure were not reported in these controlled studies.

Investigations of neurological and/or respiratory effects from ingestion exposures to water impacted with MTBE-containing gasoline have been confounded by concurrent exposures to other gasoline constituents (Prah et al. 1994. *Inhalation Toxicology*, Vol. 6, pp. 521-538). Currently, there are no epidemiological data available on specific long-term exposures and systemic effects of MTBE.

Comparison with Other Gasoline Components

The table below summarizes and compares the toxicity of MTBE with benzene, ethanol, toluene and xylene. There is insufficient evidence to suggest that the following gasoline components discussed except for benzene were carcinogenic in nature. However, in MTBE inhalation studies, an increased incidence of liver tumors was reported in mice. In male rats, increased incidences of renal tubular adenoma and carcinoma and interstitial cell adenoma in the testes were reported; however, the renal tumors may have resulted from accumulation of a protein unique to male rats and testicular tumors are common in the strain of rats used. In addition, Lymphomas, leukemia, and testicular Leydig cell tumors were reported in orally exposed rats.

Comparison of Acute, Chronic and Reproductive/Developmental Effects of MTBE, Benzene, Toluene and Xylene

Acute Effects	
MTBE	<ul style="list-style-type: none"> Nausea, vomiting, burning sensation in the nose, mouth or throat, cough, dizziness, spaciness or disorientation, eye irritation were reported after short term exposure to MTBE. However, actual exposure levels for these reported cases were unknown and the symptoms may have been caused by other factors or a combination of factors; and There are no data on the effects in people of drinking MTBE. Studies with rats and mice suggest that drinking MTBE may cause gastrointestinal irritation, liver and kidney damage, and nervous system effects.
Ethanol	<ul style="list-style-type: none"> Inhalation could lead to dizziness, headache, drowsiness, difficulty in breathing and symptoms of drunkenness; Ingestion of ethanol may result in loss of balance, loss of inhibition and behavioral changes, aggression, nausea and vomiting, dehydration, respiratory depression, diarrhea, loss of consciousness; and Irritation of the skin and eye may result from contact with MTBE.
Toluene	<ul style="list-style-type: none"> Affects nervous system. Low to moderate levels results in tiredness, confusion, weakness, drunkentype actions, memory loss, nausea, and loss of appetite.
Xylene	<ul style="list-style-type: none"> Short term high level exposure results in irritation of the skin, eyes, nose, and throat; difficulty in breathing; problems with the lungs; delayed reaction time; memory difficulties; stomach discomfort; and possibly changes in the liver and kidneys. It may even cause unconsciousness and even death at very high levels.
Chronic Effects	
MTBE	<ul style="list-style-type: none"> Same as acute effects.
Ethanol	<ul style="list-style-type: none"> Long term inhalation could result in nausea and similar effects as the reported acute effects; Long term consumption of ethanol via ingestion could result in cardiovascular disease, diabetes, nutrition-related conditions, liver diseases, pancreatitis, varices, neurological dysfunction (Korsakoffs psychosis [impaired capacity]) and death by intoxication. Liver diseases may indirectly lead to cancer; and Long term skin and eye exposure to MTBE could result in skin irritation and eye damage respectively.
Toluene	<ul style="list-style-type: none"> Hearing and color vision loss; brain damage.
Xylene	<ul style="list-style-type: none"> High levels of exposure over a long period of time may result in headaches, lack of muscle coordination, dizziness, confusion, and changes in one's sense of balance.

	Reproductive / Developmental Effects
MTBE	<ul style="list-style-type: none"> No information is available on the reproductive or developmental effects of methyl <i>tert</i>-butyl ether in humans; In rats exposed via inhalation, reduced body weight and body weight gain in pups and decreased pup viability have been reported; and Developmental effects have been reported in mice. A decreased number of viable implantations, increased maternal toxicity, late resorptions, and skeletal variations were observed in mice exposed via inhalation.
Ethanol	<ul style="list-style-type: none"> Ingestion of ethanol during pregnancy could result in foetal alcohol syndrome which is characterized by organ abnormalities, lower birth weight, abnormal brain development and behavioral problems.
Toluene	<ul style="list-style-type: none"> Large doses of toluene during pregnancy may result in birth defects, including retardation of mental abilities and growth
Xylene	<ul style="list-style-type: none"> Studies of unborn animals indicate that high concentrations of xylene may cause increased numbers of deaths, and delayed growth and development. In many instances, these same concentrations also cause damage to the mothers. However, there is no evidence that xylene harms the unborn child if the mother is exposed to low levels of xylene during pregnancy.

Sources: Agency for Toxic Substances and Disease Registry, Health Protection Agency of the Government of U.K., Queensland Ambulance Service and U.S. Environmental Protection Agency, 2015

MTBE AND AIR QUALITY

Vehicle emissions lead to the creation of urban smog (ozone, particularly NO_x and VOCs) and to PM in the atmosphere. The oxygen content of MTBE allows petroleum companies to produce cleaner-burning gasoline that reduces those emissions. Blending MTBE, with its high RON value, also replaces aromatic compounds in gasoline, which largely contribute to toxic emissions from vehicles. MTBE's presence in gasoline reduces exhaust emissions of toxic substances and other pollutants, thus lowering potential cancer risks and respiratory effects for people exposed to vehicle emissions. This section provides further details regarding the performance and air quality benefits from blending MTBE in gasoline.

MTBE AND THE U.S. CLEAN AIR ACT

In the U.S., MTBE was first approved for use in unleaded gasoline in March 1979 by the EPA's "substantially similar" waiver rule established under authority of the CAAA of 1977 (P.L. 95-95), Section 211(f). Section 211 of the Clean Air Act (CAA) gives EPA authority to promulgate regulations for the control of fuels and fuel additives. The provision in 211(f) defines those types of fuels that are allowed under the statute and those fuels that are prohibited. Under 211(f), the CAA states:

"(A)fter March 31, 1977, it shall be unlawful for any manufacturer of any fuel or fuel additive to first introduce into commerce, or to increase the concentration in use of, any fuel or fuel additive ... which is not substantially similar to any fuel or fuel additive in the certification of any model year 1975, or subsequent vehicle or model year..."

The initial MTBE blending limit under the "substantially similar" rule was 7 vol%. The waiver approval was granted to ARCO refining company, which began making MTBE in the U.S. in December 1979. In addition to the provisions allowing EPA to control or prohibit a fuel or fuel additive because of emissions that impacted public health, other provisions stated that fuel or fuel additives could not be marketed unless they were substantially similar to the fuels used in the emissions certification testing for vehicles equipped with emissions control systems. EPA could waive the limitation upon demonstration by the petitioner that the emissions from the fuel would not "cause or contribute" to the failure of the emissions control system (catalytic converter). The EPA regulations on the use of oxygenates including MTBE are promulgated under Chapter 40 Code of Federal Regulations (CFR) Part 79 – Registration of Fuels and Fuel Additives.

In November 1981, EPA approved the use of 11 vol% MTBE in gasoline, equivalent to 2.0 wt% oxygen. This approval was granted to ARCO under the "substantially similar" rule. This was followed in August 1988 with EPA's approval of the Sun Refining and Marketing Co. petition for MTBE blending up to 15 vol% (2.7 wt% oxygen). Also in 1988, EPA reached an agreement with the industry for an expanded testing program to collect additional data on health and toxicology information on MTBE. This research program was conducted over a five-year period to assist EPA with assessments about the potential health and environmental risks from expanded use of MTBE blending in gasoline.

Also in 1988, EPA finalized regulations promulgated under the HSWA of 1984 (P.L. 98-616, under the Resource Conservation and Recovery Act, P.L. 94-580, enacted in 1976) that required owners of gasoline USTs to upgrade existing systems to monitor, mitigate and report releases. The EPA allowed the industry a ten-year time frame to implement its regulations.

Under authority of HSWA, most states could establish their own programs for overseeing the UST program. As part of the HSWA, EPA created a new Office of Underground Storage Tanks (OUST) to undertake the regulatory implementation. The final regulations incorporated many industry “best practices” on UST management systems.

Concurrent with the development of the testing program, EPA approved several state programs to require oxygen content in wintertime gasoline to help reduce CO emissions from vehicles. These programs were implemented to help areas attain the National Ambient Air Quality Standard (NAAQS) for CO. The additional oxygen provided by MTBE in the gasoline blend helped promote improved combustion efficiency, especially during cold start conditions. The MTBE blend typically allowed for these wintertime “oxyfuel” seasons was 11 vol% to 15 vol%. MTBE use substantially expanded as clean fuels programs were implemented during the 1990s, following passage of the 1990 CAAA (P.L. 101-549).

The wintertime oxygenated fuels program was started in late 1992, requiring a minimum of 2.7 wt% oxygen content in gasoline to help reduce vehicle CO emissions. This was followed in 1995 by the introduction of the RFG program, which was established to reduce vehicle emissions in the cities with the worst air quality. The RFG program required a minimum of 2.0 wt% oxygen content. The RFG program required oxygenate blending to improve gasoline quality and lower emissions, thereby improving air quality in those cities.

Lack of stringent enforcement of UST regulations and poor performance in implementing the groundwater protection measures resulted in widespread gasoline releases in the U.S. When these releases included gasoline blended with MTBE, subsurface plumes began to impact groundwater resources. Multiple investigations, including those by the state of California (through the University of California system) and the EPA took place to assess the extent of the releases.

In 1999, based on the conclusions of the University of California report, Governor Gray Davis issued an Executive Order banning the use of MTBE in California gasoline. The basic finding of the review was that gasoline UST releases could not be fully mitigated and MTBE’s low taste and odor thresholds could impact water quality in the state. Additional assessments by the state determined that alternative oxygenates (at the time, only ethanol was produced in sufficient volumes to be considered as an alternative blend product) could present potential impacts and may not be sufficiently available to meet volume requirements. Consequently, the state delayed implementation of the MTBE ban until 2004. Until the start of the state ban in 2004, MTBE continued to be extensively blended in California at 11 vol%.

Following events in California, other states began to adopt restrictions on MTBE use. These actions began in the corn-based, ethanol-producing states of Iowa, Nebraska and South Dakota, then expanded to other states in the Midwest and Northeast. For the most part, aesthetic concerns (taste and odor impacts) were the basis for state actions on MTBE. By 2008, 27 states imposed limitations on MTBE use in gasoline (the remaining 23 states do not have restrictions). Of the 27 states that implemented such restrictions, 20 of them allow for some MTBE content in the gasoline, generally around 0.5 vol%. Several states (e.g., Minnesota and Arizona) also restrict the use of other oxygenates including ETBE, tertiary amyl methyl ester (TAME), methanol, butanol, etc., except for ethanol.

As the debate on oxygenates and oxygen content in RFG continued, the U.S. Congress worked on new energy policy legislation to address multiple issues concerning energy use and transportation fuels (not just the RFG program and MTBE). In August 2005, Congress

adopted the Energy Policy Act of 2005 (P.L. 109-58). This statute amended the RFG program to remove requirements for oxygen content. This provision was effective as of March 2006. Consequently, U.S. refiners and gasoline blenders decided to voluntarily remove MTBE from the gasoline supply because the previous RFG requirement for oxygen content no longer provided potential protection from liability claims. Within a short time of the statutory removal of the RFG oxygen content requirement, MTBE was no longer blended into gasoline for domestic use.

Despite the marketplace changes that resulted from the removal of the RFG oxygen content requirement, a number of U.S. MTBE producers continued to make the product for export markets. Some refiners also continue to blend MTBE into their gasoline product for export to Mexico, South America and other international markets. The table below summarizes the U.S. domestic producers of MTBE for export markets.

U.S. Domestic Producers of MTBE for Export

Location	Capacity (Kt/Y)	Company
Mont Belvieu, Texas	603	Enterprise Product Partners (Belvieu Environmental Fuels)
Channelview, Texas	503	Equistar
Channelview, Texas	141	Equistar
Port Neches, Texas	650	Huntsman
Channelview, Texas	503 (ETBE)	LyondellBasell – ETBE production is exported
Norco, Louisiana	281	Motiva
Houston, Texas	241	TPC Group – MTBE production is back-cracked to make high purity isobutylene

Source: Stratas Advisors, 2012

Clean Air Act Amendments of 1990 – Winter Oxyfuel & RFG

In 1990, the U.S. Congress passed the CAAA of 1990 (P.L. 101-549); President George H.W. Bush signed it into law. Under Title II, this statute included substantial changes to vehicle emissions programs and fuel quality requirements. The CAAA of 1990 required the use of oxygenates to reduce CO emissions in NAAQS non-attainment areas (with a minimum of 2.7 wt% oxygen content). Additionally, the law required the introduction of RFG in metropolitan areas with the worst air quality to help reduce vehicle emissions of precursors (hydrocarbons or HC) that form ground-level ozone. The RFG program included the requirement for 2.0 wt% oxygen content in the gasoline, equivalent to 11 vol% MTBE. The areas that implemented the RFG program constituted about 33% of the U.S. gasoline market.

The wintertime oxyfuel program was implemented in 1992 in 36 areas that did not meet NAAQS for CO. By 1999, only 17 areas still did not meet the CO air quality standard. As of 2007, only one area – parts of southern California – still did not meet the CO NAAQS. A number of other previous CO non-attainment areas continue to voluntarily use oxygenates (e.g., ethanol) to help maintain compliance status.

The RFG program continues to be mandated in 14 states with areas classified as severe or serious nonattainment for the ozone NAAQS. Several areas surrounding the mandated RFG zones opted into the program. Areas that are required to use RFG or opted into using RFG as

part of compliance strategies receive automatic emissions credits. Studies conducted on the effectiveness of the RFG program demonstrated the benefits of oxygenate use, including MTBE blending, to help reduce vehicle emissions and move toward ozone NAAQS compliance.

During the congressional debate in 1990 on the amendments to the CAA, former Senators Robert Dole (R-Kansas) and Thomas Daschle (D-South Dakota) offered a provision to set explicit targets to require a minimum oxygen standard for the RFG program in the nine most severe ozone non-attainment areas. This standard would be met using oxygenate blending in gasoline, with ethanol and MTBE expected to be the primary options. Intensive lobbying by agricultural interests in support of the amendment took place during the Senate debate.

Contrasting the agricultural support, the petroleum industry (and to some degree the automotive industry) was working to delay adoption of oxygenate requirements as part of the RFG standard. Both industries had recently embarked on a testing program to assess the performance properties and effectiveness of oxygenates use to reduce vehicle emissions. The industry groups argued that those tests should be completed and then used by EPA for rulemaking to set performance standards for RFG.

The final version of the “Dole-Daschle” amendment readily passed during a Senate floor vote. Differences with the House of Representatives’ provisions on cleaner-burning gasoline requirements were worked out after President Bush sent a letter to the conference committee presenting a comprehensive proposal for the RFG program. The adopted proposal included a 15% reduction in VOCs and toxic emissions, minimum 2 wt% oxygen content requirement in oxyfuel and 2.7 wt% oxygen content in RFG with implementation phased in by 1995.

The Politics of Corn: Marketplace Competition between Bio-ethanol and MTBE

The oil embargoes of the 1970s prompted federal legislation to support the development and use of domestic fuel production, including ethanol made from corn starch and other agricultural products. Over the years, various supports and incentives were adopted to promote the use of domestically produced ethanol – ranging from direct tax credits to incentives for infrastructure needed to make bio-ethanol and deliver it to the fuel blender and ultimately to the retail refueling station used by consumers. In addition to the tax credits, an import tariff was imposed to limit offshore ethanol from being used. During the 1990s, some states (mostly in the Midwest) enacted legislation to mandate the use of ethanol in gasoline.

In association with these policies, financial incentives were adopted under the *National Energy Conservation Policy Act of 1978* (P.L. 95-619) that included a US\$0.40 per gallon exemption for ethanol blending into gasoline. The *Surface Transportation Assistance Act of 1982* (P.L. 97-424) increased this tax credit to US\$0.50 per gallon of ethanol blended. This tax credit was subsequently extended in 2000 by the *1990 Omnibus Budget Reconciliation Act* (P.L. 101-508) and increased to US\$0.54 per gallon, and then reduced to US\$0.51 per gallon by the *1998 Transportation Equity Act for the 21st Century* (P.L. 105-178). Finally, as part of the *Jobs Creation Act of 2004* (P.L. 108-357), the direct tax credit was changed to a blender’s tax credit and further reduced to US\$0.45 per gallon. As of Jan. 1, 2012, the blender’s tax credit for ethanol expired and is unlikely to be re-instated.

Despite these incentives and supports, the U.S. domestic ethanol industry was slow to expand mainly because of competition from low-cost production of gasoline and other blending components such as MTBE. Ethanol blending was generally restricted to the

Midwest region where corn growth and ethanol production (and delivery to blending facilities and markets) could be cost-effective. From 1981 to about 2000, ethanol production was below 100,000 barrel per day (b/d). Since the removal of the RFG oxygen content requirement in 2005 (and the subsequent de-blending of MTBE), ethanol production and use in the U.S. has grown from just over 200,000 b/d to more than 900,000 b/d.

During the debate surrounding the CAAA of 1990, it was recognized that ethanol would have a limited place in most RFG areas because of logistical and cost constraints. Nonetheless, supporters of the Dole-Daschle amendment realized that the cleaner-burning fuel requirements would offer opportunity for ethanol blending and expanded use. When the RFG program was implemented in January 1995, about 15% of the RFG market used ethanol to meet the oxygen content requirement. Over the next several years, this penetration expanded to about 25% of the RFG market. Ethanol blending during this period continued to lag because of long supply chain challenges, cost differentials and limited infrastructure at blending facilities.

As the gasoline UST, MTBE and groundwater concerns intensified from widespread media attention, the ethanol industry began lobbying to expand state bans and restrictions on MTBE. Ethanol interests initially focused this effort in the Midwest region where strong state support existed to move legislation forward on limiting MTBE use. Along with this effort, discussions on modifications to the RFG requirements began to take place – specifically to amend existing legislation to remove the RFG oxygen content standard and replace it with a Renewable Fuel Standard (RFS).

The MTBE industry also engaged in lobbying efforts to include product liability protection language in the legislation to allow some blending to take place in the absence of an RFG oxygen content requirement. The ethanol lobby, trial lawyers and environmentalists pressed federal legislators not to include MTBE liability protection provisions. The ethanol industry saw this legislation (a modification to remove the RFG oxygen content standard and install a RFS program) as the means to reduce competitive product use, maintain (even mandate) its own product use, retain its subsidy (from the blender's tax credit) and preclude offshore imports.

Ultimately, the ethanol industry prevailed with the substitution of a RFS program for removal of the RFG oxygen content requirement. Lacking protective language for continued use of MTBE in gasoline, the refinery industry decided to modify blending practices that precluded the use of MTBE in the domestic supply. The legislation did not impose any federal ban on MTBE use. Instead, refiners' voluntary decision to not use MTBE was driven by the mandate to use biofuels under the RFS program and, more significantly, by the lawsuits being filed on groundwater contamination claims.

EPA Blue Ribbon Panel

In November 1998, the EPA convened a Blue Ribbon Panel to investigate the air quality benefits, and water quality concerns associated with oxygenates blending in gasoline. The Panel was established under the Federal Advisory Committee Act's Clean Air Act Advisory Committee (CAAAC). The Panel's directive from EPA Administrator Carol Browner was to provide independent advice and recommendations on ways to maintain air quality during oxygenate use while protecting water quality.

The Panel members consisted of experts from public health, academic and scientific organizations, automotive and fuels industries, water providers, and state and local governments. The Panel was charged with:

- Examining the role of oxygenates in meeting clean air goals;
- Evaluating oxygenate product efficiency in providing benefits and the existence of alternatives;
- Assessing the behavior of oxygenates in the environment;
- Reviewing known health impacts; and
- Comparing the cost of production and use of product availability (both currently and in the future).

The Panel's data gathering (including public hearings) and deliberations took place over six months. In September 1999, the Panel issued its report, *"Achieving Clean Air and Clean Water: The Report of the Blue Ribbon Panel on Oxygenates in Gasoline."* The basic findings of the Panel were:

- Distribution, use and combustion of gasoline pose risks to the environment and public health;
- RFG provides considerable air quality improvements and benefits for millions of citizens;
- Use of MTBE has raised issues on the effects of gasoline with MTBE and from MTBE alone;
- MTBE's mobility in water and greater persistence compared to other gasoline components indicated it is more likely to present impacts;
- Few incidents were documented where MTBE levels exceeded established EPA and/or state standards. Primary concern for water supplies is taste and odor impacts; and
- MTBE (at that time) was an integral component of the U.S. gasoline supply, providing both volume and octane. Changes in MTBE use would need to consider infrastructure modifications and capital expenses for alternative product supplies to ensure flexibility and stability of the U.S. fuel supply system and gasoline prices.

The Panel's recommendations were based on existing federal, state and local programs to protect, treat and remediate water resources impacted by gasoline releases from USTs, including MTBE-blended gasoline. The recommendations were designed to enhance and expand existing programs to improve protection of drinking water supplies. The recommendations were structured around several main areas: prevention; treatment and remediation; fuel blending for clean air and water; and changes to MTBE use.

Prevention:

- Federal and state UST programs need to be enhanced – accelerated enforcement and replacement of existing tank systems to conform to federally mandated regulations (implementation was required by Dec. 22, 1998, although less than half of the systems were compliant by that date);
- Evaluate field performance of current system design requirements and technology to minimize leaks/releases;
- Improve release-detection requirements to ensure early detection and implement rapid response to fix leaks;
- Institute monitoring and reporting of MTBE and other oxygenates/ethers in groundwater at gasoline UST leak sites;
- Encourage land-use planning and permitting decisions for gasoline USTs (refueling stations) to protect the proximity to drinking water supplies;

- Implement and/or expand programs to train UST system installers and maintenance staff;
- Coordinate source water assessment programs with UST programs to enhance protection zones and measures;
- Broad-based outreach and public education programs on the proper handling and disposal of gasoline; and
- Research and comparative studies to examine the impacts of other gasoline components.

Treatment and Remediation:

- Enhance the existing federal Leaking Underground Storage Tank (LUST) Trust Fund by appropriating adequate funding to undertake treatment and remediation of sites impacted by gasoline releases;
- Encourage states to use State Revolving Funds to help with treatment and remediation in high-priority areas (SRF are block grants to states to carry out variable programs rather than dedicated to specific uses);
- Establish prioritization of remediation efforts at gasoline UST release sites based on proximity to drinking water supplies; and
- Research to develop and implement additional cost-effective treatment and remediation technologies.

Fuel Blending for Clean Air and Water:

- National fuel system complexity results in advantages and disadvantages for each fuel-blending option in maintaining air quality benefits while at the same time protecting water resources – integrated package of congressional and EPA actions to clarify authority for regulating gasoline and blending components;
- Ensure that there is no loss of air quality benefits from oxygenated gasoline and RFG. Maintain the wintertime oxyfuel program by clarifying state authority to regulate or eliminate the use of gasoline additives that impact drinking water supplies;
- EPA should seek appropriate mechanisms to maintain real-world performance from RFG use and conventional gasoline to avoid backsliding on emissions and air quality;
- Air toxic emissions performance should be considered along the lines of California's clean-burning gasoline program that includes caps on specific fuel components; and
- Investigation, research and multi-media studies of other oxygenates (focused on other ethers) to define the potential for impacts to drinking water resources.

Changes in Use of MTBE:

- Remove the 2 wt% oxygen content requirement for RFG and at the same time ensure adequate fuel supplies are provided in a cost-effective manner;
- In removing the 2 wt% oxygen content requirement, Congress needs to seek other legislative mechanisms to fulfill national policy interests on energy security and diversity, and agricultural policy; and
- Adequate lead time must be built into changes in use to avoid any disruptions in fuel supply or price.

Two members of the Panel submitted dissenting opinions on the recommendations to eliminate the federal oxygen standard for RFG and changes in use of MTBE. One member represented the Nebraska Ethanol Board, and the other represented Lyondell Chemical Co.

The opinions opposing the removal of the RFG oxygen content standard noted that the Panel failed to accurately reflect the benefits provided by the use of oxygenates in RFG. Further, they stated that the Panel failed to fully account for congressional intent for other public policy objectives in adopting the CAAA of 1990.

Lyondell's dissenting opinion also argued that:

- The Panel did not identify any increased public health risk associated with MTBE use in gasoline;
- The Panel did not provide quantifiable evidence to show the environmental risk to drinking water from leaking gasoline USTs would not be reduced to manageable levels with full implementation of the UST regulations; and
- The Panel's recommendations also fell short in preserving air quality benefits achieved with oxygenate use in the RFG program (alternatives to MTBE do not match the emissions benefits under EPA's Complex Model for RFG regulations).

Consequently, Lyondell's dissenting opinion objected to the Panel's recommendation to seek ways to reduce the use of MTBE in gasoline.

Even 15 years past the December 1998 deadline for full implementation with the gasoline UST regulations, and despite the Panel's recommendation to increase enforcement of those requirements, EPA's OUST reports that ongoing inspections indicate non-compliance still exists in up to 30% of tank systems. Congressional appropriation levels for the Trust Fund to assist with remediation work remain substantially underfunded. Consequently, gasoline releases have continued to exist and corrective actions are often lagging.

Finally, in subsequent years to the Panel report, EPA did not resist individual state actions to impose restrictions on MTBE use in RFG areas. Air quality monitoring results reported by EPA indicated emissions increases and slightly declining performance on NAAQS requirements.

Energy Policy Act of 2005

The long debate about MTBE use and the RFG program culminated in 2005 when Congress adopted the *Energy Policy Act of 2005* (P.L. 109-58). Title XV of EAct established for the first time a program to require renewable fuel content for gasoline. This title added a new section to the CAA Section 211 that grants EPA authority to regulate fuels and fuel additives. The new section 211(o) created the RFS program that set increasingly higher volume levels of ethanol use in the U.S. gasoline supply. The statute required implementation of the RFS starting in 2006 with 4.0 billion gallons (15.1 billion liters) of renewable fuel use. By 2012, the RFS called for 7.5 billion gallons (35.9 billion liters) to be blended.

EAct included provisions to protect air quality and prevent backsliding under the RFS program. More significantly, the statute removed the RFG oxygen content requirement and did not have provisions to provide product liability protection for MTBE use. The statute, however, included congressional findings on MTBE:

- Since 1979, MTBE was used nationwide at low levels in gasoline to replace lead as an octane booster (anti-knock agent);
- The CAAA of 1990 established a fuel oxygenate standard under which RFG must contain a least 2 wt% oxygen; and

- The fuel industry responded to the fuel oxygenate standard established by CAAA of 1990 by making substantial investments in MTBE production capacity and systems to deliver gasoline containing MTBE to the marketplace.

To assist the fuel industry in managing cases being filed in various state courts, EPAAct allowed further petitions to be moved to the appropriate U.S. district court where they could be consolidated for defense efficiency.

Other key provisions included under EPAAct were:

- Study of seasonal variations in renewable fuel use;
- Waiver conditions for states to petition EPA to reduce the renewable fuel volume if the requirements would “severely harm the economy or environment” of the state, region or the U.S.;
- Small-refinery exemption from RFS requirements until 2011;
- Ethanol market concentration analysis by the Federal Trade Commission to ensure sufficient competition among industry participants;
- Analysis of motor vehicle fuel changes and emissions modeling;
- Data collection and surveys of renewable fuels by the Department of Energy;
- Fuel system requirements harmonization study by EPA to examine issues on fuel supply, volatility and prices;
- Impacts to air quality under the EPA’s Tier II vehicle emissions and motor fuel requirements; and
- Studies and authorization for appropriation of funding to support development of cellulosic-based biofuels, conversion of other biomass to fuels, and other advanced biofuels technologies.

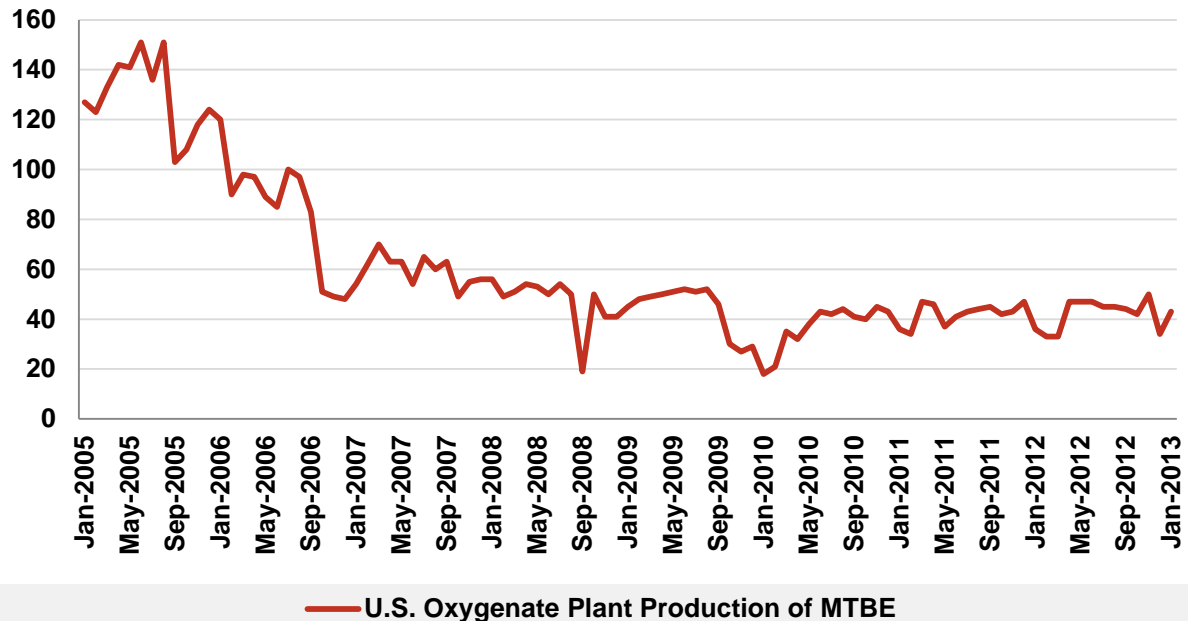
EPAAct also amended UST requirements under Subtitle B (*“Underground Storage Tank Compliance Act”*). This part of EPAAct directed EPA to distribute to states additional funds from the UST Trust Fund accounts to provide for increased inspections and enforcement, expand operator training, support release prevention and monitoring, and assist with remediation programs. The Subtitle also made it illegal to deliver a regulated substance to an UST facility identified by EPA as ineligible for such delivery, such as fuel non-compliant with UST requirements.

EPAAct, under CAA section 211(b), required EPA to conduct studies on various fuel oxygenates and other components to assess the effects on public health, air quality and water resources. The oxygenates to be tested included ETBE, TAME, DIPE, tertiary butyl alcohol (TBA), ethanol, iso-octane, alkylates, and other ethers and heavy alcohols (as determined by EPA). An industry group administered by the American Petroleum Institute conducted the testing.

EPA promulgated regulations to eliminate the 2.0 wt% oxygen standard in RFG (under Section 211(k) of the CAA) effective May 5, 2006. After this date, without the liability protection language, refiners were at increased risk of being sued in court for continued use of MTBE – **despite that the federal government did not then, nor subsequently, impose any ban on MTBE**. Once the EPA adopted the changes to the RFG regulations, refiners began to voluntarily end MTBE blending in the U.S. gasoline supply. Prior to completing this change to RFG formulations, spot shortages of gasoline developed in several eastern states because of logistical problems in getting adequate ethanol supplies to gasoline terminals. Maryland, New Jersey, Pennsylvania and Virginia were among the states affected.

After the second quarter of 2006, refiners and gasoline blenders no longer blended MTBE for domestic use. Production of MTBE, however, continued for export markets. The figure below provides MTBE monthly production in the U.S. [note that ETBE production is not included in these data by the Energy Information Administration (EIA)]. While there are seasonal fluctuations, MTBE production in the U.S. has remained relatively steady since mid-2007.

