A Model Regulatory Program For Reducing Exhaust and Evaporative Emissions From Heavy-Duty Vehicles and Engines

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

The goal of the International Council on Clean Transportation (ICCT) is to dramatically reduce conventional pollution and greenhouse gas emissions from personal, public, and goods transportation in order to improve air quality and human health, and mitigate climate change. The Council is made up of leading government officials and experts from around the world that participate as individuals based on their experience with air quality and transportation issues. The ICCT promotes best practices and comprehensive solutions to improve vehicle emissions and efficiency, increase fuel quality and sustainability of alternative fuels, reduce pollution from the in-use fleet, and curtail emissions from international goods movement.

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This report is dedicated to the memory of Kong Ha, Senior Officer of the Hong Kong Environmental Protection Department, former Chairperson of the Clean Air Initiative for Asian Cities (CAI-Asia), and an ICCT participant. In addition to the vital role he played in protecting air quality in one of Asia's largest cities, Mr. Ha contributed enormously to international efforts to control transportation emissions. His deep expertise with heavy-duty emission controls, generosity, unfailing optimism, and sense of humor made Mr. Ha a critical resource to the ICCT.

He is sorely missed, but his contributions will not be forgotten.

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Tremendous opportunities exist to improve public health around the world by reducing emissions from heavy-duty vehicles.

In an effort to accelerate progress toward this objective, the International Council on Clean Transportation (ICCT) has developed a model regulatory program for harmonizing and reducing exhaust and evaporative emissions from heavy-duty vehicles. Global alignment of regulatory programs for reducing vehicle emissions can produce greater public health benefits while reducing compliance costs for manufacturers. Regulatory programs for heavy-duty vehicles lend themselves to global alignment for a number of reasons:

- *The opportunity to improve public health through such programs is tremendous.* Diesel engines using high sulfur fuel can emit substantial amounts of particulate matter (PM), nitrogen oxides (NO_x) and sulfates (SO_x) that contribute to local and regional air pollution. Poor air quality has an adverse impact on public health. Advanced fuels and emissions-control technologies are now available to reduce emissions from diesel engines to near zero levels. Thus, the rapid introduction of the new technology and replacement of older engines and vehicles can be a cost-effective way to reduce emissions.

- *Commercial vehicle manufacturers support harmonization.* The world's leading manufacturers of heavy-duty vehicles and engines have met annually since 2003 with the aim of identifying policies and actions that would facilitate the international harmonization of regulations and test procedures. While recognizing that legislative systems differ across the world, making full harmonization difficult, the alignment of technical requirements as described under this model rule is feasible and could promote the diffusion of new, cost-effective technologies to reduce emissions and increase energy efficiency at a lower cost to manufacturers.

- *Developing nations are home to important and growing markets for commercial trucks.* In many developing nations throughout the world, heavy-duty trucks account for a substantial portion of overall emissions of harmful air pollutants. Vehicle sales reflect this situation. While the global market for light-duty vehicles continues to be dominated by the European Union (EU), Japan, and the United States (US), commercial truck sales in India and China have recently surpassed sales in the major developed markets.

- *The model regulatory program described in this document combines the best elements of heavy-duty-vehicle regulations in the EU, Japan, and the US.* Its four major components reflect the full scope of a comprehensive motor vehicle emission control program: (1) cleaner fuels to enable advanced emission controls; (2) state-of-the-art emission standards; (3) a harmonized certification test procedure that reflects real-world operating conditions; and (4) a well-supported in-use compliance and enforcement program. In this systems approach to vehicle regulation, each component of the program is necessary to achieve the expected public health and economic benefits from alignment. Based on numerous regulatory analyses and implementation experiences in those nations and regions with advanced programs to limit vehicle emissions, the ICCT believes that any nation that adopts this model regulatory program can expect to realize substantial benefits to public health and the environment that far outweigh program compliance costs.[1]

The EU, Japan and the US have each developed separate motor vehicle control programs with their own fuel quality requirements, emission standards, certification test procedures, and in-use compliance and enforcement mechanisms. Worldwide, developing nations such as China, India, and Thailand have adopted the European regulatory program, while a few regions have adopted the US regulatory track (Taiwan, China) or have allowed manufacturers the option of complying with either program (Mexico).

This model rule aims to encourage alignment of the three major regulatory programs in the EU, Japan and the United States. One important mechanism for technical alignment is the United Nations WP-29 program, which has finalized a worldwide harmonized test procedure for criteria emissions.[2] The ICCT is hopeful that the final worldwide test procedure will be acceptable to the three major regulatory programs.

Through this model rule, ICCT also hopes to provide developing nations with our assessment of current international best practices in motor vehicle emissions control in order to guide regulatory decisions. The decision is then left to each developing nation to either adopt each sequential regulatory step, or to leapfrog one or more regulatory steps to achieve air quality and public health benefits on a more rapid timescale. Independent of the regulatory pace, this model rule emphatically supports the adoption by developing nations of the full regulatory package: it is not the purpose of this model rule to encourage developing nations to mix and match various program elements into a "unique program" as this would reduce the benefits of alignment.

Table ES-1 summarizes the components of this program. They include:

1. *Ultra-Low Sulfur Diesel Fuel.* The NO_x and PM control technologies required to achieve the emission standards described in this model rule are premised on the removal of a catalyst poison — sulfur — from diesel fuel. All three of the major markets where heavy-duty vehicle emissions are regulated have taken aggressive steps to lower sulfur levels in diesel fuel, generally to near zero levels. In Europe, ultra-low sulfur diesel — that is, fuel with sulfur content below 10 parts per million (ppm) — started to be phased in from 2005; by 2009 all on- and off-road diesel fuel will meet this level at the pump. In the United States, ultra-low sulfur diesel (<15 ppm) became widely available nationwide starting in the fall of 2006. And in Japan, the petroleum industry voluntarily introduced 10 ppm sulfur diesel beginning in 2005, more than two years before required by the central government.

2. *State-of-the-Art Emission Standards for Heavy-Duty Engines and Vehicles.* The standards described in this model rule are expected to reduce NO_x and fine PM emissions from heavy-duty diesel engines by 90 percent or more from the emissions levels that characterize many of today's engines. The latest US. regulation for heavy-duty vehicles (HD07 rule) — to be phased in over model years 2007 to 2010 — set very stringent NO_x and PM emission standards. In the EU and Japan, comparable PM standards will be introduced in the same timeframe and similar NO_x standards are expected to be introduced in Japan in 2009 to 2010. As of September 2007, the European Commission was considering four options for Euro VI, ranging from 0.2 to 1.0 g/kWh for NO_x and 0.01 to 0.02 g/kWh for PM (ICCT 2007). Euro VI standards are also expected to include a limit on the absolute number of ultrafine particles, which have a disproportional impact on human health and may not be sufficiently controlled by a mass-based particulate standard alone.

3. *Worldwide Certification Test Procedure.* A major stumbling block to harmonizing vehicle emission standards historically has been the existence of several different certification test procedures. The ICCT expects that this issue will become moot in the future if the EU, Japan, and the United States adopt the United Nations Economic Commission for Europe's (UNECE) worldwide test procedure for heavy-duty engine exhaust emissions. This test procedure is based on new research into worldwide patterns of heavy commercial vehicle use and is designed to reflect real-world operating conditions for heavy-duty diesel vehicles in those three regions. Application of this test procedure will result in more effective control of in-use emissions due to improved correlation

between test methods and in-use driving behavior and will also enable manufacturers to develop new models more efficiently and with a shorter lead-time.

4. *In-Use Compliance and Enforcement.* The benefits resulting from stringent emission standards for new vehicles will be substantially diminished if emission control systems are not maintained during actual vehicle use. The ICCT model regulatory program, therefore, includes three provisions to ensure in-use compliance over the full useful life of heavy-duty engines and vehicles: (1) a requirement that manufacturers shall warrant to the purchaser and subsequent purchasers that the vehicle and engine are designed, built, and equipped so as to conform at the time of sale with all applicable regula-

TABLE ES-1: ICCT Recommendations for Regulating Heavy-Duty Vehicle Emissions

COMPONENT	SUBCOMPONENT	ICCT RECOMMENDATIONS
Emission standards	Exhaust	Engine standards of 0.3 g/kWh (NO_x), 0.02 g/kWh (PM), and 0.19 g/kWh (HC)[1] Complete vehicle standards • 3,855 – 4,535 kg GVWR: 0.12 g/km (NO_x), 0.01 g/km (PM), 0.12 g/km (HC), and 0.020 g/km (formaldehyde) • 4,536 – 6,350 kg GVWR: 0.25, 0.012, 0.14, and 0.025 g/km for NO_x, PM, HC, and formaldehyde, respectively
	Crankcase	Prohibited without exception
	Evaporative	Diurnal + Hot Soak (g/test) 3855 to 6350 kg GVWR: 1.4 (3 day) and 1.75 g (2 day supplemental) GVWR >6350 kg: 1.9 (3 day) and 2.3 g (2 day supplemental)
Fuel quality	Sulfur content	Diesel sulfur content should be <15 ppm at the pump Gasoline sulfur content should be in the range of 10~30 ppm
	Other specifications	Other specifications should match EU, Japanese, or US reference fuel or global technical regulation compromise values
Test procedure	Unified test procedure	Compliance with standard should be measured based upon world harmonized test procedure[1]
In-use compliance and enforcement	Manufacturer responsibility	Manufacturer should provide warrantee for pollution control equipment for 10 years and up to • Light heavy-duty vehicles: 177,000 km • Medium heavy-duty vehicles: 298,000 km • Heavy heavy-duty vehicles: 700,000 km Vehicle models with significant noncompliance should be subject to recall
	Not to exceed (NTE) limits	Incorporation of NTE limits to control off-cycle emissions
	On-board emissions requirements	Incorporation of on-board diagnostic (OBD) systems and, when applicable, on-board monitoring (OBM) of emissions in real time

[1] Values reflect the current, most stringent standards to date as adopted by the US EPA and measured under the US test procedure. The numerical values will need to be adjusted to fit the new worldwide harmonized test procedure.

tions, and that the vehicle or engine is free from defects in materials and workmanship which would cause such vehicle or engine to fail to conform with regulations for its full useful life (as defined in Section 4.4.1 of this report); (2) new type approval standards that require manufacturers to warrant that vehicles or engines will comply with emission standards under virtually all real-world operating conditions (i.e., not-to-exceed standards); and (3) the installation of on-board diagnostics to alert owners, operators, mechanics, and inspectors to emission control system malfunctions together with fail-safe mechanisms to ensure proper system operation during vehicle use. Properly maintained vehicles that fail to comply with the requirements in use would, of course, be subject to recall by the manufacturer.

