

AUGUST 2013

Survey of Best Practices in Emission Control of In-Use Heavy-Duty Diesel Vehicles

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Acknowledgements

The International Council on Clean Transportation (ICCT) is a non-state partner organization in the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC). The work on which this report is based contributes to the CCAC's Heavy-Duty Diesel Initiative, of which the ICCT is the lead partner. For more information about the CCAC in general and its actions to reduce black carbon emissions from heavy-duty diesel vehicles in particular, visit www.unep.org/ccac. The views and conclusions in this report do not necessarily represent those of individual CCAC partners.

In addition to the CCAC, the ICCT receives generous support from the ClimateWorks and Hewlett Foundations. The authors are grateful for the contributions of Colin Murphy of the University of California, Davis, and review by Nic Lutsey.

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Abstract

There are many ways to improve air quality and reduce the climate-forcing impacts of vehicle use. Often overlooked in discussions of advanced vehicle technology and alternative fuels are the various approaches that can impact the existing stock of in-use vehicles. Whereas new vehicle manufacturer developments and new standards for vehicles, low-sulfur fuels, and low-carbon fuels are enormously beneficial in the long term, they do not so fundamentally alter the older stock of much higher-polluting vehicles that are on the road for 10 to 20 years on average. This paper focuses on ways to reduce the emissions of the in-use vehicle fleet, with particular emphasis on heavy-duty diesel trucks, due to their disproportionate contribution to both urban air quality and greenhouse gas emissions. The report surveys measures that are in effect across the world, including programs that help identify vehicles that disproportionately contribute to overall emissions; administer inspection, maintenance, and in-use emission testing protocols to help eliminate gross-emitting vehicles; assist in the effective deployment of retrofit emission control technology; and promote improved fuel quality to directly reduce emissions and facilitate improved emission control technology. The work highlights a number of national, regional, and local examples of effective emission control programs that exhibit best practices from around the world. The report concludes by summarizing the critical actions that can be undertaken at national and local levels to install world-class emission control programs for in-use heavy-duty vehicles.

Chapter 1: Introduction

Modern motorized transport has been instrumental in promoting personal mobility and economic development throughout the last century. However, the rapid proliferation of motor vehicles has also had significant negative consequences, including urban air pollution, rising petroleum consumption and greenhouse gas emissions, congestion, accidents, and more. Managing the externalities associated with motorized transport, while still maintaining the associated economic benefits, has become a major challenge for policymakers worldwide.

This report summarizes policy approaches to controlling in-use emissions from heavy-duty vehicles (HDVs), including freight trucks, buses, municipal government and other service fleets (garbage and sanitation trucks, fire trucks, etc.). HDVs are almost exclusively commercial vehicles, transporting people and goods, delivering services, and performing vocational tasks. Some representative HDVs are shown in Figure 1.¹



MUNICIPAL POSTAL TRUCK IN CHINA



URBAN BUS IN NEW YORK CITY



FREIGHT TRUCKS IN EUROPE



FIRE ENGINE IN JAPAN

Figure 1: Examples of HDVs around the world.

HDVs, while typically accounting for only a small percentage of a region's vehicle fleet, emit a disproportionate share of total emissions of certain pollutants, especially

¹ All photos from commons.wikimedia.org. Credits, clockwise from top left: Dongfeng truck, 2009, Michael Pham; MTA NYC Orion 5 Q65 bus, 2012, Mtatrain; Nissan Diesel Resona, 2009, TTTNIS; TNT Articulated Solo Trucks, 2009, John Carver

particulate matter (PM) and nitrogen oxides (NO_x). In addition, many HDVs have useful lifespans of 20 years or longer. Even when emission standards are implemented for new vehicles on an aggressive timeline, it typically requires decades before the oldest, highest-emitting vehicles are retired from service and those standards cover the entire in-use fleet. Managing emissions from legacy heavy-duty in-use fleets is therefore a key strategy for achieving rapid improvements in urban air quality.

The control of heavy-duty vehicle emissions presents unique challenges for policy-makers. First, HDVs exist in thousands of different configurations operating across highly variable duty cycles. This huge scope of application and operation requires the careful design of control programs targeting different classes and types of HDVs, such as the establishment of detailed, specific retrofit certification programs. Second, HDVs play a critical role in virtually every sector within the economy, and older vehicles are often owned and operated by small business owners and/or self-employed individuals. Providing flexibility, fiscal incentives, subsidies, and/or loan assistance programs in parallel with mandatory control programs may be warranted. This is especially true in certain freight and vocational HDV sectors that can be highly fragmented in many regions, and in which vehicle owners may be quite sensitive to capital equipment and operation costs.

At the same time, policymakers may take advantage of certain opportunities in the control of in-use HD emissions relative to passenger vehicles. For example, certain emission control solutions—fuel switching, some retrofit technologies, and advanced technology vehicles—can be well suited for application on specific HDV fleets due to their centralized management and relatively predictable duty cycles (e.g., municipal bus or service vehicles). Similarly, local-level policymakers may be able to deploy more aggressive strategies on municipal vehicles operating exclusively in their administrative regions than national-level policymakers can on an entire fleet nationwide.

This report surveys a variety of emission control strategies for different categories of in-use HDVs, demonstrating that multiple, effective emission control solutions exist for most fleets in both developed and developing countries. The purpose of this report is to describe the full suite of control options available, to introduce specific implementation considerations, and to provide concrete examples of where such programs have been implemented successfully. In most cases, a combination of multiple control strategies will achieve the most effective and rapid emission reductions, while simultaneously giving manufacturers and consumers appropriate flexibility, regulatory certainty, and technology options.

Where applicable, clear distinctions between national, regional, and local regulatory roles are presented. In general, national-level agencies have the authority to set minimum emission standards for new vehicles and fuels, establish the legal basis for in-use emission controls, provide high-level guidance and targets, and arrange technical assistance to local-level officials. Local-level authorities, in contrast, select and implement individual programs based on specific local conditions, taking into account the local nature of air pollution problems and capabilities to target pollution sources of highest interest. This report presents specific examples from both the national and local levels, and directs readers to resources where more detailed

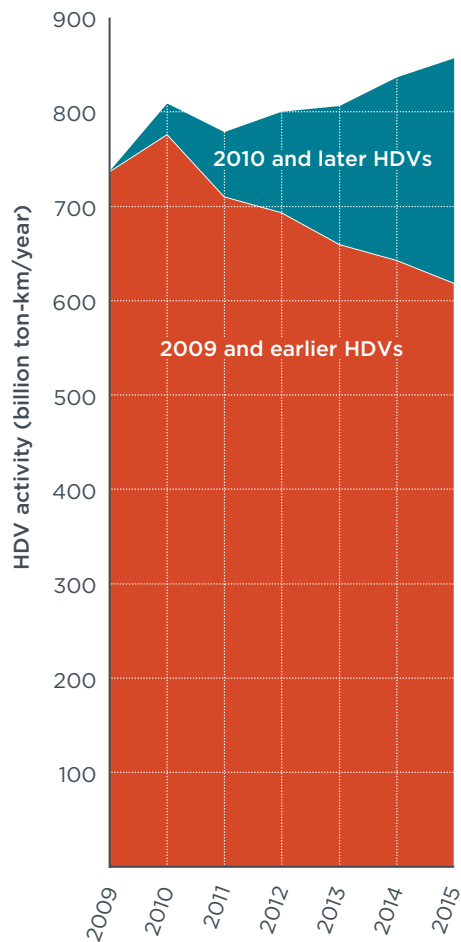
information can be found.

The primary focus of this report is the control of in-use emissions, meaning emissions from existing vehicles in the fleet (i.e., as opposed to newly manufactured vehicles). Although not the focus of this report, addressing emissions from new vehicles is a foundational piece of any comprehensive, long-term plan to improve local air quality. Effective policies will include stringent emission standards, representative test cycles, and means of requiring manufacturers to ensure that vehicles they produce remain clean in use, including durability requirements, conformity of production requirements, and robust in-use testing provisions (Walsh, 2007).