U.S. MTBE Production (thousand b/d)

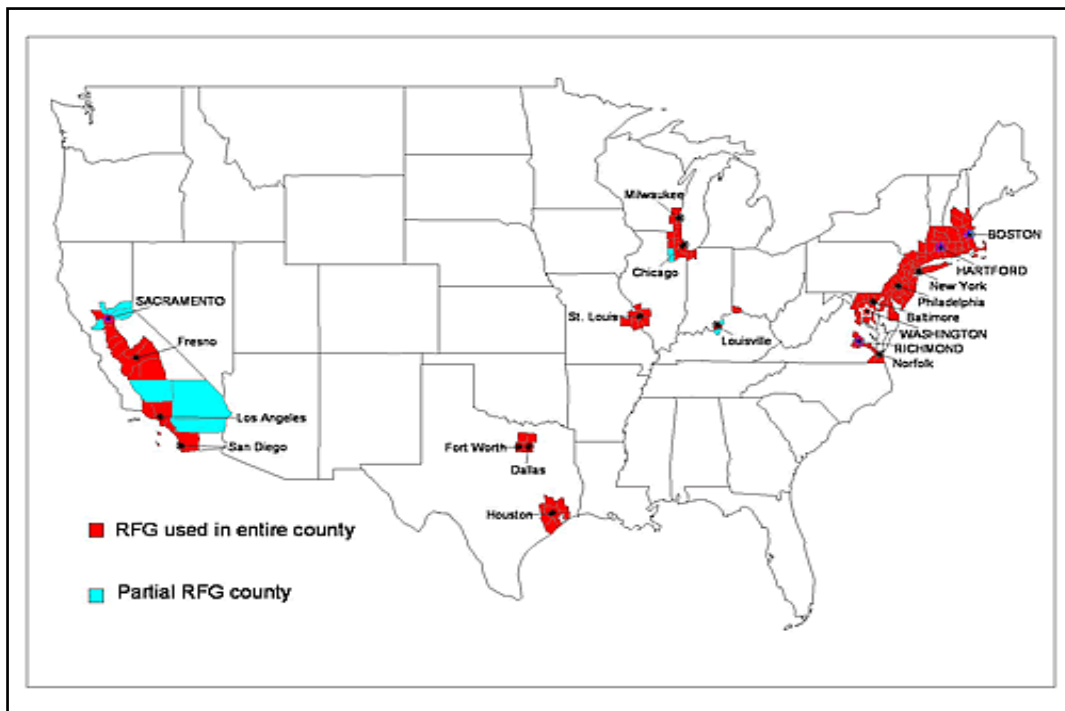


Source: Energy Information Administration, 2013

State Actions on MTBE

Metropolitan areas in 18 states (plus the District of Columbia) with the most severe air quality problems participate in the RFG program. The majority of these areas are located in the Northeast states, California, Illinois and Texas, as shown in the figure below. Today, RFG is used in about 35% of the U.S. gasoline supply, similar to the amount when the program started in January 1995. When the program was implemented, MTBE was used in about 85% of the RFG market areas, and ethanol was used in the remainder (generally the Wisconsin and Chicago areas). At the time EPA Act was passed in 2005, MTBE was still blended in more than half of the RFG market (outside of California).

U.S. Reformulated Gasoline Areas

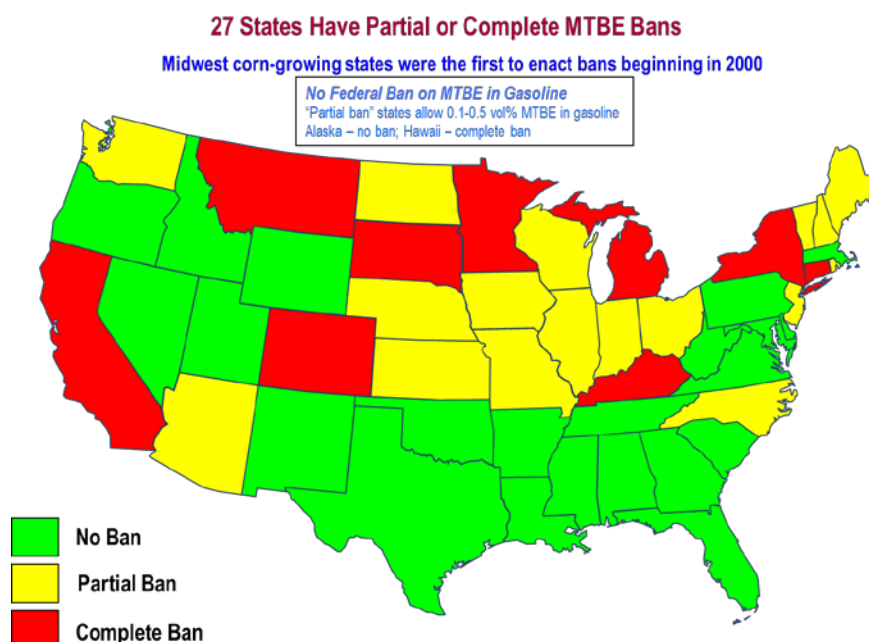


Source: EPA, 2012

In the late 1970s and early 1980s, the oil industry began to recognize the challenge of leaking gasoline USTs. The American Petroleum Institute established a task group to investigate and evaluate the environmental fate and health effects of petroleum hydrocarbons in groundwater. From survey responses, the first reported incident of MTBE detection in groundwater was in 1980 in Rockaway, New Jersey. The source of the gasoline release was a Shell service station UST. In subsequent years, the concerns about leaking USTs prompted legislation and regulations to mitigate gasoline releases and compel remediation of impacted sites.

From 1999 to 2008, a total of 27 states enacted limits or bans on MTBE use in gasoline. Most of these states are located in the Midwest or the Northeast regions of the U.S., as indicated in the figure below. The conditions under which these restrictions exist vary from complete removal of MTBE to allowances for residual levels, generally at 0.5 vol%. The rationale for imposing restrictions mainly came from water quality concerns because of taste and odor rather than concentrations detected that might exceed health risk guidelines. This progress toward restriction on MTBE use came more from evolving political interests and policy than from new scientific information. The source of virtually all MTBE detections in groundwater was from leaking gasoline USTs. By the December 1998 deadline for meeting the EPA's regulations, about 1.25 million USTs were closed down. According to EPA records, about 891,600 USTs remained in service based on upgrades to meet the leak detection and release protection requirements.

U.S. State Restrictions on MTBE Use



Source: Stratas Advisors, 2013

Multiple groundwater and surface water surveys in various states were conducted by the U.S. Geological Survey (USGS) as part of its National Ambient Water-Quality Assessment Program (NAWQA). One survey, in cooperation with the EPA, analyzed the occurrence and distribution of MTBE and other VOCs in the Northeast and Mid-Atlantic regions. This survey looked at drinking water supplied by community water systems from 1993 to 1998, prior to the implementation of the UST regulations. The two most commonly found chemicals were disinfection by-products: chloroform and trichloroethane (TCE).

MTBE was the third most-detected constituent. Median concentration of MTBE detected was less than 5.0 µg/L, and overall detections were mostly below 20 µg/L (EPA's lower limit consumer advisory for taste and odor). The NAWQA also detected other gasoline hydrocarbons, including benzene, toluene and trimethylbenzene. The USGS concludes that leaking gasoline USTs are the principle source of these hydrocarbons found in water resources. In some urban areas with high run-off rates, detections in surface waters were more frequent, albeit generally at low concentrations.

California

The most recognized incidents of gasoline UST releases and MTBE detections in groundwater occurred in California. The state's cleaner-burning gasoline regulations included the requirement for oxygen content. Because of the large volume of gasoline demand, need for fungibility and specifications that severely restricted volatility because of extremely poor air quality in much of the state, California was the largest consumer of MTBE and most gasoline blends contained the product.

Two of the highest-profile cases took place in Santa Monica (where municipal groundwater wells were impacted) and South Lake Tahoe. Both of these cases became engaged in protracted litigations that ultimately were settled by the refining companies. These settlements (payments amounting to hundreds of millions of dollars to the municipalities and to the plaintiffs' lawyers) helped to finance other litigations filed in other states. While most of the lawsuits were settled over the past decade, several are still proceeding through the court system. Of note for these two cases, other gasoline constituents, including benzene, were detected in the groundwater as well as MTBE. In the Santa Monica case, 23 known leaking gasoline USTs were identified as potential sources that impacted the municipal water wells, including a finished gasoline pipeline running under the street adjacent to the property.

Much of the MTBE detections that were found in California originated from leaking USTs prior to implementation of the more stringent regulations that were designed to prevent further releases. The high profile of the Santa Monica and the South Lake Tahoe cases prompted the state legislature to appropriate funding to the University of California system to conduct a study of MTBE and potential substitute products. In November 1998, the UC-Davis (which administered the overall effort) delivered to Gov. Pete Wilson a report that concluded that the state could not adequately protect its water resources from UST releases and that MTBE's taste and odor properties and uncertainties about results from toxicology tests warranted a gradual phase-out of MTBE from gasoline in California. The report included options for moving forward with the phase-out and recommended that the environmental impacts of any chosen strategy be undertaken prior to implementation.

In March 1999, California Gov. Gray Davis issued an executive order directing the removal of MTBE from gasoline sold in the state. Under the timeline, this action was to take place by 2001; however, it would be contingent on the state receiving a waiver from the EPA on the oxygen content requirement for RFG used in the state. The state was concerned about the increased use of ethanol that would be needed (in place of MTBE) and the likely drastic increase in costs to consumers. In 2001, Davis requested a waiver from EPA, which was denied by the agency in 2002 because cost increases and ethanol availability were deemed insufficient causes to justify waiving the RFG oxygen requirement. Consequently, Davis reversed his executive order and extended the phase-out of MTBE use in the state's gasoline for another two years. The removal of MTBE from California's gasoline was finally implemented in January 2004, once the state's Air Resources Board (ARB) modified its regulations. As part of its regulatory changes, ARB adjusted its fuel compliance model, called the Predictive Model, to accommodate the use of ethanol as the only oxygenate allowable to meet RFG requirements (mainly because of volatility and distillation properties of ethanol).

Northeast States

The Northeast region of the U.S. is highly dependent on imports of gasoline either from offshore, Canada or via pipeline from the U.S. Gulf Coast (USGC). In the Northeast market, about two-thirds of the gasoline sales are RFG. Because of the diversity of gasoline supply

into the region, a high level of fungibility is necessary to ensure product availability to consumers at competitive pricing. Changes to the RFG formulation could disrupt supply chains, particularly for foreign suppliers that may not be able to provide MTBE-free RFG (also known as Reformulated Blendstock for Oxygenate Blending, or RBOB). Any reduction in RFG and RBOB imports would need to be made up by additional supplies from domestic refiners, typically from the USGC, and likely at additional costs. Furthermore, because of volatility concerns and EPA Mobile Source Air Toxics (MSAT) rules, commingling of MTBE-blended gasoline with ethanol-blended gasoline was prohibited. At the time, the baselines for cleaner-burning MTBE-blended gasoline in much of the Northeast would be impacted from transition to ethanol blending (ethanol use slightly increases the air toxics emissions that must be compensated by other blending changes to avoid the “anti-backsliding” regulations under MSAT).

As the movement to impose restrictions on MTBE use migrated to the Northeast, concerns increased about the availability and costs of ethanol to meet the RFG oxygen content requirement. The EIA concluded that the ethanol industry could be expanded to substitute for MTBE blending; however, transportation/logistical and infrastructure issues existed that would likely increase costs – projected to be about US\$0.036 per gallon on national average for RFG in 2004. EIA further projected that RFG price increases would be substantially higher than the national average in California, New York and Connecticut (the latter two states were considering MTBE bans at the time). EIA stated that sufficient lead time for investments and assumptions of perfect foresight by investors (for timing of capital-cost infrastructure changes) would be necessary to avoid supply imbalance and price spikes during a MTBE phase-out.

In 1999, at the request of former New Hampshire Gov. Jeanne Shaheen, NESCAUM, an association for air program directors from eight Northeast states, conducted a review of the RFG program and MTBE use in the region. The challenge facing the Northeast states was to identify a pathway that effectively mitigated environmental issues from MTBE while maintaining the air quality and public health benefits from the RFG program. NESCAUM also wanted to prevent disruption of gasoline supply and increases in prices for consumers. RFG used in the Northeast region relied almost entirely on MTBE to meet the oxygen content requirement and achieve the emissions reductions needed to help urban areas reach ozone NAAQS. NESCAUM developed a series of technical papers that looked at environmental issues, air quality, fuel supply and costs, remediation and treatment, and health aspects of RFG and MTBE.

Key findings by NESCAUM included:

- RFG is a proven and cost-effective emissions reduction strategy;
- Aggregate public health benefits of RFG (at the time blended with MTBE) outweighed potential impacts from exposure to MTBE levels in air and water;
- MTBE at levels typically found in the region’s air and water does not pose a health threat (high levels exceeding drinking water standards due to unmitigated UST releases could pose increased risk);
- Northeast gasoline refiners and suppliers over-complied with RFG toxic emissions performance standards by more than 75%, in part because of the blending of MTBE. These emissions benefits may be diminished or lost if MTBE is phased out of RFG;
- Exposure to conventional gasoline components presents potential health risks to the public and steps should always be taken to prevent and avoid exposures;
- Taste and odor characteristics of MTBE can make drinking water unacceptable to consumers;

- Testing requirements for gasoline components and additives need to be strengthened to ensure protection of public health and environmental quality;
- Leaking gasoline USTs represent the primary threat to drinking water because of lack of leak detection;
- Because of water solubility traits, MTBE posed unique challenges to groundwater treatment compared to other gasoline components;
- Replacement products (aromatics, alkylates, ethanol) present economic and environmental disadvantages and advantages compared to MTBE;
- Changes to the RFG program are likely to have substantial impacts on conventional gasoline's environmental characteristics. Existing regulations are inadequate (at the time) to prevent back-sliding and degradation of conventional gasoline fuel quality; and
- Economic impacts – higher gasoline prices – are likely in implementing changes to gasoline on a regional or national basis.

NESCAUM's strategies and recommendations on the RFG program included:

- Legislative and regulatory initiatives to lower the amount of MTBE blended in gasoline (including removal of the RFG oxygen content standard, and extended phase-down and cap on MTBE use);
- EPA action to prevent air quality backsliding (including for air toxics emissions);
- Regional assessment to enhance gasoline UST programs, including improved monitoring and enforcement;
- Regional multi-media monitoring and assessment programs for fuels;
- Scientific assessments of alternative blending components;
- Expanded analysis of fuel supply and price impacts due to changes in the RFG; and
- Public education and outreach on proper gasoline handling and disposal.

The Northeast region strategy in dealing with MTBE issues was to coordinate the time frame for restricting use to minimize supply disruptions and price increases. New York and Connecticut proceeded with MTBE phase-out at the start of 2004. Six other Northeast states (except for Massachusetts, which has not restricted MTBE) implemented MTBE restrictions in 2007 or later – well after the RFG oxygen content requirement was removed and refiners voluntarily deselected MTBE from the gasoline supply.

MTBE AND THE EUROPEAN FUEL QUALITY DIRECTIVE

Commercial production of MTBE started in Europe in 1973. Initially, MTBE was added to gasoline at low blend levels, typically 2 vol% to 5 vol%, to boost the octane rating of unleaded gasoline or high-performance gasoline grades. In the 1990s and 2000s, MTBE was blended at higher concentrations between 11 vol% to 15 vol% to promote more efficient combustion of gasoline and help reduce vehicle emissions. MTBE was the most commonly used fuel oxygenate. ETBE was used in small volumes (there was a small amount of production in Spain and France¹) similar to TAME and next-TAME (C4-C7 tertiary alkyl methyl ethers).

¹ In Europe, ETBE was used in France for the first time in 1992.

Despite its popularity as a fuel oxygenate, MTBE was not regulated at the EU level or at the Member State level until 1998.

Fuel Quality Legislation

In 1998, the first FQD (*Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels*) was discussed and adopted together with *Directive 98/69/EC of the European parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles (...) (Euro 3 and 4 stages for light duty vehicles)*. These directives resulted from the European Auto Oil I Programme, and the comprehensive European Programme on Emissions, Fuels and Engine Technologies (EPEFE). The programs provided sound technical evidence that both fuels and engine technologies are important determinants of motor vehicle emission levels and that the relationships among fuel properties, engine technologies and exhaust emissions exist and are complex. EPEFE investigated the effects of each fuel parameter on the vehicle/engine emission levels. These fuel parameters were:

- Sulfur content, mid-range distillation (E100) and aromatic content of gasoline; and
- Cetane number, poly-aromatics, density and back-end distillation (T95) of diesel fuels.

The FQD set new mandatory specifications for gasoline. Among other changes, it introduced from 2000 new limits for:

- Aromatics – 42 vol% (reduced to 35 vol% in 2005);
- RVP – 60 kPa;
- Sulfur – 150 ppm (reduced in 2005 to 50 ppm);
- Benzene – 1 vol%; and
- Olefins – 18 vol%.

Oxygen content was established as 2.7 wt% max. This limit originated in the U.S. and was considered the optimal level for air quality benefits from oxygenates blending while avoiding potential disadvantages of higher levels. Increasing the oxygen level can lead to higher exhaust emissions of NO_x and reduced VOC emissions. Depending on the oxygenate, there may be offsetting effects from higher evaporative and permeation emissions of VOCs.

The FQD also specified the maximum volumetric content of various oxygenates including alcohols and ethers. The overall maximum permitted oxygenate content was determined by these volumetric limits in conjunction with the global oxygen limit of 2.7 wt%. The chemical formula of each compound determined its oxygen content and was a basis for the limit in the legislation. The table below summarizes the FQD oxygen/oxygenates limits.

Oxygen and Oxygenates Content in the FQD, 2000 to 2009

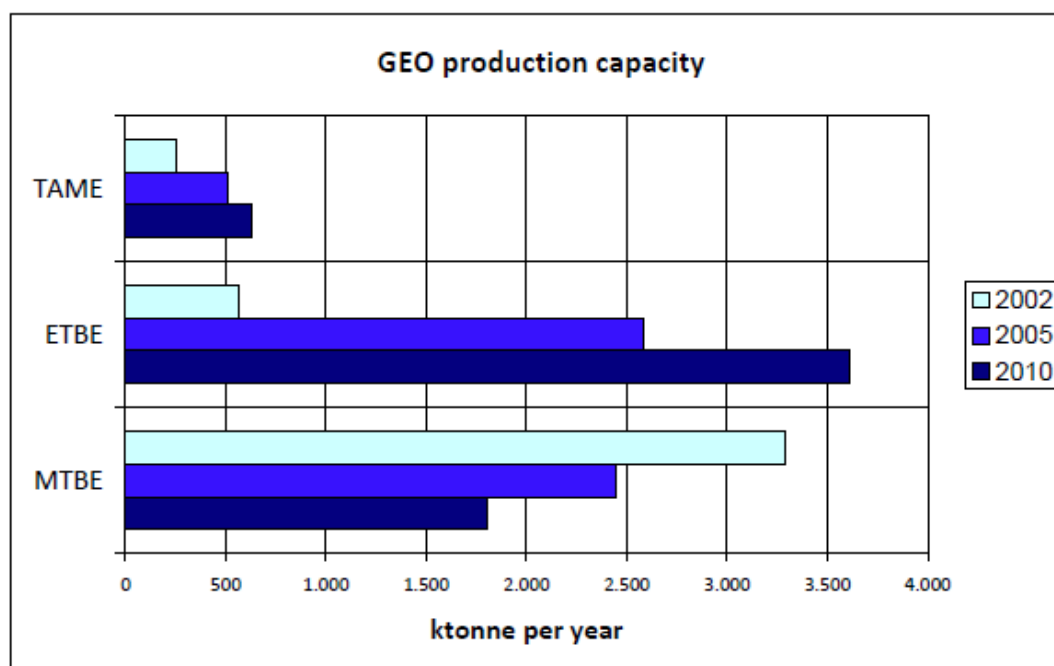
Parameter	Maximum Limit
Oxygen	2.7 m/m%
Oxygenates:	
Methanol	3 vol%
Ethanol	5 vol%
Iso-propyl alcohol	10 vol%
Tert-butyl alcohol	7 vol%
Iso-butyl alcohol	10 vol%
Ethers containing five or more carbon atoms per molecule	15 vol%
Other oxygenates	10 vol%

Source: Directive 78/90/EC, 2000-2009

Upon the adoption of the legislation, MTBE consumption was expected to increase because of the decreased overall aromatics concentration and the need for high-octane blend components. Because of the high intrinsic octane rating of aromatics, any decrease in aromatics content leads to loss of octane rating in base gasoline. It was believed that the change in aromatics by 7 vol% (from 42 vol% to 35 vol%) would require 7 million to 8 million metric tons of aromatics to be replaced with non-aromatic high-octane blending components. The FQD did not mandate a specific oxygenate, therefore different types of ethers or alcohols could be used as octane boosters. However, owing to the availability and extended use of MTBE (3 million tons in 1999), it was believed that MTBE would be one of the favored choices (experts projected 4 million tons by 2005) despite its higher price.

However, in contrast to projections, the European market did not record increased MTBE usage; instead, producers transitioned to making ETBE. The market share of ETBE has grown from 15% in 2002 to about 60% in 2010, while MTBE production capacity has decreased (see figure below).

European Production Capacities of MTBE, ETBE and TAME in 2002, 2005 and 2010



Source: "Gasoline ether oxygenate occurrence in Europe, and a review of their fate and transport characteristics in the environment," Concawe, 2012

The main reason for MTBE's displacement by ETBE was that ETBE is derived from bio-ethanol. Therefore, it can be qualified under the EU's and individual MS' biofuel targets that have been established by majority of MS from 2004 onward. In 2003, EU institutions adopted *Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels in transport*, which introduced the indicative target of 5.75% by energy content for biofuels and other renewable fuels in the EU by 2010. Some MS decided to make biofuels targets mandatory; therefore, fuel suppliers were obliged to blend biofuels into fossil-based gasoline and diesel. Gasoline in the EU market could contain up to 5 vol% of ethanol (E5) and, as indicated above, up to 15 vol% of ethers. Among ethers, ETBE made from bio-ethanol became the most popular, displacing MTBE.

In 2009, the EU's institutions adopted a Climate Change and Energy Package aimed at achieving a triple target by 2020:

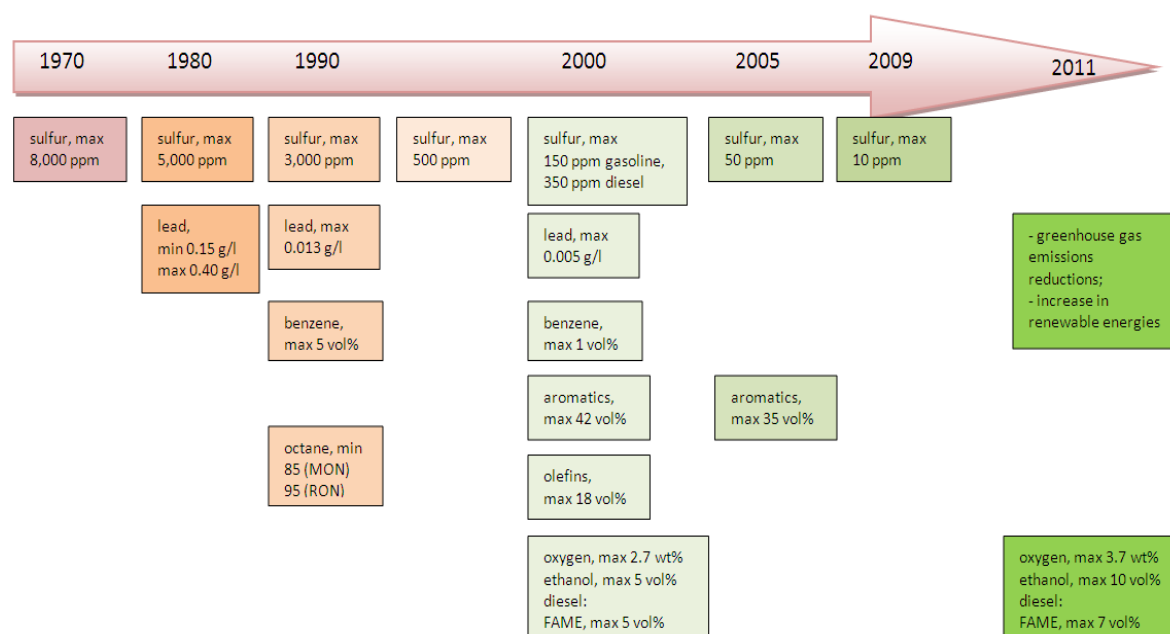
- 20% GHG emissions reduction compared with 1990;
- 20% renewable energy share in the total energy mix; and
- 20% energy efficiency compared with the energy use projections for 2020.

This policy package was incorporated in a number of legislative and non-legislative acts, including two crucial directives pertaining to fuels and biofuels: *Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions (...)* (referred to as the FQD) and *Directive 2009/28/EC of the European parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC* (referred to as the Renewable Energy Directive or RED).

In essence, fuels became an element of the European strategy on climate change mitigation. The strong push for the development of measures that may help reduce GHG emissions and increase the share of renewable energies also affected the fuel quality properties through the increase in bio-components volumes used to blend with gasoline and diesel. The RED requires from MS that they achieve 10% renewable energy in transport by 2020; the FQD requires that GHG emissions from fuels delivered to the market by 2020 are reduced by 6% (possibly 10%) compared with the 2010 baseline. As a consequence, ethanol and oxygen content in gasoline were increased to 10 vol% and 3.7 m/m%, respectively (i.e., E10 grade).

The figure below illustrates the evolution of the fuel quality specifications in the EU.

Evolution of the Fuel Quality Specifications in the EU, 1970-2013



Note: This figure illustrates only some of the parameters regulated in the EU.

Source: Stratas Advisors, 2011

According to the FQD, in addition to E10, MS must ensure availability of E5 (gasoline with ethanol content no higher than 5 vol% and oxygen content no higher than 2.7 m/m%) at least until 2013. MS may decide to keep E5 for a longer period if considered necessary.

Other Legislation

Other legislative measures in the region that indirectly pertain to MTBE are:

- *Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances* as amended. This is aimed at the prevention of major accidents and the limitation of their consequences for man and the environment. Its scope covers gasoline if stored in volumes exceeding 2,500 metric tonnes.
- *European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations* as amended (stage I vapor recovery). This is aimed at preventing release to the atmosphere of VOCs during the storage of gasoline at terminals and its subsequent distribution to service stations. It

contains measures that terminals should employ such as floating roofs and reflective coatings to reduce evaporative losses from storage tanks. In addition, the directive aims to ensure that, when gasoline is loaded in the tankers and transported to filling stations, any vapors are recovered and returned to the tanker or terminal.

- *Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refueling of motor vehicles at service stations.* This is aimed at reducing the amount of gasoline vapor emitted to the atmosphere during the refueling of motor vehicles at service stations. All service stations should have a recovery system with a minimum efficiency of 85% (certified in accordance with the European standard).
- Technical specifications and control of underground tanks are regulated at MS level.
- Type-approval legislation on vehicle emission limits:
 - Euro 5 and Euro 6 emission requirements for light duty vehicles (LDV) are provided in *Regulation (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information (...)*;
 - Euro V and Euro VI emission requirements for heavy-duty vehicles (HDV) are provided in *Directive 2005/78/EC of 14 November 2005 implementing Directive 2005/55/EC of the European Parliament and of the Council on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fueled with natural gas or liquefied petroleum gas for use in vehicles and amending Annexes I, II, III and VI thereto (Euro V) and Commission Regulation (EU) No 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy-duty vehicles (Euro VI) and amending Annexes I and III to Directive 2007/46/EC of the European Parliament and of the Council (Euro VI).*
 - “Euro” legislation establishes limits for certain pollutant emissions from vehicles: CO, HC, non-methane hydrocarbons (NMHC), NO_x, PM, number of particles, ammonia (NH₃) and smoke. Gasoline (including all compounds) must meet quality requirements that enable the achievement of these emission standards.
- Ethers, including MTBE, are subject to registration under the Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemical Agency (...). The aim of the regulation is to improve the protection of human health and environment. All companies must register chemicals they produce or import to the EU and submit a set of relevant safety data. Fuel ethers (ETBE, MTBE, TAME) were registered in summer 2010 by the fuel ether REACH consortium (FERC) established by EFOA (European Fuel Oxygenates Association) members. According to EFOA, the REACH assessment demonstrates the safe use of MTBE for production, formulation and use as an octane enhancer in gasoline.
- The European Water Framework Directive (WFD; Directive 2000/60/EU of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy) sets goals to ensure that surface water bodies attain good chemical and ecological status and that groundwater bodies achieve good

chemical and quantitative status; it also targets the prevention and progressive reduction of groundwater pollution. Therefore, the interaction between surface water bodies and groundwater bodies is an important aspect which must be understood, especially when groundwater containing ethers enters surface water. However, the directive and its implementing measures do not provide a value for any ether oxygenates.

Current MTBE Allowable Levels

The MTBE allowable limit is regulated in the FQD. It is also reflected in the European gasoline standard “EN 228:2012 Automotive fuels – Unleaded petrol – Requirements and Test Methods.” The FQD and EN 228:2012 require maximum oxygen and oxygenates limits as presented in the table below.

Oxygen and Oxygenates Content in the FQD Since 2009

Parameter	Maximum Limit
Oxygen	3.7 m/m%
Oxygenates:	
Methanol	3 vol%
Ethanol	10 vol%
Iso-propyl alcohol	12 vol%
Tert-butyl alcohol	15 vol%
Iso-butyl alcohol	15 vol%
Ethers containing five or more carbon atoms per molecule	22 vol%
Other oxygenates	15 vol%

Source: Fuel Quality Directive, 2009

As previously noted, E10 is a conventional gasoline grade in the EU. MS are obliged to ensure that E5 is also available in the market owing to the fact that some older vehicles (produced before 2000) may not be suitable to run on E10. E5 limits only oxygen content to 2.7 m/m% and ethanol content to 5 vol%, other oxygenates may be used in volumes corresponding to the maximum oxygen content.

The fuels market is impacted by the EU policy promoting the use of renewable energy and GHG emission reduction targets. Because suppliers must deliver annually certain volumes of biofuels to fulfill their biofuels mandates (which differ from country to country), they chose to use bio-components that would be best for them given numerous aspects: price, energy content, bio-component share, their sustainability, including GHG emissions performance. For these reasons, to-date choice was either ethanol or ETBE; however this varies between countries.

It should be noted that the RED and the FQD introduced a set of sustainability criteria for biofuels that they must meet to be counted toward the 10% renewable energy target and 6% GHG emission reduction target. One of the requirements is that biofuels achieve GHG emission savings threshold:

- Of 35% compared with the fossil fuel comparator (until the end of 2016);

- Of 50% compared with the fossil fuel comparator (from 1 January 2017);
- Of 60% compared with the fossil fuel comparator (from 1 January 2018) – only for fuels from new installations established in 2017.

For biofuels' GHG emissions calculation, the directives give three options to fuel suppliers (based on certain conditions): They may either use default values provided by the directives, use their own calculations or both. For default GHG emissions, directives establish values as shown in the table below.

Default GHG Emission Saving for Selected Biofuel Production Pathways

Biofuel Production Pathway	Default GHG Emission Saving
Sugar beet ethanol	52%
Wheat ethanol	16%
Wheat ethanol (straw as process fuel in CHP plant)	69%
Wheat straw ethanol	85%
Sugar cane ethanol	71%
Corn ethanol, EU production	49%
Waste wood ethanol	74%
Farmed wood ethanol	70%
ETBE	Equal to that of the ethanol production pathway used*
TAAE	
Waste wood methanol	94%
Farmed wood methanol	91%
MTBE	Equal to that of the methanol production pathway used*

Note: * ETBE – 37% from ethanol; TAAE – 29% from ethanol; MTBE – 22% from methanol.