Although the model rule deals primarily with global alignment of regulatory control for new diesel engines, international coordination of in-use engine strategies may also be beneficial, given that in-use engines are a major source of emissions and many countries have developed, or are in the process of developing, their own set of retrofit regulations.

Most of the emphasis in this Model Rule is on diesel-fueled vehicles and engines because they dominate heavy-duty truck and bus markets worldwide. However, because there still remain limited sales of heavy-duty spark ignition vehicles and engines, in a few cases (e.g., evaporative hydrocarbon emissions) specific requirements are included for these vehicles as well.

1. INTRODUCTION

The model regulatory program ICCT has developed for reducing exhaust and evaporative emissions for heavy-duty vehicles rests on the premise that global alignment of state-of-the-art heavy-duty vehicle regulatory programs would be beneficial to public health while also serving the interests of international commercial vehicle manufacturers. Reducing emissions from today's new heavy-duty vehicles will produce tremendous public health and environmental benefits over the many decades that these vehicles are in use. Benefits to industry include lower technical barriers to enter new markets, simplified product development and manufacturing, lower research and development costs, and greater certainty about environmental requirements.

Worldwide, many millions of people live in areas where poor air quality endangers public health and welfare. The World Health Organization (WHO) estimates that 800,000 people die prematurely each year as a result of urban air pollution caused by all sources. In many major cities across the globe, emissions from heavy-duty vehicles account for a substantial fraction of total emissions of PM, NO_x, and ground-level ozone precursors. Without aggressive efforts to reduce emissions from heavy-duty vehicles, people in cities throughout the world will continue to breathe polluted air for the foreseeable future.

Emissions from heavy-duty vehicles that impact public health include ozone precursors, such as NO_x and volatile organic compounds (VOCs); PM and PM precursors, such as NO_x and SO_x; and toxic and carcinogenic compounds, such as formaldehyde. Health impacts from these pollutants include premature death, aggravation of respiratory and cardiovascular disease, cancers of the lung and other organs, increased respiratory symptoms, changes to lung tissues and structure, chronic bronchitis, and decreased lung function. These impacts result in lost productivity and increased medical spending for hospital admissions and emergency room visits, reduced learning due to school absences, work losses, and restricted-activities. NO_x and PM emissions from diesel vehicles also contribute to anthropogenic climate change – NO_x by promoting the formation of ground-level ozone, and diesel soot particles directly by reradiating visible light as heat and indirectly by lowering the albedo of snow and ice-covered regions. Other impacts from these pollutants include: crop and forestry losses; damage to and soiling of building materials and culturally important art and architectural structures; visibility impairment; and acidification, nitrification and eutrophication of water bodies.

PM and NO_x are the two pollutants of primary concern for human health that are emitted by heavy-duty vehicles and targeted by this model rule. Diesel exhaust emissions present special hazards for two reasons:

(1) most of the particles are very small, in the 10–100 nanometer range; and (2) diesel exhaust (composed of particles and gases) is considered a likely or probable human carcinogen by a variety of health and environmental organizations, including the International Agency for Research into Cancer, the World Health Organization, the California Air Resources Board, and the United States Environmental Protection Agency. Fine particles (aerodynamic diameter < 2.5 micrometers or µm) and ultra-fine particles (diameter < 0.1 µm) are able to penetrate deep within lung tissues. As illustrated in Figure 1, most of the particles emitted by diesel vehicles fall in the fine or ultra-fine size range. In addition, these particles collectively provide a large surface area for adsorbing toxic organic compounds, which can account for 20–40 percent of total particle weight.

PM mass emissions can be effectively controlled by diesel particulate filters, which can also reduce the number of ultra-fine particles by over 95 percent and dramatically reduce diesel toxicity. A variety of technologies are being explored to reduce NO_x emissions. All of these technologies are discussed in Section 3 of this report.

The world's leading manufacturers of heavy-duty vehicles and engines support harmonized emission regulations because it is economically inefficient to have to prepare substantially different models to meet different emission regulations and comply with different certification protocols that, in principle, are intended to achieve the same objective. A group of the industry's chief executives have met annually in recent years, starting in Amsterdam in 2003, in

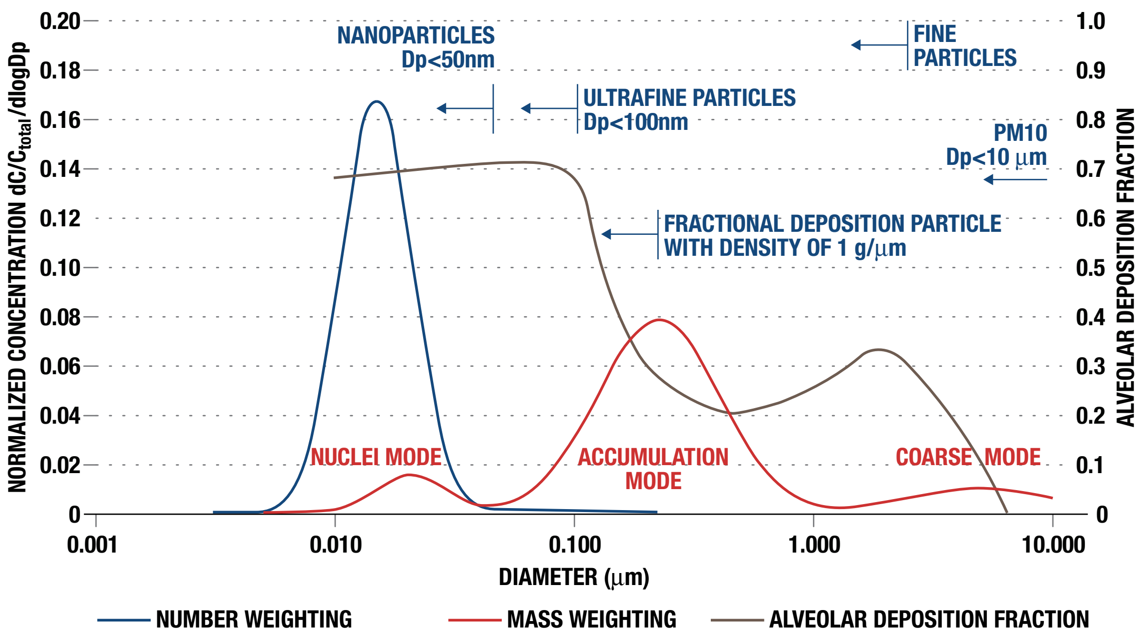

FIGURE 1. Fractional Particle Deposition in Humans and Mass and Number Weighting of Diesel Emissions According to Particle Size

Source: Modified from Kittelson (1998).

Tokyo in 2004, and in Chicago in 2005, to identify policies and actions that would promote the harmonization of government regulations and test procedures. In 2005, the group called on nations to adopt (as soon as they are developed) global technical regulations that would establish new worldwide emissions certification test procedures, new requirements for on-board diagnostics, and engine and vehicle certification standards to cover nearly all real-world operating conditions (i.e., not-to-exceed standards).

Similarly, the European Commission's 2006 CARS 21 report calls for harmonized motor vehicle regulatory programs, stating that:

> *Regulation on heavy-duty vehicle emissions is a potential area for global harmonization. While the preparatory work for the next stage requirements in the Community should go on, the possibility of reaching international harmonization in this area is recommended, in particular with regard to the development of global technical regulations on emission test cycles (both steady and transient cycles), off-cycle emissions and on-board diagnostic systems. International emission limit values should be agreed on the basis of the above test procedures. The long-term aim should be the adoption of worldwide emission standards.*

The CARS 21 report reflects the opinions of a group of high-level policy makers assembled and staffed by the European Commission and composed of representatives from the European auto and oil industry, members of the European Parliament, EU member states, trade unions and non-governmental organizations (NGOs).