However, even in cases where world-class new standards are adopted, the implementation of such regulatory standards may be gradually phased in over a period of multiple years, followed by a 10-to-20-year period during which older equipment is retired and replaced by newer, cleaner vehicles. Because of this time lag between the start of new emission standards and their effect on the average emissions from the existing fleet, in-use emission control policies offer powerful near-term options that complement new vehicle regulatory standards (see box).

New vehicle emission standards versus the older in-use vehicle fleet

Within the next five years, nearly every major industrial nation—including the United States, Canada, Mexico, Japan, the members of the European Union, China, India, Brazil, and Australia—will have HDV emission standards that will reduce tailpipe emissions of smog precursors (e.g., NO_x and hydrocarbons) and particulate emissions of new vehicles by more than 90% compared to mid-1990s model year vehicles. Although these standards will result in major gram-per-kilometer emission reductions for new vehicles, the slow turnover of HDVs will limit their near-term effects. For example, the new U.S. EPA standards for model year 2010 and later heavy-duty trucks affect less than 5% of all HDV activity in 2010 and less than a third of activity by 2015. The delayed penetration of new vehicle standards, in turn, limits their ability to quickly improve local air quality and reduce CO₂ emissions from freight transport. In contrast, the in-use measures addressed in this report have the potential to impact the existing in-use stock of vehicles in the near term.



Health impacts of heavy-duty vehicle emissions

Heavy-duty vehicle use has a substantial and growing impact on human health. Millions of people worldwide live in areas where poor air quality endangers public health and welfare. The most recent Global Burden of Disease study estimated that over 3.2 million people die prematurely each year as a result of outdoor air pollution (Lim et al, 2012). Although the relative contribution of motor vehicles varies by region, they are typically the most important pollution source in urban areas. For example, in 2010 the Chinese Ministry of Environmental Protection announced that vehicle emissions had become the dominant source of urban air pollution, and that more than one-third of Chinese cities could not meet the country's ambient air quality standards (MEP, 2010a). In India, a Ministry of Environment and Forests air quality summary report in 2011 noted a "severe" particulate matter pollution problem and rising NO₂ concentrations in many major urban areas, with the transportation sector noted as a significant contributor, particularly at curbside monitoring locations (CPCB, 2011). Health impacts depend not only on emissions, but also exposure. Across the world, high air pollution levels near roadways mean that residents of dense urban areas are at particularly high risk (McConnell et al, 2006; Zhu et al, 2002). Without aggressive efforts to reduce emissions from motor vehicles, people in cities throughout the world will continue to breathe polluted air for the foreseeable future.

Emissions from diesel-fueled HDVs are particularly worrisome. Diesel engines are widely used around the world in commercial and HD applications due to their higher efficiency, better torque at low engine speeds, reliability, and durability. However, diesel exhaust, which is made up of numerous gaseous and solid chemical compounds, is widely recognized to be harmful to human health. Specific emissions of concern include ozone precursors, such as NO_x and volatile organic compounds (VOCs); particulate matter (PM) and PM precursors (e.g. NO_x and SO_x); and toxic and carcinogenic compounds such as formaldehyde. Known human health effects of diesel exhaust include cancer (especially lung cancer), heart disease and stroke, asthma, bronchitis, and other respiratory infections and diseases, as well as acute effects such as irritation, lung function changes, headaches, nausea, and fatigue (e.g. IARC, 2012; Kagawa, 2002; Sydbom et al, 2001; CARB, 1998). These result in significant societal losses in the form of premature deaths, lost productivity and increased medical spending for hospital admissions and emergency room visits, reduced learning due to school absences, work losses, restricted activities, and more.

Many of the acute health effects caused by diesel exhaust are linked to particle size. Many diesel particles can penetrate into the deepest portion of the lungs due to their small size (below 100 nm, or 0.1 μm, in aerodynamic diameter), where they can pass through cell walls and be transported via the bloodstream to other organs of the body (Gehr, 2010; Prasad and Bella, 2010). Smaller particles also provide a large surface area for adsorbing toxic organic compounds.

HDVs, both new and in-use, are attractive targets for policymakers hoping to reduce PM and NO_x emissions. Due to a combination of higher operation rates (e.g., vehicle kilometers traveled each year) and elevated emission factors, diesel HDVs are responsible for a disproportionately high share of PM and NO_x emissions from motor

vehicles in both developed and developing countries. In addition, in many regions around the world HDV emission control programs have lagged behind programs for passenger vehicles. Table 1 summarizes the relative contribution of HDVs to fleets and highway emission inventories for several countries and regions around the world. In nearly every major country, HDVs represent less than 5% of the vehicle population but 40-60% of the on-road NO_x and PM emissions.

Table 1: Examples of HDV shares of total highway vehicle emissions around the world

Region	Year	HDV percent of vehicle fleet	HDV percent of vehicle PM emissions	HDV percent of vehicle NO _x emissions	Reference
California	2008	1%	44%	48%	CARB, 2009
China	2009	4%	57%	40%	MEP, 2010b
Brazil	2009	3%	45%	46%	MMA, 2011

Within the HDV sector, emissions of older HDVs are of particular concern. A single, uncontrolled HDV may emit as much pollution per kilometer as dozens of vehicles meeting a modern, advanced emission standard.² In China in 2009, uncontrolled “pre-Euro vehicles”—vehicles that entered the fleet prior to 2000—accounted for only 17% of the highway vehicle fleet but emitted 56% of PM and 50% of total NO_x emissions (MEP, 2010b). In Brazil in 2009, 28% of diesel vehicles were certified to the older Pre-Proconve, P1, and P2 standards yet emitted 50% of total particulate matter (MMA, 2011).

Climate impacts of heavy-duty vehicle emissions

In addition to their effects on local air quality, HDV emissions also contribute to global climate change. The primary greenhouse gas emitted by HDVs is carbon dioxide (CO₂), formed as a direct result of the combustion of diesel fuel. In developing countries with lower car ownership rates, HDVs account for a far larger share of transport sector oil consumption and CO₂ emissions than the countries’ populations might suggest.

Figure 2 illustrates the contribution of HDVs to transport sector CO₂ emissions. The HDV share of total transport CO₂ emissions is highest among all sources in China, India, Brazil, and Mexico, and second highest in the United States. This disproportionate contribution to CO₂ emissions and energy consumption is particularly notable for countries like China, where the heavy-duty CO₂ emissions are 44% in 2010 and projected to increase to 48% by 2030. In Brazil, buses and trucks accounted for just 4% of the vehicle fleet in 2009 but more than 50% of CO₂ emissions from all vehicles (MMA, 2011). In China, trucks are currently the largest consumer of oil among all highway vehicles and are expected to remain so until at least 2050, even as the population of passenger cars continues to grow rapidly (Wang et al, 2006).

² For example, in the European COPERT emission inventory model, the baseline NO_x and PM_{2.5} emission factors for a pre-Euro HD diesel truck are 30 and 15 times higher, respectively, than those of a Euro VI truck.