Source: Renewable Energy Directive and Fuel Quality Directive, 2009

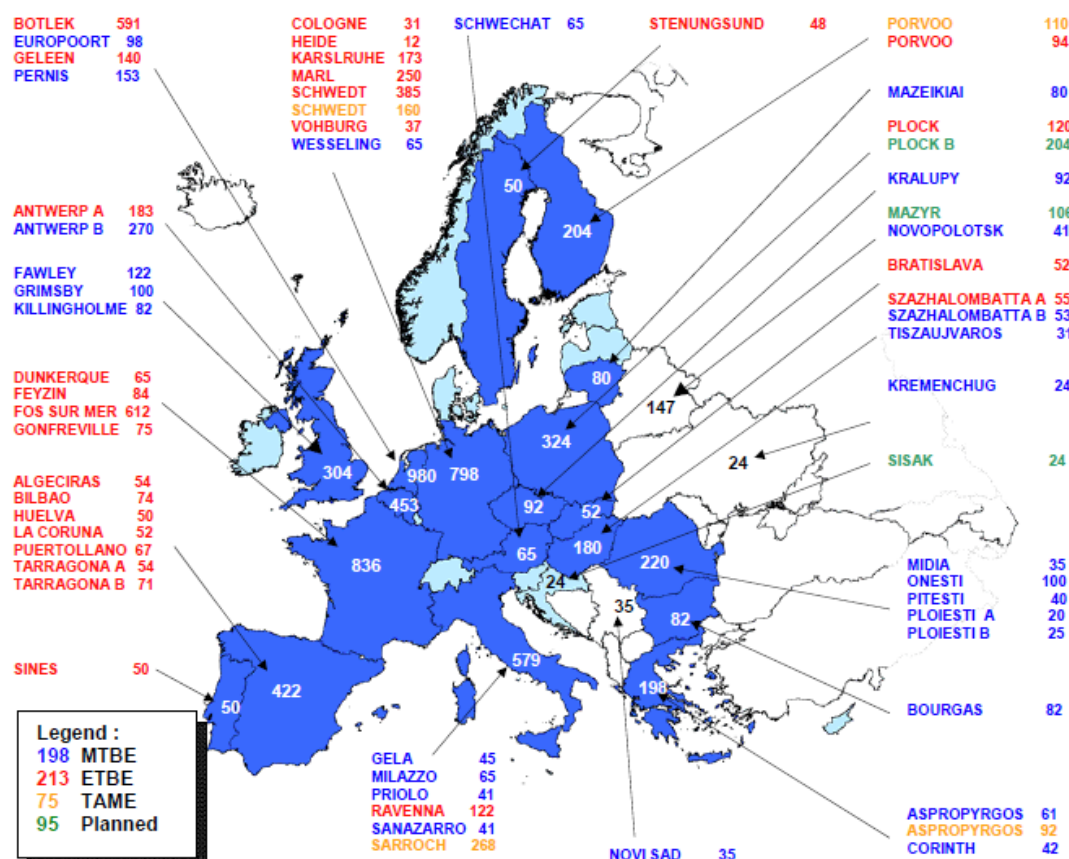
Only methanol derived from renewable sources through advanced technologies can be considered serious competition for renewable ethanol when GHG emissions savings are taken into account. Its direct blend in gasoline is restricted by a rather low limit of 3 vol%; therefore, the petroleum industry would mainly use it for the production of biodiesel or for the production of MTBE. There are already two plants in Sweden, one plant in the Netherlands and one plant in Germany producing methanol from forest residues. The table above does not include several other options of methanol production from renewable sources that are being developed in Europe. For example, there is a production plant in the Netherlands using crude glycerin as a feedstock and one geothermal CO₂-to-methanol plant in Iceland. However, methanol is blended directly into gasoline in Iceland.

These examples show that the EU policy promoting lower carbon fuels results in development of renewable methanol, which becomes an attractive compound given the GHG emissions savings it offers compared with fossil fuels and other types of biofuels.

Over the past few years, two ETBE plants were converted into MTBE plants where MTBE is produced from methanol derived from renewable sources. It is expected that this trend will

continue. Currently, the European production capacity is split mainly between MTBE and ETBE, with a small production capacity for TAME, as presented in the figure below. The actual production volumes of ethers in the EU are not communicated openly (because it is commercially sensitive information).

Production Capacity in Europe (thousand metric tonnes per year)



Source: "Gasoline ether oxygenate occurrence in Europe, and a review of their fate and transport characteristics in the environment," Concawe, 2012

The table below presents results of a survey conducted by Société Générale de Surveillance (SGS) in the period from winter 1999/2000 until summer 2009 in 27 EU countries, Norway, Switzerland and Turkey. This survey concerned ethers composition of six gasoline types. The survey contains information from 1,239 sampling events on MTBE, ETBE and TBA, and 650 sampling events on TAME and DIPE.

Mean, Median and Maximum Reported Concentrations of Ethers (m/m%) in Gasoline in 27 EU Countries in SGS Database

	Ether Oxygenates				
	MTBE	ETBE	TAME	DIPE	TBA
Total number of sampling events (n)					
	1,239	1,239	650	650	1,239
Mean (average) concentration in all European gasoline samples in 2000-2009 (m/m%)					
	5.39	0.91	0.29	0.00	0.03
Median concentration in all European gasoline samples in 2000-2009 (m/m%)					
	4.25	0.00	0.00	0.00	0.01
Maximum concentration observed in individual sampling rounds (m/m%)					
Concentration (m/m%)	20.43	15.50	11.22	0.88	1.03
Gasoline type	PULP	PUL	PUL	PULP	PULP
Period	Summer 2001	Winter 2008/2009	Winter 2007/2008	Winter 2002/2003	Winter 2000/2001
Country	Romania	France	Finland	Greece	Switzerland

Note: Minimum levels were all 0.00 m/m%.

Source: "Gasoline ether oxygenate occurrence in Europe, and a review of their fate and transport characteristics in the environment," Concawe, 2012

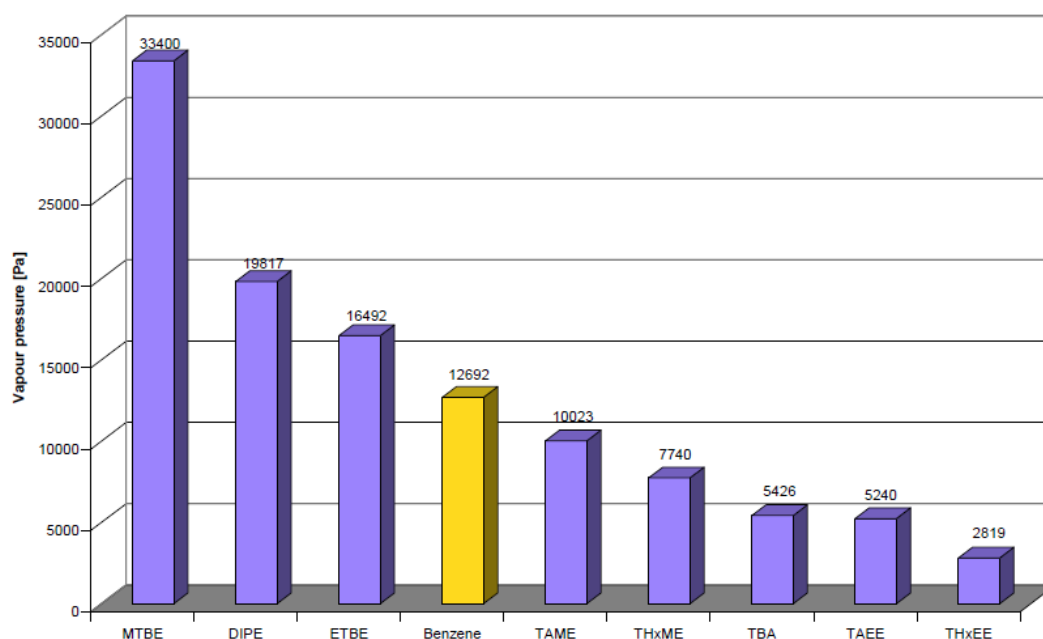
These data cannot be considered representative for the use of ethers in the EU. However, for maximum concentration, it actually depicts the trend mentioned earlier in this report about the wide use of MTBE until the early 2000s and subsequent switch to ETBE caused by the wider use of bio-components.

Air Quality Benefits and Impacts

Environmental emissions of MTBE are related to production of MTBE, blending with gasoline and its storage, distribution and use. Gasoline is a major source of MTBE that may be detected in ambient air via the automobile exhaust gases. Oxygenates are considered VOCs (having boiling point <250 C°) and have vapor pressure values ranging from approximately 2.8 kPa for THxEE up to approximately 17.6 kPa (at 10°C) for MTBE (see figure below). MTBE's vapor pressure allows it to transfer into the gas phase.

The vapor pressures of MTBE, DIPE and ETBE are higher than benzene's vapor pressure of approximately 12 kPa, and oxygenates generally partition readily from an organic liquid (e.g., gasoline) into the vapor phase. Vapor pressure reduces in the order of MTBE > DIPE > ETBE > TAME > THxME > TBA > TAE > THxEE.

Vapor Pressure of Different Ether Oxygenates Compared with Benzene



Source: "Gasoline ether oxygenate occurrence in Europe, and a review of their fate and transport characteristics in the environment," Concawe, 2012

The vapor pressure and density of MTBE is close to the typical European grades of commercial gasoline.

Studies performed in Europe in 1990s showed that MTBE concentration in gas phase (headspace) was directly proportional to on the concentration in gasoline, e.g., 12 wt% MTBE in summertime quality Finnish RFG led to a mean mass concentration of 10.5 wt% in the vapor phase. Therefore, it can be expected that evaporative VOC gases from gasoline would contain on average approximately 8.5 wt% to 9.5 wt% of MTBE if the liquid gasoline originally contained, for instance, 10 wt% of MTBE (0.85 wt% to 0.95 wt% of MTBE in VOC per 1 wt% of MTBE in gasoline, assuming linearity).

Half Life

Emissions of MTBE in the atmosphere are relatively modest; typical average diurnal urban concentrations are less than 10 µg/l. MTBE reacts with hydroxyl radicals in the atmosphere and the average half-life is 3-6 days. The indirect effect is most likely the ozone forming; however, MTBE is not expected to significantly contribute to ozone forming compared with other more reactive compounds in gasoline. In fact, MTBE is added as an oxygenate to reduce the ozone-forming potential of gasoline. In comparison to the alcohols they are made from, ethers reduce the overall vapor pressure of gasoline and the related evaporative emissions to air which causes ozone.

According to the EU's 2003 risk assessment conducted by the European Chemicals Bureau, there were no studies that would show that ambient air concentrations of MTBE may cause direct adverse effect for plants or animal species.

IMPACT ON VEHICLE EMISSIONS

Gasoline-related emissions from vehicles are usually evaluated from two separate sources: exhaust emissions from the vehicle's tailpipe when the engine is operating, and the evaporative emissions that generally escape (or permeate) from the vehicle's fuel system when the vehicle is both operating (running losses) and not operating. The evaporative emissions are VOCs escaping through elastomers and plastic parts and from the carbon canister used to capture vapors from the fuel tank and system.

Vehicle emissions research has been conducted for both of these emission sources with gasoline blends containing up to a nominal 20% MTBE (~3.7 wt% oxygen such as in 10% ethanol). In addition to standard vehicle emissions such as VOCs, NO_x and CO, the effects of oxygenates such as MTBE on vehicle emissions have also been investigated for air toxics (e.g., benzene, formaldehyde, acetaldehyde and butadiene) and also fine PM in the vehicle exhaust.

As part of evaporative emissions, the impact of the various oxygenates on the rate of VOC permeation from the vehicle elastomers has also been investigated. Based on these studies conducted over the past 30 years, vehicles operating on fuels containing up to a nominal 20% MTBE (~3.7 wt% oxygen) will have lower exhaust emissions and also should not experience any degradation in performance as compared to gasoline containing no oxygenates.

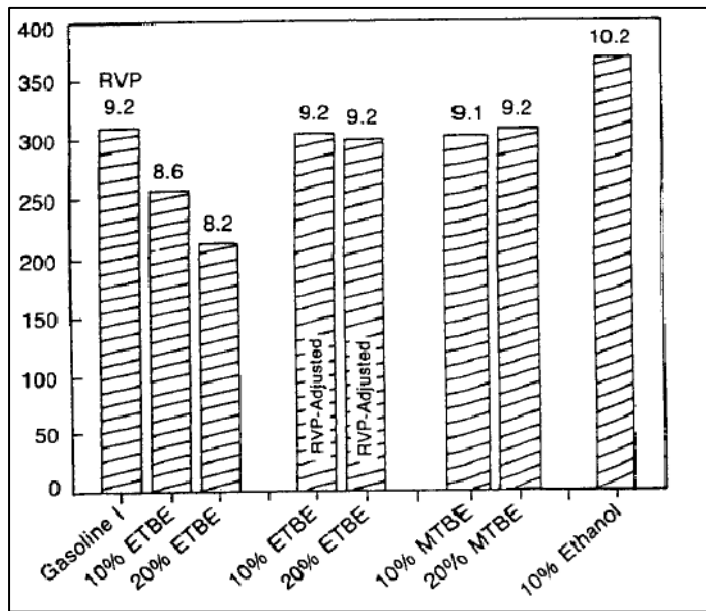
Evaporative Emissions

The evaporative emissions for oxygenate blends containing up to 20 vol% MTBE was evaluated by General Motors Research Laboratories (GM) during the 1990s. In general, the results show that the mass of evaporative emissions from the vehicle would be only a function of the gasoline's volatility properties and not related to the oxygenate composition of the gasoline. The results in the first figure below show that the diurnal emissions (from daily temperature changes) would not be affected with MTBE concentrations up to 20 vol% in the fuel. This implies that the absorption efficiency of the carbon canister would not be affected by any MTBE in the gasoline vapor.²

In the same study, GM also evaluated the effect of oxygenate blends on the amount of hot soak evaporative emissions, which are the vehicle's vapor emissions emitted immediately after the warmed-up vehicle is shut off. The results from the study are illustrated in the second figure below. In general, the amount of hot soak emissions was much greater than the amount of diurnal emissions. Although the results also showed higher hot soak emissions for the oxygenate blends, GM found these increased emissions to be a function of the change in the gasoline's E70 distillation property from the oxygenates and not related to the composition of the oxygenates in the fuels.

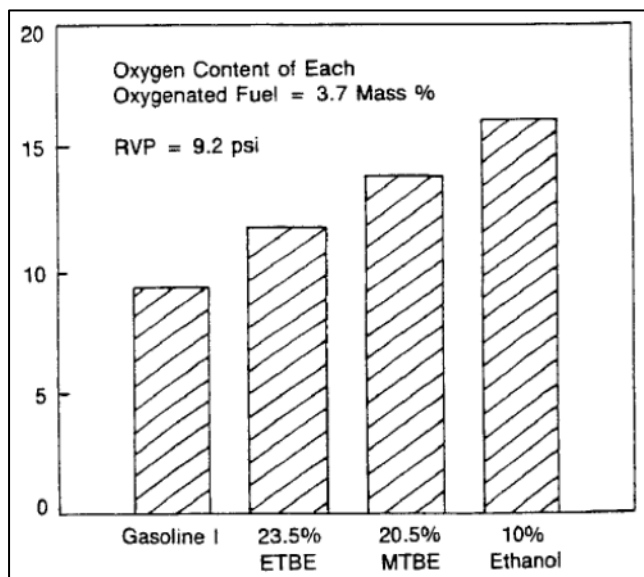
² SAE 901114, "Volatility Characteristics of Blends of Gasoline with Ethyl Tertiary-Butyl Ether (ETBE)," Robert Furey and Kevin Perry, GM Research Laboratories, 1990

Diurnal Evaporative Emissions for Oxygen Blends (mass of vapor, mg)



Source: General Motors Research Laboratories, SAE 901114, 1990

Hot Soak Evaporative Emissions for Oxygenate Blends (mass of vapor, mg)

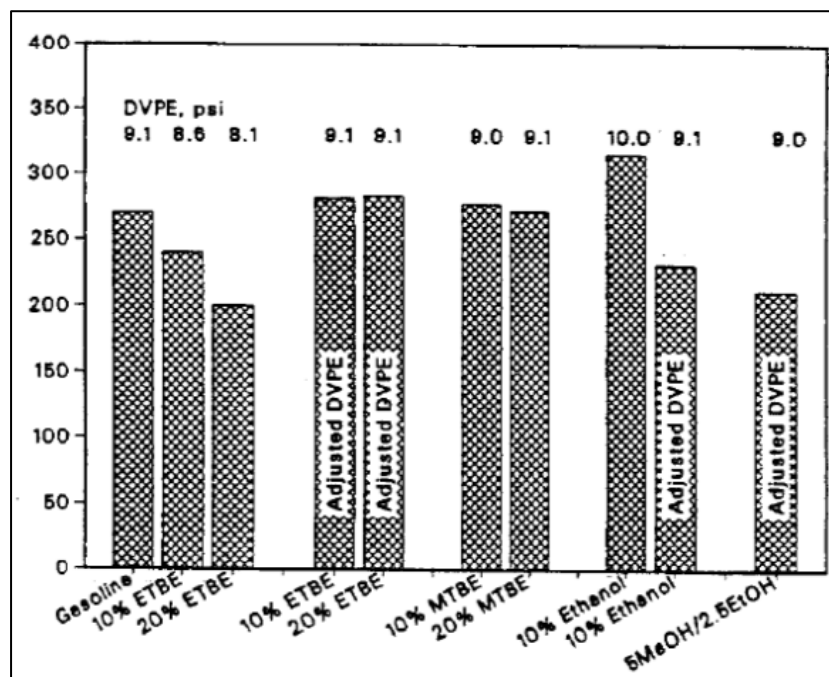


Source: General Motors Research Laboratories, SAE 901114, 1990

In a follow-up study, GM evaluated the potential ozone contribution of the evaporative emissions from the oxygenated fuel blends by also measuring the individual component composition of the evaporative emissions, and then applying the incremental atmospheric reactivity for each component in the emissions.³ As in the previous study, GM found the total amount of diurnal emissions not to be generally affected by the type and concentration of the oxygenates used in the gasoline blend when the gasoline RVPs are the same as observed in the first figure below.

However, after applying the reactivity factors to the individual components in the vapor emissions, the results show that there is a significant difference in the potential ozone contribution from the different types and concentrations of the oxygenates used in the fuel blend. As illustrated in the second figure below, the evaporative emissions from MTBE blends are expected to have a lower ozone contribution by as much as 20% for a 20 vol% MTBE blend, which is due to the relatively low reactivity of the MTBE factor in the atmosphere. Based on the results of the two separate gasolines evaluated, GM estimated the reactive contribution of MTBE to be about 60% to 70% lower than that of the hydrocarbon vapors of gasoline as illustrated in the third figure below.

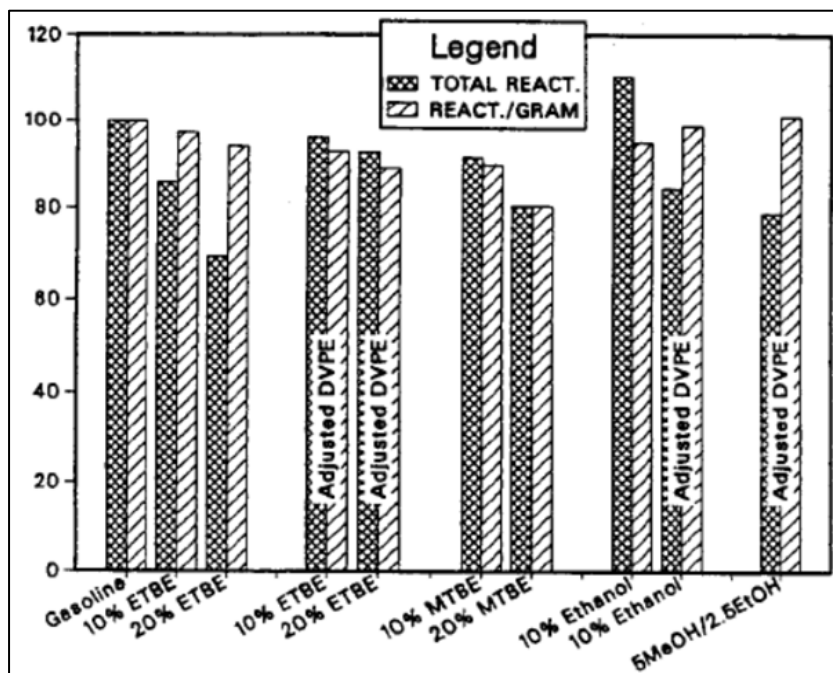
Evaporative Emissions for Oxygenate Blends (mass of vapor, mg)



Source: General Motors Research Laboratories, SAE 912429, 1991

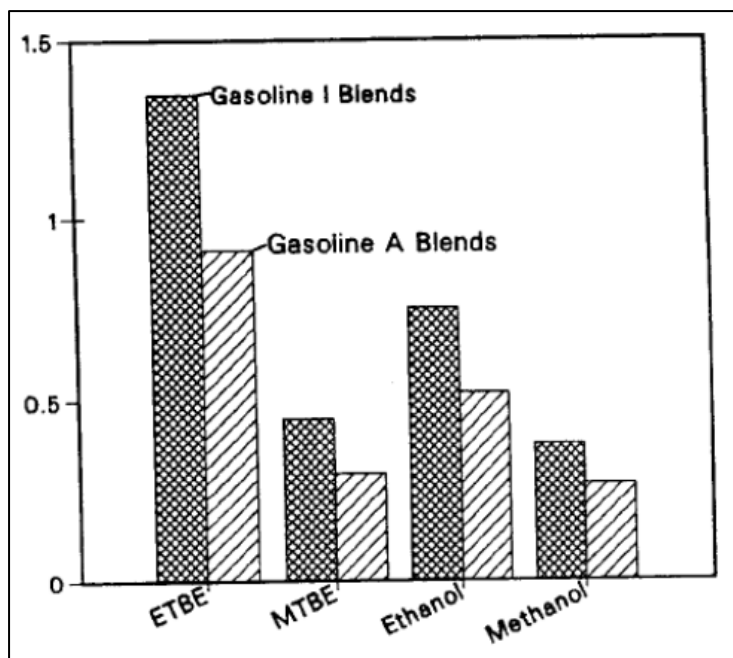
³ SAE 912429 "Composition and Reactivity of Fuel Vapor Emissions from Gasoline-Oxygenated Blends," Robert Furey and Kevin Perry, GM Research Laboratories, 2004

**Relative Ozone Contribution from Evaporative Emissions of Oxygenate Blends
(gasoline=100)**



Source: General Motors Research Laboratories, SAE 912429, 1991

**Relative Reactivity Contribution from Oxygenates in Evaporative Emissions Ratio:
(% of reactivity)/(% of mass)**



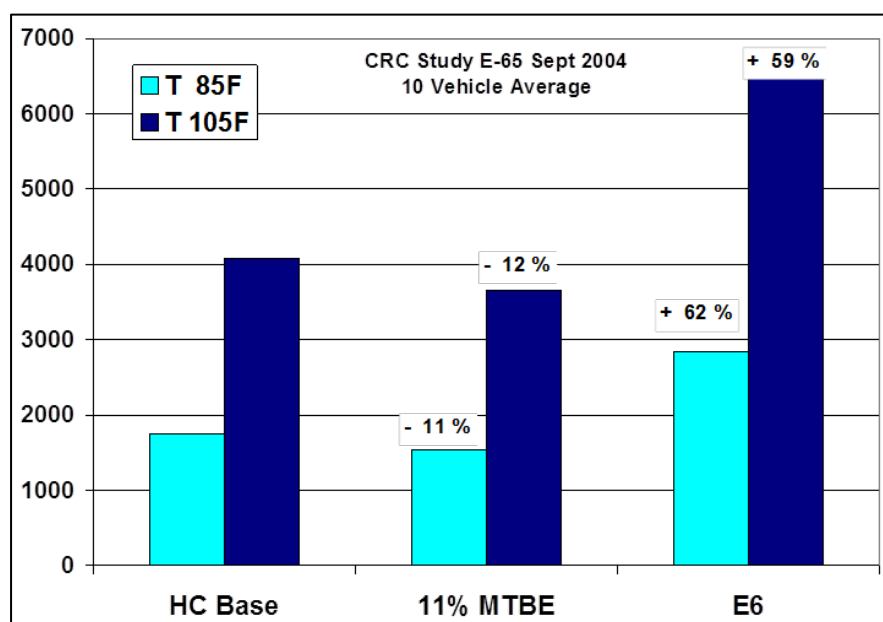
Source: General Motors Research Laboratories, SAE 912429, 1991

VOC Emissions from Permeation

Following elastomer studies in the late 1990s, research determined that some oxygenates in fuel would increase the rate of VOC permeation from some fuel system elastomers after being given sufficient time to come into a new equilibrium with the oxygenated fuel. Unfortunately, this delayed change in evaporative emissions rate is not easily detected in the relatively short diurnal emissions test since the equilibrium change with a new fuel composition usually takes days to be established before the change in evaporative emissions can be measured.

A new procedure was developed by the Coordinating Research Council (CRC) in 2004 to measure the oxygenate effects on vehicle permeation emissions as illustrated in the figure below found that even low concentrations of ethanol (6 vol% ethanol) will substantially increase permeation emissions (+60%) while the use of 11 vol% MTBE appears to decrease permeation emissions (-11%). These vehicle measurements reflect the compilation of the permeations from all the elastomers and plastics used in the vehicle fuel systems.⁴⁵⁶

Vehicle Permeation Emission with Oxygenated Fuels (emissions mg/day)



Source: Coordinating Research Council, Study E-65, 2004

Some earlier studies had focused on the fluoroelastomers application because of its increased propensity to swell with both MTBE blends and ethanol blends. The results in the first figure below show that 10 vol% ethanol blends and 15 vol% MTBE blends can potentially increase the permeation rates from regular fuel hoses by 30% to 50%, but the addition of

⁴ CRC Study E-65, Sept. 2004

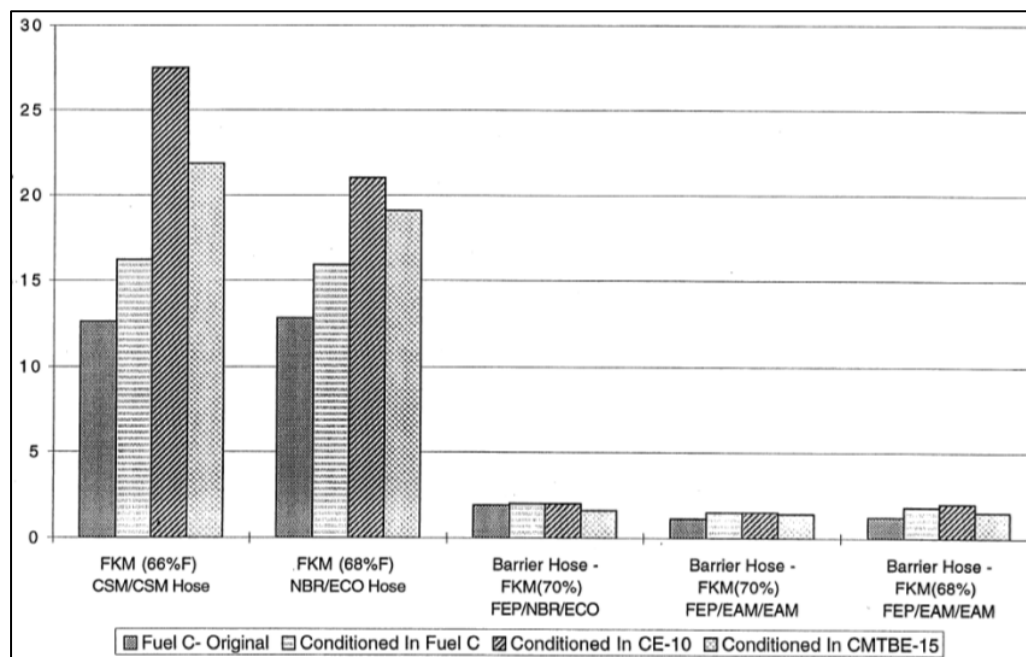
⁵ SAE 970307 "Fuel Permeation Rates of Elastomers After Changing Fuels," R.D. Stevens & R.D. Fuller, DuPont Dow Elastomers, 1997

⁶ SAE 930992 "Fuel Hose Permeation of Fluoropolymers," D. Roy Goldsberry, E.I. Du Pont de Nemours & Co., 1993

barriers in the hose material reduces the permeation rates by 80% to 90% for all fuel compositions.⁷

As illustrated in the second figure below, a separate study using fluoropolymer fuel hoses found very low permeation rates and also showed no increases with 20 vol% MTBE fuel blends compared to the base fuel (C).⁸

Permeation Rate for Fuel Hose (grams/m2/day)

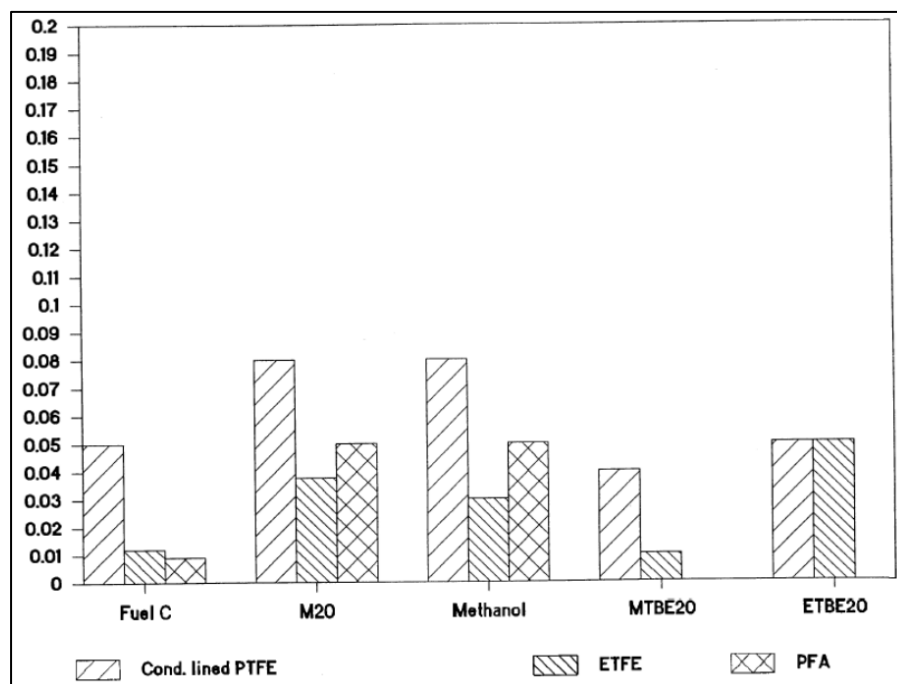


Source: E.I. DuPont de Nemours & Co., SAE 970307, 1997

⁷ SAE 970307 "Fuel Permeation Rates of Elastomers After Changing Fuels," R.D. Stevens & R.D. Fuller, DuPont Dow Elastomers, 1997

⁸ SAE 930992 "Fuel Hose Permeation of Fluoropolymers," D. Roy Goldsberry, E.I. Du Pont de Nemours & Co., 1993

Fuel Hose (Fluoropolymers) Impacts for Oxygenate Blends (grams x mm)/(m² x day)



Source: E.I. DuPont de Nemours & Co., SAE 93092, 1993

Based on the above permeation studies, the use of 20+ vol% MTBE fuel blends is not expected to contribute to higher VOC permeation rates from the vehicles or from the fuel distribution systems.