In the early 1990s, industry experts used the term "emerging markets" to describe commercial truck markets outside Europe, North America, and Japan. Today, these markets rival the traditional markets in size and importance. Since 1999, commercial truck sales have doubled in India and more than quadrupled in China, leaving these two emerging nations securely positioned within the top four commercial truck markets in the world. As seen in Figure 2, total truck sales in China and India surpassed sales in Europe and North America by close to one million units in 2004. Latin American nations such as Brazil, Argentina, Chile, Peru, and Venezuela have likewise experienced a sharp rise in commercial truck sales over the last few years. Growth opportunities for commercial truck manufacturers are likewise concentrated in formerly emerging markets. For European manufacturers, sales in markets outside of the EU, Japan, and North America grew by 22 percent for Mercedes, 29 percent for Volvo, and 33 percent for Scania between 2002 and 2004; the Japan Automobile Manufacturers Association (JAMA) reports that Europe and the U.S. accounted for less than a quarter of Japanese exports of large trucks during fiscal year 2006 (JAMA 2007). Given their prominence in terms of the global market for commercial trucks, developing nations have the ability to influence the future evolution of control technologies and pollution regulations for this industry.

Developing nations also have an increasingly important stake in the regulation of heavy-duty diesel emissions insofar as these emissions have significant consequences from a public health and global warming standpoint. Rapid industrialization has caused steady deterioration in the air quality of many large cities throughout the developing world, creating substantial health risks for the growing urban population that is exposed to chronically high ozone and fine particle levels.

The model regulatory program described in this paper is intended to reduce compliance costs and market barriers for heavy-duty vehicle manufacturers and to improve human health in cities and nations around the world. The model program includes four major components, which reflect the full scope of a comprehensive motor-vehicle emission-control program: (1) cleaner fuels to enable advanced controls, (2) state-of-the-art emission standards, (3) a type approval test procedure that reflects real-world operating conditions and (4) a well-supported in-use compliance and enforcement program. The next section of this paper describes the regulatory landscape from which the best practices used to develop this model regulatory program have been drawn. Section 3 discusses the technology options for control of emissions from heavy-duty vehicles. Section 4 lays out each component of the model regulatory program in detail. In closing, Section 5 offers some brief conclusions.

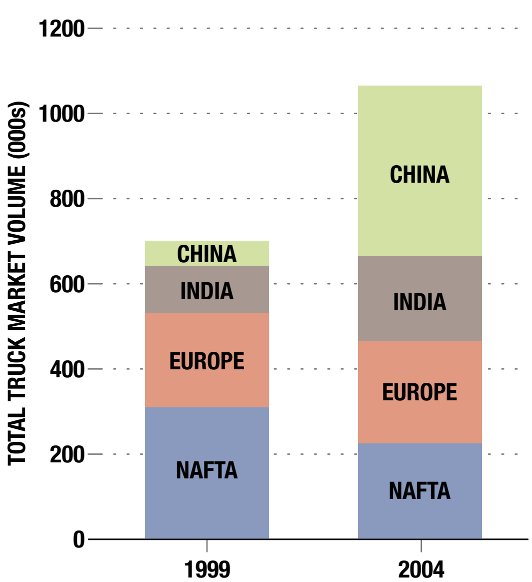

FIGURE 2. Sales of Heavy-Duty Trucks in Traditional and Emerging Markets

Source: Hinks-Edwards 2005.

2. INTERNATIONAL REGULATORY LANDSCAPE

This section reviews emissions standards for heavy-duty diesel vehicles in the EU, Japan, and the United States together with related regulatory developments elsewhere in the world. Recent regulatory decisions in the major developed markets reflect a broadly held international consensus about the importance of reducing PM emissions — especially fine PM emissions — to very low levels and the feasibility of doing so using catalyzed diesel particulate filters in combination with ultra-low-sulfur fuels (Figure 3). The latest U.S. rule governing emissions from heavy-duty vehicles (HD07) sets the most stringent NO_x and PM emission standards to date. Japan and Europe are expected to establish similar NO_x standards in 2009 and approximately 2012, respectively.

2.1 THE EUROPEAN UNION, JAPAN, AND THE UNITED STATES

The EU has been the global leader in pursuing ultra-low sulfur diesel fuel. As early as the mid-1990s, Sweden established tax policies that successfully encouraged domestic oil companies to produce 10 ppm sulfur fuels. Euro IV emission standards apply since October 1, 2005, and Euro V standards will phase in starting October 1, 2008. Separate but corresponding fuel specifications preceded these

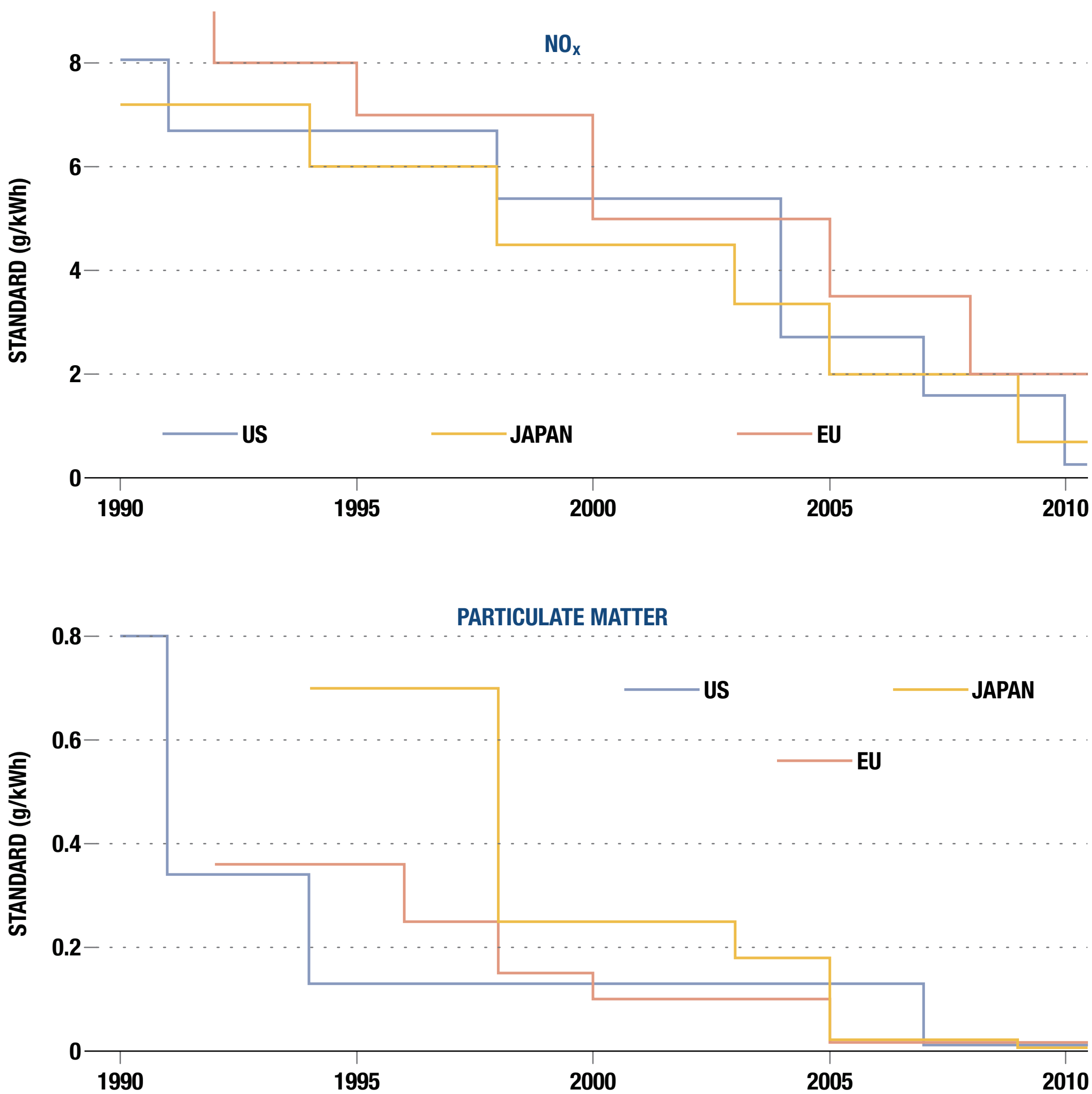

FIGURE 3. Average NO_x and Particulate Emission Standards for Heavy-Duty Diesel Trucks in the European Union, Japan, and the United States, 1990-2010

Note: The stringency of an emission standard is influenced by the applicable type approval test cycle. As different test cycles are used in Europe, Japan, and United States, there are limits to the accuracy of a simple comparison of numerical emission values.

Source: Modified from Tokyo Metropolitan Government (2003).

emission standards. Ultra-low sulfur (<10 ppm) diesel already dominates fuel markets in several EU countries, while the Euro IV program limits sulfur levels to 50 ppm for both gasoline and diesel. The EU will further reduce fuel sulfur levels for gasoline and diesel to a maximum of 10 ppm in 2009. As of the fall of 2007, the European Commission is deliberating on a proposal for Euro VI emissions standards likely to be enforced from 2012 (Table 1). The new standards are expected to introduce more stringent requirements for NO_x and include limits on particle emissions in terms of numbers.