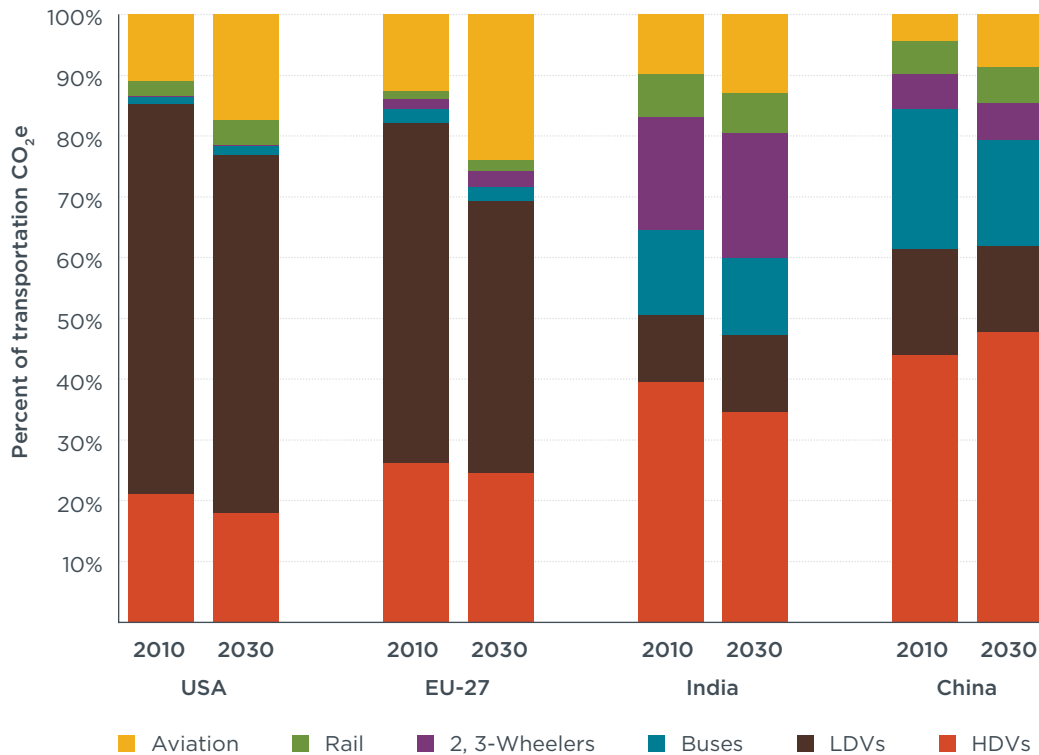


Figure 2: Relative modal contribution to transport CO₂-equivalent inventory
(Source: ICCT Transportation Roadmap Model)

In addition to diesel-related CO₂, recent research suggests that diesel particulate matter, long known to be damaging to human health, is also a strong contributor to global climate change. The dominant fraction of particulate matter emitted by diesel vehicles is black carbon, commonly called soot. Black carbon contributes to climate change in multiple ways, including direct warming, promoting snow and ice melt by reducing the albedo of white surfaces, and more (Kopp and Mauzerall, 2010; Molina et al, 2009). Black carbon may be the second strongest anthropogenic climate-forcing agent behind carbon dioxide (Ramanathan and Carmichael, 2008). However, unlike other greenhouse gases, black carbon has an atmospheric lifetime of just several weeks. Therefore, targeting black carbon emissions, particularly from in-use vehicles, may represent a short-term strategy for rapid climate change mitigation while also providing significant human health benefits.

Ultimately, better controls of both conventional pollutants and greenhouse gases (GHGs) from HDVs are desirable. Fortunately, many of the control strategies described in this report address both types of emissions simultaneously. Indeed, considering the air quality and climate benefits together (so-called “co-benefits”) of a given vehicle emission control program may be critical to assessing the necessity of the program in advance and evaluating its effectiveness. For example, fuel efficiency improvements tend to have net benefits, given that upfront capital costs are more than offset by vehicle users’ associated fuel-saving benefits.

Overview of strategies

Controlling emissions from in-use HDVs will remain a key priority as long as policymakers around the world face the dual challenges of air quality and climate change. This report, which highlights international best practices in the control of in-use emissions from on-road diesel vehicles, is meant to serve as a general reference guide for policymakers designing and implementing in-use emission control strategies. Appropriate policy and technology options are presented along with information on when and how they may be used effectively. Wherever possible, detailed case studies at both the national and subnational levels are described.

In this report, five overall categories of in-use emission control solutions are described:

- 1. Target gross-emitting vehicles:** Characterizing vehicle emissions and identifying gross-emitting vehicles through programs such as inspection and maintenance (I&M) (Chapter 2);
- 2. Use cleaner fuels:** Programs to promote the use of cleaner fuels that lower emissions either directly or by facilitating the use of advanced emission control technologies (Chapter 3);
- 3. Scrap older vehicles:** Programs to replace existing high-emitting vehicles with cleaner ones (Chapter 4);
- 4. Retrofit high-emitting vehicles:** Programs to reduce in-use emissions by installing aftertreatment control technologies, replacing the engine, or by reducing aerodynamic drag where significant useful vehicle life remains (Chapter 5); and,
- 5. Employ complementary strategies:** Complementary emission reduction programs, including behavioral change incentives and transportation network improvements (Chapter 6).

Individual solutions are described in detail in each respective chapter, while Chapter 7 summarizes the report's conclusions, with special emphasis on the respective roles of national and local policymakers in implementing effective policies and programs to reduce in-use emissions.

Chapter 2: Target gross-emitting vehicles

This chapter describes critical background, characterization, and baseline control efforts that may be implemented in almost all regions of the world. The foundational best practices introduced here may be undertaken in parallel with other in-use emission control programs presented in the remainder of the report. Two general categories of best practices are introduced here: fleet characterization and programs to identify and prevent gross emitters.

Characterization of the fleet

Although the absence of detailed fleet characterization need not delay aggressive control action, creating a good understanding of current emission levels will be instrumental in developing targeted, effective control programs. This is especially important in jurisdictions in which policymakers need to prioritize limited resources. Perhaps the most core emissions characterization activity is the establishment of an emissions inventory—an accounting of the total emissions from different types of vehicles. Emissions inventories allow policymakers to identify priority areas or types of vehicles for control, as well as to track progress over time. Advanced inventories may also provide inputs into ambient air quality models for evaluating the impact of specific control efforts on ambient pollutant concentrations.

At the national level, policymakers typically have responsibility for establishing base model structure and default inputs, training local policymakers on model operation, and comparing and integrating regional or local model outputs into a national-scale emissions evaluation. Local-level policymakers typically collect localized data inputs for the models, run the models, and report results to national authorities. Local authorities may also perform custom or project-based modeling consistent with local needs and circumstances.

For the development of a vehicle emissions inventory, required inputs typically include the vehicle population, activity levels, and emission factors by vehicle and fuel type. For certain pollutant inventories (for example, CO₂ inventories), total fuel consumption may also be used as an input. In cases where local data are not available (for example, emission factors for specific vehicle types), established domestic or international models may be used by identifying representative vehicles with equivalent technology levels.

There are multiple international precedents for emissions inventory and emission factor software models. Certain models are applicable for national-level inventories, while others are more targeted towards city or even smaller-scale evaluations. A brief overview of the primary existing, publicly available models is presented in Table 2. A detailed discussion on the selection and application of these models is beyond the scope of this report and has been covered by other authors (e.g. Lents et al, 2011).