Exhaust Emissions

The addition of oxygenates to gasoline has been known to reduce exhaust emissions mostly by oxygen enleanment of the air-fuel mixture during fuel combustion in the engine. Therefore, the effect on exhaust emissions has been shown to be mostly a function of the oxygen content in the fuel.⁹ The vehicle emissions studies have used varying MTBE concentrations up to the nominal 20%, which has about the same fuel blend oxygen content as 10% ethanol (~3.7 wt% oxygen). To better define the effect of MTBE's oxygen contribution on reducing exhaust emissions, vehicle exhaust emissions studies that include 20% MTBE are mostly evaluated in this section.¹⁰¹¹¹²¹³¹⁴

One such study compared the addition of 10 vol% ethanol and 20% MTBE (both ~3.7 wt% oxygen) in six U.S. vehicles.¹⁵ The results summarized in the figure below show that a 20

⁹ SAE 841210 "The Properties and Performance of Modern Automotive Fuels," P. Dorn & A.M. Mourao, Texaco Research Center, 1984

¹⁰ SAE 930372 "Effect of Gasoline Reformulation on Exhaust Emissions in Current European Vehicles," G.J. den Otter, R.E. Malpas and T.D.B. Morgan, Shell Research, 1993

¹¹ SAE 920326 "Effects of Oxygenated Fuels and RVP on Automotive Emissions – Auto/Oil Air Quality Improvement Program," Robert M. Reuter, et.al., Texaco Research Center, 1992

¹² SAE 892063 "The Effect of Oxygenated Fuel, Altitude and Temperature on CO Emissions," Phillip A. Yaccarino, GM Research Laboratories, 1989

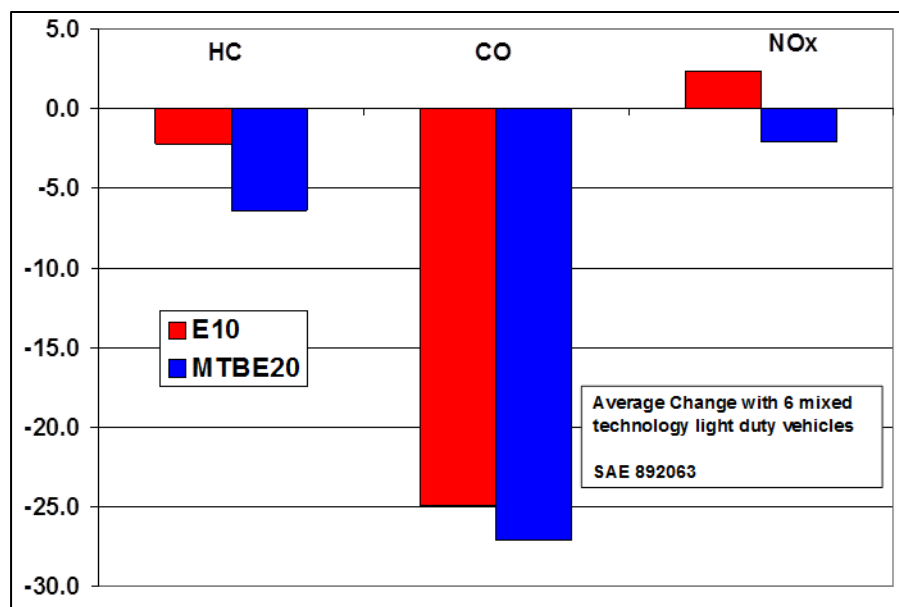
¹³ "MTBE - The Refiner's Key to Future Gasoline Production," 1988 NPRA Conference, W.J. Piel

¹⁴ "MTBE: A Key Ingredient for Reformulated Gasoline," 1990 HART Conference, W.J. Piel

¹⁵ SAE 892063 "The Effect of Oxygenated Fuel, Altitude and Temperature on CO Emissions," Phillip A. Yaccarino, GM Research Laboratories, 1989

vol% MTBE blend will significantly reduce CO and HC emissions, which is similar to the 10 vol% ethanol blend. However, unlike the ethanol blend, the MTBE blend also decreased NO_x emissions by about 2% while the ethanol blend increased NO_x emissions.

Exhaust Emission Changes with 3.7 wt% Oxygenated Fuels (percent change)



Source: General Motors, SAE 892063, 1989

In a European study, a refiner conducted an emissions study with four vehicles with four fuels with different MTBE contents as summarized in the two tables below.¹⁶ In this study, MTBE fuel contents were 0, 8, 15 and 19 vol% MTBE. As illustrated in the third figure below, the percent reduction in exhaust emissions generally decreased as the MTBE content in gasoline increased for both the carbureted vehicles as well as the port fuel injection vehicles.

Vehicle Emissions Characteristics of Test Fuels

Fuel	U. S. aver	A	B	C	D
A romatics %vol	32	47	27	1	38
M TBE %vol	0	0	15	19	8
O lefins %vol	12	12	4	<1	1
T 90 % C	180	161	150	106	146
RVP kPa	(60)	70	67	78	70
T 10% C		48	49	43	44
T 50% C		105	89	84	74

Source: Shell Research, SAE 930372, 1993

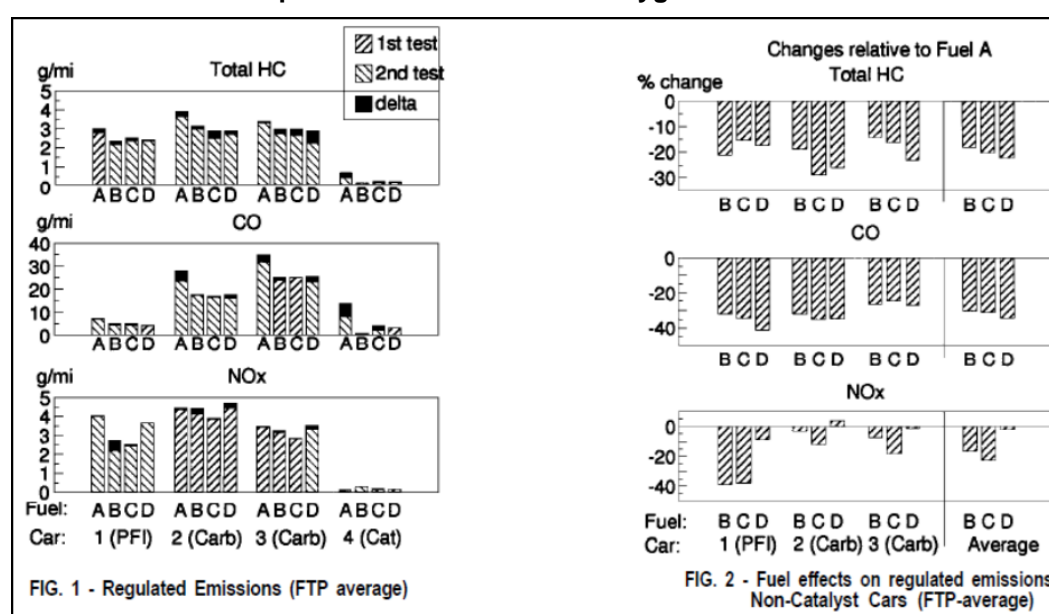
¹⁶ SAE 930372 "Effect of Gasoline Reformulation on Exhaust Emissions in Current European Vehicles," G.J. den Otter, R.E. Malpas and T.D.B. Morgan, Shell Research, 1993

Vehicle Details

Vehicle	Year	Mileage	Displ. (liters)	Fuel system	Catalyst
1	1989	11,000	2.0	PFI	None
2	1990	17,000	1.4	Carb	None
3	1989	10,500	1.6	Carb	None
4	1989	13,000	1.6	TBI	TWC canister

Source: Shell Research, SAE 930372, 1993

Exhaust Emission Impacts from Reformulated Oxygenate Blends



Source: Shell Research, SAE 930372, 1993

One of the most recent vehicle emissions studies conducted using MTBE blended in low emissions vehicle technology was presented to California's Air Resources Board in 2001.¹⁷ The study shows that the use of 11% MTBE in gasoline still provides significant reductions of exhaust emissions (HC, CO and NO_x) even when operating with the latest emission control technology vehicles (see figure below)

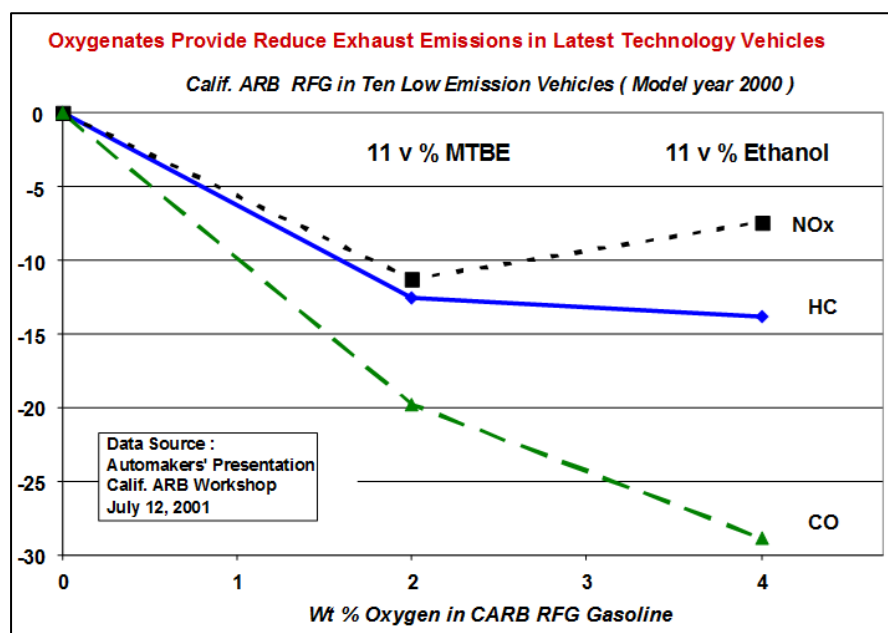
The addition of MTBE in gasoline will also reduce vehicle air toxic emissions in the exhaust.¹⁸ As illustrated in the table below, which was taken from the Auto/Oil oxygenate study, the emissions changes show the average percentage changes in exhaust emissions for the specific oxygenated fuel blends tested in their vehicle test group. These results show that

¹⁷ Automakers Vehicle Emissions Study on Sulfur and Oxygenates in CARB RFG, July 2001 ARB workshop, <http://www.arb.ca.gov/fuels/gasoline/meeting/2001/allianceprestrn.pdf>

¹⁸ SAE 920326 "Effects of Oxygenated Fuels and RVP on Automotive Emissions – Auto/Oil Air Quality Improvement Program," Robert M. Reuter, et.al., Texaco Research Center, 1992

total air toxics in the exhaust emissions decrease by about 7% with 15 vol% MTBE in the fuel, which produces lower toxics than with the other oxygenated fuels that showed slight percentage increases. In addition, benzene emissions in the evaporative emissions decrease by about 9% with the 15 vol% MTBE blend – unlike ethanol, which increases evaporative emissions of benzene because of the ethanol azeotrope with benzene that effectively makes benzene in the ethanol blend more volatile.

Exhaust Emission Changes with MTBE and Ethanol Blends (avg. percent emission change)



Source: California Air Resources Board, 2001

Vehicle Emission Effects from Adding Oxygenates (percent change with change in fuel variable)

<u>Emission Constituent</u>	<u>Ethanol 0% → 10%</u>	<u>MTBE 0% → 15%</u>	<u>ETBE 0% → 17%</u>
<u>EXHAUST (based on g/mi)</u>			
Total HC	-4.9 ± 2.6	-6.5 ± 3.4	-5.2 ± 3.7
NMHC	-5.9 ± 2.7	-7.0 ± 3.6	-6.3 ± 3.9
CO	-13.4 ± 4.9	-9.3 ± 6.7	-14.6 ± 7.4
NO _x	5.1 ± 4.1	3.6 ± 5.4	5.5 ± 6.3
Benzene	-11.5 ± 6.0	-11.1 ± 8.0	-8.1 ± 8.4
1,3-Butadiene	-5.8 ± 5.7	-1.7 ± 7.7	-3.8 ± 8.8
Formaldehyde	19.3 ± 31.2	15.8 ± 41.3	-15.7 ± 48.9
Acetaldehyde	159.0 ± 43.6	-0.9 ± 34.9	254.2 ± 71.0
Total Air Toxics	3.6 ± 7.0	-7.3 ± 8.7	2.9 ± 9.4
<u>EVAPORATIVE (based on g/test)</u>			
Diurnal HC	30.3 ± 11.3	-5.8 ± 12.6	-5.0 ± 15.9
Benzene	27.7 ± 15.4	-9.2 ± 17.1	-5.8 ± 23.5

Source: Texaco Research Center, SAE 920326, 1992

Exhaust Emission Durability

The impact of 15 vol% MTBE blends was evaluated in the 15% Waiver Application to the U.S. EPA by the Sun Oil Co.¹⁹ To accomplish the comparison, two separate matched model vehicles were operated for 50,000 miles with one using a base fuel and the other using 15 vol% MTBE blended with the base fuel. The emissions for each vehicle had been measured at the same mileage intervals using the base fuel for the emissions measurements. As illustrated in the table below, the delta increase in emissions (exhaust and evaporative) between 0 miles and 50,000 miles (80,500 km) is used to compare the durability impact of the fuels on the emissions systems. For all emissions, the delta increase is less with the vehicle operated on the MTBE blend than the base fuel, which suggests that MTBE had no adverse impact on the emission system of the vehicles. Based on these favorable results, the durability of the emissions systems is not expected to be adversely impacted with 15 vol% or higher MTBE blends.

Vehicle Emission Durability Effects from Adding 15 Vol% MTBE (comparison of emissions increases with mileage)

Base Fueled Vehicle						
<u>Mileage</u>	<u>HC (g/m)</u>	<u>CO (g/m)</u>	<u>NOx (g/m)</u>	<u>CO2 (g/m)</u>	<u>F.E. (m/6)</u>	<u>Evap. (g/t)</u>
0	0.18	2.13	0.32	510.7	17.2	0.85
5,000	0.37	3.49	0.68	465.7	18.8	0.85
27,500	0.79	4.79	0.89	424.8	20.4	1.01
50,000	0.87	6.24	0.86	435.4	19.8	1.95
MTBE Fueled Vehicle						
<u>Mileage</u>	<u>HC (g/m)</u>	<u>CO (g/m)</u>	<u>NOx (g/m)</u>	<u>CO2 (g/m)</u>	<u>F.E. (m/6)</u>	<u>Evap. (g/t)</u>
0	0.19	3.59	0.80	526.2	16.7	0.79
5,000	0.23	3.15	0.48	455	19.3	0.82
27,500	0.34	3.17	0.87	428.3	20.4	0.46
50,000	0.35	3.93	0.89	417.6	20.9	1.129

Source: Sun Refining and Marketing Co., 1988

¹⁹ 15% MTBE Waiver Application to U.S. EPA, Sun Refining and Marketing Co., April 1988

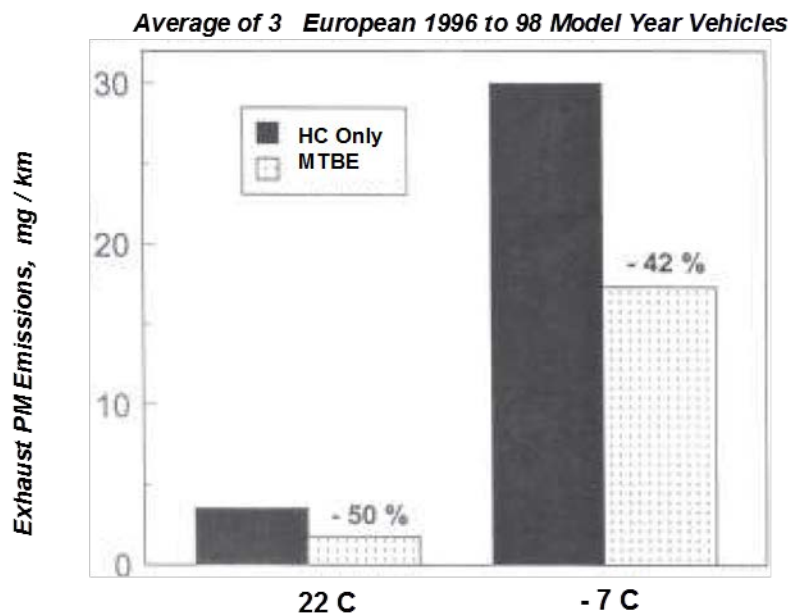
Particulate Matter (PM) Emissions

Fine particles (less than 2.5 microns) in the atmosphere are considered to be a significant health hazard; these small particles can be breathed into the lungs where they can be lodged and irritate the lung linings. Measurable fine particulates in the engine exhaust tend to be formed when the fuel does not fully vaporize or mix with the oxygen in the air prior to the combustion process in the engine, which then leads to some pyrolysis of the unmixed fuel that then generates small carbon-based particles.

Since light boiling oxygenates such as MTBE are easy to vaporize and also contain some oxygen that helps improve the oxygen-to-fuel ratio in the fuel mixture prior to combustion, its use in gasoline helps reduce the production of particulates during the combustion of gasoline. The results in the figure below illustrate the significant impact of MTBE blends reducing the measurable fine PM_{2.5} in the vehicle tailpipe exhaust.²⁰ As the chart suggests, PM emissions are greater at colder ambient conditions because of poorer fuel vaporization associated with cold engine operation, but adding 11% MTBE to the gasoline reduced these PM emissions by 40% or more.

Exhaust PM Emission Impacts with MTBE Blends

11% MTBE Reduces Vehicle Exhaust PM Emissions at All Temperatures



Source: Fortum Oil and Gas Oy, 1998

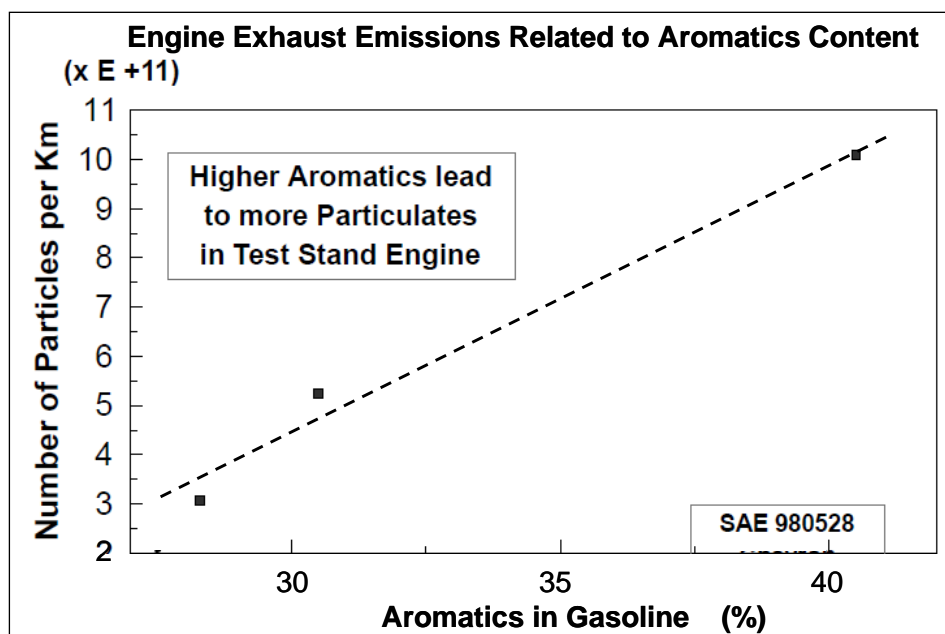
Separately, increasing the aromatics content in gasoline will contribute to greater measurable PM emissions in the engine's exhaust as illustrated in the figure below. Aromatics have higher boiling point temperatures, which make them more difficult to vaporize in cold engine operation before the engine fully warms up.²¹ Since the high-octane MTBE is generally used

²⁰ "Mobile 124Y-12," Neste Oy (Fortum Oil) Translated: (European norm satisfy the reformulated gasoline impact of regulated and non-regulated emissions, the AD measurements). Juha Pentikainen et al, Fortum Oil and Gas Oy & VTT, 1998

²¹ SAE 980528, "Characterization of Exhaust Particulate Emissions from a Spark Ignition Engine," Chevron, 1998

as an octane alternative to adding aromatics in gasoline, adding MTBE to gasoline is expected to reduce total exhaust PM by both adding MTBE and replacing some of the aromatics in gasoline.

Exhaust PM Emission Impacts from Aromatics in Gasoline



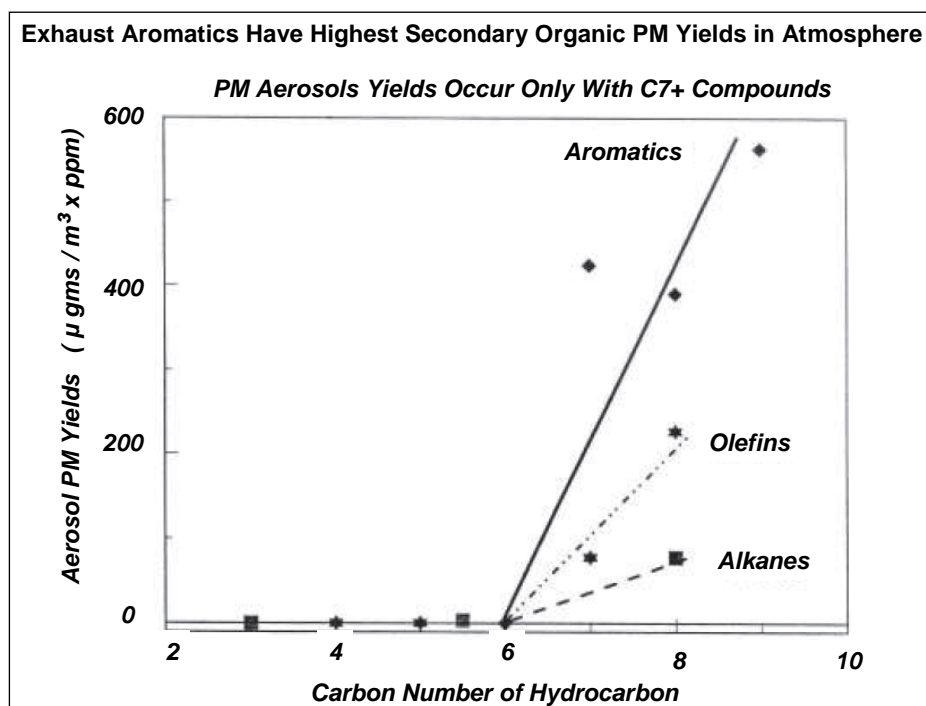
Source: Chevron, SAE 980528, 1998

In addition to the aromatics content in gasoline affecting the amount of measurable PM in the vehicle's exhaust, the vehicle's aromatic emissions in the atmosphere will also contribute to the production of secondary organic aerosols ($PM_{2.5}$) when the aromatics become partially oxidized. The yield of secondary organic aerosols for gasoline type hydrocarbons that are formed under atmospheric conditions is illustrated in the first figure below. Compared to other hydrocarbons, aromatics generate the highest yield of secondary organic aerosols.²² As the second figure below shows, the amount of aromatic emissions in the vehicle's exhaust is strongly related to the aromatic content of the gasoline.²³ Therefore, using MTBE to replace the aromatics in gasoline should further reduce the amount of $PM_{2.5}$ in the atmosphere in addition to reducing the amount of measurable $PM_{2.5}$ in the vehicle's exhaust.

²² "Ozone and aerosol productivity of reactive organics," Bowman F.M.; Pilinis C.; Seinfeld J.H., Atmospheric Environment, Vol. 29, No. 5, p. 579-589, 1995

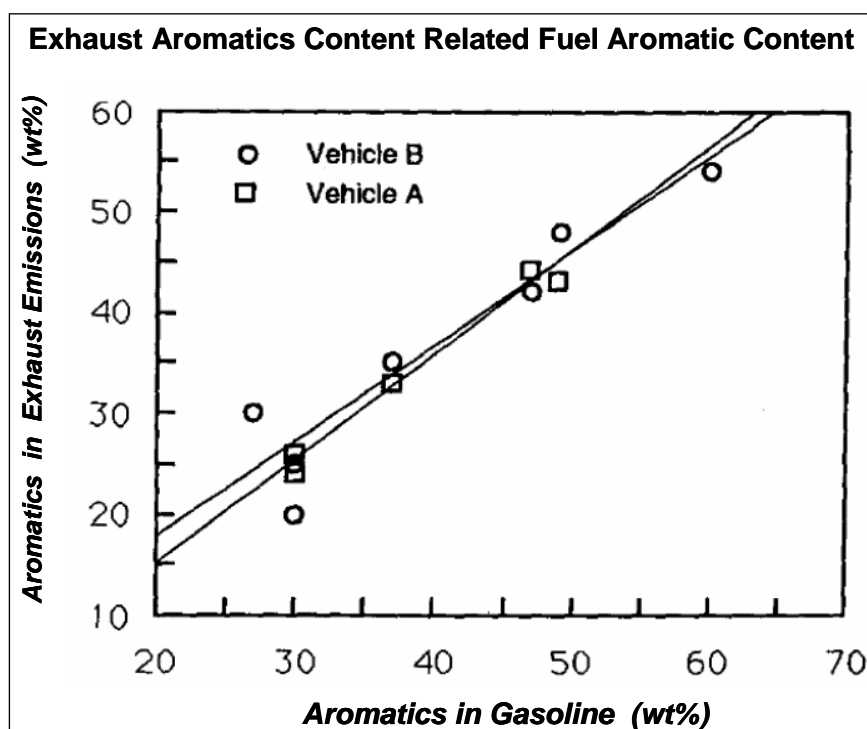
²³ SAE 922182, "Effects of the Gasoline Composition and Emissions Control Systems on Exhaust HC Emissions," Toyota, 1992

Exhaust PM Emission Impacts from Aromatics, Olefins, and Alkanes in Gasoline”



Source: Bowman et al, 1995

Exhaust Aromatic Emission Impacts from Aromatics in Gasoline



Source: Toyota, SAE 922182, 1992

Review of Exhaust Emissions Studies

The above emissions studies show that adding MTBE up to the nominal 20% concentration to the fuel will reduce exhaust emissions of CO, HC, air toxics and PM as more MTBE is added to the fuel, and that the emissions reductions are generally greater for MTBE than that for ethanol at the same oxygen level. Unfortunately, most of these emission studies are conducted by splash blending the oxygenates into the base fuel, and not making any other fuel property adjustments that normally occur in commercial refinery gasoline blending operations. Therefore, besides adding oxygen to the fuel blend, other fuel properties such as 50% distillation temperature, aromatic content, sulfur content, etc., will also change as MTBE is blended into gasoline, and have some impact on exhaust emissions. Fortunately, all these other fuels properties changes are generally favorable for exhaust emissions impact.

Because MTBE has about half the oxygen content of ethanol, blending MTBE to a target oxygen limit in the fuel blend will provide more motor octane and more dilution volume of the other less-favorable fuel properties, which may produce some additional emissions reductions as compared to ethanol at the same oxygen content in fuel. This unequal dilution of gasoline fuel properties makes it difficult to directly compare MTBE's oxygen and ethanol's oxygen impact on a constant property basis, but it will still reflect the comparative emission reductions in the real-world fuel blending conditions between using the two different oxygenates. The general observation is that adding MTBE in any amount (up to 3.7 wt% oxygen tested) into a refinery operation will result in improved fuel quality performance and emissions reduction since the MTBE not only adds oxygen to the fuel blend, but also adds octane to replace aromatics and dilutes other less-favorable gasoline components such as sulfur, olefins and high boiling gasoline components.

The vehicles used in the above studies reflect a range of fuel system technologies as well as emissions control technologies. The results from these studies show that MTBE blends will provide a favorable reduction in exhaust emissions for any of the vehicle technologies from the oldest to the newest.

In the above emissions studies with gasoline containing up to a nominal 20 vol% MTBE concentration, there were no operational problems reported for any of the vehicles during the emission studies. Given that adding up to 20% MTBE in gasoline does not cause gasoline properties to exceed ASTM gasoline specifications, and does raise fuel oxygen level above 3.7 wt% (similar to 10% ethanol in gasoline), no vehicle performance issues should be expected. Based on the favorable results observed in the above studies, there is no reason to expect adverse performance with fuel blends containing up to 20% MTBE blends (3.7 wt% oxygen) in U.S. or European vehicles manufactured since 1990 (or possibly earlier).

GREENHOUSE GAS IMPROVEMENTS

Given the global trends in fuel economy regulations, global fuel economy solutions will become required, which motivates the search for cost-effective technology options for compliance. Although future fuel economy or GHG legislation poses a significant challenge, the rough global harmonization in regulatory trends will promote global approaches for compliance across markets and LDV platforms.

In the EU, apart from transmission or aerodynamics improvement and optimization of the drivetrain, vehicle technology research has been focusing on smarter vehicles, through the means of increased connectivity and vehicle automation. Smarter cars and intelligent infrastructure have the potential to markedly reduce the CO₂ emissions of the whole vehicle fleet, as well as reducing fuel usage and improving the efficiency of mobility.

In Japan, auto manufacturers have long called for the upgrading of regular grade gasoline (RON 90) to higher octane levels (RON 95) for better fuel economy performance. Despite an opposition by the refining industry because of arguably insufficient cost-effectiveness of well-to-wheel CO₂ reduction, it is expected that vehicle fuel efficiency will improve by 2-8% by upgrading regular grade gasoline to 95 RON. In particular, vehicle fuel efficiency can improve by 2-4% for conventional engines (due to compression ratio increase, ignition time optimization and continuously variable transmission shift point optimization), and up to 8% for supercharged engines. In 2013, the share of turbo engine cars in Japan was 11.5%, which is expected to gradually increase to 32% by 2019.

In the U.S., Tier 3 fuel economy and vehicle emissions regulations will require new vehicle technologies and fuel quality improvement. In terms of sulfur reduction, regulating a lower sulfur limit for U.S. fuel specifications is especially important for lean NO_x catalysts, because recoverability by lower sulfur fuel is poorer than 3-way catalysts. Despite this requirement, lean-burn gasoline direct injection (GDI) engines will not be commercialized in the near future. Even though automotive companies have been developing such systems for a long time now, technological and cost barriers still exist. In fact, GDI engines have been reported to produce significantly more PM and particulate number (PN) emissions than auto-ignition engines. In the EU, research suggests that the current cut-off size at 23 nm for the PN regulation in Euro 6 must be further reduced to include sub-23-nm carbon nanoparticles.

IMPORTANCE OF OCTANE IN REDUCING CO₂ EMISSIONS

In August 2015, ACFA and EFOA contracted Ricardo to conduct a study on fuel octane effects on the fuel consumption of LDVs. The study focuses on regulatory requirements for fuel economy or GHG emissions, the LDV technology roadmap to meet those requirements, and the role of fuel octane in this future challenge.

Regulatory requirements for LDV fuel economy or GHG emissions are driving significant changes in how LDV especially their powertrains are being designed. Ricardo's technology roadmap suggests that internal combustion engines will continue to play an important role in LDV powertrains, even as LDV are increasingly electrified. Ricardo also sees an increasing role for fuels to contribute to an overall "wells to wheels" GHG reduction strategy.

From the literature review conducted for this study, the direct effect of increasing fuel octane on fuel consumption is limited, as octane only comes in play when an engine operates in a

knock-limited regime. With downsized engines being an important part of future engine design, though, operation in high-load, knock-limited regimes becomes more likely. That said, the main benefit of increasing the commonly available octane in fuels appears to be that it facilitates engine design changes, such as increases in compression ratio, that directly lead to improved fuel consumption.

Therefore, Ricardo concluded that fuel octane number, especially RON, to be an important contributor to future GHG emissions reduction from LDV in all markets.

Octane Index Metric for Modern Engines

The measurement standards for RON and MON were developed in the early 20th century. For contemporary engines, Kalghatgi²⁴ has defined the Octane Index (OI) as a weighted average of RON and MON,

$$OI = RON - K (RON - MON).$$

For the case where $K = +0.5$, OI is the same as AKI. Since octane sensitivity S is defined as $S = RON - MON$, then $OI = RON - K \cdot S$.

The challenge of the OI metric is that the value of K is a function of both engine design and engine operating condition. Several researchers, including Kalghatgi²⁵; Beck, et al²⁶; Davies, et al²⁷; Orlebar, et al²⁸; Remmert, et al²⁹; and Stradlign, et al³⁰, have all found that K is usually negative for modern SIDI engines with boost. Thus, with $K < 0$, OI increases by increasing RON or by increasing S .

Remmert, et. al, noted that the rating scale is defined by paraffins, which do not represent the auto-ignition behavior of a real fuel, and the knock propensity of a real, sensitive fuel depends on the in-cylinder temperature and pressure history which can change with engine design and operating conditions.” Thus, it is not surprising that K is a function of engine design and operating condition.