Japan mandated ultra-low sulfur (<10 ppm) fuel by 2007, and domestic refiners responded by voluntarily introducing 10 ppm diesel fuel two years ahead of schedule. In early 2005, the Japanese Central Environment Council (CEC) — an advisory body of the Ministry of the Environment — reached consensus on a next tier of heavy-duty diesel emission standards to take effect in 2009–2010. The agreed-to standards will reduce PM and NO_x emissions by a further 43–65 percent relative to the standards that took effect in October 2005. As can be seen in Table 1, Japan's proposed PM limits for 2009 are more stringent than the Euro V standards and are comparable to the US's 2007 PM standards. Japan's 2009 NO_x limits are also more stringent than Euro V but less stringent than US heavy-duty standards for 2010. However, Japan has also identified a "challenge" NO_x limit that would require an additional two-thirds reduction from the 2009–2010 values, which would be comparable to the U.S. limit for NO_x in 2010. Japan will decide in 2008 whether to trigger the

TABLE 1: Heavy-Duty Vehicle Emission Standards in the EU, Japan, and the United States

REGION	REGULATION AND YEAR	AVERAGE STANDARD VALUES (g/kWh)	
		NO_X	PM
United States	2002-2004	2.7	0.13
	2007	1.6	0.013
	2010	0.27	0.013
European Union	Euro III (2000)	5	0.1
	Euro IV (2005)	3.5	0.02
	Euro V (2008)	2	0.02
	Euro VI (Proposed)[1]	0.2 - 1.0	0.01 - 0.02
Japan	2003-2004	3.38	0.18
	2005	2	0.027
	2009-2010	0.7[2]	0.01

Note: The stringency of an emission standard is influenced by the applicable type approval test cycle. As different test cycles are used in Europe, Japan, and United States, there are limits to the accuracy of a simple comparison of numerical emission values.

[1] As of October 2007, the European Commission was considering four options for Euro VI, ranging from 0.2 to 1.0 g/kWh for NO_x and 0.01 to 0.02 g/kWh for PM.

[2] Japan has also adopted a so called "challenge value" of 0.23 g/kWh for NO_x; depending on the status of technology development a decision will be made in 2008 about whether to make this value mandatory.

target standards following a survey of the development of applicable pollution control technologies.

In the US, the Environmental Protection Agency's (EPA) Heavy-Duty Vehicle, Engine and Low-Sulfur Highway Diesel Fuel Rule (HD07 rule) established stringent, technology-forcing NO_x and PM standards for heavy-duty engines and vehicles and a 15-ppm sulfur limit for highway diesel fuel starting in 2006. In model year 2007, tighter PM and NO_x standards were mandated.[3] An even more stringent NO_x standard is mandated in 2010. As can be seen in Table 1, combined US NO_x and PM standards are the most stringent currently in place for any of the three major developed-nation vehicle markets.

2.2 OTHER NATIONS

Many other countries have proposed or adopted new emission standards for heavy-duty diesel vehicles that will take effect before the end of this decade. These recent developments are summarized below.

- China has adopted Euro II, III, IV, and V standards for heavy-duty vehicles to go into effect in 2005, 2007, 2010, and 2012, respectively. Euro II fuel standards (500 ppm sulfur) have been voluntarily introduced in some major cities throughout the country, but national diesel fuel sulfur standards remain at 2000 ppm. The City of Beijing, however, has adopted Euro III fuel sulfur specifications for 2005 and Euro IV (50 ppm sulfur for gasoline and diesel) for 2008. Similar fuel requirements are expected to follow soon in other major cities.
- Taiwan, China established a sulfur limit of 50 ppm for diesel fuel in 2005 and will allow sales of heavy-duty vehicles compliant with either US HD04 or Euro IV standards.
- Thailand is planning to proceed with the introduction of Euro IV standards and 50 ppm sulfur diesel by the end of the decade. Discussions are currently ongoing in Thailand concerning a possible further reduction of diesel sulfur levels to a maximum of 10 ppm.
- South Korea reduced diesel sulfur levels to 30 ppm by 2006 and will adopt its own emissions control program by 2010. New standards are expected to require at least a 50 percent reduction in diesel emissions.
- Starting in 2006, New Zealand required that heavy-duty vehicles imported into the country be built to comply with whatever emission standard was in effect in Australia, the United States, Japan, or Europe on the date the vehicle was manufactured.
- India has adopted Euro II standards for 2005 and Euro III standards for 2010. Major cities, however, are on a faster schedule for reducing emissions. Specifically, vehicles in 11 cities previously operating under the Euro II standards are

required to meet Euro III emission standards in 2005 and Euro IV standards by 2010.[4]

- In Brazil, Euro III emission standards for heavy-duty vehicles are being phased in from 2004 to 2006 and Euro IV standards will take effect in 2009. Sulfur will be limited nationally to 2000 ppm starting in 2006. Diesel at 500 ppm sulfur, already available in São Paulo, will be available in all metropolitan regions beginning in 2006 and will be required nationally starting in 2012. Petrobras — the country's national oil company with 80 percent of Brazil's fuel market — previously agreed to make 50 ppm sulfur diesel available at a second pump in stations throughout the country beginning in 2009, although it is now expressing concern about the feasibility of doing so.
- Mexico has adopted 15 ppm sulfur diesel beginning in 2007 for the border region and 2009 for the rest of the country. Current heavy-duty vehicle emissions standards allow either U.S. or European standards.
- Canada has adopted virtually identical emissions standards for heavy-duty vehicles and fuels as the United States, on the same approximate schedule.

2.3 PROGRESS TOWARDS GLOBAL ALIGNMENT

The appropriate mechanism for seeking global alignment is worth considering within the context of a discussion of model regulations. One method currently employed — primarily for technical requirements such as certification standards — is the Global Technical Regulations (GTR), a concept introduced by the United Nations Economic Commission for Europe in 1998. This format can produce useful results, such as the worldwide certification test procedure incorporated in the model regulatory program described here. The ICCT strongly supports the alignment of regulatory programs based on identifying and compiling best practices from those nations with mature programs and avoiding the proliferation of different programs throughout the rest of the world.

3. REVIEW OF HEAVY-DUTY DIESEL PM AND NO_X CONTROL TECHNOLOGIES

This section describes the major engine and after-treatment PM and NO_x control technology options that have emerged in recent years with the advent of more stringent pollution control requirements in the EU, Japan, and the United States. We begin with a short discussion of low-sulfur diesel fuel, which is crucial to the viability of advanced after-treatment control technologies. We then review the two primary after-treatment options for PM control: oxidation catalysts and particle filters. Finally, we turn to the three primary control options for NO_x: exhaust gas recirculation, selective catalytic reduction, and NO_x adsorbers.

3.1 LOW-SULFUR DIESEL FUEL

Though distinct from the after-treatment control technologies that are the primary focus of this paper, the advent of lower-sulfur diesel fuel deserves separate mention as a key development in the worldwide effort to reduce air pollution and public health impacts associated with diesel vehicle emissions. Fuel quality has significant direct and indirect consequences for diesel vehicle emissions. Reducing sulfur in diesel reduces direct emissions of sulfate particles as well as emissions of sulfur dioxide (SO_2), which can convert into particles and acids in the atmosphere. These reductions will occur in new vehicles and throughout the existing fleet of diesel vehicles. In addition, sulfur is a catalyst poison. All advanced after-treatment control technologies perform better with the use of lower sulfur fuel and some of the most important technologies require fuels with sulfur levels of 15 ppm or less.[5]

Because low-sulfur fuels are a prerequisite for many advanced after-treatment technologies for diesel engines, fuel sulfur standards have preceded emissions standards for heavy-duty vehicles in the EU, Japan, and the United States, as well as in some developing countries. As shown in Figure 4, more than half of all diesel fuel globally will

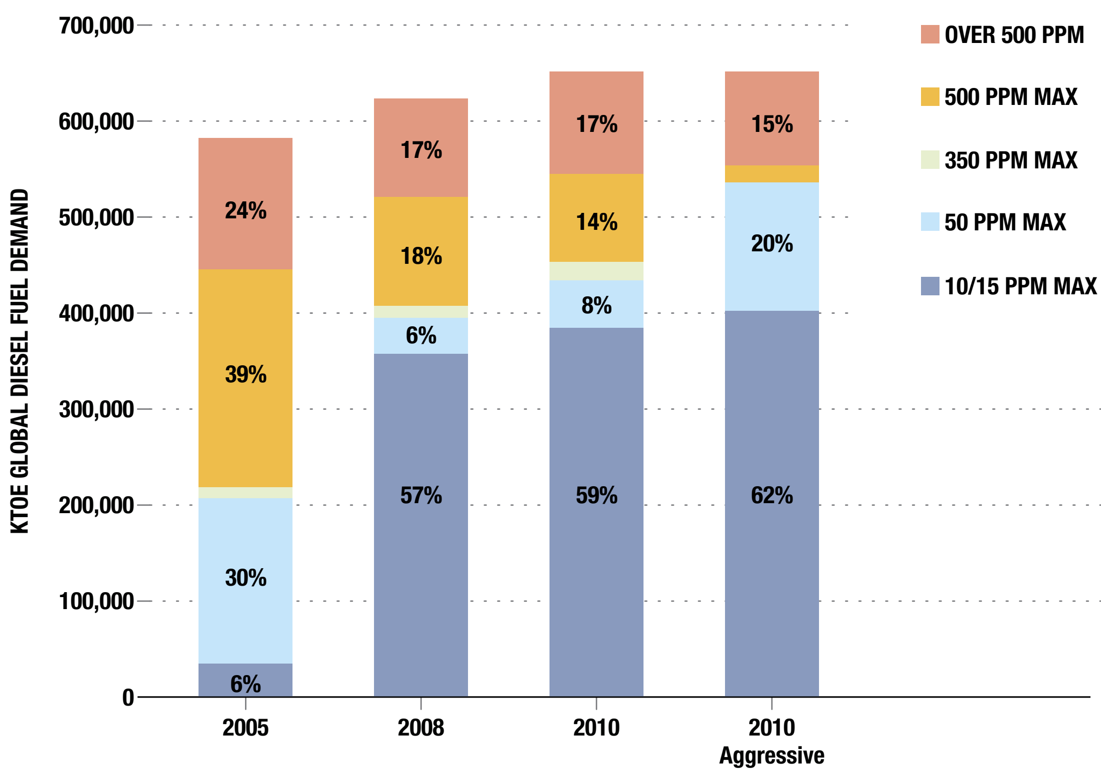

FIGURE 4: Increasing Global Demand for Lower-Sulfur Diesel Fuel

Source: Walsh 2007.

have sulfur levels of 50 ppm or less by 2010 (Walsh 2007). If all countries with fuel standards under development succeed in finalizing and complying with their regulations, 82 percent of automotive diesel in the world will be 50 ppm sulfur or less by 2010. But this is far from a foregone conclusion. Many of the most populous countries in the world have not yet adopted the necessary low sulfur fuel quality.