Table 2: Existing vehicle emission inventory models

Model name	Region(s) used	Type	Link
MOVES	U.S.	Multiple-scale emissions inventory modeling	http://www.epa.gov/otaq/models/moves/index.htm
MOBILE	U.S., Mexico	Emission factor estimation	http://www.epa.gov/oms/m6.htm
EMFAC	California, Hong Kong	Emission factor estimation	http://www.arb.ca.gov/msei/onroad/latest_version.htm ; http://www.epd.gov.hk/epd/english/environmentinhk/air/guide_ref/emfac.html
COPERT	Europe	Emissions inventory modeling	http://www.emisia.com/copert/
HBEFA	Europe	Emission factor estimation	http://www.hbefa.net/e/index.html
IVE	Various cities	City-level emissions inventory modeling	http://www.issrc.org/ive/

The development of a baseline vehicle emissions inventory does not have to be limited to developed countries. Experience in Mexico, China, and Brazil shows that reasonable, first-order inventory estimations may be made even in countries with limited data availability. The Mexican government developed a first-ever vehicle emissions inventory using a modified version of the EPA's MOBILE emission factor software (U.S. EPA, 2006). In Brazil, IEMA, a nongovernmental organization, developed an inventory for Brazilian motor vehicles covering 1980–2020; the inventory was ultimately adopted by the Brazilian Ministry of Environment and released as the official national inventory (MMA, 2011). In China in 2007, the Ministry of Environmental Protection (MEP) launched a multiple-year effort to develop a nationwide Pollution Source Census (Xinhua, 2010). As part of the effort, Chinese policymakers developed a China-specific emissions inventory model, and subsequently released a first-ever Motor Vehicle Emission Control Annual Report detailing trends and emissions shares for China's highway vehicle fleet (MEP, 2010b). The results of the inventory were instrumental in both setting specific pollutant reduction targets for China's 12th Five-Year Plan (2011–2015), as well as developing individual programs to meet those targets.

The characterization of the vehicle fleet via an emissions inventory is a core foundation for a strong vehicle emission control program. The creation of an emission inventory is not a discrete project, but rather an ongoing task, a fact with two implications for policymakers. First, as mentioned earlier, the completion of a detailed emissions inventory should not be viewed as a prerequisite for the adoption of emissions control programs based on international best practices. Second, whenever possible emission inventories should be continually refined based upon the latest data, including real-world emission factors from portable emission measurement system (PEMS) testing, emission factors estimated from tunnel or chase studies, and data from ambient air quality monitors, chemical speciation source apportionment studies, and so on.

Identifying and mitigating effects of gross-emitting vehicles

Regulators have developed several approaches to identify and prevent gross-emitting vehicles that pollute far more than expected based on their certified emission standards. Foremost are strong regulatory compliance programs that legally bind manufacturers to keep vehicles within certified emission limits for their useful life. In addition, there are programs that help facilitate the inspection, monitoring, and maintenance to ensure that the initially certified emission levels are maintained over time. This section surveys these types of programs for gross-emitting vehicles.

Compliance programs to ensure that vehicles continue to meet the emission limits to which they are certified throughout their useful lives are an equally important component of an effective vehicle emission management program. These programs contain multiple components, many of which are explicitly established alongside emission standards for new vehicles as part of the type certification process. These components include requirements on emission control durability and on-board diagnostics, limits on off-cycle emissions, clear expectations for conformity of production (COP) testing or selective enforcement audits (SEA), and systematic laboratory and/or real world in-use compliance (IUC) testing. In the United States, which has the world's best developed compliance programs, the primary burden for testing is borne by the manufacturers themselves, with the EPA conducting confirmatory testing only if investigating some specific suspected problem. Manufacturers have a strong incentive to self-police because the EPA has authority to require manufacturers to recall vehicles or enforce strict fines for noncompliance (Walsh et al, 2007).

The development of a robust, comprehensive in-use compliance program linked to new vehicle emission standards is the most effective way of ensuring that a vehicle's emissions remain controlled for its entire useful life. However, in parallel with the introduction of comprehensive compliance requirements for new vehicles, policymakers also have several tools they can use to enforce compliance of the in-use vehicle fleet.

Even the most robust compliance program cannot prevent all vehicles from having excessive emissions. Many factors, including level of maintenance, technology malfunction, vehicle age and use, engine part deterioration, user tampering, and overloading can lead to vastly higher than average regulated emission levels. Such vehicles are generally and popularly referred to as "gross emitters."

Gross emitters emit pollution well in excess of the levels at which they were certified. Vehicles may become gross emitters for a variety of reasons. Although on-board diagnostic (OBD) technologies do exist to alert a driver of emission control failures or excessive emissions, these technologies have only just begun to be deployed on HDVs.³ Even after these OBD requirements take effect, it will be many years before they have widespread penetration into the in-use fleet.

³ In the United States, OBD systems on HDVs began to be phased in in 2010. The systems monitor NO_x emissions as well as proper functionality of the diesel particulate filter (DPF) for PM control (though the OBD system does not measure PM directly) (U.S. EPA, 2008).

In the meantime, policymakers have several options for the identification of gross-emitting vehicles. Where feasible, efforts to collect data on the causes of excess emissions, coupled with programs to catch individual gross emitters, will help prevent future problems. Whether excessive emission levels are caused by manufacturing defects, improper fueling, poor maintenance, overloading, tampering, or other reasons can influence how to best identify and attempt to remedy their high emission levels.

Inspection and maintenance (I/M) programs require vehicle owners to regularly submit their vehicles to a certified emissions test, with vehicles with emissions exceeding a certain threshold generally required to undergo repair or maintenance. Many different I/M approaches have been tried globally, with various system designs, testing methods, pass/fail cut points, fees and incentives, etc. Experience suggests that successful I/M programs that are very carefully planned and implemented are most likely to be cost-effective and receive public support (USAID, 2004).

In most places, including the United States, the I/M experience has been mixed. Although I/M programs are required in areas not meeting ambient air quality standards and are a regular part of State Implementation Plans (SIPs) for improving air quality, analyses of those programs have shown that actual reductions from the programs have generally been much lower than expected due to overly optimistic assumptions about consumer compliance, gross emitter identification rates, and the effectiveness of repair.

Historically, I/M programs have targeted light-duty vehicles only due to challenges associated with the testing of HDVs, including the lack of inexpensive means of testing PM and NO_x emissions—the two primary pollutants of concern from diesel vehicles—for individual HDVs under a transient, loaded test. Instead, most HDV I/M testing around the world has focused exclusively on visible smoke by means of the “snap-idle” opacity test as defined by SAE J1667 (St. Denis and Lindner, 2005). Although opacity measurements for light duty I/M testing are useful, they are not effective for HDVs when attempting to address emissions of ultrafine particles and NO_x. In some cases, repairs to reduce visible smoke may actually increase both the number of ultrafine particles and NO_x emissions (St. Denis and Lindner, 2005). In addition, studies have shown that opacity is a relatively poor predictor of total PM mass (McCormick et al, 2003).

Due to these drawbacks, regulatory authorities throughout the developed world, including in the United States, Europe, and Japan, have relied more upon OBD than I/M testing to identify gross emitters. However, the development of new test methods and equipment for measuring emissions of ultrafine particles and NO_x from in-use HDVs is an active area of research in the developed world. China is actively engaged in the development of a nationwide I/M system for evaluating NO_x emissions from in-use HDVs as part of efforts to meet the NO_x reduction goals outlined in the 12th Five-Year Plan. China’s Ministry of Environmental Protection also plans to link all testing centers to a centralized database for easier monitoring of test facilities and identification of vehicle problems across multiple regions.

There are also a number of methods to identify gross emitters that do not involve direct emission measurements. Remote sensing entails determining a vehicle’s

exhaust composition using beams of infrared light (to estimate concentrations of CO₂, CO, and HCs) and/or UV light (to estimate concentrations of NO_x) passed through a vehicle's exhaust plume during operation. Remote sensing is currently not accurate enough to determine discrete emission factors for individual vehicles, although it can be a useful tool in identifying gross emitters, evaluating fleet-wide trends over time, and evaluating the effectiveness of I/M programs. Figure 3 (reproduced with permission from Lents et al, 2011) shows a typical remote sensing setup. A camera records vehicle information so that policymakers may identify the vehicle owner and require him or her (or provide fiscal incentives) to take steps to retest and clean up the vehicle.