Octane Benefit to Performance and Fuel Consumption

As modern SI engines approach knock-limited operation, as indicated on the example operating map in the figure below, the knock sensor feedback triggers mitigating actions to cool the in-cylinder combustion gases, including fuel enrichment ($\lambda < 1$) and spark retard. Both of these mitigating actions increase the fuel consumption and reduce the available

²⁴ SAE Technical Paper 2001-01-3585, “Fuel Anti-Knock Quality – Part II. Vehicle Studies – How Relevant is Motor Octane Number (MON) in Modern Engines?” Kalghatgi, G., 2001

²⁵ SAE Technical Paper 2005-01-0239, “Auto-Ignition Quality of Practical Fuels and Implications for Fuel Requirements of Future SI and HCCI Engines” Kalghatgi, G., 2005

²⁶ SAE Technical Paper 2006-01-3407, “The Impact of Gasoline Octane on Fuel Economy in Modern Vehicles”, Beck, C., Stevenson, P., and Ziman, P., 2006.

²⁷ SAE Technical Paper 2011-01-1985, “Fuel Effects in a Boosted DISI Engine”, Davies, T., Cracknell, R., Lovett, G., Cruff, L., and Fowler, J., 2011

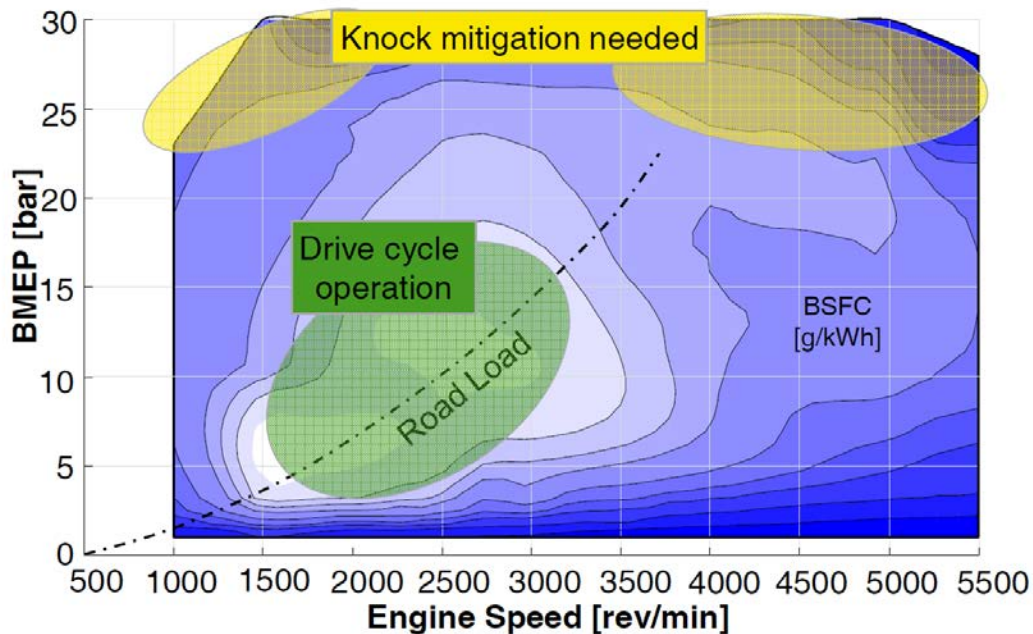
²⁸ SAE Technical Paper 2014-01-1216, “The Effects of Octane, Sensitivity and K on the Performance and Fuel Economy of a Direct Injection Spark Ignition Vehicle”, Orlebar, C., Joedicke, A., and Studzinski, W., 2014

²⁹ SAE Int. J. Fuels Lubr. 7(3):743-755, “Octane Appetite: The Relevance of a Lower Limit to the MON Specification in a Downsized, Highly Boosted DISI Engine”, Remmert, S., Campbell, S., Cracknell, R., Schuetze, A., Lewis, A., Giles, K., Akehurst, S., Turner, J., Popplewell, A., and Patel, R., 2014

³⁰ SAE Technical Paper 2015-01-0767, “Effect of Octane on the Performance of Two Gasoline Direct Injection Passenger Cars”, Stradling, R., Rieckard, D., Hamje, H., Williams, J., and Zemrock, P., 2015

torque, thus for a given engine, a fuel with higher OI will be able to support higher load operation without knock mitigation.

Example Brake-Specific Fuel Consumption (BSFC) Map for an Advanced SI Engine



The benefits of higher OI fuel are expected in real world driving, and should be greatest with off-cycle driving that incorporates hard acceleration events, as legislative drive cycles for GHG emissions or fuel economy do not have knock-limited operation. The introduction of the World-Harmonized Light-Duty Transient Protocol (WLTP) may change the operating points experienced on cycle, as it is a more aggressive drive cycle than the NEDC it will replace. For example, Kalghatgi found that better OI yielded better acceleration performance, but there is only an indirect link between that and on-cycle fuel consumption.

Prakash, et al³¹, and Stradling, et al, both studies the effect of OI on acceleration performance over repeated acceleration events. Both groups found that higher OI reduced acceleration times, especially in lower speed ranges. Prakash, et al, also found that steady-state power increased with OI. These benefits to acceleration time and power correlate to the vehicle, which suggest they are a function of engine design and control.

Orlebar, et al. found that acceleration times improved with increasing RON, but less strongly with increasing S. Beck, et al, looked at fuel consumption effects over three aggressive driving cycles – Fuel Consumption Off-Cycle (FCOC), ARTEMIS Motorway 130, and US06 – and found that fuel consumption improved with increasing OI, both with fuels in their test matrix and when comparing 91 and 95 RON pump fuels.

³¹ SAE Technical Paper 2013-01-0883, "Octane Response of Premium-Recommended Vehicles", Prakash, A., Jones, A., Nelson, E., Macias, J., Jimenez, E., and Hinojosa, M., 2013

Studies suggest that fuel consumption can be influenced by fuel octane number, but the direct effect is subtle. Shuai, et al³² found a 0% to 1% improvement in fuel consumed per point increase in RON over the cold and hot start NEDC in the five vehicles they tested. The six fuels they used had RON values ranging from 91.9 to 98.4. The selectivity was not varied as significantly, ranging from 10.3 to 13.1. Also, the selectivity generally increased with increasing RON. Shuai, et al found an inconsistent relationship between MON and engine performance, which is consistent with the narrow range of S studies and with the effects of K varying with operating condition.

By contrast, Orlebar et al found little effect on volumetric fuel consumption with respect to OI in a premium-recommended vehicle over the FCOC drive cycle, which is a Shell proprietary aggressive drive cycle. For the vehicle tested K was about +0.3 for the fuel consumption testing, although they found that K was -0.75 at full throttle. Thus, the fraction of time spent in knock-limited operation will affect the final fuel consumption figure, given that knock mitigation increases fuel consumption for a given net power target from the engine.

Engine downsizing and downspeeding trends may also influence the octane requirements for future vehicles. Milpied, et al³³ found that the knock load limit increased with increasing RON, especially at medium engine speeds, and to a lesser degree with the fuel's heat of vaporization. However, with engine downspeeding being a likely element of future engine design, Davies, et al, raise the concern that a high-sensitivity fuel could trigger low-speed pre-ignition (LSPI, or "mega-knock") at low engine speeds, which would offset the benefits of increasing OI by increasing S in engines with a negative K-factor. As noted by Morikawa, et al³⁴, oil droplets are believed to be the primary cause of mega-knock, not the fuel, but this hypothesis is not fully proven yet.

Fuel Ethers

Wallace, et al³⁵ noted that S of ETBE is reported as 15 and of MTBE, 16, so both additives will increase S for a given RON target. Although this makes meeting current EU and WWFC targets more challenging, given that in modern engines OI improves with increasing S, this property may not penalize in-use performance of the fuels. Wallace, et al. also reported that using ETBE provides an opportunity to reduce GHG emissions within the refinery compared to blending ethanol directly because of how the ETBE blends into gasoline fuels.

³² SAE Int. J. Fuels Lubr. 6(3):702-712, "Impact of Octane Number on Fuel Efficiency of Modern Vehicles", Shuai, S., Wang, Y., Li, X., Fu, H., and Xiao, J., 2013

³³ SAE Technical Paper 2009-01-0324, "Impact of Fuel Properties on the Performances and Knock Behaviour of a Downsized Turbocharged DI SI Engine – Focus on Octane Numbers and Latent Heat of Vaporization", Milpied, J., Jeuland, N., Plassat, G., Guichaous, S., Dioc, N., Marchal, A., and Schmelzle, P., 2009

³⁴ SAE Technical Paper 2015-01-0756, "Investigation and Improvement of LSPI Phenomena and Study of Combustion Strategy in Highly Boosted SI Combustion in Low Speed Range", Morikawa, K., Moriyoshi, Y., Kuboyama, T., Imai, Y., Yamada, T., and Hatamura, K., 2015

³⁵ Technical Report ORNL/TM-2015-16, "Effects of High-Octane Ethanol Blends on Four Legacy Flex-Fuel Vehicles, and a Turbocharged GDI Vehicle", Thomas, J.F., West, B.H., and Huff, S.P., 2015

MTBE AND WATER QUALITY

In comparison to hydrocarbon-based petroleum products, MTBE has greater water solubility and poses additional considerations when it enters the environment through gasoline releases (typically from UST systems or pipelines). MTBE is capable of moving through the soil to come into contact with groundwater. Because of a higher affinity for water compared to hydrocarbons, it can travel farther than those gasoline constituents, which increases the potential for impacts to water resources. The chemical structure of MTBE also makes it more difficult for natural biodegradation processes to take place, resulting more often in active remediation to be employed for cleanup.

In the mid- to late 1990s, various reports circulated about MTBE being discovered in groundwater resources in areas where it was blended with gasoline. Most of these reports came from the U.S., where gasoline was found to have leaked from USTs. Invariably, the presence of MTBE in groundwater has been predominantly linked to leaking gasoline USTs, in many cases for extended periods of time. In recent years, a closer examination by U.S., European, Asian and international government entities has since shown that MTBE does not pose a significant threat to groundwater resources and that proper gasoline containment in USTs and secure pipelines are the most cost-effective methods to protect the environment. More specifically, other developed countries in Europe and Asia that closely monitor water quality have not encountered similar developing problems with such detections.

Currently, more effective enforcement of UST standards in the U.S. has greatly reduced the potential for gasoline releases. Such standards, long the practice in Europe and many other countries, have provided effective measures to ensure protection of groundwater resources.

In July 2005, WHO issued a report titled “WHO Guidelines for Drinking Water Quality: Methyl tertiary-Butyl Ether in Drinking Water”. This report concluded that the vast majority of MTBE detections in the U.S., Canada and Europe have been at or below 2 ppb. The WHO recommended a guideline for treating MTBE of 15 ppb – the lowest level eliciting a response in a study of taste- and odor-sensitive participants. This level is generally considered to be well below that which would pose any environmental or human health concern.

In 1997, the EPA issued guidance on drinking water protection for MTBE. The guidance, titled “Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on MTBE,” recommended that keeping levels in the range of 20 µg/L to 40 µg/L or below for MTBE detections would protect consumer acceptance of the water resource and would also provide a large margin of safety from potential health effects. The advisory recognized that some people may detect MTBE below the range of 20 µg/L to 40 µg/L and that water suppliers should determine the level of treatment required for aesthetics based on the consumers they serve and the site-specific water quality conditions. This advisory concluded that animal toxicology data “do not support confident, quantitative estimation of risk at low exposures.” The taste and odor guidance levels represent potential exposures that are several thousand times lower than those in which effects were observed in animal tests.

TASTE AND ODOR PROPERTIES

The taste and odor properties of MTBE have generally played a more prominent role in state actions to protect water quality. The odor-detection threshold of MTBE tends to be lower than many other common chemicals and gasoline constituents. Some individual thresholds have

been reportedly below 5 µg/L and some find its odor and/or taste objectionable. When confronted with an unusual odor or taste, consumers understandably consider the water as tainted. Unfortunately, a statistically representative study of consumer responses to the taste and odor of MTBE in water has not been reported. Several sensory threshold studies have been conducted using a small number of trained individuals as panel members in the tests. The results from these tests can assist water suppliers and utilities in determining appropriate aesthetic limits based on their consumer responses.

A study from Great Britain evaluated the taste and odor of multiple drinking water contaminants, including MTBE (Young et al. 1996, *Water Research*, Vol. 30, No. 2, pp. 331-340). The specially trained panel members reported threshold MTBE odor detection that averaged 34 µg/L, with 15 µg/L as the lowest concentration. The taste-detection threshold averaged 48 µg/L, with 40 µg/L as the lowest concentration.

In 1998 in the U.S., consulting firm Malcolm Pirnie, Inc., reported a study of taste and odor of MTBE in water, also using expert trained panelists. The odor threshold reported in this testing was 15 µg/L; the taste threshold was 40 µg/L.

The Orange County Water District in California performed a study on threshold odor concentrations of MTBE (Shen et al. 1997. Presented at 213th American Chemical Society National Meeting in San Francisco, Vol. 37, pp. 407-409). This study reported the MTBE threshold odor concentration geometric means ranged from 13.5 µg/L to 43.5 µg/L. The geometric means for odor thresholds were of the same magnitude, regardless of water type or temperature. The lowest odor threshold concentration of 5 µg/L was reported in 2.5% of tests.

The EPA has not established a national drinking water limit for MTBE, either as a health-based primary standard or non-health-based secondary standard. The agency has issued an advisory recommending a protective level of 20 µg/L to 40 µg/L for taste and odor, as discussed previously.

The state of California has set an MTBE secondary water standard of 5 µg/L based on taste and odor characteristics reported by the Shen study (the state's primary standard was set at 13 µg/L, higher than the taste/odor level).

While some odor detections of MTBE in various tests were as low as 2.5 µg/L, generally the sensory experience was not deemed objectionable at low concentrations. In most tests, panel members did not report the MTBE concentrations to be objectionable until they reached 50 µg/L or greater for taste and 90 µg/L to 100 µg/L or higher for odor.

REMEDIATION OF GASOLINE CONTAINING MTBE

According to EFOA, there is a large array of well-proven remediation technologies for treating soil and groundwater contaminated by conventional gasoline. In general, these methods are applicable to gasoline containing MTBE, and remediating gasoline containing MTBE is not

necessarily more expensive compared to gasoline that does not contain MTBE. The critical determining factor for cost depends largely on how long the release has gone undetected.³⁶

At the outset, hydrocarbons and oxygenates do degrade naturally in the subsurface soil and groundwater because of microbial activity. However, especially for ether oxygenates such as MTBE, the reaction rates are slow because electron acceptors, such as oxygen, are quickly depleted in contaminated soil and groundwater and are recharged only slowly. As a result, contaminated groundwater may have significant contaminant concentrations but depleted electron acceptors, whereas the overlying unsaturated zone may contain oxygen but low contaminant concentrations.

According to EPA, because MTBE has a higher vapor pressure and a lower affinity for sorption to soil, it can be effectively remediated by two soil treatment technologies, typically without any costs beyond those needed for remediating other petroleum constituents. **Soil vapor extraction (SVE)** (i.e., “dig and dump”) is an *in situ* soil treatment technology that removes volatile contaminants from soil in the unsaturated zone above groundwater by extracting the contaminant vapors with a vacuum that is applied to the subsurface.

Low-temperature thermal desorption (LTTD) is an *ex situ* soil treatment technology that uses temperatures below ignition levels to separate volatile contaminants from soil. Because of its high vapor pressure, both methods are very effective in removing MTBE from soil. However, both remediation techniques must be used soon after a release, before most of the MTBE moves from the soil into the groundwater.³⁷

EPA has cautioned that, because MTBE behaves differently from petroleum hydrocarbons when released into the environment, a remedial investigation may need to be modified to properly characterize the area of MTBE contamination, especially as it affects groundwater, vs. characterizing the gasoline plume. The frequency of sampling should be determined based on the velocity of the groundwater and the number of monitoring wells. Determining the impact of the selected remediation method may be difficult without accurate historical sampling data.

There are several remediation methods to treat groundwater contamination of gasoline containing MTBE. The most common groundwater remediation methods are pump-and-treat, air stripping, activated carbon or other adsorbent treatment and biological degradation. Traditional pump-and-treat technologies available for water treatment plants have been proven effective in remediation of gasoline-contaminated water, even if it contains MTBE.

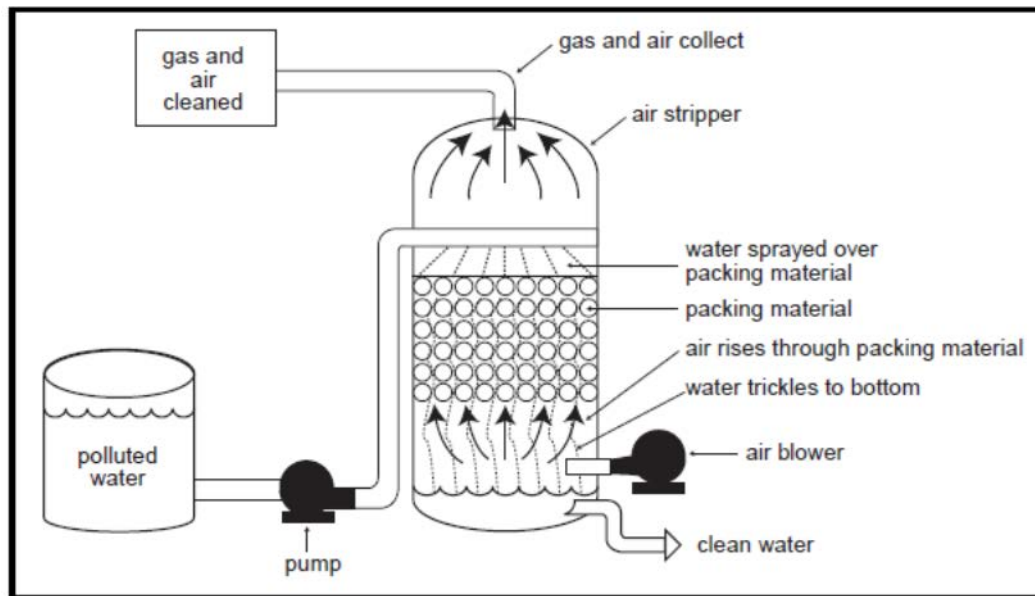
Pump-and-treat, wherein contaminated groundwater is pumped and then treated above ground to remove gasoline and MTBE, is often effective because MTBE does not adsorb to the soil. Thus, fewer aquifer volumes are required to remove the MTBE than are required to remove the slowly desorbing petroleum hydrocarbons. Also, because of MTBE’s high solubility, most of the MTBE mass may quickly dissolve into groundwater, which makes pumping an efficient method for removing it.

³⁶ European Fuel Oxygenates Association, “MTBE Resource Guide,” February 2006

³⁷ See EPA, “MTBE Fact Sheet #2: Remediation of MTBE Contaminated Soil and Groundwater,” EPA 510-F-97-015, January 1998

Air stripping is the process of forcing air through polluted groundwater or surface water to remove harmful chemicals.³⁸ The air causes the chemicals to change from a liquid to a gas (i.e., evaporate). The gas is then collected and cleaned. Air stripping is commonly used to treat groundwater as part of a pump and treat remedy. According to the American Petroleum Institute, air stripping alone was the most cost-effective strategy for remediating water containing 20 ppm MTBE down to 10 ppb.³⁹ The figure below illustrates how air stripping works.

How Air Stripping Works



Source: EPA, "A Citizen's Guide to Air Stripping," EPA 542-F-01-016, December 2001

Air stripping uses equipment called an air stripper to force air through polluted water. An air stripper usually consists of a large tank filled with a packing material, made of plastic, steel or ceramic. The polluted water is pumped into the tank and sprayed over the packing material. The water trickles down through the spaces between the packing material toward the bottom of the tank. At the same time, a fan at the bottom blows air upward. As the air passes upward through the trickling water, it causes the chemicals to evaporate. The air carries the evaporated chemical gases to the top of the tank where they are collected and cleaned.

Air sparging injects air directly into the groundwater to volatilize the contaminants in situ. Case studies have shown that reductions in MTBE levels from more than 1,000 ppb to less than 10 ppb are possible in less than two years. Air sparging is generally appropriate in homogeneous sands because heterogeneous sediments may cause dispersion of contaminants and channeling of air flow. Air sparging is most often used together with soil SVE, but it can also be used with other remedial technologies. When air sparging is combined with SVE, the SVE system creates a negative pressure in the unsaturated zone through a

³⁸ EPA, "A Citizen's Guide to Air Stripping," EPA 542-F-01-016, December 2001

³⁹ American Petroleum Institute, API Publication No. 4497, 1991

series of extraction wells to control the vapor plume migration. This combined system is called AS/SVE.⁴⁰

Bioremediation allows natural processes to clean up harmful chemicals in the environment. Microscopic “bugs” or microbes that live in soil and groundwater like to eat certain harmful chemicals, such as those found in gasoline and oil spills. When microbes completely digest these chemicals, they change them into water and harmless gases such as carbon dioxide.⁴¹

According to EPA, for microbes to clean up harmful chemicals, the right temperature, nutrients (fertilizers) and amount of oxygen must be present in the soil and groundwater. These conditions allow the microbes to grow and multiply — and eat more chemicals. When conditions are not right, microbes grow too slowly or die, or they can create more harmful chemicals. One way they improve conditions is to pump air, nutrients or other substances (such as molasses) underground. Sometimes microbes are added if enough are not already there.

The right conditions for bioremediation cannot always be achieved underground. At some sites, the weather is too cold or the soil is too dense. At such sites, EPA might dig up the soil to clean it above ground where heaters and soil mixing help improve conditions. After the soil is dug up, the proper nutrients are added. Oxygen also may be added by stirring the mixture or by forcing air through it. However, some microbes work better without oxygen. With the right temperature and amount of oxygen and nutrients, microbes can do their work to “bioremediate” the harmful chemicals.

Best Containment, Handling and Safety Practices

This section briefly summarizes best practices for prevention and emergency response, spill and leak procedures, storage and unloading stations, transfer operations and marine transport. These best practices are generally applicable to gasoline as well as to MTBE. MTBE producers have done a great deal over the years to develop, implement and externally promote best practices. As a result, spills, fires and other sorts of safety and environmental emergencies have been kept to a minimum.

Many companies that blend MTBE into gasoline have developed and implemented **prevention control and emergency response plans** that include the following elements:

- Prompt spill-detection methods;
- Emergency notification procedures;
- Community contacts for notification and advice on evacuation needs and proper actions to protect the environment;
- Fire prevention and protection;
- Provisions covering spill containment and cleanup;
- UST leak detection devices and monitoring wells to detect the presence of MTBE;
- Identification and protection of any neighboring drinking water receptors or environmentally sensitive areas; and

⁴⁰ EPA, “Air Sparging,” last updated Dec. 12, 2012

⁴¹ EPA, “A Citizen’s Guide to Bioremediation,” EPA 542-F-01-001, April 2001

- Compliance with any other applicable laws and regulations.⁴²

For **spills and leaks**, the following procedures have been recommended:

- Facilities that store and/or handle MTBE should be designed to control spills from process areas, loading and unloading operations. For subsurface releases that are known or suspected, groundwater monitoring wells should be installed down-gradient of any UST and these wells should be regularly sampled;
- The installation of curbs, sumps and impervious containment areas can minimize soil, surface water and groundwater contamination. Such containment could include concrete, synthetic liners or compacted clay;
- Pumps, piping and other equipment should be compatible with MTBE;
- Accidental releases into a municipal sewer system should be reported immediately to the applicable authorities. The discharge should also be diluted with water to reduce fire and explosion hazards;
- All nonessential personnel should be evacuated and ignition sources immediately extinguished. Firefighting foam may be used to minimize potential fire hazards; and
- Soil contaminated with MTBE should be excavated and transported to a hazardous waste treatment or disposal facility.⁴³

With respect to **storage**, LyondellBasell generally stores bulk quantities of MTBE in ABTs equipped with internal floating roofs operating at atmospheric pressure. Fixed-head tanks combined with vapor management systems may also be used. The company also recommends diking outside storage tanks to contain spills with an adequate nearby water supply available in case of fire. **Unloading stations** should include instrumentation for off-loading stations to warn of potential for overfilling as well as an independent device that shuts off flow when an overfill is imminent. Also, loading racks should be 150 feet from all equipment and tanks.⁴⁴

Best practices governing **transfer operations** should provide for the following:

- Personal protective clothing for all personnel;
- Fire prevention procedures (mentioned above as well);
- Unloading systems dedicated to MTBE service, and ensure lines and equipment are free of water and then cleared with a compatible hydrocarbon, such as gasoline;
- Eyewash stations and safety showers;
- Non-sparking tools;
- Unloading block valve;
- Stainless steel double-braided accordion-type hose;
- Grounding connectors; and
- Nitrogen supply with pressure regulator and check valve.⁴⁵

⁴² LyondellBasell, "Product Safety Bulletin, Methyl Tertiary Butyl Ether," March 13, 2006. See also European Fuel Oxygenates Association, MTBE Resource Guide, February 2006.

⁴³ More information and precise requirements are described in LyondellBasell's "Product Safety Bulletin, Methyl Tertiary Butyl Ether," March 13, 2006.

⁴⁴ *Id.*

⁴⁵ *Id.*

For **marine transport** of MTBE, best practices will be similar to that of gasoline. The differences, highlighted by LyondellBasell, include the following:

- Materials compatibility;
- Water solubility – water contact should be avoided;
- Fire foams (alcohol-resistant foams may be required); and
- Exposure – vented marine transfer operations should be monitored to ensure vapor exposure is within acceptable means.⁴⁶

If inerting is necessary, MTBE can be blanketed in tanker transport, and nitrogen is an acceptable blanketing material. In case of a spill, MTBE's partial water solubility will cause it to dissolve in water, though the amount will depend on air and water temperature. MTBE should only be unloaded into uncontaminated tanks. Marine/shore transfer systems should be dry before transfer begins, and water should not be used to clear lines or displace MTBE.⁴⁷

U.S. EXPERIENCE

When Stratas Advisors followed UST issues back in the early 2000s with respect to the impact on MTBE and gasoline, we estimated that compliance with UST program regulations was less than 50%. Moreover, insufficient enforcement was being done at the state or federal level to require compliance with the UST regulations. Consequently, unfortunate timing existed with respect to the increased blending of MTBE into the U.S. gasoline pool.

Congress enacted legislation in the 1980s governing USTs under Subtitle I of the HSWA of 1984 to the *Resource Conservation and Recovery Act* (P.L. 94-580). The U.S. EPA promulgated regulations under these amendments to guide the states in the late 1980s and 1990s on establishing programs to upgrade and monitor USTs. In turn, the states began constructing and implementing their own UST compliance and enforcement programs in the 1990s. UST owners began to upgrade their USTs and install new USTs around that same time. All of this was happening at the same time MTBE use in the U.S. gasoline pool began to dramatically expand, primarily in response to the oxygenate requirement under the federal RFG program.

MTBE appearance in groundwater supplies was generally very low, under EPA's odor and taste threshold levels of 20-40 ppb. From 2000 to 2005, EPA collected MTBE sampling data in finished drinking water from many large public water systems nationwide and a nationally representative subset of small public water systems. From the 34,000 samples, MTBE was detected above 5 ppb (the minimum reporting level for the study) in only 26 samples – or less than 0.1% – and above 20 ppb (the minimum threshold for taste or odor issues) in only five samples – or less than 0.015%.

In many cases where MTBE was found, USTs had not been upgraded as the regulations required, or there were installation and filling mistakes and/or equipment failures. Unfortunately, in many cases, service station operators simply shut off or overrode detection systems and shut off alarms and failed to investigate releases that occurred. Many releases had gone undiscovered for years and were only found during the UST closure process. Keep

⁴⁶ *Id.*

⁴⁷ *Id.*

in mind that not all USTs are regulated and not all components of USTs are regulated. There were also inadequate compliance and enforcement activities at the state level. This factor was cited as the No. 1 problem that led to issues with gasoline containing MTBE in groundwater supplies.⁴⁸ This criticism was leveled directly at the state of California, the site of several serious and high-profile gasoline releases.

Adequate enforcement remains a problem at the state and federal level; this will be discussed further in a later subsection. In Stratas Advisors' direct experience working with UST program officials in the states, the key issue is funding to hire and train qualified UST inspectors. In the past 10 years, this has become an even bigger issue with the financial crisis and economic downturn in the U.S., which has particularly impacted state governments. Ironically, the federal LUST fund contained about \$1.16 billion as of September 2012.⁴⁹ However, Congress has only allocated \$73.9 million for cleanups in fiscal year 2012.

Underground Storage Tank Regulations

EPA develops the regulations under the federal UST program, and these are implemented by the states, territories (e.g., Puerto Rico) and tribal lands. By law, an UST system is a tank and any underground piping connected to the tank that has at least 10 percent of its combined volume underground. The federal UST regulations apply only to underground tanks and piping storing either petroleum or certain hazardous substances⁵⁰. States must receive approval of their UST programs by EPA⁵¹, which judges the program by three criteria:

1. It sets standards for eight performance criteria that are no less stringent than federal standards;
2. It contains provisions for adequate enforcement; and
3. It regulates at least the same USTs that are regulated under federal standards.

As of February 2012, 38 states and the District of Columbia as well as Puerto Rico have approved programs.⁵²

History

More than 50% of drinking water in the U.S. comes from groundwater. According to EPA⁵³, until the mid-1980s most USTs were made of bare steel, which tended to corrode over time and allow UST contents to leak into the environment and, in particular, groundwater supplies. After numerous publicized instances of this occurring, the U.S. Congress passed legislation to address this issue in 1984 and then again in 2005 (*Energy Policy Act of 2005*; P.L. 109-58). The 1984 legislation created a federal program to regulate USTs and then amended that program in 1986 (*Superfund Amendments and Reauthorization Act*; P.L. 99-499). In 2005,

⁴⁸ White Environmental Associates, "MTBE/USTs: A True Perspective," November 2002

⁴⁹ U.S. EPA, "UST Program Facts," December 2012

⁵⁰ These substances are listed [at 40 C.F.R. § 302.4](#), which was last updated April 12, 2013.

⁵¹ The primary advantage to EPA approval of a UST program is avoiding two sets of laws and regulations to implement.

⁵² The states with approved programs are: Alabama, Arkansas, Colorado, Connecticut, Delaware, Georgia, Hawaii, Idaho, Indiana, Iowa, Kansas, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Carolina, North Dakota, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington and West Virginia.

⁵³ U.S. EPA, "What Is The History Of The Federal Underground Storage Tank Program?" last updated Dec. 20, 2012

additional requirements were enacted, and in 2009 more than \$200 million in funding was allocated for spill cleanup. A short time line and history of these congressional legislative actions follows:

1984: Subtitle I was added to the Solid Waste Disposal Act through the HSWA:

- Created a federal program to regulate USTs containing petroleum and hazardous chemicals to limit corrosion and structural defects and thus minimize future tank leaks; and
- Directed EPA to set operating requirements and technical standards for tank design and installation, leak detection, spill and overfill control, corrective action and tank closure.

1986: Subtitle I was amended through the Superfund Amendments Reauthorization Act:

- Authorized EPA to respond to petroleum spills and leaks;
- Directed EPA to establish financial responsibility requirements for UST owners and operators to cover the cost of taking corrective actions and to compensate third parties for injury and property damage caused by leaking tanks; and
- Created a LUST Trust Fund. The fund is used to oversee cleanups by responsible parties, enforce cleanups by recalcitrant parties, and pay for cleanups at sites where the owner or operator is unknown, unwilling or unable to respond or where emergency action is required.

2005: Energy Policy Act of 2005 amended Subtitle I of the Solid Waste Disposal Act:

- Added new leak detection and enforcement provisions to the program;
- Required that all regulated USTs be inspected every three years;
- Expanded the use of the LUST Trust Fund;
- Required EPA to develop grant guidelines regarding operator training, inspections, delivery prohibition, secondary containment, financial responsibility, public record and state compliance reports on government USTs; and
- Required EPA to develop a strategy and publish a report regarding USTs in Indian Country.

2009: American Recovery and Reinvestment Act of 2009 (Recovery Act):

- Provided a one-time supplemental appropriation of \$200 million from the LUST Trust Fund to EPA for cleaning up leaks from federally regulated USTs; and
- Majority of funds (\$190.7 million) allocated to states/territories in the form of assistance agreements to address shovel-ready sites within their jurisdictions.