3.2 PM CONTROL TECHNOLOGY OPTIONS

The desire to reduce PM emissions from diesel engines has led to the development of several aftertreatment technologies such as diesel oxidation catalysts and diesel particulate filters. As discussed in the next section, selective catalytic reduction of NO_x also offers the option of tuning the engine to deliver low PM mass emissions.

3.2.1 Diesel Oxidation Catalyst

The diesel oxidation catalyst (DOC) is a flow-through device that replaces the muffler and makes use of precious metals to oxidize carbon monoxide (CO), gaseous hydrocarbons (HC), and liquid hydrocarbon particles (unburned fuel and oil). DOCs reduce overall PM mass and many toxic organic compounds but are not as effective as catalyzed diesel particle filters in controlling the large number of fine and ultra-fine particles in diesel exhaust. As previously noted, the smallest carbon particles are believed to pose the most significant risks from a public health standpoint. According to emission control manufacturers, DOCs are capable of reducing overall diesel PM mass emissions by 10 – 60 percent, and HC emissions by 50–90 percent, depending on engine technology and age, the application duty cycle, and fuel quality. While some new DOC formulations are intended to function with fuels of up to 2000 ppm sulfur, most current DOCs require lower sulfur levels. The most common DOCs in use today convert some portion of the fuel sulfur into sulfate and, when used under certain conditions with higher sulfur fuels, can actually increase particle emissions.

Especially in Europe where DOCs were widely used to comply with Euro 3 and Euro 4 standards, there have been growing concerns regarding increased nitrogen dioxide (NO_2) emissions. NO_2 is produced from NO in the exhaust system by means of oxidation catalysts as a side effect of removing CO and hydrocarbons.

3.2.2 Diesel Particle Filter

Diesel particle filters (DPFs) reduce diesel PM emissions by capturing the soot (solid carbon) portion of the exhaust stream and then transforming it into carbon dioxide by oxidizing (burning) it. DPFs have demonstrated their effectiveness at reducing both the mass and number of particles on the order of 95 percent or better.

Active DPFs require a small amount of additional fuel to burn off the collected soot. When designed to function with higher sulfur fuels, they typically require more operator involvement and may have higher costs than passive systems. Catalyzed or passive DPFs lower the exhaust temperature required to combust the captured soot to within the normal range of vehicle operation. Low fuel-sulfur levels reduce the temperature needed to burn off the soot collected in the filter, improving vehicle fuel economy and reducing operating costs.

Major engine manufacturers began to use DPFs in Japan starting in 2005 and all manufacturers introduced catalyzed DPFs in the U.S. starting in model year 2007. When Euro IV and V standards were adopted, regulators expected the stringent PM emission standards to require the use of DPFs in commercial heavy-duty trucks but it is now apparent that truck manufacturers are able to comply without DPFs. Engine manufacturers tune their engines for high-NO_x, high-fuel economy and relatively low PM emissions. As will be discussed in the next section, these manufacturers will use selective catalytic reduction to lower tailpipe NO_x emissions to meet Euro IV and Euro V standards. This compliance strategy will not reduce emissions of the smallest and most hazardous particles to nearly the same degree as DPFs. In an effort to also obtain reductions in the number of ultra-fine particles, several European nations have adopted, or are in the process of adopting, new tax policies — such as road tolls linked to emissions performance — to encourage the commercial introduction of DPFs.

3.3 NO_X CONTROL TECHNOLOGY OPTIONS

This section reviews the three major NO_x emission control technologies currently available or under development.

3.3.1 Exhaust Gas Recirculation

In contrast to the other technologies discussed in this section, exhaust gas recirculation is an engine modification rather than an after-treatment technology. NO_x emissions increase with combustion temperature: all other things being equal, the hotter the combustion, the more NO_x is created. Exhaust gas recirculation (EGR) lowers combustion temperatures in the cylinder by recirculating some of the exhaust gas into the intake manifold. The inert exhaust gas does not combust and dilutes the combusting gases, thereby reducing peak combustion temperature and limiting NO_x formation.

Low sulfur fuel reduces the corrosive nature of the exhaust gases being recirculated, increasing engine durability, lowering maintenance needs, and reducing production costs.

In the United States, a number of heavy-duty engine manufacturers are using cooled EGR to comply with the NO_x control requirements in effect from 2007 to 2009. EGR is being used to meet the current US NO_x standard but is not likely – by itself – to be sufficient for compliance with the more stringent NO_x requirements due to go into effect in the United States in 2010. EGR is also expected to be the primary technology used in Japan to meet standards before the end of the decade. A few engine manufacturers have also indicated that they intend to comply with the Euro IV standards using cooled EGR. One advantage of this technology is that it is less expensive than other NO_x control options.

3.3.2 Selective Catalytic Reduction

Selective catalytic reduction (SCR) involves the use of a NO_x reducing agent that is injected into the exhaust gas before the exhaust gas reaches the catalyst. The reducing agent used for vehicle SCR systems consists of a mixture of water and urea. Urea is an organic compound that is used commercially for many applications and is highly soluble, non-toxic, and transportable by truck. The more stringent the required NO_x control effectiveness, the greater the amount of reductant (urea/ water mixture) is required. Compliance with the Euro IV standard, a 30 percent reduction from Euro III, requires that urea be added in quantities amounting to about 3 to 4 percent of fuel consumption. A larger quantity of urea (roughly 5 to 6 percent of fuel consumption) will likely be necessary to comply with Euro V, a 60 percent reduction from Euro III.

SCR systems are less impacted by sulfur than other advanced control technologies. A small downstream oxidation catalyst may be needed, however, to prevent emissions of unreacted ammonia (a pollutant with chronic and acute human health impacts) and some manufacturers will use an upstream oxidation catalyst, which would enable them to reduce the size and cost of the SCR system itself. Therefore, fuel quality remains important, because higher sulfur levels will increase PM emissions from any integrated oxidation catalysts. In addition, sulfur reactions in urea-based SCR systems can form ammonium bi-sulfate, a severe respiratory irritant.

The primary advantage of SCR technology is that it can achieve low tailpipe NO_x emissions, even if initial, “engine-out” NO_x emissions are high. As a result it allows for the engine to be tuned for high-temperature, highly efficient operation, which generates high engine-out NO_x emissions but improves fuel economy and reduces PM mass emissions. Fuel economy improvements result in reduced greenhouse gas emissions and can also generate operating cost savings, depending on the difference between urea and diesel fuel prices. Operating cost savings are greatest in many European nations and Japan where substantial fuel taxes result in high diesel fuel prices.

A large percentage of engines sold in Europe and subject to the Euro IV standards are equipped with SCR systems; SCR technology is also expected to be adequate for meeting the Euro V NO_x standards in 2008/ 2009. Indeed, SCR is likely to be the dominant NO_x-control technology in Europe, as it will allow manufacturers to utilize a single control technology for both Euro IV (which will apply for only three production years) and Euro V. The possible introduction of NO_x-emissions-dependent pricing on German toll roads may provide a further incentive for any additional NO_x reductions achieved through the use of SCR for compliance with the Euro IV standards. SCR is also the primary emissions control technology used by two of Japan's four major manufacturers of heavy-duty diesel vehicles – Nissan Diesel and Mitsubishi Fuso – as a means of complying with Japan's 2005 emission standard.

Whenever SCR technology is to be used to comply with emissions standards, a urea infrastructure must be in place. The primary regulatory concern with SCR is that, if the system is not properly maintained, very high levels of NO_x emissions will result. This creates additional in-use compliance challenges in terms of ensuring that vehicle operators keep their vehicles adequately supplied with urea. Failure to keep the urea tank filled, or to maintain the proper ratio of urea to water, will render the control system ineffective but will not automatically affect vehicle operation. In that case, an SCR-equipped vehicle that has been tuned to maximize fuel savings will produce very high levels of NO_x emissions. Because vehicle operators will have to take the time and incur the expense of keeping their vehicles supplied with urea on an ongoing basis, this situation creates some potential in-use enforcement issues. European regulators are requiring engine manufacturers to install a feedback mechanism that limits engine torque in the event that the urea tank is not refilled. The question remains whether vehicle operators will have the ability to defeat such compliance-enforcement mechanisms.