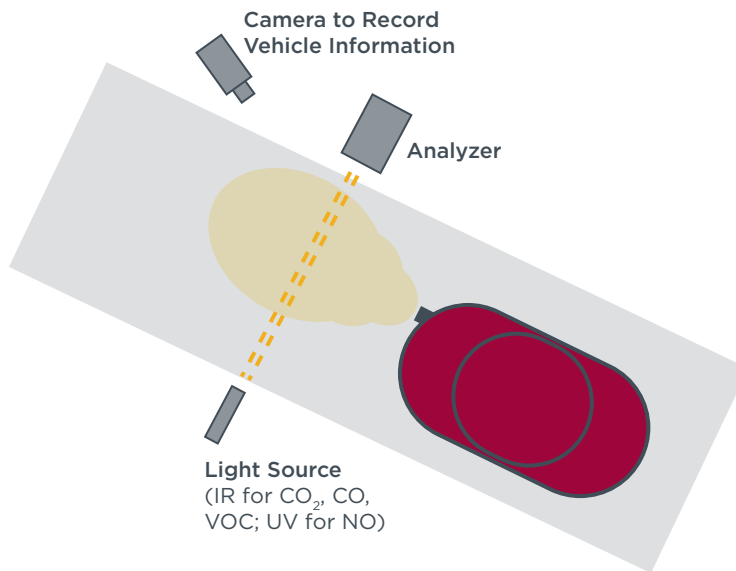


Figure 3: Typical remote sensing setup

Choosing a location for remote sensing can be a challenge. To obtain useful data, the remote sensing system must be positioned to detect the exhaust plume of a single vehicle operating under load—thus, a freeway on-ramp with accelerating vehicles may make a good location. Other challenges include preventing drivers from cheating by intentionally not accelerating as they pass, and establishing enough remote sensing systems to adequately cover the entire vehicle fleet.

Although remote sensing holds promise, policymakers have struggled to integrate such systems into mandatory enforcement programs, or to use them to replace I/M programs. The most successful remote sensing programs have been voluntary. One such program, the High Emitter Repair or Scrap (HEROS) Program, was used by California's South Coast Air Quality Management District to identify gross-polluting passenger cars between 2007 and 2008. The goal of the program was to collect one million unique remote sensing device readings, and offer fiscal incentives of \$500 (for vehicle repair) or \$1,000 (for vehicle retirement, or "scrappage") to the owners of the highest emitting 2% of vehicles. During the program, 17,000 letters were mailed to the owners of potentially gross-emitting vehicles. However,

only 1,200 owners responded and brought their vehicles in for voluntary testing. Approximately 70–80% of these vehicles were demonstrated through laboratory testing to indeed be gross emitters, confirming that remote sensing is a technically feasible method of identification. However, the subsidies offered were not adequate to pay for the repairs necessary, so fewer than 400 owners chose to repair or scrap their vehicles under the program. The district is currently preparing the implementation of a second phase HEROS II program, in which larger subsidies (\$3,000–\$4,000) will be offered to consumers.

The South Coast AQMD has also piloted a diesel HDV remote sensing study in two locations, one at the Port of Los Angeles and one along an inland freeway, measuring opacity and NO_x . The program has successfully demonstrated fleet-wide emissions reductions due to clean truck rules at the port, but it is unclear whether or not the program has been successful specifically at identifying gross emitters.

Other international remote sensing experience includes Hong Kong, which has conducted pilot studies for several years, and Beijing, which has used mobile remote sensing to identify gross emitters since before the Olympics in 2008. One Hong Kong study identified that 17% of liquefied petroleum gas (LPG) taxis were gross emitters (HKEPD, 2007). Based on these results, the government is preparing a subsidies program to assist LPG taxi drivers to replace the catalytic converters on gross emitting vehicles.

In addition to enforceable in-use testing and more sophisticated remote sensing programs, visual spotting programs have had some success in identifying gross emitters. Under a “spotter program,” local authorities train citizens to report the license plate numbers of vehicles visibly emitting smoke from their tailpipes. Based on the vehicle’s registration information, policymakers can identify the owner and require him or her to take steps to clean it up.

Hong Kong has one of the most developed spotter programs in the world. Begun in 1988, the program currently has more than 5,000 trained citizen volunteer spotters. The program has resulted in thousands of high-emitting vehicles being tested and repaired each year (Cheng, 2010; HKEPD, 2009). In the United States, many state environmental protection authorities have hotlines consumers may call to report smoky vehicles. However, like opacity testing in I/M programs, spotter programs are only effective at reducing visible smoke, and may not result in reductions of the most health-damaging pollutants: ultrafine particulates and NO_x .

Proper vehicle maintenance is important to ensure that a vehicle meets the emission standard to which it is certified over its entire useful lifetime. In general, defects that result in reduced combustion efficiency (for example, clogged air or fuel filters or worn fuel injectors) will increase PM, HC, and CO emissions while reducing NO_x emissions (NJ DEP, 2012; Yanowitz et al, 2000). Accordingly, in some cases repair for excess smoke emissions may increase NO_x emissions (McCormick et al, 2003). Other categories of defects, such as failure of an electronic component, can affect levels of all pollutants in unpredictable ways.

The impact of vehicle maintenance on in-use emissions was shown during the Beijing diesel bus retrofit demonstration project jointly conducted by the U.S. EPA, Beijing EPB, Chinese SEPA (now MEP), and Southwest Research Institute (SwRI) from 2005 to 2007. Emissions testing of sample buses prior to retrofitting revealed tremendous variability in engine-out PM emissions from buses certified to the same new vehicle emission standard. The wide range of variability was attributed in part to varying degrees of maintenance, though it was also noted that the vehicles displayed a much wider range of emissions than would be expected for vehicles certified for their Euro I and II emission levels (U.S. EPA, 2008).

Maintenance is especially important for vehicles with advanced pollution control technologies, such as diesel particulate filters (DPFs), which must be carefully monitored and maintained when used in retrofit applications to ensure proper functionality and to prevent damage to the engine. During Beijing's demonstration project, buses with actively regenerated filters that were not regularly serviced experienced severe blockages, leading to high engine backpressure, catastrophic filter failures, and overall system malfunction. (DPFs are discussed in further detail in the Retrofits section of this report.)

Maintenance affects not only conventional pollutant emissions but also fuel economy and CO₂. Repairing a car that has failed an emissions test or is otherwise grossly out of tune can improve fuel economy by several percent. Similar benefits may be achieved by ensuring operation with proper tire pressure (U.S. DOE and U.S. EPA, 2012).

Mandatory periodic inspections, remote sensing, and spotter programs are all important tools to help policymakers ensure that drivers maintain their vehicles. For captive fleets—especially government fleets such as urban buses and municipal service vehicles—strong centralized service facilities, regular maintenance training and, if necessary, additional maintenance-related regulations (such as required daily visual inspections of emission control equipment prior to operation) are recommended. Ultimately, as mentioned previously, OBD systems on new vehicles are the critical long-term solution to ensuring proper maintenance of vehicles in use.

Another reason vehicles can grossly exceed their regulated emission levels is overloading. Vehicles are certified to meet emission limits up to a specified maximum loading. Exceeding that maximum, in turn, greatly increases the engine load and the emissions. Overloading of HDVs can significantly increase emissions of both air pollutants and greenhouse gases at the vehicle level (Cai et al, 2004). Accordingly, programs to reduce overloading, for example by mandating the use of weigh stations along freight truck routes and levying heavy fines for being overweight, could dramatically reduce emissions, as well as reducing long-term road maintenance requirements and improving road safety.

Best practices for gross-emitting vehicles

In concluding this chapter, two overarching best practices are identified here. It should be noted, though, that the foundational best practices described in this chapter, while useful, are only one part of a comprehensive in-use emission control program. The remainder of this report details additional elements of a comprehensive program to reduce emissions from in-use HDVs.

1. Continuously improve emissions inventories to better characterize overall fleet emissions and understand which vehicles have disproportionately high emissions.