Summary of the Regulations

Under the legislative acts passed in 1984 and 1986, EPA developed comprehensive regulations⁵⁴ addressing both existing USTs and new USTs that would be installed after Dec. 22, 1988, as summarized in the table below. Requirements for new USTs included provisions on correct installation, leak detection, and spill, overfill and corrosion protection. Existing USTs had to have leak detection installed by December 1993, and spill, overfill and corrosion protection installed by December 1998. The regulations also required UST owners to take corrective action in response to leaks and to follow the specific requirements for closing tanks. In addition, owners had to demonstrate financial responsibility for the cost of cleaning up a leak and compensating people for bodily injury and property damage. Specifically, owners needed either “per occurrence” or “aggregate” coverage ranging from \$500,000-\$2 million, depending on the category of coverage. New UST installations must be certified by a qualified installer that carefully follows installation procedures established by industry codes.

Summary of Leak Detection, Spill/Overfill Protection and Corrosion Protection Requirements

Leak Detection	
New Tanks	<ul style="list-style-type: none"> • Monthly Monitoring*; or • Inventory Control Plus Tank Tightness Testing** • (only for 10 years after installation)
Existing Tanks	<ul style="list-style-type: none"> • Monthly Monitoring*; or • Inventory Control Plus Tank Tightness Testing** • (only for 10 years after adding spill, overfill and corrosion protection); or • Inventory Control Plus Annual Tank Tightness Testing (only until December 1998)
New & Existing Pressurized Piping	<ul style="list-style-type: none"> • Automatic Shutoff Device or Flow Restrictor or Continuous Alarm System; AND • Annual Line Tightness Test or • Monthly Monitoring* [except Automatic Tank Gauging]
New & Existing Suction Piping	<ul style="list-style-type: none"> • Monthly Monitoring*; or • Line Tightness Testing (every three years); or • No Requirements
Spill & Overfill Protection	
All Tanks	<ul style="list-style-type: none"> • Catchment Basins; AND • Automatic Shutoff Devices or Overfill Alarms or Ball Float Valves

⁵⁴ See 40 C.F.R. Parts 280-282, 302, available at <http://www.epa.gov/oust/fedlaws/cfr.htm>; current as of April 12, 2013.

Corrosion Protection	
New Tanks & Piping	<ul style="list-style-type: none"> Coated and Cathodically Protected Steel; or Fiberglass Reinforced Plastic (FRP); or Steel Tank Clad With FRP (does not apply to piping)
Existing Tanks & Piping	<ul style="list-style-type: none"> Same Options As For New Tanks & Piping; or Cathodically Protected Steel; or Tank Interior Lining; or Tank Interior Lining AND Cathodic Protection

Notes:

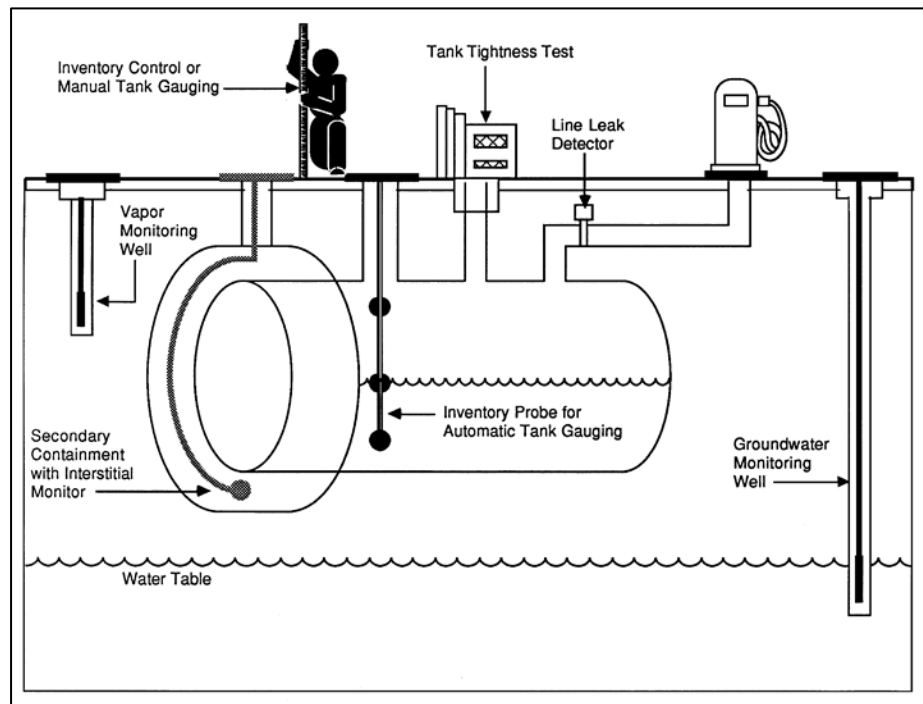
*Monthly Monitoring includes: Interstitial Monitoring; Automatic Tank Gauging; Vapor Monitoring, Groundwater Monitoring; Statistical Inventory Reconciliation; and other methods approved by the regulatory authority.

**Tanks 2,000 gallons and smaller may be able to use manual tank gauging.

Source: EPA, "A Summary of Federal Regulations for Underground Storage Tank Systems," July 1995, EPA 510-K-95-002

A graphical representation of **leak detection** methods is illustrated in the figure below.

Graphical Representation of Leak Detection Methods



Source: EPA, "A Summary of Federal Regulations for Underground Storage Tank Systems," July 1995, EPA 510-K-95-002

As noted in the table below, monthly monitoring for leak detection is a requirement under the UST regulations. The table shows the types of monitoring methods that can be used. One of a combination of these methods can be used under the regulations.

Additional leak detection is required for piping and must meet the following requirements:

- The piping must have devices that automatically shut off or restrict flow or have an alarm that indicates a leak; and
- The owner/operator must either conduct an annual tightness test of the piping or use one of the following monthly methods noted above for tanks: interstitial monitoring,

vapor monitoring, groundwater monitoring, statistical inventory reconciliation or other approved monthly methods.

Leak Detection Monthly Monitoring Methods

Method	Description
Interstitial Monitoring	This method detects leaks in the space between the UST and a second barrier. The regulations describe general performance requirements for interstitial monitoring with double-walled USTs, USTs fitted with internal liners and USTs using interception barriers.
Automatic Tank Gauging Systems	This method uses automated processes to monitor product level and inventory control.
Monitoring for Vapors in the Soil	This method samples vapors in the soil gas surrounding the UST. Leaked petroleum produces vapors that can be detected in the soil gas. The regulations describe several requirements for using this leak detection method. For example, this method requires using porous soils in the backfill and locating the monitoring devices in these porous soils near the UST system.
Monitoring for Liquids on the Groundwater	This method monitors the groundwater table near an UST for the presence of released free product on the water table. Monitoring wells near the UST are checked frequently to see if petroleum can be detected. The regulations describe several requirements for the use of this method. For example, this method cannot be used if the water table is more than 20 feet below the surface of the ground.
Statistical Inventory Reconciliation	In this method, a trained professional uses sophisticated computer software to conduct a statistical analysis of inventory, delivery and dispensing data, which must be supplied regularly.
Other Methods Approved By the Regulatory Authority	If other methods can be shown to work as effectively as the methods described above for leak detection, these alternative methods can be approved by the regulatory authority.

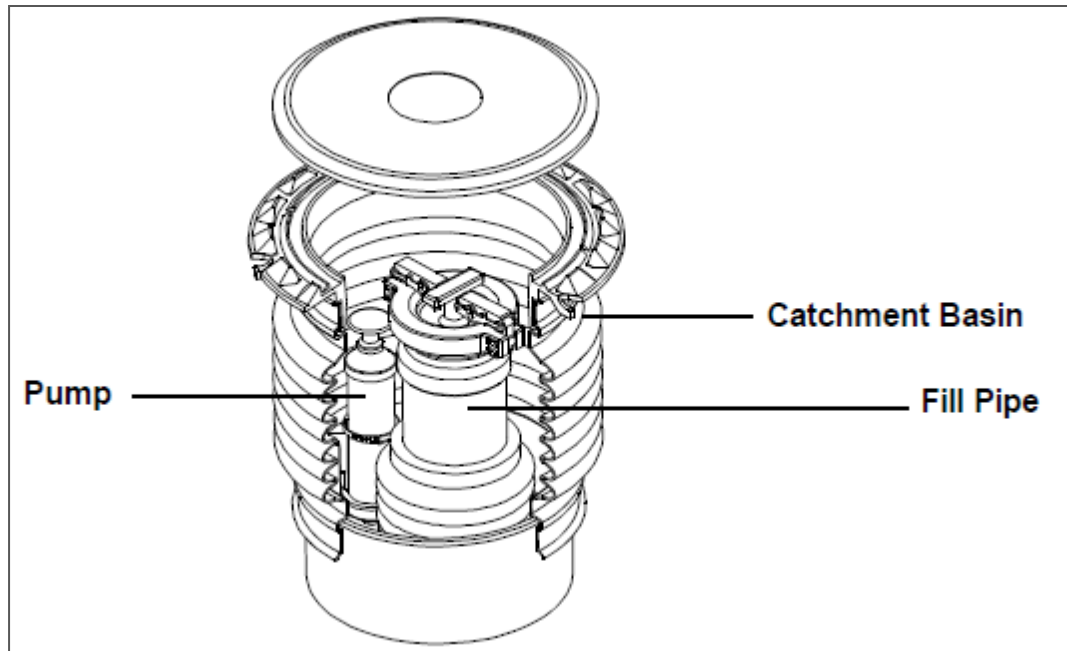
Source: EPA, "A Summary of Federal Regulations for Underground Storage Tank Systems," July 1995, EPA 510-K-95-002

If the UST has suction piping, leak detection requirements will depend on which type of suction piping is in place.

- One type of suction piping does not require leak detection if it has the following characteristics:
 - Below-grade piping operating at less than atmospheric pressure is sloped so that the piping's contents will drain back into the storage tank if the suction is released; and
 - Only one check valve is included in each suction line and is located directly below the suction pump.
- Suction piping that does not exactly match the characteristics noted above must have leak detection, either monthly monitoring (using one of the monthly methods noted above for use on pressurized piping) or tightness testing of the piping every three years.

With respect to **spill protection**, USTs must have catchment basins to contain spills, which are a common source of releases at UST sites. A graphical representation of catchment basin is shown in the figure below.

Representation of a Catchment Basin



Source: EPA, "A Summary of Federal Regulations for Underground Storage Tank Systems," July 1995, EPA 510-K-95-002

To protect against spills, the basin should be large enough to contain what may spill when the delivery hose is uncoupled from the fill pipe. Basins range in size from those capable of holding only a few gallons to those that are much larger. The larger the catchment basin, the more spill protection it provides. Manufacturers equip catchment basins with either pumps or drains to remove liquid. The illustration in the figure below shows a catchment basin with a pump but catchment basins also include those with drains.

USTs are also required to have overfill protection, and there are three main types:

- Automatic shutoff devices: Can slow down and then stop the delivery when the product has reached a certain level in the tank;
- Overfill alarms: Use probes installed in the tank to activate an alarm when the tank is either 90% full or within 1 minute of being overfilled; and
- Ball float valves: These are placed at the bottom of the vent line several inches below the top of the UST. The ball floats on the product and rises with product level during delivery until it restricts vapor flowing out of the vent line before the tank is full. If all tank fittings are tight, the ball float can create enough back pressure to restrict product flow into the tank, which can notify the driver to close the truck's shutoff valve.

New USTs must have one of the following to meet **corrosion protection** requirements:

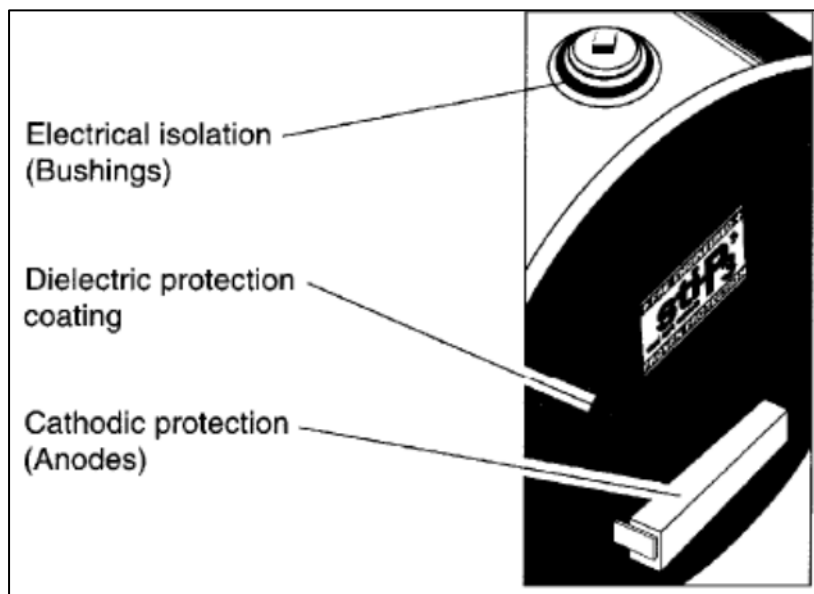
- Tank and piping completely made of noncorrodible material, such as fiberglass. Corrosion protection is also provided if tank and piping are completely isolated from

contact with the surrounding soil by being enclosed in or "jacketed" in noncorrodible material;

- Tank and piping made of steel having a corrosion-resistant coating and having cathodic protection (such as a sti-P3® tank with appropriate piping). A corrosion-resistant coating electrically isolates the coated metal from the surrounding environment to help protect against corrosion; or
- Tank made of steel clad with a thick layer of noncorrodible material (such as an ACT-100® tank). This option does not apply to piping.

Cathodic protection methods include sacrificial anode systems and impressed current systems. Sacrificial anodes can be attached to the UST for corrosion protection (as illustrated in the figure below). Sacrificial anodes are pieces of metal more electrically active than the steel UST. Because these anodes are more active, the corrosive current will exit from them rather than the UST. Thus, the UST is protected while the attached anode is "sacrificed."

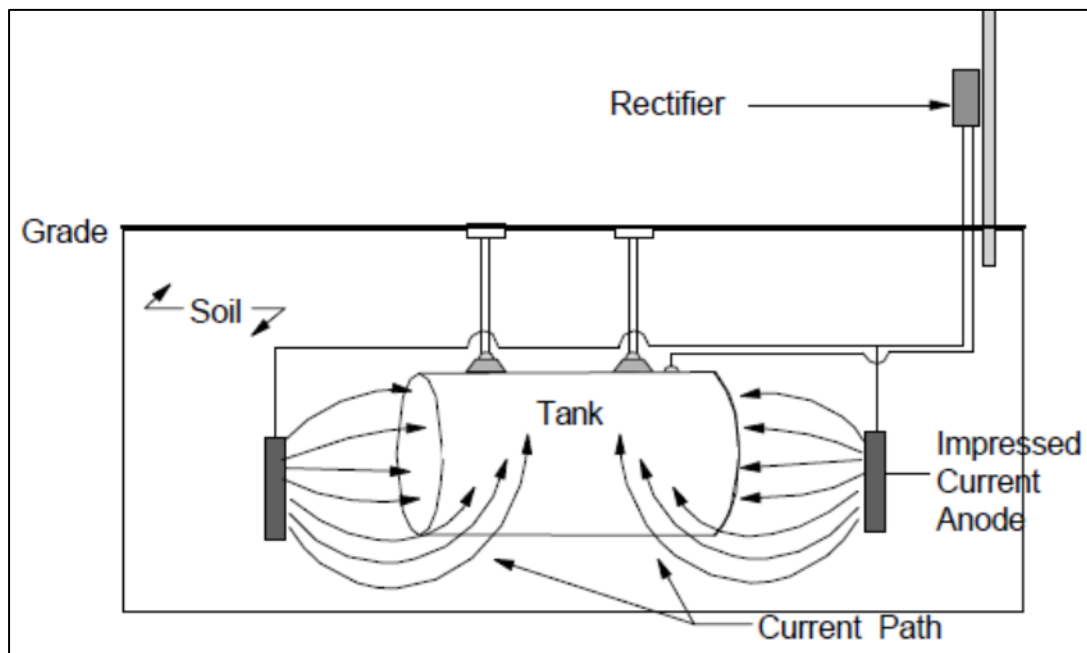
Sacrificial Anode System



Source: EPA, "A Summary of Federal Regulations for Underground Storage Tank Systems," July 1995, EPA 510-K-95-002

An impressed current system uses a rectifier to convert alternating current to direct current (see illustration in the figure below). This current is sent through an insulated wire to the anodes, which are special metal bars buried in the soil near the UST. The current then flows through the soil to the UST system and returns to the rectifier through an insulated wire attached to the UST. The UST system is protected because the current going to the UST system overcomes the corrosion-causing current normally flowing away from it.

Impressed Current System



Source: EPA, "A Summary of Federal Regulations for Underground Storage Tank Systems," July 1995, EPA 510-K-95-002

For hazardous substances, UST tanks must also be double-walled. While more expensive, double-walled tanks with interstitial monitoring have been recommended by MTBE producers and are in use in other regions around the world as a standard practice with gasoline products. These are really the safest systems to employ to all but eliminate the possibility of leaks. Steel tanks tend to be stronger and more resilient than fiberglass tanks and are less prone to corrosion.

Note: Under the regulations, the following USTs do not need to meet federal requirements for USTs:

- Farm and residential tanks of 1,100 gallons or less capacity holding motor fuel used for noncommercial purposes;
- Tanks storing heating oil that is used on the premises where it is stored;
- Tanks on or above the floor of underground areas, such as basements or tunnels;
- Septic tanks and systems for collecting storm water and wastewater;
- Flow-through process tanks;
- Tanks of 110 gallons or less capacity; and
- Emergency spill and overfill tanks.

Enforcement Provisions in the UST Program

States with approved UST programs take the lead in enforcement of their programs. EPA is the lead enforcer for states without such programs, tribal areas, federal lands or in cases that are referred by states to the EPA for enforcement. Once a decision is made that the violations following a regular inspection merit an EPA enforcement response, an enforcement action may proceed along one of three different pathways:

- Issuance of a field citation with a pre-determined penalty;

- Negotiation of a settlement prior to or after issuance of a complaint; or
- Issuance of an administrative complaint and proposed final order.

Field citations are the most commonly used form of enforcement on noncompliant USTs. According to EPA, field citations are appropriate for violations that are clear-cut, easily verifiable and easily correctable; and for first-time violators. EPA has stated:

“Experience suggests that field citations can result in the resolution of UST violations in a manner that is effective and resource-efficient for both the government and the owners and operators of underground storage tanks. Generally, the inspector issues the field citation and conducts necessary follow-up to ensure that the facility has returned to compliance and paid the assessed penalty amount.

If violations are not corrected and the penalty is not paid within a specific number of days of the date the field citation was issued, the citation is normally withdrawn, unless a request for an extension has been submitted and granted. The next appropriate step is to consider whether or not to take a more formal enforcement action or another course of action. Any more formal enforcement action should include higher penalties than the field citation settlement terms in order to achieve compliance and ensure the integrity of the Field Citation Program.”⁵⁵

In settlement negotiations, the inspector prepares an inspection report, a case developer is assigned and the EPA Regional Program Manager requests assignment of an attorney to the matter. The attorney and case developer may ultimately decide to send a “show cause” letter to the facility owner/operator, describing the alleged violations. The letter would invite the facility owner/operator to engage in pre-filing negotiations in an attempt to settle the matter. If the owner/operator does not respond to that invitation, or if negotiations fail to result in a settlement, the attorney may file a complaint.⁵⁶

In the administrative complaint stage, a formal enforcement action may take place. Typically this happens in the following types of situations:

- Violations of 1998 upgrade installations (e.g., no corrosion protection, no leak detection or no spill/overfill protection);
- Non-reporting of releases;
- No release detection equipment on both tanks and piping;
- Willful negligence;
- Leaking tanks with recalcitrant owners;
- Repeat violators (same violation); and
- Any violations for which a field citation cannot be issued.

In addition to requiring the UST owner/operator to come into compliance, penalties may be assessed as well. Such civil penalties are not to exceed:

- \$16,000 per tank per day for each violation of a requirement; and

⁵⁵ See EPA, “Underground Storage Tank (UST) Enforcement Compendium,” updated May 2009

⁵⁶ *Id.*

- \$16,000 per tank for failure to comply with the notification requirements.

Efforts of the owner/operator to comply should be accounted for in the penalty assessment, as well as notice that continued noncompliance could result in further legal action, including the assessment of additional penalties of up to \$37,500 for each day of noncompliance with the compliance order.

Note: Similar enforcement actions may be taken against noncompliant above-ground storage tanks (ASTs) as well.

Success and Challenges in the UST Program

Since the inception of the UST program, more than 1.7 million USTs have been closed.⁵⁷ As of December 2012, there are 584,000 active USTs at approximately 214,000 sites. According to EPA, 85.5% of the active USTs are in significant operational compliance with the spill, overfill and corrosion protection requirements, and 78.9% of USTs are in significant operational compliance with the leak detection requirements. Approximately 71% of USTs are in significant operational compliance with both sets of requirements. In addition, as of December 2012:

- 507,540 releases have been confirmed;
- 481,614 cleanups have been initiated;
- 424,637 have been completed; and
- 82,903 cleanups had not been completed.

Stratas Advisors notes that compliance rates have increased significantly since the 1998 upgrade deadline. When Stratas Advisors followed UST issues back in the early 2000s with respect to the impact on MTBE (and vice versa), we estimated compliance was not even 50%. Moreover, not enough enforcement had been done at the state or federal level to require compliance with the UST regulations. Thus, there was an unfortunate timing issue with respect to MTBE. Many UST owners waited until the last minute, until Dec. 31, 1998, to comply with the UST regulations.⁵⁸

In other words, Congress enacted new legislation in the 1980s and EPA set regulations under that legislation to guide the states in the late 1980s and 1990s. States, in turn, began constructing and implementing their own UST compliance and enforcement programs in the 1990s. UST owners began to upgrade their USTs and install new USTs around that same time. All of this was happening at the same time MTBE use in the U.S. gasoline pool began to dramatically expand, primarily in response to the oxygenate requirement under the federal RFG program.

As a general matter, MTBE appearance in groundwater supplies was generally very low, under EPA's threshold level of 20-40 ppb, which is sufficient to avoid taste and odor concerns and render water fully potable. From 2000 to 2005, EPA collected MTBE sampling data in finished drinking water from all large public water systems nationwide, and a nationally representative subset of small public water systems. From the 34,000 samples, MTBE was detected above 5 ppb (the minimum reporting level for the study) in only 26 samples – or less

⁵⁷ See EPA, "UST Program Facts," December 2012

⁵⁸ White Environmental Associates, "MTBE/USTs: A True Perspective," November 2002

than 0.1% – and above 20 ppb (the minimum threshold for taste or odor issues) in only five samples – or less than 0.015%.

In many cases where MTBE was found, USTs had not been upgraded as the regulations required, or there were installation and filling mistakes and/or equipment failures. Many operators simply shut off or overrode lead detection systems and shut off alarms and failed to investigate releases. Many releases were found during the UST closure process and had gone undiscovered for years. Not all USTs are regulated and not all components of USTs are regulated. There were also inadequate compliance and enforcement activities at the state level. This one factor was cited as the No. 1 problem that led to issues with gasoline containing MTBE in groundwater supplies.⁵⁹ This criticism was leveled directly at the state of California, the site of several gasoline releases.

Adequate enforcement remains a problem at the state and federal level. In Stratas Advisors' direct experience working with UST program officials in the states, the key issue is funding to hire and train qualified UST inspectors. In the last 10 years, that has become an even bigger issue with the financial crisis and economic downturn in the U.S., which has particularly impacted state governments. Ironically, the federal LUST fund contained approximately \$1.16 billion as of September 2012.⁶⁰ However, Congress has only allocated \$73.9 million for cleanups in fiscal year 2012.

Many states do have their own cleanup funds and, according to EPA, spend about \$600-700 million annually. The average cost per site is approximately \$133,000, according to some estimates.⁶¹ Multiply that by the number of uncompleted cleanups noted above (82,903) and the average cost of cleaning up all the remaining sites is more than \$11 billion.⁶² Some of that funding will come from UST owners, but some will also need to come from the states and their cleanup funds are woefully underfunded. There also remains a backlog in cleanups that still need to be done, though they are slowly decreasing over time as the figure below shows. Notice that less than 5,000 cleanups were done nationally between 2011 and 2012.

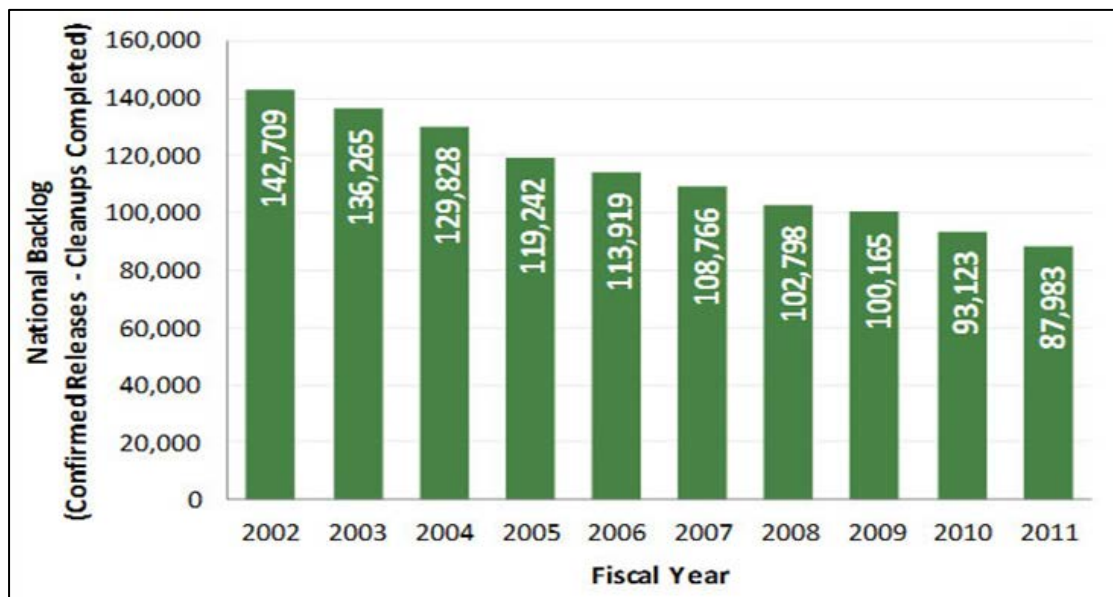
⁵⁹ *Id.*

⁶⁰ EPA, "UST Program Facts," December 2012

⁶¹ Association of State and Territorial Solid Waste Management Officials, "State Fund Survey Results," 2011, [Table 3: Level of Activity in State Financial Assurance Funds](#)

⁶² *Id.*

UST Cleanup Backlog in the U.S.



Source: EPA, "The National LUST Cleanup Backlog: A Study of Opportunities," January 2013

Litigation Surrounding Gasoline Releases with MTBE

Despite the deficiencies in the U.S. gasoline containment policies and the slow pace in implementing the UST program, demanding compliance and taking the necessary enforcement actions against UST owners, EPA continued to support the use of MTBE in gasoline during this period. Moreover, EPA knew about the risks to groundwater that releases of gasoline with MTBE posed going back to the 1980s and so did the oil industry, which, it has been alleged, lobbied for lax UST standards in the first place.⁶³ Once MTBE detections began to occur more often in groundwater supplies in the late 1990s, state and local authorities as well as lawyers for individual homeowners filed lawsuits. The argument behind many of these lawsuits was that MTBE was inherently defective as a product because of its impact on water quality.

Between late 2003 and early 2004 alone, approximately 60 cases were filed on behalf of about 150 water providers or governmental entities against more than 75 defendants in 16 states. The target of these lawsuits was generally the oil industry and some MTBE producers. These defendants argued that they were essentially required to use MTBE to satisfy CAA requirements, specifically the oxygenate requirement in the federal RFG program. Counter-arguments to this defense were that, while an oxygenate requirement existed under the federal RFG program, the industry could have used ethanol. Stratas Advisors' notes that such an option was not realistic since ethanol production was at very modest levels around this time, representing less than 1% of overall gasoline demand. From an availability and economic standpoint, MTBE and ethanol were the only oxygenate products in the marketplace to allow compliance with RFG requirements.

⁶³ See, for example, EPA, "Clean Up of Releases from Petroleum USTs: Selected Technologies," April 1988. See also Thomas O. McGarity, "MTBE and the Need for Effective Tort Law," March 2005.

EUROPE'S EXPERIENCE

In Europe, the releases from gasoline USTs have not been a significant issue compared to such leaks in the U.S. Serious groundwater impacts may happen in the case of undetected LUSTs or piping. The main reason for the lack of regulatory thresholds and especially drinking water quality standards is related to the fact that the WHO decided not to set up a health-based guideline for MTBE. As indicated by the WHO (2005) and explained by Fawell (2007), the known odor and taste thresholds are four to five orders of magnitude lower than the concentration for effects on human health derived from different toxicology studies.

The information on the distribution of ethers in groundwater is relatively good. A lot of monitoring and research data and evaluation reports are available for some European countries. The table below shows results from selected surveys.

Results of MTBE Monitoring in Some European Countries

Country	MTBE Monitoring	Number of samples (including gasoline stations)	MTBE Detected Levels
Austria	2 monitoring cycles finalized in 2002 and 2004	In 2002: 101 samples, including 6 gasoline stations; In 2004: 217 samples	<ul style="list-style-type: none"> • In 2002: At service stations, 0.129 µg/l – 1.594 µg/l; median: 0.369 µg/l. • In 2004: From all samples, only 32 were above the detection limit of 0.01 µg/l; the highest concentration was 1.2 µg/l.
Switzerland	6 monitoring cycles finalized in 2002, 2003, 2004, 2005 and 2006	In 2002: 162 samples; in 2006: 431 samples	<ul style="list-style-type: none"> • In 2002: Only 9 samples had 0.12 µg/l to 0.34 µg/l. • In 2004: Min value 0.04 µg/l, max 6.4 µg/l.
Germany	2002	420	<ul style="list-style-type: none"> • Detectable concentration of MTBE in 15.5% of sampled wells; values ranged from 0.05 µg/l to 18 µg/l, of which only 4 values exceeded 1 µg/l. • Other reports on industrial sites and former storage facilities: • In Hesse (1999-2002): median value <0.01 µg/l, highest value 2.2 µg/l (rural) and median value 0.26 µg/l, highest value 47.6 µg/l (urban). • Leuna (former GDR): Up to 185,000 µg/l.
Netherlands	2000-2003; 2006	89 In 2006: 54 gasoline stations and 3 depots	<ul style="list-style-type: none"> • MTBE detected in 60% of all samples. The highest concentration ranged from 0.3 µg/l to 0.41 µg/l. • 2006 data: 45% of gasoline stations had MTBE concentration above 1 µg/l.

Country	MTBE Monitoring	Number of samples (including gasoline stations)	MTBE Detected Levels
United Kingdom	1990s; 2009	1990s: 300 gasoline retail, storage and distribution sites; plus public water supply wells. Monitoring project finalized 2009: 524 sites.	<ul style="list-style-type: none"> • 1990s: 33% of the sites had a detectable concentration; max was from 1 µg/l to 800,000 µg/l; from public water wells – MTBE detected in 13% of the wells. Usually close to the detection limit. Ten wells had a concentration above 1 µg/l. • 2009: MTBE detected at 373 retail filling stations (71%); 340 samples (65%) had a concentration above 15 µg/l.
Denmark	1997 2000 2003	1997: 22 samples 2000: 20 samples 2003: 50 sites	<ul style="list-style-type: none"> • 1997: 7 out of 22 samples with positive detection values from 0.1 to 0.6 µg/l. • 2000: 7 samples out of 20 with detectable concentration from 0.1 to >30 µg/l. • 2003: For 40 sites, the values ranged from 0.22 to 530,000 µg/l, mean value 2,900 µg/l, median value 44.5 µg/l.
Finland	2009 report	2009: 398 MTBE investigations	<ul style="list-style-type: none"> • 2009: 33.7% were above 15 µg/l (a higher contamination level in comparison to other European countries but it is difficult to draw a conclusive opinion about the cause).