Manufacturers are also working in the United States to address EPA's concerns about in-use compliance and urea infrastructure so that they can use SCR, especially in the heaviest trucks (Class 8). SCR will violate EPA's prohibition on emissions-related scheduled maintenance on heavy-duty vehicles on intervals of less than 150,000 miles. As a result, manufacturers will need to design SCR-equipped vehicles to ensure that they will not be operated without urea by including systems that: 1) warn operators of the need to refill the urea tank; 2) induce refilling through constraints on vehicle operation (e.g. no engine restart, fuel lockout, reduced performance); and 3) can identify an improper reducing agent. Those systems must also be tamper resistant and durable to 435,000 miles for Class 8 trucks. EPA has also announced its intention to review manufacturer plans for infrastructure to provide urea to operators, including at dealerships, truck stops, and other backup locations (EPA 2007).

Another concern regarding SCR is that heavy-duty vehicles will be able to meet Euro IV and Euro V standards without a DPF. While engine tuning allows for the reduction of particulate mass emissions, it does not reduce the number of very fine particles emitted to the same degree as PM filters.

These very fine particles are of particular concern from a health standpoint and to date can only be effectively controlled using particle filters.

3.3.3 NO_x Adsorbers

A NO_x absorber works by temporarily storing NO_x on the catalyst's adsorbent coating material during normal engine operation. When the adsorbent becomes saturated, engine operating conditions and fuel delivery rates are adjusted to produce a temporarily fuel-rich exhaust, which is used to release the NO_x and reduce it to N_2. NO_x adsorbers are the most promising control technology for achieving very low NO_x levels that does not require vehicle operators to add reagents or perform other ongoing maintenance.

NO_x adsorbers are highly susceptible to sulfur poisoning. The adsorbent is especially effective at attracting sulfates, which are not removed during the typical regeneration cycles that release NO_x for reduction to N_2. Even when using very low sulfur content fuel, periodic high temperature regeneration cycles are required to remove sulfur from the adsorber. The frequency of these events is directly linked to fuel sulfur content. Unlike other after-treatment devices that can return to previous efficiency levels after a brief exposure to higher sulfur levels (e.g., three-way catalysts, diesel PM filters, SCR with diesel oxidation catalysts), certain elements of a NO_x adsorber are permanently impaired when exposed to elevated diesel fuel sulfur levels.

U.S. EPA considers NO_x adsorbers to be a significant technology option for meeting its final NO_x standard beginning in 2010. Commercialization began in Japan in 2007, when Hino Motors began selling a medium-duty diesel truck adding a lean NO_x adsorber to its existing combination of EGR and DPF. That combination reduces emissions to 1.0 g/kWh for NO_x and 0.013 g/kWh for PM, or about 80% of the reduction required under the 2009 emission standards (Hino 2007).

Table 2 offers a brief review of the fuels and engine and aftertreatment technologies discussed above.

4. MODEL REGULATORY PROGRAM FOR HEAVY-DUTY VEHICLES AND ENGINES

The ICCT's proposed model regulatory program for controlling exhaust and evaporative emissions from heavy-duty vehicles and engines includes four major components, each of which is discussed in detail below:

1. Stringent fuel standards
2. State-of-the-art emissions standards
3. Worldwide certification test procedures
4. Strong in-use compliance and enforcement

Taken together these components reflect the full scope of a comprehensive vehicle emission control program. For purposes of this model regulatory program, the ICCT has adopted a systems approach in which each component of the program supports other components. Cleaner fuels are required by advanced emissions control technologies. Strong enforcement and in-use compliance measures are required to ensure that emissions controls are operating correctly. In addition to the worldwide certification test program, not-to-exceed or equivalent requirements and in-use testing protocols that ensure local in-use compliance are necessary.

4.1 STRINGENT FUEL STANDARDS

In order to enable state-of-the-art emissions standards, heavy-duty vehicles will require cleaner fuels. The primary contaminant of concern in diesel fuel is sulfur because it not only impacts emissions directly but also impairs and in some cases destroys the performance of advanced pollution controls. Reducing sulfur from diesel is technologically feasible at relatively low cost and is very cost effective (in terms of the cost per ton of emissions reduced) when combined with tighter diesel emissions controls. In addition to enabling the advanced after-treatment technologies that are required to meet the tailpipe standards proposed above, removing sulfur reduces vehicle emissions by directly reducing SO_2 and sulfate particles, and by reducing the formation of secondary sulfate particles in the atmosphere.

While sulfur standards are critical for diesels to meet stringent emissions standards, even fuels thought of as cleaner, such as natural gas, must be of the highest quality to ensure that the proposed standards can be met. In areas where other fuels are widely used for

TABLE 2: Review of Emission Control Technologies

TARGET	TECHNOLOGY	CONTROL EFFICIENCY		STATUS
		PM	NO_x	
Fuel Quality	Low Sulfur Fuel (<50 ppm)	5-20%	-----	In wide use globally Enables use of NO_x Adsorbers and DPFs Improves functioning of DOCs, SCR, and EGR
PM	Diesel Oxidation Catalyst (DOC)	10-60%[1]	-----	Established technology Compatible with all vehicles Durable, minimal maintenance
	Diesel Particulate Filter (DPF)	>95%[2]	-----	Used in LD and some HD applications Best with newer engines (post-'94) with higher exhaust temperatures
NO_x	Exhaust Gas Recirculation (EGR)	-----	80%	In commercial use Widespread use in US starting in 2007
	Selective Catalytic Reduction (SCR)	-----[3]	60-90%	Used in marine and stationary engines Widespread use in Europe (Euro IV/V) and key technology in Japan (2005) Allows improved vehicle efficiency
	NO_x Adsorber Catalyst	-----	>85%	In development Limited application in Japan in 2007 May compete with SCR in 2010

[1] Mass only – no reduction of ultra-fine PM.
[2] Only technology that reduces ultra-fine PM
[3] Allows engine tuning to reduce PM mass by ~80% at the expense of NO_x control

heavy-duty applications, specifications for these fuels will also be required. For example, heavy-duty gasoline vehicles will also require lower sulfur fuel. Moreover, gasoline volatility will directly affect the ability to meet evaporative emissions standards. For compressed natural gas (CNG), fuel specifications should address methane, propane, and butane content, water, and residual compressor oil in addition to sulfur content.

4.1.1 Sulfur Specifications

This model regulatory program specifies that refiners must produce highway diesel fuel that meets a maximum sulfur content of 10 to 15 ppm at the pump. Sulfur is the most important component of concern, although several other diesel fuel properties, such as cetane, lubricity, aromatics and density, can be targeted or affected by desulfurization. Gasoline should also meet a sulfur standard of 10 to 30 ppm if gasoline trucks are sold in the country implementing this program.

4.1.2 Other Specifications

While not the specific focus of this Model Rule, it is worth noting that other diesel fuel parameters can have important effects; these include cetane number, density, and distillation curve and polyaromatic hydrocarbon content. Table 3 outlines reference fuel specifications for diesel fuel in the EU, Japan, and the US, along with compromise values suggested under the UNECE global technical regulation.

Cetane number is a measure of auto-ignition quality. High cetane number fuels enable an engine to be started more easily at lower air temperatures, reduce white smoke exhaust, and reduce diesel knock. An increase in cetane number generally results in a decrease in carbon monoxide and hydrocarbon emissions, nitrogen oxide emissions (most notably in heavy-duty engines), as well as benzene, 1,3 butadiene, formaldehyde and acetaldehyde emissions from light duty

TABLE 3: Reference Fuel by Country With Suggested GTR Compromise

SPECIFICATION	UNIT	REFERENCE FUEL BY COUNTRY			SUGGESTED GTR COMPROMISE
		EU	JAPAN	US	
Sulfur	ppm	max 10	max 10	7 – 15	max 15
Cetane number	-----	52 – 54	53 – 57	40 – 50	45 – 55
Density	kg/m^3	833 – 837	824 – 840	840 – 865	835 – 845
50% BP	° C	min 245	225 – 295	243 – 282	243 – 295
FBP	° C	max 370	max 370	321 – 366	321 – 366
PAHs	%	2.0 – 6.0	max 5.0	-----	2.0 – 6.0
Aromatics	%	-----	max 25	min 10	10 – 25
Viscosity	mm^2/s	2.3 – 3.3	3.0 – 4.5	2.0 – 3.2	2.0 – 4.0
Lubricity	µm	max 400	-----	-----	-----

Source: UNECE- WP29 GRPE, WHDC Working Group 2007.

engines. For diesel vehicles equipped with oxidation catalysts or catalyzed PM filters, emissions of CO, HC and the toxics (e.g. benzene, 1,3 butadiene, formaldehyde and acetaldehyde) will tend to be less sensitive to cetane number.

Density relates to the energy content of fuel; the higher the density of the fuel the higher its energy content per unit volume. Too high a fuel density for the engine calibration has the effect of over-fuelling, increasing black smoke and other gaseous emissions. 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 (ACEA 1995).

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 (the temperature at which 90% of the fuel evaporates), T95 and final boiling points. 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. ACEA (1995) indicates 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.

Polyaromatic hydrocarbons (PAHs) are increasingly attracting special attention because many are known human carcinogens. For heavy-duty vehicles, reducing polyaromatics decreased NO_x, particles and hydrocarbon emissions (ACEA 1995).

4.2 STATE-OF-THE-ART EMISSION STANDARDS

This section establishes requirements for emission standards. Elements include stringent exhaust emissions standards for heavy-duty engines and complete vehicles, a prohibition of crankcase emissions for all heavy-duty vehicles, and evaporative emissions standards for spark-ignition (i.e. gasoline-powered) heavy-duty vehicles.