A number of models are available to help estimate the contribution of different types of vehicles in various areas to given emission species of interest (e.g., NO_x, PM, CO₂). Using existing models updated with locally collected emission data, or developing new tailored models that better characterize a particular fleet with given vehicle types, are both strong analytical methods. The goal of such vehicle emission inventory calculations is to improve decision-making about which vehicles should be targeted for in-use emissions control programs given limited resources. Generally, these modeling efforts show how HDVs are disproportionate emissions contributors, but the exact types of HDVs, their local emission levels, their local vehicle use patterns, and the relative prevalence of gross emitters all merit particular investigation wherever a model is being developed.

2. Establish strong in-use compliance programs to identify and reduce prevalence of gross-emitting vehicles.

In the strongest in-use programs, there are enforceable regulations where government agencies have the authority, based on taking vehicles out of the real-world fleet and testing their emissions level, to both recall vehicles and levy strict fines for emissions non-compliance. These programs are based on new vehicle regulations, whereby provisions hold that the vehicles must maintain at or below given certification emission levels within given thresholds and for given useful vehicle lifetimes. Ideally, these compliance programs have useful vehicle life requirements that are true to real-world vehicle lifetime. For example, the U.S. heavy-duty Class 8 truck regulation assumes a useful life of 435,000 miles, but many Class 8 trucks travel in excess of this. In addition, various methods—aside from in-use compliance testing by national regulatory agencies—such as inspection and maintenance, remote sensing, spotter programs, and weigh stations all have demonstrated success in identifying different types of gross emitters in various locales.

Key take-home points from Chapter 2 on targeting gross-emitting vehicles

- An effective in-use vehicle emission control program requires a strong foundation, including proper characterization of the fleet via a robust emissions inventory and basic compliance programs to identify and manage gross emitters.
- Emissions inventories are instrumental for developing targeted control policies, tracking progress over time, and understanding the impact of vehicle emissions on air quality and climate change.
- Strategies to identify and prevent gross emitters include vehicle inspection programs, remote sensing, and spotter programs, as well as measures to ensure maintenance and prevent overloading.
- Programs to identify and prevent gross emitters must be very carefully designed and implemented in order to be effective. International experience shows that the actual benefits of some programs, notably I/M, have been less than expected.

Chapter 3: Use cleaner fuels

The use of higher quality conventional fuels or certain alternative fuels can be an effective—and sometimes essential—strategy to control emissions from in-use HDVs. Fuel switching can lower pollution in at least two ways: first by directly reducing emissions from conventional diesel vehicles, and second by enabling advanced pollution control technologies that require higher-quality fuels for their proper operation.

Both national and subnational actors have critical roles to play in promoting cleaner fuels. At the national level, policymakers typically set minimum fuel quality requirements to ensure that vehicles with advanced pollution control equipment have access to high quality fuel regardless of where they operate. This is especially important for long-distance diesel trucks and buses, which may travel across multiple states or provinces within a country. National-level policymakers also play a key role in promoting alternative fuels by setting national production targets and ensuring the development of necessary supply infrastructure.

Regional and local action is likewise important. In some cases, subnational policymakers can improve fuel quality at the city or regional level in advance of full nationwide implementation. In many countries, including China, Japan, Brazil, and India, selected cities and provinces have gained access to dedicated supplies of higher-quality fuels by negotiating directly with fuel suppliers, yielding immediate emissions reductions from in-use vehicles and paving the way for more stringent new vehicle emission standards. Sub-national policymakers can also implement alternative fuel pilot projects using local captive fleets. National and subnational actors typically work together to enforce standards, perform compliance testing, and prevent adulteration of both conventional and alternative fuels.

This chapter surveys practices to improve conventional fuel quality and expand the use of alternative fuels in HDVs, where possible presenting both national- and subnational-level case studies.

Low-sulfur diesel fuel and high fuel quality

Reducing the sulfur content of diesel fuel is crucial to reducing emissions from conventional diesel engines. Elevated fuel sulfur levels increase both the number and mass of diesel exhaust particles, as well as emissions of other conventional air pollutants. Reducing the sulfur level in diesel fuel will result in lower emissions—especially particulate emissions—from any diesel engine regardless of the emission standard to which it is certified (Figure 4, adapted from Liu et al, 2008, with data provided by author in personal communication). Accordingly, fuel sulfur reductions may be considered as an in-use emissions control strategy.

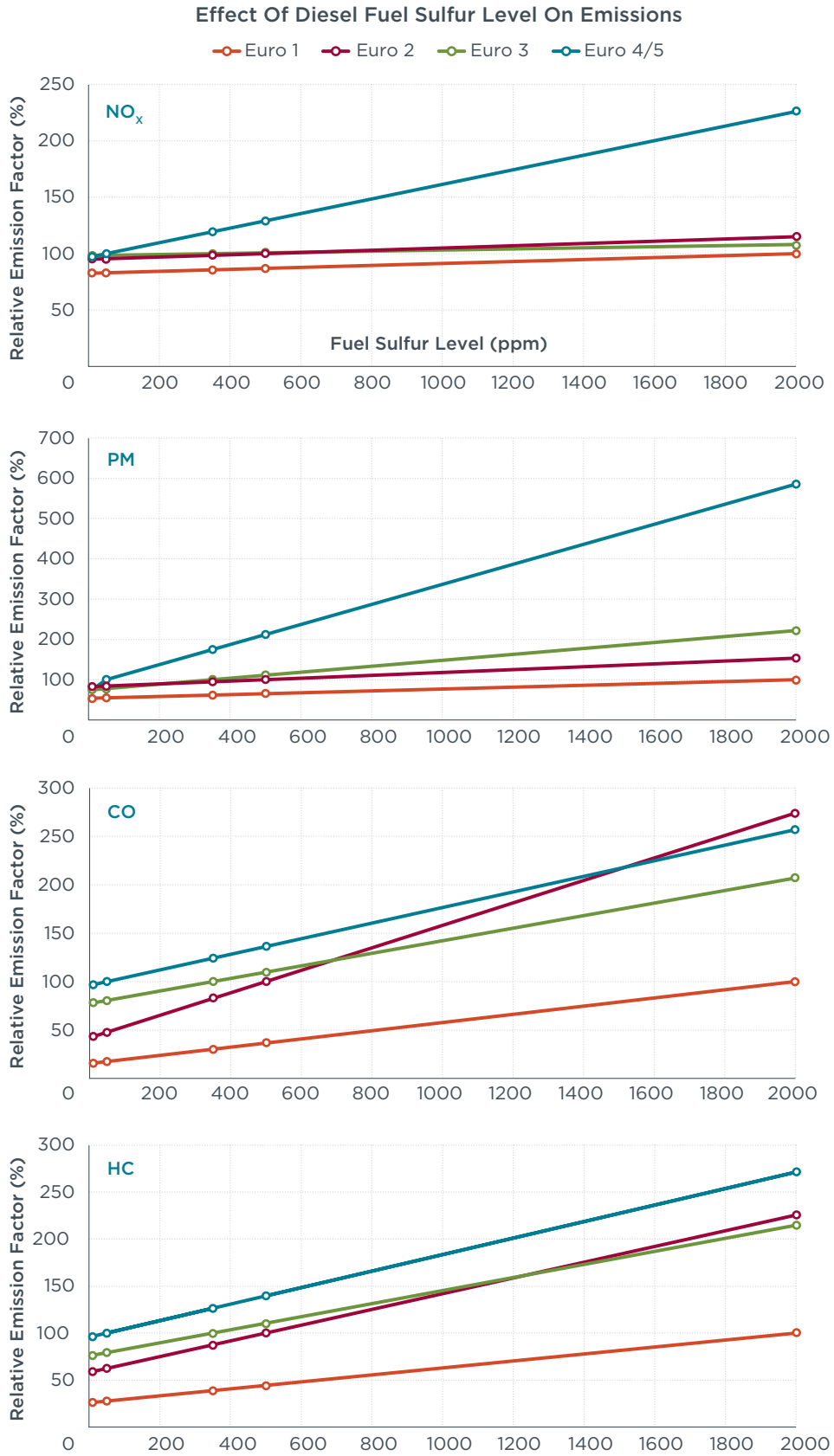


Figure 4: Impacts of diesel fuel sulfur content on NO_x, PM, CO, and HC emissions