Source: Stratas Advisors, based on “Gasoline ether oxygenate occurrence in Europe, and a review of their fate and transport characteristics in the environment,” Concawe, 2012

The European data showed that MTBE is reported in European groundwater over a wide range (both in terms of location and time). Gasoline stations, depots and related production facilities represent the majority of the sites with high concentration levels of GEO. Low concentration “background” MTBE was observed in urban areas; it was much lower in rural areas. Diffuse source concentration for MTBE typically ranges from 0.01 to 1 µg/l (i.e., well below the taste, odor and health-related thresholds). Concentrations of MTBE above 1 µg/l were often assumed to be an indication of proximity to a point source.

In the EU, only Denmark has a legally enforced drinking water quality standard for MTBE, with a threshold of 5 µg/l. The Dutch Ministry of Housing, Spatial Planning and the Environment set a target value for remediation of 1 µg/l within drinking water collection areas for MTBE and ETBE, in accordance with the precautionary principle and the existing drinking water legislation. Outside drinking water collection areas, a value of 15 µg/l was set (VROM, 2008 / van Wezel, et al, 2009).

In Germany, the water consortium of the federal states (Länderarbeitsgemeinschaft Wasser, LAWA) defined a concentration of 15 µg/l that represents the level of insignificance for MTBE

in groundwater. This value does not represent a legally binding groundwater quality standard; it is used as an assessment value for groundwater contamination. In addition, Switzerland has a guideline value for MTBE in groundwater of 2 µg/l (BUWAL, 2004b). This is a precaution value and it is used as a tracer for gasoline compounds in groundwater. The Finnish government adopted Decree 214/2007, which includes provisions relating to soil contamination and remediation. It indicates a threshold value of 0.1 mg/kg for MTBE. Additionally, lower (5 mg/kg) and higher (50 mg/kg) critical limits are given.

TRANSPORT AND STORAGE

ABOVE-GROUND TANK REGULATIONS

ASTs are tanks and other containers that are above ground, partially buried, bunkered or in a subterranean vault and can include floating systems. The key regulations governing ASTs in the U.S. are the Spill Prevention, Control and Countermeasures (SPCC), which require owners and operators of the following types of ASTs to prepare and comply with written, site-specific, spill-prevention plans:

- Facilities with a total above-ground oil storage capacity of more than 1,320 gallons;
- Single above-ground tanks with an oil storage capacity of more than 660 gallons; and
- Facilities with a combined underground oil storage capacity greater than 42,000 gallons.⁶⁴

Regulations in some states may be more stringent than the federal government's. Some states require owners/operators of ASTs that have been inactive for a year or more to maintain and monitor the tank, declare the tank inactive or remove it.

The spill-prevention plans required under the SPCC regulations must address the following topics:

- **Facility Security:** The plan must describe how:
 - Access is controlled to oil handling, processing and other storage areas; and
 - The facility prevents unauthorized access to starter controls on oil pumps and master flow and drain valves are secured. This includes out-of-service loading and unloading connections oil pipelines.
- **Integrity Testing:** The plan must provide for:
 - A regular schedule of testing and inspection on each above-ground tank;
 - Required testing whenever material repairs are made on any above-ground tank; and
 - Frequency of testing should take into account design, configuration and size of the storage.
- **Tank integrity-testing requirements:**
 - The rule requires owners/operators of qualified facilities to test and inspect each above-ground container for integrity on a regular schedule and whenever material repairs are made;
 - Where there are applicable industry standards, it allows qualified facilities the flexibility to determine, in accordance with industry standards, the appropriate qualifications for personnel performing tests and inspections, as well as the frequency and type of testing and inspections that take into account container size, configuration, and design; and
 - SPCC regulations also require self-certifying facilities to institute methods and frequency of inspections and testing in their SPCC Plans, including monthly, yearly and five-year interval inspections.⁶⁵

⁶⁴ See EPA, "Source Water Protection Practices Bulletin: Managing Above-Ground Storage Tanks to Prevent Contamination of Drinking Water," EPA 916-F-01-022, July 2001

According to EPA, releases can be caused by corrosion, failure of piping systems, spills and overfills, as well as equipment failure and human operational error. AST requirements are designed to decrease the instance of these types of occurrences by requiring the following:

- **Secondary containment:**
 - The containment area surrounding the tank should hold 110% of the contents of the largest tank plus freeboard for precipitation;
 - Secondary containment for ASTs must be impermeable to the materials being stored. Methods include berms, dikes, liners, vaults and double-walled tanks;
 - A manually controlled sump pump should be used to collect rain water that may accumulate in the secondary containment area; and
 - Any discharge should be inspected for petroleum or chemicals prior to being dispensed.
- **Routine monitoring:**
 - An audit of a newly installed tank system by a professional engineer can identify and correct problems such as loose fittings, poor welding and poorly fit gaskets;
 - After installation, inspect the tank system periodically to ensure it is in good condition;
 - Depending on the permeability of the secondary containment area, more frequent containment area checks may be necessary. Areas to inspect include tank foundations, connections, coatings, tank walls and the piping system: and
 - Integrity testing should be done periodically by a qualified professional and in accordance to applicable standards.

Other prevention measures are “highly recommended” but are not provided for in the AST regulations:

- Site location selection for ASTs and the distance from surface and drinking water supplies;
- Corrosion protection;
- Periodic cleanup of containment areas; and
- Preventing evaporation.

JAPAN’S EXPERIENCE

In Japan, MTBE was used at one time to help raise octane in gasoline. However, Japanese oil companies voluntarily abandoned the practice for economic reasons and after concerns arose in the U.S. regarding groundwater pollution by fuel leaking from gas tanks. Although the Japanese government does not place a ban on the use of MTBE, the ethers blending limit in gasoline has been capped at 7 vol% max (equivalent to 1.3 wt% oxygen) since April 1996. Out of all the Asian countries, only Japan is currently using ETBE that is produced from bio-ethanol after ensuring that the infrastructure is ready for its use. So far, two of its idle MTBE

⁶⁵ “Above-Ground Tanks, Regulation for SPCC & Integrity Testing,” as of April 2013

plants have been converted to ETBE and are operated by JX Nippon and Cosmo Oil, while the remaining ETBE demand is imported from the U.S.

It is worthwhile to note that risk or groundwater assessments concerning MTBE have never been carried out in Japan before its usage in gasoline, or before discontinuing its usage. In particular, the petroleum industry highlighted that the safety criteria for underground tanks are stricter than in the U.S. Therefore, the industry recognizes that the leakage rate of tanks in Japan is low, resulting in a low risk of MTBE leaks to underground areas. However, no detailed studies have been made on verifying the actual risks.

Leaking Underground Storage Tanks (LUST)

There are a number of major regulations that govern UST in Japan including the primary law on the Fire Service Law (1948) which governs the storage methods of hazardous materials (inclusive of UST – standards on tank installation, secondary containment, etc.). Other regulations include the Soil Contamination Countermeasure Law (2003): Prevention of contamination on soil and groundwater and the Water Pollution Control Law (1970): Prevention of contamination on surface water.

Japan's regulations on UST are summarized as follows:

- UST is governed by Fire Service Law primarily, with more emphasis on seismic protection (to avoid tank failure as a result of earthquake)
- Steer towards safety on UST management, rather than environmental focus
- No penalty towards the contamination occurred due to UST failure, but the authority may request for cleanup (not mandatory)
- UST regulations:
 - Existing UST regulations - more emphasis on corrective action (containment of spillages etc.),
 - Future - looking towards preventive (better tank specification, etc.)
- Soil and groundwater standards
 - Existing soil and groundwater standards - available primarily focused on industrial chemicals, which include only limited contaminants which are petroleum-related chemicals, such as benzene.
 - Future – potential inclusion of more petroleum-related contaminants, such as TPH etc.

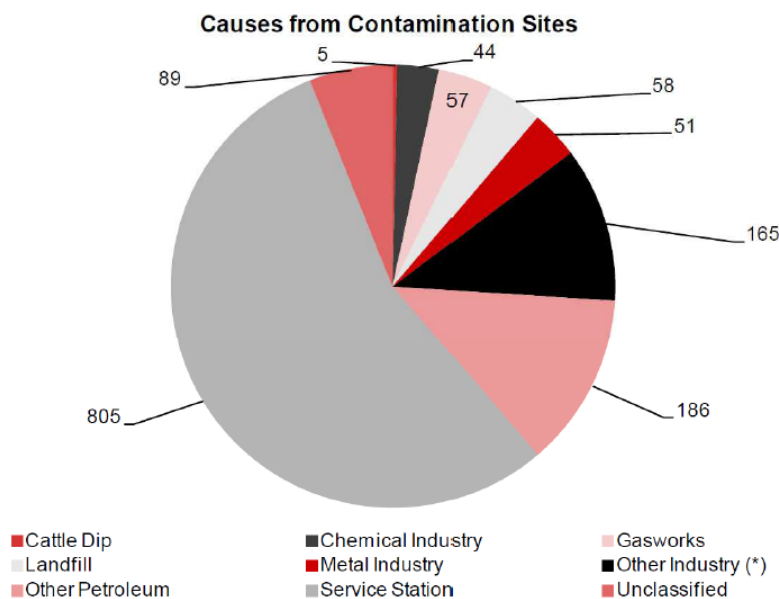
At the end of 2001, Japanese petroleum companies voluntarily terminated the usage of MTBE as an additive of gasoline, due to its potential in contaminating groundwater. In February-March 2001, the Japan Environmental Protection Agency (EPA) carried out a national MTBE monitoring by performing groundwater monitoring on 196 wells in the vicinity of gasoline stations. They found that 36 out of the 196 wells (18%) were detected with MTBE concentrations ranging from 0.01 – 1.5µg/L, far lower than the U.S. drinking water standards of 20 - 40µg/L. Based on the above investigation, the Japanese EPA reported that there was no issue related to the usage of MTBE.

AUSTRALIA'S EXPERIENCE

New South Wales (NSW)

Currently, the NSW EPA adopts an Underground Petroleum Storage System (UPSS) Regulation in view of contamination sites mostly coming from service stations, petroleum and chemical industries (see figure below). Implemented since 2011, the regulation is based on AS 4897-2008 which includes system design and installation, operational management and system backup.

Causes from Contamination Sites



Source: OEH's website. Details contaminated sites known by EPA at 13 August 2012 with regard to its regulatory role under the CLM Act.

* includes former tannery, mines, explosives, timber treatment, waste oil sites, railway workshops and many other government agencies.

Source: Auditor-General's Report, NSW EPA, 2012

Generally, the EPA's requirements are as follows:

- Environmental Protection Plan (EPP) – up to date and accessible
- Loss monitoring (LM) procedures (capable of detecting 0.76L/hr with at least 95% accuracy)
- Recordkeeping – SIRA (Statistical Inventory Reconciliation Analysis) records for indications of leaks, procedures for loss detection/investigation
- Groundwater monitoring wells installed and tested

Subsequently, an inspection program was carried out in the surrounding districts of Sydney including Ashfield, Canada Bay, Leichhardt, Marrickville and Wyong. In addition to the EPA requirements, additional requirements at the council-level in these districts include:

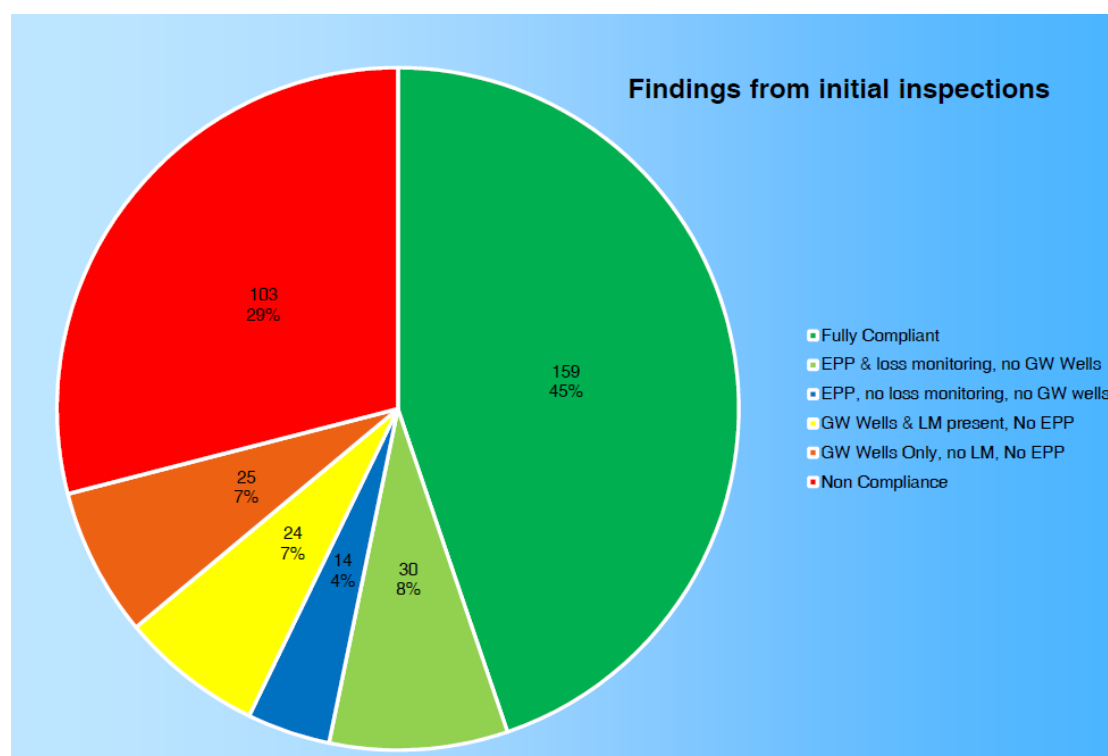
- Drainage – knowledge, design and maintenance
- Forecourt design, oil water separator use and maintenance, isolated diesel bowsters
- Spill response – spill kit, training and maintenance
- Materials management – storage of chemicals, MSDS

- Waste management – appropriate disposal, waste tracking receipts, recycling facilities
- Trade waste agreements.

In general for NSW, about 45% of inspected sites were fully compliant but 29% were not (see first figure below). Among the sites inspected, 46% of inspected sites in the metro area were fully compliant but 26% were not, while 41% of inspected sites in the non-metro area were fully compliant but 38% were not. This revealed the following observations:

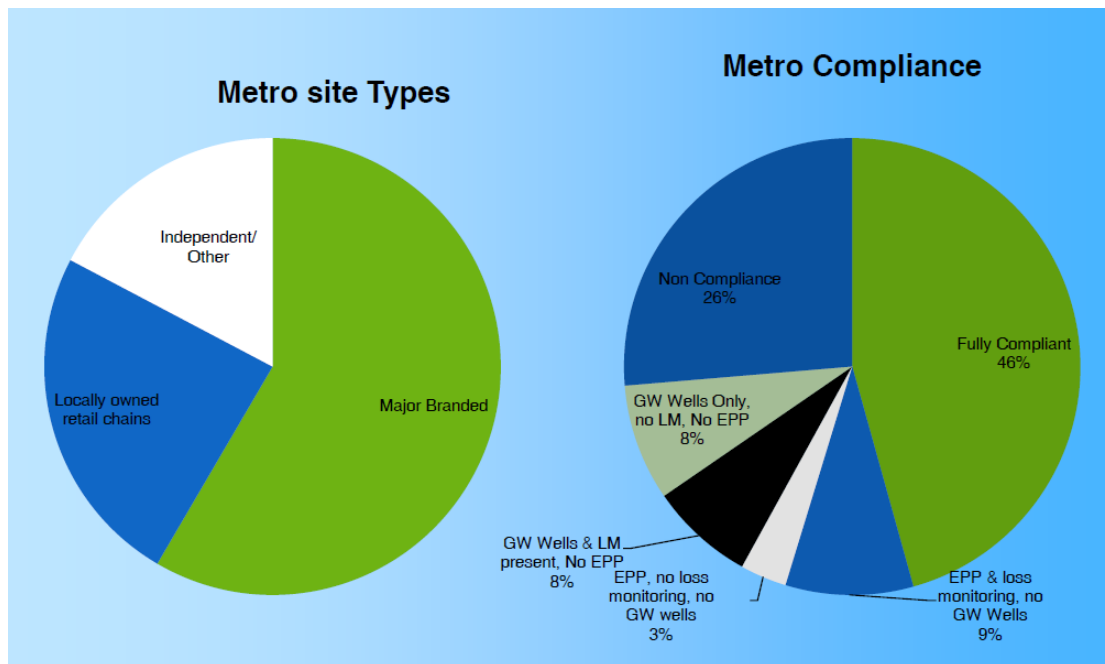
- EPP not used for daily operation
- Person responsible not easily identified
- Groundwater well information absent
- Some definitions are not clear, such as significant modification
- Groundwater monitoring well installation not possible
- Loss monitoring difficult at low-turnover sites
- Fuel leaks not considered in incident management plans
- Non-compliant sites generally operated under lease by sole traders:
 - Responsibility shared between owner, leaseholder, and commission agent
 - Landholders have a minimal understanding of the daily operations carried out by leaseholders
 - Operators show less awareness of the regulations governing fuel management and handling

Findings from Initial Inspections



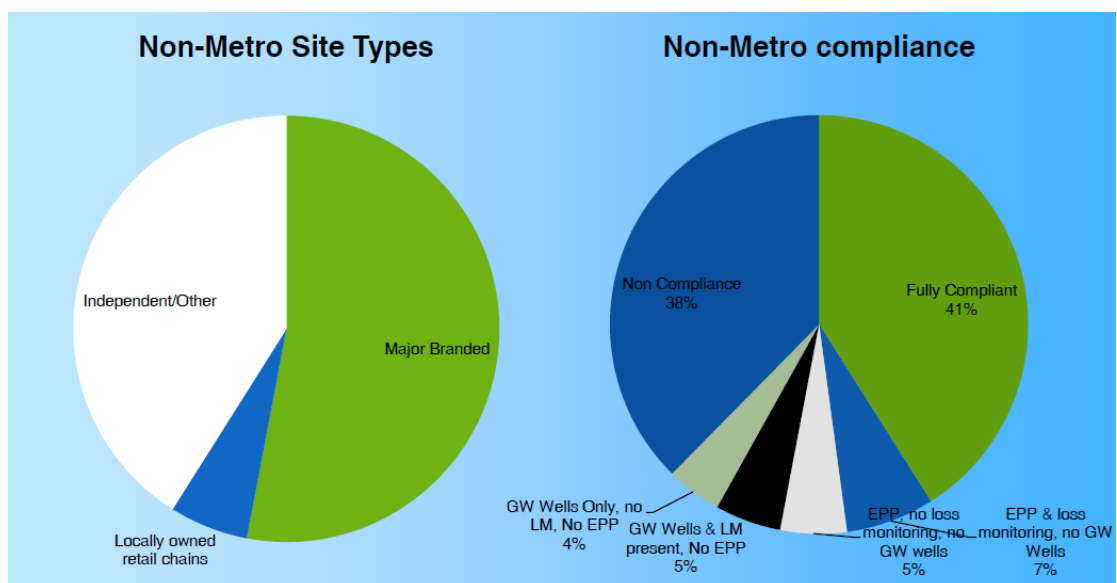
Source: NSW EPA, September 2014

Metro Compliance Trends



Source: NSW EPA, September 2014

Non-Metro Compliance Trends



Source: NSW EPA, September 2014

As a result in June 2014, the NSW EPA drafted legislation on the “Protection of the Environment Operations (Underground Petroleum Storage Systems) Regulation 2014”, which was gazetted and enforced starting Sept. 1, 2014. The amendments include:

- Include new definitions such as leak;
- Clarify the meaning of existing definitions, including petroleum, routine maintenance, significant modification and storage site

- Clarify certain reporting requirements – validation and EIT
- Enable the EPP to be kept electronically and as either a consolidated document or a collection of documents
- Enable the use of alternative secondary leak detection systems
- Provide a greater flexibility in the developing of loss monitoring procedures

In view of the above, NSW EPA demonstrated a proactive approach in maintaining its underground petroleum storage systems, thus showing a potential readiness to use MTBE.

Other Notable Efforts

Based in Callaghan, NSW, CRC CARE is an independent organization that performs research, develops technologies and provides policy guidance for assessing, cleaning up and preventing contamination of soil, water and air. Their research is divided into four complementary programs:

- Best practice policy: More effective, efficient and certain national policy for assessing and remediating contamination
- Better measurement: More accurate, rapid, reliable and cost-effective measurement and assessment
- Minimizing uncertainty in risk assessment: New technology, methods and knowledge for assessing risks to human health and the environment
- Cleaning up: Innovative clean-up technologies and a wider range of effective management options

In particular, MTBE is currently one of CRC CARE's priority research areas and CRC CARE is currently seeking proposals from April 2015 through February 2016 for the management of MTBE through the development of:

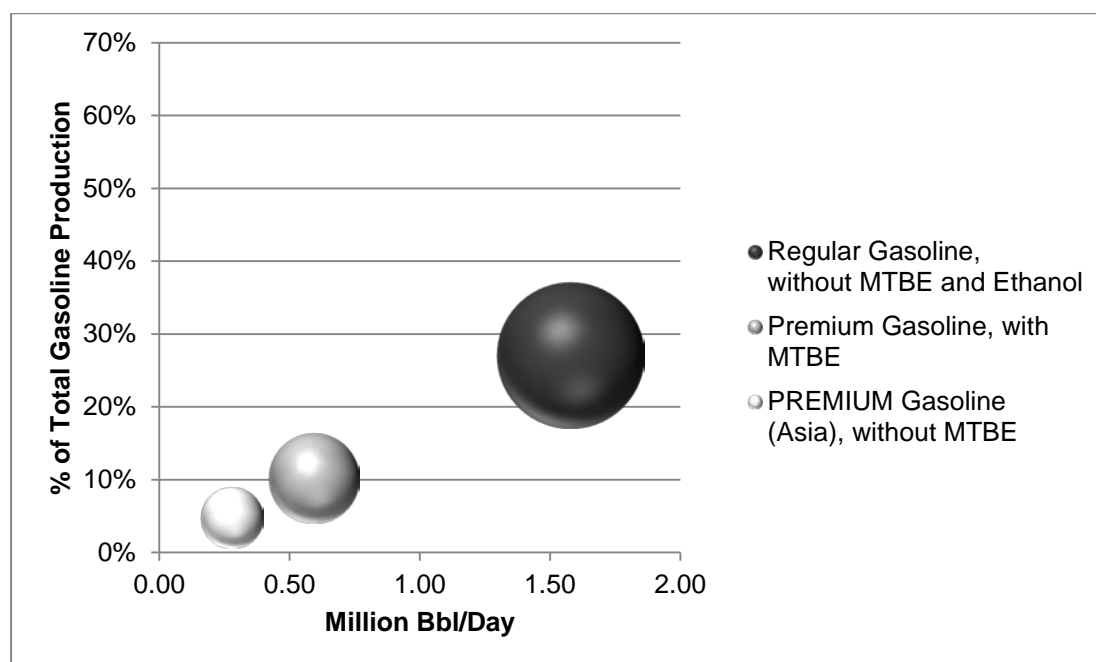
- Odor-based screening criteria for groundwater,
- Ecological screening criteria for groundwater, and
- Risk-based remediation and management guidance.

MTBE AND ITS BENEFITS TO AUSTRALIA

SUPPLY SECURITY IMPACT OF “BOUTIQUE” FUEL

The plot below displays the gasoline split with different blendstocks Asia produces right now. The assessment here will help understand the supply security and impact of going without MTBE in gasoline pool.

Asia Gasoline Production Based on Blending Component

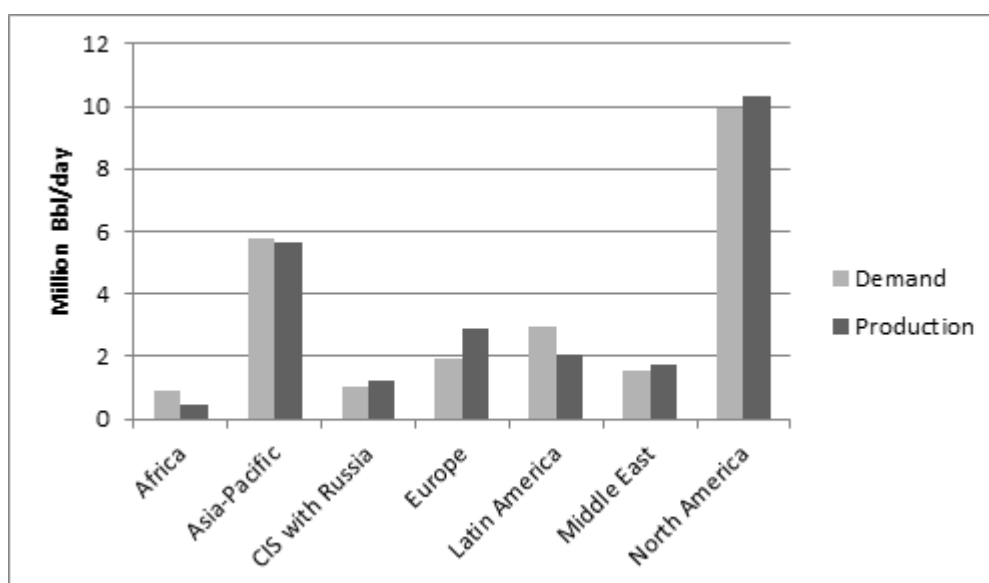


Source: Stratas Advisors, 2015

Asia's total production of gasoline is estimated to be 5.82 million b/d in 2015. Australia needs to import 95,000 b/d of gasoline without MTBE. The gasoline pool for import purposes without MTBE blendstock added to gasoline available to Australia is only 1.86 million b/d. Australia cannot import from rest of the gasoline pool in Asia which is close to 70% as it contains MTBE. Supply for the country will thus become constrained and prices potentially increasing, as fuel distributors and blenders look for limited supplies available within the Asian region or likely more costly supplies from other regions around the world, such as Europe or North America.

The chart below displays the gasoline demand and production for each region. With gasoline demand growing in most regions, there are fewer supply options available – especially those that would also meet the MTBE limit in Australia's current gasoline specifications.

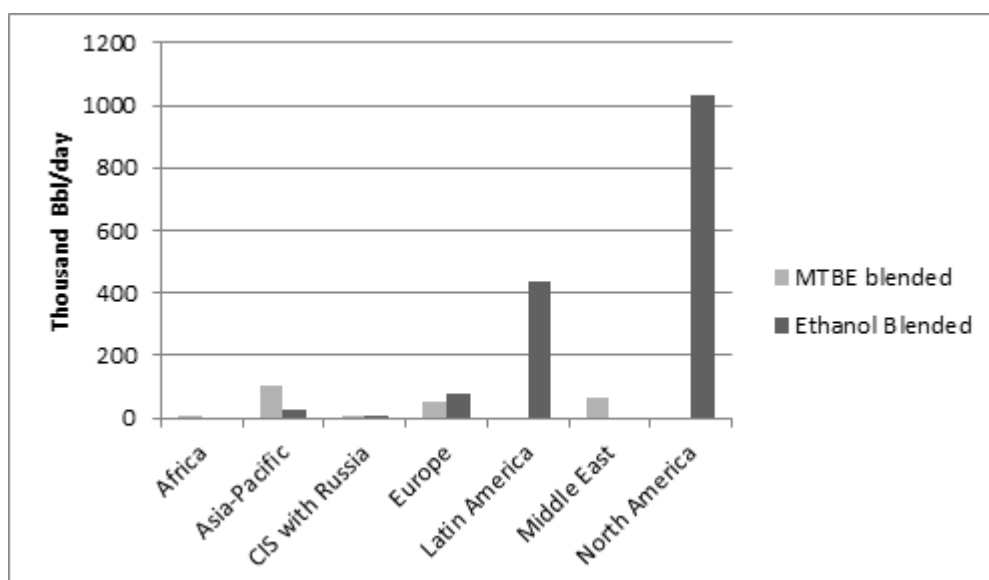
Global Gasoline Production and Demand



Source: Stratas Advisors, 2015

The chart below displays the MTBE and ethanol being added to the gasoline pool in each region. Gasoline in several regions including Asia Pacific, Europe and the Middle East are blending MTBE in the gasoline pool for both domestic consumption and export. Ethanol is blended into gasoline primarily in North America, and to a much lesser extent, Latin America, Europe and Asia Pacific.

Regional MTBE and Ethanol Volumes Blended with Gasoline



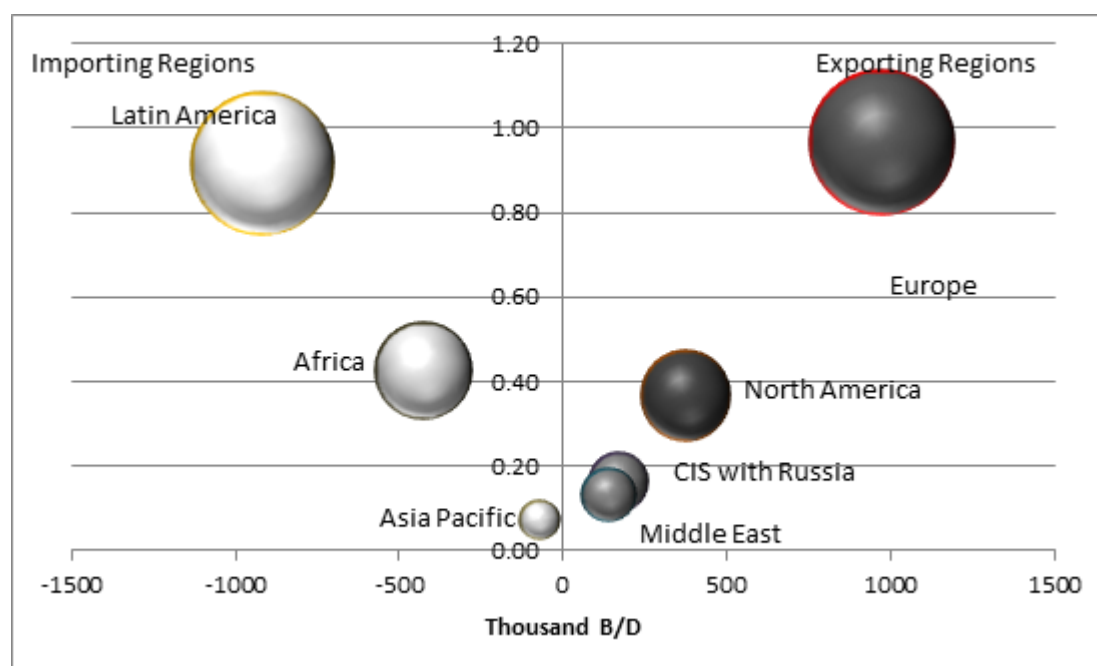
Source: Stratas Advisors, 2015

North America does not blend MTBE with gasoline for reasons described in other parts of this paper. Other regions use both MTBE and ethanol for gasoline blendstock. Outside the Asia-Pacific region, Australia's major source of gasoline imports that do not contain MTBE can be

from Europe and North America. However, North America's refineries are running at maximum capacity to meet demand from Latin America; the region also has reduced dependence on gasoline coming from Europe. In this scenario, Europe is better positioned to supply gasoline to Australia as it is looking for markets after reduced export opportunities to North America's gasoline market.

From the global perspective, Europe has capability to export gasoline, which had been going to Latin America and North America. Europe is in a better position than other regions to supply gasoline to Australia as the figure below shows.