While the ICCT's model regulatory program does not define standards for greenhouse gas emissions from heavy-duty vehicles, ICCT does not expect industry to diminish truck fuel economy or increase greenhouse gas emissions in order to comply with our proposed requirements. Indeed, recent technology advancements have demonstrated that it is not technically necessary to trade reductions in one group of pollutants against reductions in another. In 2006, Japan finalized the world's first regulatory program to improve fuel economy from commercial trucks while simultaneously requiring stringent standards on conventional pollutants. In the United States, model year 2007 heavy-duty vehicles are expected to comply with stringent new emissions standards and at least one manufacturer has indicated a simultaneous 1 percent fuel economy gain. Hybrid technologies designed to improve fuel economy also achieve significant reductions in conventional and greenhouse gas emissions.[6] And one of the emerging NO_x control technologies — SCR — is expected to enable manufacturers to tune engines for higher engine-out NO_x emissions, and this in turn may result in better fuel economy.

4.2.1 Exhaust Emissions

This model rule sets out emission standards for diesel and gasoline engines, as well as complete heavy-duty vehicles between 3,855 and 4,535 kg (8,500 – 10,000 lb) and between 4,536 and 6,350 kg (10,000 – 14,000 lb) gross vehicle weight rating (GVWR, a measure that includes the vehicle weight plus carrying capacity). Complete vehicle standards are of comparable stringency to engine standards.

The exhaust emissions standards proposed for ICCT's model regulatory program are summarized in Table 4. The program includes emissions standards for PM, NO_x and non-methane hydrocarbons (NMHC) for new heavy-duty engines and for PM, NO_x, NMHC, and formaldehyde from complete heavy-duty vehicles.[7] Complete vehicle standards are included to provide flexibility for manufacturers of light and medium heavy-duty trucks.

4.2.2 Crankcase Emissions Control

Crankcase emissions are prohibited without exception under this model regulatory program for all heavy-duty engines. Crankcase emissions, also referred to as blowby gases, are the gases that are vented from the engine's crankcase in order to prevent high pressures from building up.

TABLE 4: Exhaust Emission Standards for Heavy-Duty Engines and Vehicles[1]

STANDARD TYPE	GVWR IN KG (LBS)	UNITS	NO_x	PM	HC	FORMALDEHYDE
Engines[2]	------	g/kWh (g/bhp-hr)	0.3 (0.2)	0.02 (0.01)	0.19 (0.14)	------
Complete Vehicles[3]	3,855 – 4,535 (8,500 – 10,000)	g/km (g/mi)	0.12 (0.19)	0.01 (0.02)	0.12 (0.19)	0.020 (0.032)
	4,536 – 6,350 (10,001 – 14,000)	g/km (g/mi)	0.25 (0.40)	0.012 (0.019)	0.14 (0.23)	0.025 (0.040)

[1] Values reflect the current, most stringent standards to date as adopted by the US EPA and measured under the US test procedure. The numerical values will need to be adjusted to fit the new worldwide harmonized test procedure.

[2] Compression ignition (CI) and spark ignition (SI)

[3] SI only

Historically, many countries have prohibited crankcase emissions from all highway engines, with the exception of turbocharged heavy-duty diesel engines. The most common way to eliminate crankcase emissions has been to vent the blowby gases into the engine air intake system, so that the gases can be re-combusted. For turbocharged heavy-duty diesel engines, however, this has raised concerns about fouling that could occur by routing the diesel particulates (including engine oil) into the turbocharger and aftercooler. These concerns are now alleviated by newly developed closed crankcase filtration systems, specifically designed for turbocharged heavy-duty diesel engines.

4.2.3 Evaporative Emissions

The ICCT's proposed model regulatory program includes evaporative emissions standards for heavy-duty engines and vehicles tested over a three-day and supplemental two-day cycle. These standards, summarized in Table 5, apply to heavy-duty gasoline-fueled vehicles and engines. Because of the lower volatility of diesel fuel, evaporative emissions are not a concern from diesel fueled vehicles. The standard for the two day diurnal plus hot soak test sequence would not apply to liquid petroleum gas (LPG) fueled and natural gas fueled HDVs.

TABLE 5: Evaporative Emission Standards for Heavy-Duty Vehicles

GVWR IN KG (LBS)	DIURNAL + HOT SOAK TEST (g/test)	
	3 DAY	SUPPLEMENTAL 2 DAY
3,855 – 6,350 (8,500 – 14,000)	1.4	1.75
> 6,350 (> 14,000)	1.9	2.3

This standard is closely linked to fuel volatility; these standards are based on the use of test fuel with a Reid Vapor Pressure of 60.0 to 63.4 kPa (8.7 to 9.2 psi).

4.3 WORLDWIDE CERTIFICATION TEST PROCEDURES

The test procedures used for type approval or certification of heavy-duty vehicles are important for two reasons: 1) to be able to correctly determine the impact of heavy-duty vehicle exhaust emissions on the environment, the test procedure needs to be adequately representative of real-world vehicle operation; and 2) in order for harmonized emissions standards to have meaning to vehicle and engine manufacturers, the certification test on which the emissions are measured must also be the same.

Over the course of the past fifty years, three major regulatory systems have evolved in the EU, Japan, and the United States with each using their own driving cycles and test procedures. Complying with each of these systems requires a certain degree of unique vehicle and engine design, and a large amount of unique and expensive testing to demonstrate compliance. A major technical impediment to combining vehicle regulatory systems in the EU, Japan, and United States into one comprehensive program has been the concern that driving characteristics are sufficiently different in each region that unique test procedures are needed. As illustrated in Figure 5, the US test procedure has tended to emphasize the high-speed portion of the engine map along with the idle portion. Conversely, the Japanese emphasize the lower-speed portion. Within the EU, the emphasis tends to be mostly on the mid-speed range. However, the spread of the EU vehicle program to countries as diverse as China and Brazil calls into question the assertion that each nation must develop its own unique certification test procedure.

Once adopted by major regulatory regions and nations (e.g. Europe, Japan, and the US), the ICCT recommends the use of the worldwide certification test procedure recently finalized by the World Forum for Harmonization of Vehicle Regulations (WP-29), a body of the United Nations Economic Commission for Europe.The key characteristics of the worldwide harmonized heavy-duty certification (WHDC) procedure, including transient and steady state test cycles representative of the worldwide pattern of heavy commercial vehicle use, were sketched out by WP-29 in 2006.[8] Compared with the measurement methods defined in existing international agreements, those test procedures reflect worldwide on-road heavy-duty engine operation as closely as possible and provide a marked improvement in the realism of the test procedure.

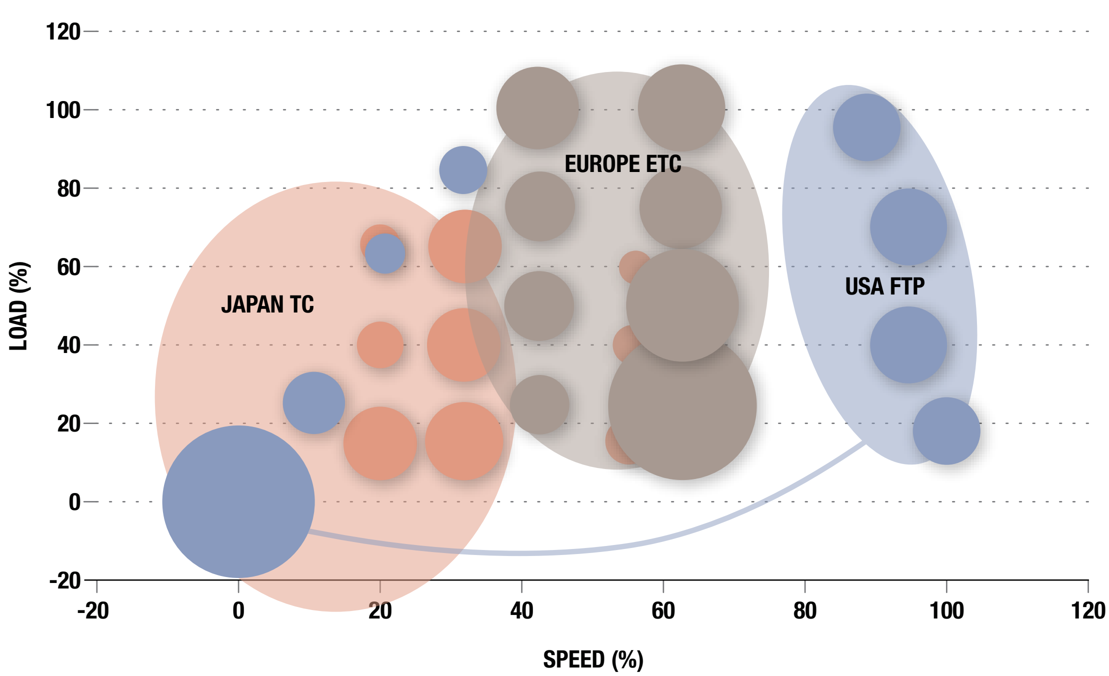

FIGURE 5: Portion of the engine map covered by current certification tests.

4.4 IN-USE COMPLIANCE AND ENFORCEMENT

This section addresses three key concepts related to in-use compliance and enforcement: (1) manufacturers are liable for and should design vehicles that can meet emissions standards for the full useful life of the vehicle; (2) in-use compliance with standards will be measured using not-to-exceed protocols; and (3) on-board diagnostics and monitors will be used in conjunction with fail-safe mechanisms to ensure that emissions controls are operating correctly. ICCT believes that all three of these elements should be adopted as a package.