Sulfur also inhibits the proper operation of many emission control devices, including passively regenerating particulate filters and high-performance selective catalytic reduction (SCR) systems, in some cases permanently damaging their effectiveness. Without low-sulfur fuel, many effective diesel pollution control technologies cannot be deployed, either on new vehicles or as retrofits. Accordingly, the European Union, countries such as the United States and Japan, and cities such as Hong Kong and Beijing have reduced diesel sulfur levels for highway vehicles to near-zero levels. In Europe, the Euro III, IV, and V HD diesel emission standards were accompanied by corresponding fuel standards requiring a maximum of 350, 50, and 10 parts per million (ppm) sulfur in diesel fuel, respectively. This progressive ratcheting down of fuel sulfur levels facilitates the introduction of the advanced emission control devices summarized in Table 3.

Table 3: Summary of emission control technologies for HD diesel vehicles

Technology	New Vehicle Application	Retrofit Application (see Chapter 5)	Control Efficiency	Sulfur Level Requirement (ppm)	Notes
Exhaust gas recirculation (EGR)	Euro IV+	No	20–80% NO _x reduction	<350	NO _x reduction depends on load conditions: Higher loads lead to higher reductions
Diesel oxidation catalyst (DOC)	Euro IV+	Yes	20–50% PM reduction; >80% CO and HC reduction	<350 viable; <50 preferred	Only reduces soluble organic fraction (SOF), not fine particles; NO ₂ /NO ratio may increase
Partial flow Filter (PFF)	Euro IV+	Limited	30–60% PM reduction; >80% CO and HC reduction	<350	Long-term durability and effectiveness still not proven
Diesel particulate filter (DPF)	Euro VI	Yes	>99% PM (particle number); >90% PM (particle mass)	<50 required for catalyzed DPFs; <10 preferred	Only proven technology for reducing ultrafine particles
Selective catalytic reduction (SCR)	Euro IV+	Limited experience with DPF+SCR combined retrofits; Pilot programs for exclusive SCR retrofits	50–95% NO _x reduction	<2,000 for vanadium catalysts (350 preferred); <50 for zeolite catalysts	Systems must be carefully designed and controlled to function properly and prevent secondary emissions; Requires urea supply infrastructure

Although sulfur level is perhaps the single most important fuel quality indicator impacting in-use HD emissions, other fuel characteristics, including polyaromatic content, cetane number, density, distillation, ash, suspended solids content, and viscosity, are also important. Improvements in these characteristics can yield immediate environmental benefits for the entire vehicle fleet (See Table 4). Further information about recommended diesel fuel quality specifications can be found in ICCT's model rule for HDVs and engines (Walsh, 2007) and its recent retrospective on China's emission control efforts (Fung et al, 2011).

Table 4: Impact of various fuel characteristics on heavy-duty diesel vehicle emissions

Diesel fuel characteristic	Pre-EURO	EURO I	EURO II	EURO IV	EURO V
Decrease sulfur content	Decrease SO ₂ , PM		Decrease SO ₃ , SO ₂ , PM		50 ppm S maximum (if filter) 10 ppm S maximum (if NO _x adsorber)
Increase cetane	Decrease CO, HC, benzene, 1,3-butadiene, formaldehyde, acetaldehyde				
Decrease polyaromatics	Decrease NO _x , PM, HC				

Based on ICCT (Fung et al, 2011); CO = carbon monoxide; HC = hydrocarbon; NO_x = oxides of nitrogen; PM = particulate matter; ppm = parts per million; S = sulfur; SO₂ = sulfur dioxide; SO₃ = sulfur trioxide

In certain jurisdictions, even when low-sulfur diesel fuel is available it is either not used at all or is somehow adulterated. Such behavior is commonly driven by economics, as operators seek the lowest-price or lowest-taxed fuels. For example, high-sulfur diesel intended for non-road applications may be used on-road to reduce operating costs. Fuel adulteration to evade diesel taxes was widespread in eastern Japan until 2000, when a group of local authorities, led by the Tokyo Metropolitan Government (TMG), began to crackdown on the practice. TMG found that mixing of heavy oil with diesel fuel and kerosene increased particulate matter emissions by 15% and NO_x by 7%, with even larger increases seen by the direct use of heavy oils in diesel vehicles (TMG, 2003). Fuel mixing also tends to increase sulfur levels, which reduces the effectiveness of many aftertreatment strategies. Further information on the importance of a strong fuel compliance programs, including details about TMG's successful campaign to reduce fuel adulteration, may be found later in this chapter.

Alternative fuels

In parallel with improving conventional fuel quality, national and local policymakers may also consider introducing alternative fuels. At the national level, typical drivers of alternative-fuel policy include a desire for fuel diversification for energy security and reduced greenhouse gas emissions. At the local level, policymakers generally promote alternative fuels with the goal of improving local air quality, although there are increasing examples of cities deploying them as part of a strategy for meeting local greenhouse gas reduction targets.

It is important to note that most vehicles are built to use one specific fuel; for HDVs, generally this is diesel fuel. With the exception of low levels of biodiesel blending, using alternative fuels for existing vehicles requires some combination of engine modifications, changes to fuel storage and delivery, and/or other vehicle systems. Accordingly, successful alternative fuel deployment will depend not only on effective programs to convert existing vehicles, but also on measures to accelerate vehicle turnover and introduce new, dedicated alternative fuel vehicles.

The selection and deployment of any alternative fuel will depend on numerous considerations, including cost, potential supply, the necessary technical expertise, technology availability, and national targets as well as local conditions. It is important to note that not all alternative fuel vehicles will have lower emissions than conventional diesels. For example, HDVs certified to U.S. 2010 or Euro VI standards are likely comparable with advanced CNG buses in terms of emissions. The use of biodiesel may result in reduced particulate, CO, and hydrocarbon emissions, but slightly increased tailpipe NO_x and, depending on the source of the biodiesel, higher lifecycle greenhouse gas emissions. Lifecycle assessments of all pollutants (both air pollution and greenhouse gas) should be considered prior to establishing any alternative fuel vehicle strategy.

This section describes the basic principles and international experience related to two alternative fuel types: biodiesel and gaseous fuels. Electricity can also be considered a fuel for hybrid diesel-electric, pure electric, and fuel cell buses. However, due to extremely limited international experience converting existing HDVs to use electricity as a motive force, the use of electricity as an alternative fuel is not discussed in depth here. Electricity is sometimes used in retrofit applications to power vehicle support systems (e.g. air conditioning); these applications are described further in anti-idling strategies in Chapter 6.

The most easily deployed alternative fuels are liquid biofuels that can directly be mixed with conventional diesel, with little to no effect on the vehicle user. Biofuels are a renewable energy source produced from animal or plant products. Biodiesel, which is the most common biofuel for HDVs, may be used in any conventional diesel engine with no required engine modifications. However, the use of pure biodiesel may decrease engine life due to corrosion, and the viscosity of biodiesel makes it unsuitable for use in low-temperature environments. Therefore, in practice biodiesel is commonly blended into petroleum diesel at fractions of 2%, 5%, or 20% (called B2, B5, and B20). Low-fraction biodiesel blends also avoid the need for modifications to fuel delivery infrastructure.