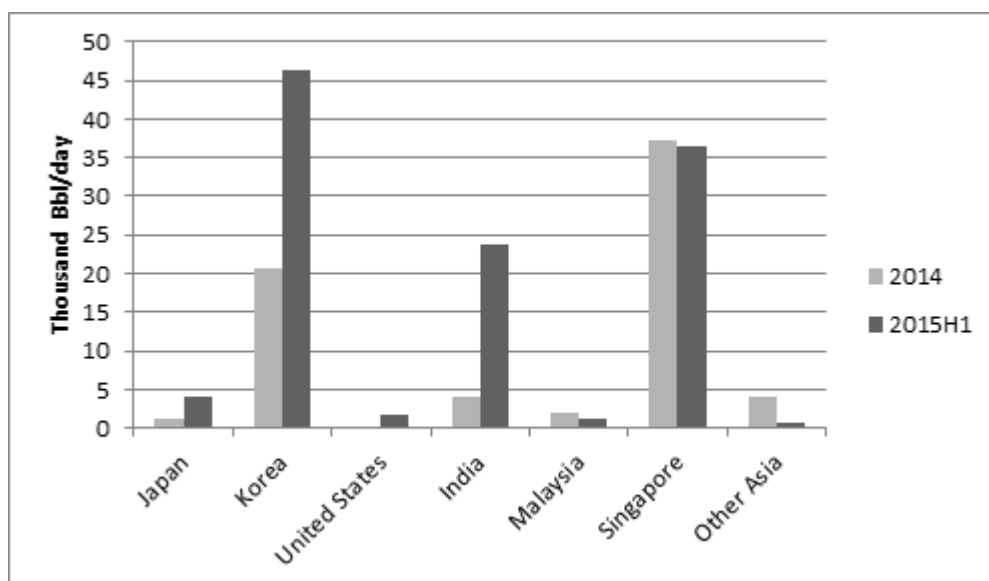
Gasoline Import and Export by Region



Source: Stratas Advisors, 2015

From the Asia Pacific region, the countries displayed below have been exporting gasoline to Australia. South Korea, Singapore and India had been the major sources of gasoline to Australia in the first half of 2015.

Regional Gasoline Exporting Countries to Australia



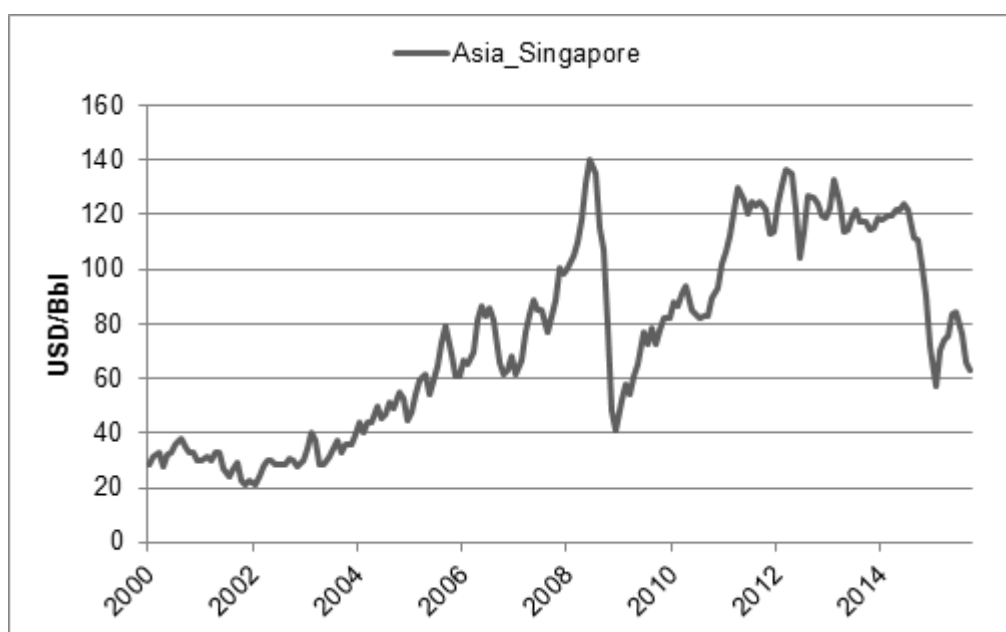
Source: Stratass Advisors citing the “Australian Petroleum Statistics”, Department of Industry and Science, July 2015

PREMIUM PRICE OF IMPORTED GASOLINE WITHOUT MTBE

With a limitation on blending MTBE, Australia will have to find alternative gasoline supplies, and as the analysis above shows, the options will be limited.

The premium price of imported gasoline is displayed in the figure below. Premium gasoline is priced US\$5-6/Bbl cheaper to the MTBE price. Blending 1% of MTBE with premium gasoline adds about \$0.05/Bbl to premium gasoline price. The current price differential between Australia imported gasoline and Singapore price is \$3.0 /Bbl. This will add to overall gasoline cost imported to Australia.

Premium Price of Imported Gasoline



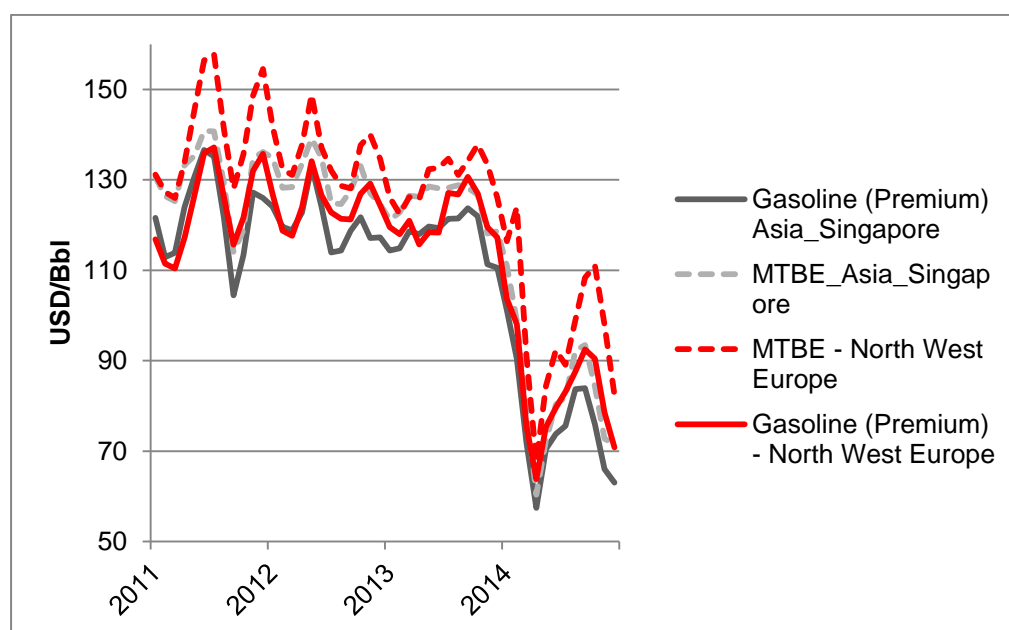
Source: Bloomberg, 2015

The gap between ethanol and MTBE prices has decreased in Asia recently. Based on the issues related with addition mixing cost (mixing at retail or outside refinery) and less energy content, the overall cost of gasoline will increase by 22.5 cents/Bbl to blend MTBE into gasoline. Replacing MTBE with ethanol will reduce the energy content by 0.15% of current blended MTBE gasoline in Asia, but less than that with ethanol blended into gasoline.

Replacing MTBE with isomerate will increase the energy content of gasoline by 0.23%. However, for additional isomerate and alkylate, Australia needs to depend on European imports which would increase the price of gasoline by \$2.22 b/d as Asia is currently short on light oil processing capability such as isomerization and alkylation.

On the other hand, producing both MTBE (US\$8-9/Bbl) and gasoline (US\$4-5/Bbl) in Asia are cheaper as compared to Europe (see figure below). This means that importing gasoline from Europe will be more expensive for Australia.

Prices of MTBE and Gasoline in Asia vs. Europe



Source: Bloomberg, 2015

Price Assessment, Ethanol vs. MTBE in Gasoline

Australia's current gasoline imports are compared against proposed gasoline import with different blendstocks, shown in the table below. The ethanol price has recently increased as compared to the MTBE price. However, traditionally ethanol had been cheaper by US\$15-16/Bbl. This will impact the current assessment, when blending with ethanol can be cheaper. Considering energy content, blending costs at retail and evaporation loss of ethanol, it is currently more expensive to blend ethanol in gasoline than MTBE, which applies to Australia.

Price Assessment of Ethanol and MTBE in Gasoline

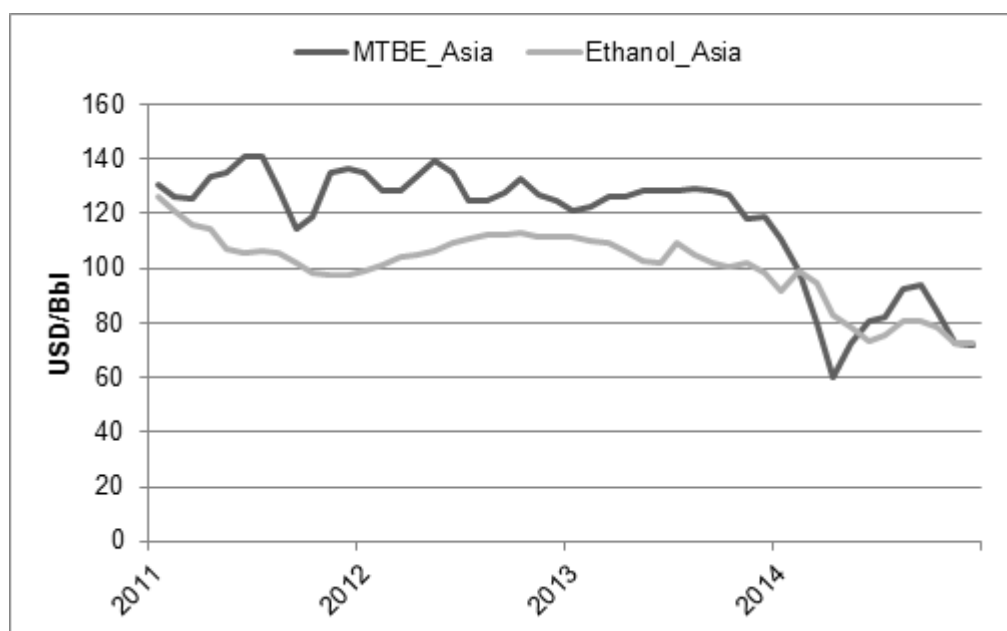
	Current	Proposed
Australia's Gasoline Import	Vol%	Vol%
MTBE	1.0%	0.0%
Naphtha	53.6%	53.6%
Isomerate (C5+)	2.1%	2.1%
Reformate and Raffinate	32.6%	32.6%
Others (Cracked)	3.0%	4.9%
N-Butane	1.8%	0.0%
H2SO4 Alkylate	4.8%	4.8%
Ethanol	1.0%	2.0%
Product Qualities		
Oxygen, wt%	0.84	0.70
RVP, psi	9	9

Energy Loss / BBL	0.00%	-0.15%
Cost increase in per BBL, USD/BBL		0.225
Energy, Kcal/Bbl	81374	81252

Source: Stratas Advisors, 2015

The chart below shows the MTBE price vs. ethanol price, where ethanol has maintained a price advantage of US\$15-16/Bbl. However, recently falling oil and gas prices have reduced the price advantage toward ethanol.

Price of MTBE and Ethanol in Asia



Source: Bloomberg, 2015

Price Assessment, Isomerate vs. MTBE

Replacing isomerate with MTBE will make the gasoline costlier by US\$2.218/Bbl. Isomerization needs high investment cost, operating cost (needs H₂ and catalyst). Since Asia has high demand of naphtha as well as petrochemical feedstock (naphtha is feedstock for isomerization unit), Australia has to look outside Asia Pacific region for isomerate.

Price Assessment of Isomerate and MTBE

	Current	Proposed
Australia's Regular Gasoline Import	Vol%	Vol%
MTBE	1.0%	0.0%
Naphtha	53.6%	46.7%
Isomerate (C5+)	2.1%	14.5%
Reformate and Raffinate	32.6%	30.2%
Others (Cracked)	3.0%	1.4%
N-Butane	1.8%	1.5%

H2SO4 Alkylate	4.8%	4.8%
Ethanol	1.0%	1.0%
Product Qualities		
Oxygen, wt%	0.84	0.35
RVP, psi	9	9
Energy gain / BBL	0.00%	0.23%
Cost increase in per BBL, USD/BBL		2.218
Energy, Kcal/Bbl	81374	81560

Source: Stratas Advisors, 2015

Energy Content Assessment

The energy content of MTBE is 80% of conventional gasoline, while the energy content of ethanol is 65% of conventional gasoline. To calculate energy content, the values used for heat of combustion are displayed in the table below.

Comparison of Energy Content between MTBE, Ethanol and Gasoline

Heat of Combustion	MTBE	EtOH	Gasoline
kcal/L	6,229	5,063	7,795
% of Energy content as compared to Gasoline	80%	65%	100%

Source: Stratas Advisors, 2015

MTBE BENEFITS TO AUSTRALIA'S FUEL QUALITY IMPROVEMENT

Based on the above analysis and Stratas Advisors' report⁶⁶ to New Zealand's Ministry of Business, Innovation and Employment, it is likely that the majority of gasoline imports to Australia will continue to come from Asia, even though Australia is starting to see some imports coming from Europe and the U.S. over 2014-2015. This is primarily because of advantages in the pricing and supply availability of gasoline in Asia over Europe. However if Australia continues to restrict the use of MTBE in gasoline, more expensive gasoline is likely to be imported from Europe since Asia is currently short on light oil processing capability such as isomerization and alkylation, as mentioned in the above analysis.

Similarly to Australia, the majority of the countries in the Asia Pacific region adopt fuel specifications similar to those implemented in the EU, although their respective timetables vary considerably. Asian countries use a variety of blending components to help replace or enhance octane levels in their gasoline pools, including MTBE, ETBE, MMT and alcohols. MTBE is widely produced, imported and blended into the Asian gasoline marketplace. Australia's current top three gasoline importing countries include India, Singapore and South

⁶⁶ Stratas Advisors, "[Information on Asia-Pacific Fuel Quality Standards and their Implications for New Zealand](#)", February 2015

Korea. Even though India does not actively use MTBE in its gasoline, up to 15 vol% MTBE (and 2.7 wt% oxygen) is allowed in its gasoline specifications, while South Korea sets current oxygen content limit based on season (0.5 wt% in summer and 1 wt% during winter). Singapore currently does not set a limit on oxygen or ethers in its gasoline specifications but plans to set limits for oxygen and ethers at 3.7 wt% and 22 vol% respectively by 2017 (see table below), similar to the existing EN 228:2012 specifications.

In the region, only the Philippines sets a 2 vol% maximum limit on ethers because of ethanol blending (E10) requirements in its Biofuels Act. Thailand does not have an ethanol mandate but has seen 75% of its gasoline pool contain E10 in the first quarter of 2014. Its conventional gasoline grade (RON 95) continues to allow the use of oxygenates of 5.5 vol% min – 11 vol% max, while separate specifications for its E10 grade do not restrict the use of other oxygenates like MTBE.

With the exception of the Philippines, Asian countries do not restrict the use of MTBE in their gasoline specifications because of its major benefits in octane enhancement, reduction of sulfur and aromatics, as well as gasoline pool extension. Looking at the existing gasoline importing countries to Australia, the table below also shows that given a sulfur reduction to 10 ppm and below and additional reductions in aromatics for some of the countries, none of them restrict the use of MTBE, or ethers in general.

Expected Changes in Gasoline Specifications for Gasoline Importing Countries to Australia

Country/ Region	Sulfur Reduction, ppm, max	Year of Implementation	Changes in Specifications for Aromatics and Oxygenates	Usage of MTBE
China	50 -> 10	January 2017	None, but for manganese from 8 mg/l to 2 mg/l	Yes
India	50 -> 10	April 2020	Not expected	Yes
EU	50 -> 10	January 2009	Oxygen ⁽¹⁾ : 2.7 wt% -> 3.7 wt% max Ethers: 15 vol% -> 22 vol% max	Yes
Japan	50 -> 10	January 2008	None, but currently uses ETBE	No
Singapore	50 -> 10	January 2017	Proposed new limits for aromatics at 42 vol% max, oxygen at 3.7 wt% max and ethers at 22 vol% max	Yes
South Korea	50 -> 10	January 2009	None, only for aromatics: 30 vol% -> 24 vol% max	Yes
Taiwan	50 -> 10	January 2012	None, only for aromatics: 36 vol% -> 35 vol% max	Yes
U.S.	30 ⁽²⁾ -> 10 ⁽²⁾	January 2017	Not expected	No ⁽³⁾

Note:

(1) Changes to other oxygenates include ethanol, iso-butyl alcohol, iso-propyl alcohol, tert-butyl alcohol and other mono-alcohols.

(2) Annual average limit.

(3) The U.S. produces and exports MTBE.

Source: Stratas Advisors, 2015

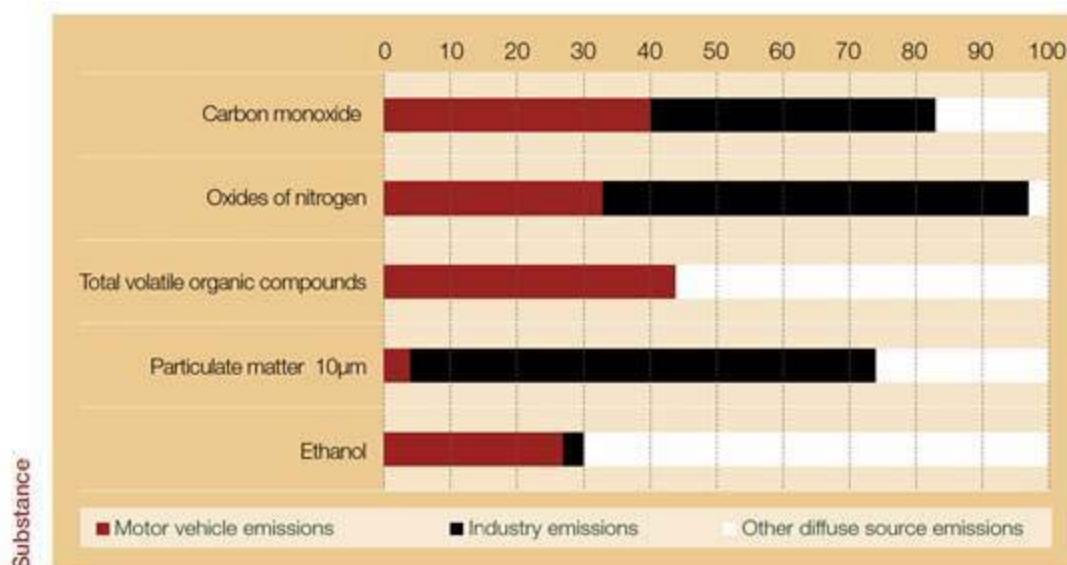
MTBE BENEFITS TO AUSTRALIA'S AIR QUALITY

As discussed in the section on “MTBE and Air Quality” in this whitepaper, the oxygen content of MTBE allows petroleum companies to produce cleaner-burning gasoline to reduce vehicle emissions leading to the creation of urban smog (ozone, particularly NO_x and VOCs) and to PM in the atmosphere. Blending MTBE, with its high RON value, also replaces aromatic compounds in gasoline, which largely contribute to toxic emissions from vehicles. MTBE's presence in gasoline reduces exhaust emissions of toxic substances and other pollutants, thus lowering potential cancer risks and respiratory effects for people exposed to vehicle emissions.

Studies in the EU found that an indirect effect of MTBE usage would most likely be ozone forming; however, MTBE is not expected to significantly contribute to ozone forming compared with other more reactive compounds in gasoline. In fact, MTBE is added as an oxygenate to reduce the ozone-forming potential of gasoline. In comparison to the alcohols they are made from, ethers reduce the overall vapor pressure of gasoline and the related evaporative emissions to air which causes ozone.

Looking at the figure below showing VOCs, CO and NO_x as Australia's major air pollutants from vehicle emissions, MTBE usage is likely to benefit Australia in further reducing their levels. However, this will require further assessment since Stratas Advisors was unable to obtain the latest official information on Australia's air quality.

Australia's Contribution of Top Five Substances to Air by Source, in % (Year 2006-07)



Source: National Pollutant Inventory, Australian Department of Environment, 2014

OUTSTANDING ISSUES

LEGACY POLLUTION ISSUES

From the experiences of various countries and the research materials available on MTBE, it is clear that MTBE has been well-researched with respect to its usage as an octane enhancer. As laid out in the case studies of this whitepaper, an outstanding issue remains with groundwater contamination, most often a result of LUSTs. However, not all UST operators have retrofitted or switched to new USTs to improve their leakage prevention and monitoring features. Therefore, this will continue to present a risk for groundwater contamination. On a bigger picture, leaking USTs will also present groundwater and soil contamination issues, albeit in terms of other contaminants depending on the quality of gasoline used.

RURAL GASOLINE STORAGE

According to Stratas Advisors' local sources in Australia and as highlighted in the NSW's experience, storage tanks in rural areas tend to be older and non-compliant to regulations than those in urban areas. This continues to be an outstanding issue.

According to the Australian Institute of Petroleum's (AIP) GL12-2003 "Guidelines for Safe Above Ground Fuel Storage on Farms and Industrial Sites"⁶⁷, as the name suggests, ASTs are typically used in rural areas of Australia for gasoline storage. These are overhead storage tanks with capacities not exceeding 10,000 liters raised above ground level on support structures such as metal legs, situated on premises other than those belonging to the fuel supplier. The tanks are typically made of commercial grade low carbon steel construction designed to hold conventional gasoline according to the Australian Standard AS 1692 – Tanks for Flammable and Combustible Liquids. Under respective state legislations in Australia, both the owner and fuel supplier are obliged to ensure their tanks' structural integrity and safety, and breaches may result in heavy penalties.

Comparing Storage of Gasoline Containing Ethanol vs. MTBE

According to the corrosion lab tests⁶⁸ carried out by the National Institute of Standards and Technology's (NIST), ethanol and acetic acid vapors from gasoline blended with ethanol were found to have a corrosive impact on steel alloy surfaces. Acetic acid is produced from ethanol in the presence of bacteria *Acetobacter aceti*. While NIST's study focused mainly on USTs, ASTs could be more vulnerable to corrosion since they are exposed to weather conditions. Compared to gasoline blended with MTBE, ethanol blended gasoline could potentially present higher risk of corrosion in these ASTs.

In addition, because ASTs are usually located in unobstructed areas, they are often exposed to heat from the sun to a greater extent compared to USTs. This means that evaporative emissions of ASTs could potentially be higher compared to USTs. Filling up ASTs with ethanol blended gasoline instead of conventional gasoline or gasoline blended with MTBE, as

⁶⁷ Australian Institute of Petroleum' (AIP), [GL12-2003 "Guidelines for Safe Above Ground Fuel Storage on Farms and Industrial Sites"](#), January 2003

⁶⁸ National Institute of Standards and Technology (NIST), ["NIST Corrosion Lab Tests Suggest Need for Underground Gas Tank Retrofits"](#), July 29, 2014

previously mentioned studies have suggested, could lead to high evaporative emission rates of benzene which forms an azeotrope with ethanol.

Another potential issue with rural gasoline storage is that there could be little supervision on the condition of the ASTs, leading to higher possibilities of considerable vapor and fuel leakages. With little supervision and possibly maintenance performed on these tanks, they could be more vulnerable to ethanol blended gasoline than MTBE blended gasoline. Therefore, filling them up with ethanol blended gasoline could accelerate internal corrosion more quickly than filling them up with gasoline blended with MTBE.

Hence, regardless of storage tanks containing gasoline blended with or without MTBE, or other oxygenates, the above demonstrates that it is important to align USTs and ASTs with international standards in any case.

RECOMMENDATIONS

MTBE's unique properties of high octane rating, low boiling temperature and moderate vapor pressure make it a versatile gasoline-blending component to help refiners and fuel blenders meet quality requirements and expand production. MTBE allows petroleum refiners to adjust fuel production and product qualities to meet changing markets and achieve environmental specifications. These unique blending properties coupled with MTBE's oxygen content allow refiners to make cleaner-burning RFG to help reduce vehicle emissions that are precursors to ground-level ozone and PM pollution. MTBE blending can replace aromatic compounds in gasoline, which largely contribute to air toxics emissions from vehicles. Global auto manufacturers have preferred MTBE (and similar ethers) as an optimal blending component for gasoline.

The following are principal findings from Stratas Advisors' review of available assessments, technical reports and scientific resources:

- MTBE is one of the most tested and evaluated components in gasoline and in commerce today (first tests were conducted as early as 1969). The results from these testing programs throughout the 1980s, 1990s and early 2000s were either published in scientific literature or the final reports submitted to government agencies and made publicly available. Assessments carried out by recognized authoritative bodies collectively demonstrate that blending MTBE into gasoline does not pose increased risks to human health.
- At the national level in the U.S., MTBE has not been banned or otherwise restricted for use in gasoline at the levels allowed for oxygenates. Under the EPA's "substantially similar" waiver rule, MTBE can still be blended at levels up to 15 vol% for the U.S. marketplace, except for those individual states that have enacted restrictions on its use.
- Based on the long-term experience of other major gasoline markets (e.g., Europe, Asia and the U.S.) that have used oxygenated gasoline for more than three decades, adding MTBE (or other aliphatic ethers) in any ratio up to a total oxygen content of 2.7 wt% results in fully fungible gasoline. MTBE can be commingled (in any ratio up to 15 vol% MTBE) with non-oxygenated gasoline or domestically produced MTBE-gasoline blends in the product distribution system, the fuel storage tanks at refueling stations and fuel tanks of vehicles without loss of performance quality and without environmental degradation or hazard concerns.
- The WHO report referenced in this paper concluded that the vast majority of MTBE detections in water samples in the U.S., Canada and Europe have been at or below 2 ppb. The WHO recommended a guideline for treating MTBE concentrations exceeding 15 ppb – the lowest level eliciting a response in a study of taste- and odor-sensitive participants. This level is generally considered to be well below that which would pose any environmental or human health concern.
- MTBE-gasoline blends can be intermixed, stored and shipped with conventional gasoline in barges, oceangoing tankers, pipelines, rail tank cars and tank trucks without restrictions or loss of product quality (i.e., specifications). Furthermore, the properties for commingled gasoline, including MTBE blends, will meet quality specifications and existing safety and hazard controls as a final mixture provided the properties of the original gasoline prior to commingling met requirements for quality specifications, safety and hazard controls.

- Europe began commercial production and blending of MTBE in 1973. The EU's FQD and amendments (along with European gasoline standard EN 228:2012) establish the parameters for MTBE blends. The highest blending volume allowed for MTBE in the EU is up to 22 vol%. Because of the RED, many producers have transitioned to ETBE; however, MTBE is still widely used.
- MTBE is widely produced, imported and blended in the Asia Pacific region to help replace or enhance octane levels in those countries' gasoline pools. In China, MTBE represents about 6.4% of the total gasoline pool. The oxygen content limit in the region varies and fuel quality specifications are being implemented along various time lines.
- As lead phase-out took place, refineries in the GCC countries found MTBE to be the most compatible and available product to serve as an octane replacement. Except for Bahrain, GCC countries use MTBE in their gasoline at levels ranging from 10 vol% to 15 vol%. However, it is worthwhile to note that Bahrain received conditional approval in 2014 by the government to allow the use of MTBE.
- Vehicle research has been conducted for both exhaust and evaporative emissions with gasoline blends containing up to a nominal 20 vol% MTBE. Based on these studies conducted over the past 30 years, vehicles operating on fuels containing up to a nominal 20 vol% MTBE (~3.7 wt% oxygen) will have lower exhaust emissions and also should not experience any degradation in performance as compared to gasoline containing no oxygenates.
- The EPA's drinking water advisory on MTBE recommends a protective level of 20 µg/L to 40 µg/L for taste and odor.
- EPA regulations establishing programs to upgrade and monitor fuel and gasoline USTs were finalized in 1988 with a 10-year phase-in period. The UST standards include provisions to prevent gasoline releases:
 - Leak detection systems;
 - Spill/overfill protection;
 - Corrosion protection requirements; and
 - Monitoring and record-keeping.
- EPA public drinking water sampling data for MTBE collected from 2000 to 2005 found it was detected above 5 ppb (the minimum reporting level for the study) in only 26 samples – or less than 0.1% – and above 20 ppb (the minimum threshold for taste or odor issues) in only five samples – or less than 0.015%. In many cases where MTBE was found, gasoline USTs had not been upgraded as the regulations required, or there were installation and filling mistakes and/or equipment failures.
- In the U.S., inadequate compliance and enforcement activities at the state level was cited as the No. 1 problem that led to issues with gasoline containing MTBE in groundwater supplies. According to EPA, 85.5% of the active USTs are in significant operational compliance with the spill, overfill and corrosion protection requirements, and 78.9% of USTs are in significant operational compliance with the leak detection requirements. Approximately 71% of USTs are in significant operational compliance with both sets of requirements.
- There is a large array of well-proven remediation technologies for treating soil and groundwater contaminated by conventional gasoline. In general, these methods are applicable to gasoline containing MTBE, and remediating gasoline containing MTBE is not necessarily more expensive compared to gasoline that does not contain MTBE. The critical determining factor for cost depends largely on how long the release has gone undetected. MTBE can be effectively remediated from soil by vapor extraction or low-temperature thermal desorption. When groundwater is impacted, MTBE

remediation methods include pump-and-treat, air stripping, air sparging and enhanced bioremediation.

- Best practices are well established for prevention and emergency response; spill and leak procedures; storage and unloading stations; transfer operations and marine transport. These best practices are generally applicable to gasoline as well as to MTBE. MTBE producers have done a great deal over the years to develop, implement and externally promote best practices. As a result, spills, fires and other sorts of safety and environmental emergencies have been kept to a minimum.

Recommendations to Optimize Benefits for Australia via MTBE and Balancing Against Measures to Protect Water Quality

Based on Stratas Advisors' review, assessment and findings, ACFA recommends MTBE use in Australia as follows:

Impacts of Limiting MTBE Usage

- Based on the established safety from its long history of use, and recognizing the assessments carried out by respected authoritative bodies demonstrating MTBE use does not pose increased risks to human health, MTBE can be imported, stored and blended into gasoline.
- We advise that limiting MTBE could potentially encourage fuel blenders/traders to blend gasoline with illegal or unauthorized chemicals.

Storage and Blending Management

- We recommend that Australia reviews its operations for handling, transport, storage, blending and delivery of gasoline to ensure best practices are employed that are readily applicable to all gasoline, including MTBE-containing gasoline.
- We recommend that Australia develops educational information about the safety, benefits and cost-effectiveness of MTBE and MTBE-blended gasoline for its customers and workers and for motorists/consumers.
- We recommend that Australia reviews its prevention control and emergency response plans for all gasoline, MTBE and MTBE-blended gasoline to assure up-to-date practices and preparations are established.
- We recommend that Australia examines its contingency plans for gasoline storage, transfer, delivery and sales to determine if specific adjustments are necessary for all gasoline and MTBE-blended product.
- In the event that the use of MTBE is approved in Australia, we recommend implementation of annual inspections and monitoring procedures for storage facilities and service stations to ensure worker safety, public health and environmental protections. These additional inspections should be conducted for the first five years of implementation of MTBE-blended gasoline.
- We recommend that reporting procedures for terminals and service stations be reviewed to ensure that emergency response procedures are fully established prior to any blending of MTBE.
- We recommend that as part of product delivery agreements non-company operator-owned service stations demonstrate annual inspections of their facilities by qualified third party to attest to compliance with best practices.

- We recommend that implementation of MTBE use and blending include educational advisory to vehicle dealers and rental agencies about changes in fuel composition and quality improvements.

In view of the above, we suggest a country-wide allowance of MTBE use of up to 15 vol%.

Should a more cautious approach be needed, to use a phased-in approach:

- First phase of 7 vol% MTBE; and
- Second phase of 15 vol% MTBE.

Alternatively, we suggest the following three stages if an even a more vigilant approach is preferred:

- First phase of 5 vol% MTBE;
- Second phase of 10 vol% MTBE; and
- Third phase of 15 vol% MTBE.

In addition, individual states may set lower limits based on their own concerns. Note that the above recommendations have been made based on the NSW EPA's proactive approach in maintaining its underground petroleum storage systems and their potential readiness to use MTBE.

With Australian-based CRC CARE taking the lead on setting odor-based and ecological screening criteria for groundwater, and risk-based remediation and management guidance, it is expected for Australia to be able to safely use MTBE rather than limiting its use. Last but not least, we recommend for Australia to use a science-based system to address groundwater issues like what the EU and Japan have done, and avoid stagnating in its role to protect the environment.



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