Two of these issues are also working their way through the WP-29 approval process — harmonized global technical regulations for on-board diagnostics and off-cycle emissions (i.e. not-to-exceed standards). The ICCT looks forward to reviewing the final versions of these regulations.

4.4.1 MANUFACTURER RESPONSIBILITY

Successful in-use emissions performance of the pollution control system could be jeopardized if the manufacturer were to design systems that require more extensive or more frequent maintenance than one can reasonably expect the operator to perform. Therefore, this program requires that manufacturers shall warrant to the initial purchaser and each subsequent purchaser that the vehicle and engine is designed, built and equipped to conform at the time of sale with all applicable regulations, and the vehicle or engine is free from defects in materials and workmanship which would cause the vehicle or engine to fail to conform with regulations at any time throughout its full useful life. In this model regulatory program, useful life for heavy-duty diesel vehicles and urban buses is defined as either ten years, or in terms of the distance thresholds by vehicle weight class shown in Table 6, whichever comes first.

If substantial numbers of properly maintained and used heavy-duty vehicles and engines are found to be out of compliance, manufacturers will be required to initiate a recall campaign to repair defective engines or components.

Heavy-duty diesel engines — particularly the largest class that power long-haul tractor-trailer trucks and urban buses — are

TABLE 6: Regulatory Useful Life Requirements by Weight Classes

CLASS	GVWR IN KG (LBS)	USEFUL LIFE IN KM (MI)
Light heavy-duty	3,855 – 8,844 (8,500 – 19,499)	177,000 (110,000)
Medium heavy-duty	8.845 – 14,968 (19,500 – 33,000)	298,000 (185,000)
Heavy heavy-duty	> 14,968 (> 33,000)	700,000 (435,000)

often rebuilt because rebuilds are cheaper than purchasing an entirely new engine. This model regulatory program requires that rebuilt engines must achieve the same environmental performance as specified in their original type approval or certification. Manufacturers must also ensure that any ongoing emission control requirements will be widely available. For example urea must be easily accessible for all trucks that are using SCR systems. Finally, manufacturers will be responsible for conducting in-use testing on a random selection of vehicles each year, according to specified protocols, with all data collected to be provided to the appropriate government authorities. It should be emphasized that such manufacturer testing will in no way preclude government controlled testing; in fact such independent government controlled testing is encouraged.

4.4.2 Not-To-Exceed (NTE) Limits

The ICCT proposes an additional element of certification and in-use compliance that would require each heavy-duty engine or vehicle certification to include a statement that the diesel heavy-duty engine family will comply with the emission limits when operated under all conditions which may reasonably be expected to be encountered in normal vehicle operation and use. The proposed requirement is modeled after the United States' Not-To-Exceed (NTE) regulations and ongoing efforts in the UNECE to develop a World Harmonized Not-To-Exceed (WNTE) global technical regulation. NTE protocols will help to ensure that engines will operate at or below the lawful emission limits on the road by requiring that emission control technologies are effective under all normal operating conditions.

The NTE procedure defines limited and specific engine operating regions (i.e., speed and torque conditions) and ambient operating conditions (i.e., altitude, temperature, and humidity conditions) that are subject to the NTE emission standards. The test covers the portion of the engine map derived from the speed frequency distribution of the test cycle. Emission results from this test procedure must be less than or equal to the emission standards for NO_x, NMHC, and PM as adjusted by an NTE factor.

Over the last several years, it has become clear that in-use emissions might inappropriately exceed the applicable emission limits when engines were operated under conditions not found during traditional laboratory testing (i.e., off-cycle emissions). The growing sophistication of engine technology and advanced electronic control systems has greatly increased the potential that emission control systems will be modified under conditions not included or under-represented on the laboratory test procedures, resulting in substantially higher emission levels under actual driving conditions. For this reason, the proposed not-to-exceed standard is an important step forward to ensure emission limits are met in-use, under a wide range of operating conditions.

Protocols for regulating off-cycle emissions under the WNTE global technical regulation are scheduled to be completed by early 2009, although concerns have been raised by some participants that proposed test procedures do not adequately cover the full range of urban driving conditions in Europe. It is expected that alternative test procedures to cover a wider range of in-use operating conditions will be adopted at a later date, either through amendment of the current rule or through the creation of an additional regulation.

4.4.3 Onboard Emissions Requirements

Modern vehicles with on-board computers can monitor a vehicle's emission control system and report potential malfunctions. Systems that monitor emission control equipment as a means of determining if there are potential emissions exceedences are called on-board diagnostics, or OBD. ICCT recommends that new heavy-duty vehicles employ these systems to help ensure in-use compliance with emission standards over the vehicle's full useful life.

OBD systems monitor key pollution control components to identify any malfunctions that could cause the vehicle to exceed the emissions standards. When the computer system of the vehicle identifies a fault in the emission control system, three things happen. First, a warning light on the dashboard informs the driver that a problem exists. Second, any excursions over the designated thresholds is stored on the vehicle's on-board computer with non-deletable memories. To be accepted, systems must continue to store data even if the power to the on-board computer is disconnected. Third, a code is recorded in the computer's memory that can later be retrieved by a technician for diagnosis and repair.

As discussed previously, one of the technologies emerging for control of NO_x emissions — selective catalytic reduction — requires the periodic addition of a chemical reagent such as urea to be effective. OBD systems should be designed to require proper use of urea, with performance of the vehicle severely curtailed within a short time if sufficient reagent is not added to the vehicle.

An emerging technology for ensuring in-use compliance are devices that directly measure vehicle emissions, called portable emissions monitoring systems (PEMS) or on-board monitors (OBMs). These devices are currently used to gather real world emissions data from on-highway and non-road vehicles in order to improve the accuracy of emissions inventories. In the future, it may be possible to incorporate these devices into on-board monitoring systems.

5. CONCLUSIONS

Heavy-duty trucks and buses are a major source of pollution across the world and cause or contribute to serious ozone, particulate matter and nitrogen dioxide air quality problems in many cities. As the World Health Organization noted in its recent air quality guidelines, these pollutants are the cause of a wide variety of adverse health effects and in some cases even premature death.

This report has placed a special focus on controlling emissions from heavy-duty trucks and buses not only because they are a serious source of adverse health effects but also because, in our view, they provide a unique opportunity for global regulatory program alignment. Global alignment could substantially reduce the costs of compliance with standards in many countries and accelerate the introduction of cleaner trucks and buses. In particular, we have noted and appreciated the European Commission's leadership in convening the CARS 21 high-level group. Their report also called for harmonized heavy-duty vehicle regulatory programs and stated that:

> *Regulation on heavy-duty vehicle emissions is a potential area for global harmonization. While the preparatory work for the next stage requirements in the Community should go on, the possibility of reaching international harmonization in this area is recommended, in particular with regard to the development of global technical regulations on emission test cycles (both steady and transient cycles), off-cycle emissions and on-board diagnostic systems. International emission limit values should be agreed on the basis of the above test procedures. The long-term aim should be the adoption of worldwide emission standards.*

While recognizing that legislative systems differ across the world, making full harmonization difficult, the alignment of technical requirements as described under this model rule seems feasible and likely to provide significant environmental, health, and economic benefits.

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ENDNOTES

[1] Public health benefits were estimated to outweigh compliance costs by a factor of 16:1 for the U.S. heavy-duty vehicle rule promulgated in 2001 and 40:1 for the U.S. regulation affecting non-road (e.g. construction, agriculture, etc.) vehicles and equipment promulgated in 2004. In Mexico, public health benefits from stringent emission standards for passenger vehicles and heavy-duty trucks and buses, combined with ultra-low sulfur gasoline and diesel fuel, are estimated to exceed compliance costs by a factor of 10 to 20 for the nation, and up to 40 times for Mexico City.

[2] Five parameters influencing the emissions profile of vehicles under the worldwide harmonized test procedure include options to be finalized by 2009. See Section 4.3 for further details.

[3] The US HD07 regulatory program phases in NO_x emission standards from 2007 to 2010. In practice, this provides engine manufacturers with an interim NO_x emission standard of 1.61 g/kWh from 2007 to 2009.

[4] The 11 cities are New Delhi, Mumbai (Bombay), Kolkata (Calcutta), Bangalore, Chennai, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, and Agra.

[5] For more detail on the importance of reducing sulfur in transportation fuels, readers are encouraged to read the 2003 ICCT report Low-Sulfur Gasoline & Diesel: The Key to Lower Vehicle Emissions.

[6] A recent evaluation of the New York City hybrid electric buses found a 50 percent reduction in NO_x, a 60 to 90 percent reduction in PM, with fuel efficiency gains of 20 to 40 percent (Hybrid Vehicles 2005).

[7] When and if the World Harmonized Test Procedure is adopted by the EU, Japan and the US, these limits will be adjusted accordingly. Also, the EU is expected to include a number based PM standard in its Euro VI requirements. At that time ICCT will consider adding such a requirement as well.

[8] Five test parameters under the WHDC (net versus gross engine power determination, the reference fuel specification, the length of the hot soak period, the cold-start weighting, and the size and material of the test filter for PM) include various options to be finalized by 2009. In the interim, the EU has already declared its intention to use the WHDC, along with the established EU conventions for these five parameters, as the basis for its Euro VI standard.

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