Multiple countries and regions around the world have established biofuel mandates or renewable energy/fuel targets as a means of promoting energy security and climate protection. Europe has been active in promoting biodiesel use. EU Directive 2009/28/EC sets a goal for European transport sector energy consumption to be 10% from biofuels by 2020 (Europa, 2012). Various countries are well on their way toward that goal. For example, the earlier 5.75% biofuel targets for 2010, per Directive 2003/30/EC, were achieved by Sweden, Austria, France, Germany, Poland, Portugal and Slovakia and nearly achieved on average for the entire EU27 (Uslu and van Stralen, 2012).

However, recent research has highlighted two key areas of environmental concern related to biofuel use. First, the lifecycle greenhouse gas (GHG) benefits of a given biofuel are highly dependent on the feedstock(s) and production pathways used. Of particular concern are land-use changes triggered by increased crop demand due to biofuels, with the total GHG intensity of a given biofuel sometimes higher than for conventional petroleum fuel if pristine land is converted for farming, or other food production increased to replace crops diverted, to produce biofuels. Due to such concerns, Europe has replaced direct biofuel targets with more general renewable energy targets along with specific greenhouse gas intensity and sustainability requirements.

Second, emissions of certain conventional pollutants can also be a concern. There is widespread agreement that the use of biodiesel results in reduced engine-out emissions of hydrocarbons, CO, and PM. However, the use of biodiesel blending has been shown to result in modest increases in NO_x emissions compared to conventional diesel (Posada et al, 2012; Andersson et al, 2011).

Cities may also set local-scale biofuel targets to supplement national ones. For example, in 2006 San Francisco announced a plan to fuel all municipal diesel vehicles with B20 biodiesel blend to reduce GHG emissions and improve local air quality. San Francisco now has the largest municipal fleet of biodiesel buses in the United States (Mellera and Bignardi, 2011). The city has attempted to mitigate land-use concerns by sourcing local, sustainable biodiesel (SFMTA, 2008). With regard to air quality, San Francisco has reported reductions in CO and PM but reports that NO_x impacts have been unchanged as compared to conventional diesel.

Beyond biofuel mixing within diesel, there are also a number of gaseous fuels that offer the potential for lower HDV emissions. The primary gaseous fuels used for highway transportation are compressed natural gas (CNG), liquefied natural gas (LNG), and liquified petroleum gas (LPG). CNG and LNG are both predominantly methane, differing only in how they are stored. LPG, a mixture of mostly propane and butane, is more commonly used in light-duty applications, while CNG and LNG are sometimes used in both light- and heavy-duty applications. While gaseous fuels are most often used in dedicated, purpose-built gaseous fuel engines, it is also possible to convert an existing diesel vehicle to run on a gaseous fuel by replacing the engine and fuel system.

The principle advantages of gaseous fuels are fuel diversification for energy security, lowered tailpipe GHG emissions, and, historically, improved local air quality. Gaseous fuels are generally understood to have a marginal GHG benefit compared to conventional diesel vehicles on a lifecycle basis. Tailpipe CO₂ emissions from CNG buses have been estimated to be 22% lower than those of conventional diesel buses, but this benefit may be offset by potential upstream leakage of methane, a potent GHG. When considering full lifecycle emissions, the greenhouse gas emissions from CNG buses may be no better than 5% lower than diesel (Lowell, 2012). However, in areas with sparse refueling infrastructure, even this benefit may be eliminated due to the additional driving required to reach CNG stations.

CNG vehicles have traditionally had significantly lower NO_x and PM emissions compared to older diesel vehicles, though slightly higher HC and CO emissions. The

NO_x and PM benefits of gaseous-fueled vehicles have largely been eliminated due to more stringent standards for new diesel vehicles. Conventional pollutant emissions from diesel vehicles meeting the world's most advanced standards (e.g. Euro VI, US 2010) are comparable with those from gaseous vehicles (Posada, 2009). Still, in regions where advanced emissions standards have not yet been implemented, the selective switching or replacing of some diesel vehicles with natural gas vehicles can be an effective and rapid air quality improvement strategy.

Infrastructure requirements for gaseous fuels, which typically require specialized fuel tanks, lines, and dosing systems for high pressure or cryogenic storage, can be onerous. As a result, few regions have invested in significant gaseous-fuel-dispensing infrastructure. Additionally, on-board fuel storage can add significant weight and volume to a vehicle. The fuel system requirements make gaseous fuels more appropriate to “captive” urban fleets or other high-density, homogenous fleets such as taxis or port facility trucks. Gaseous-fueled vehicles have found some traction in private fleets in areas where sufficient refueling options exist.

Best practices in using cleaner fuels

Adopting and implementing policies to improve fuel quality and promote the use of alternative fuels can be a complex process requiring coordination among multiple actors at both the national and local levels from a variety of legislative and regulatory departments (environment, finance, economic planning, state-owned oil companies, etc.). The following international best practices characterize effective setting and enforcing of conventional fuel quality standards:

1. Adopt a systems approach.

The best vehicle emissions performance can only be achieved if vehicles and fuels meet complementary standards in parallel. This “systems approach” phases in vehicle tailpipe emission and fuel quality standards concurrently, ensuring that appropriate fuels are available when advanced vehicles enter the market, if not before. The systems approach avoids potential engine malfunction due to misfueling of advanced vehicles, and limits political infighting between automakers and fuel providers—who otherwise tend to blame each other for a lack of technology development—during policy design. The systems approach has been successfully pursued in Japan since 1992, the United States since 1994, and Europe since 2000 (Euro III). Failure to adopt such an approach risks suboptimal emissions performance and the delay of vehicle emission standards vital to protecting human health.

2. Give authority over fuel quality to environmental policymakers, and allow local authorities leeway to set higher standards.

The systems approach described above is commonly implemented by granting a single regulatory agency authority over both vehicle emissions and fuel quality as related to emissions. For example, in the United States the EPA holds authority over both vehicles and fuels under the Clean Air Act.

Nationwide requirements for low sulfur diesel fuel are preferable so that vehicles with advanced emission control devices can be operated anywhere within a country. However, in situations where nationwide fuel quality improvement lags, cities or regions may choose to introduce higher quality fuels prior to national requirements. In China, local Environmental Protection Bureau officials in key regions, including Beijing, Shanghai, and Guangdong, have negotiated with local refineries to supply low-sulfur diesel well in advance of the rest of the nation. China's Air Pollution Prevention and Control Law grants them this authority, contingent on approval from the national-level State Council.

3. Adopt progressive pricing to encourage cleaner fuels.

In many cases, the largest obstacle to the introduction of low- or ultra-low-sulfur diesel fuel is cost. The cost of producing ultra-low-sulfur diesel depends on many factors such as base refinery configuration, local economic conditions, crude slate sulfur levels, and more. However, multiple analyses across a variety of regions have concluded that the cost of producing ultra-low-sulfur diesel is on the order of cents per liter or even less (Hart Energy and MathPro, 2012; ADB, 2008; U.S. EPA, 2000). Still, in countries with fixed fuel prices or large fuel subsidies, this may act as a significant barrier to the introduction of cleaner fuels.

Refineries may require appropriate fiscal incentives or subsidies to justify upgrading capital equipment to refine higher quality fuel. Fiscal policies to encourage the supply of higher-quality fuel—in combination with mandatory regulations—have been used successfully in many places around the world, including Japan, Hong Kong, Germany, the United Kingdom, and the United States. Some examples of fiscal policy precedents to encourage the production and use of low-sulfur fuels are summarized in Table 5.

Table 5: Examples of fiscal policies used to encourage diesel fuel desulfurization

Policy type	Region	Goal	Magnitude	Result
Tax differentials at the pump	Hong Kong	<ul style="list-style-type: none"> 2000: Accelerate 500 → 50 ppm transition 2007-2008: Accelerate 50 → 10 ppm transition 	<ul style="list-style-type: none"> 2000: Reduced import duty for 50ppm diesel by HK\$ 0.89/L (USD 0.11/L) 2007-2008: Concessionary duty on 10 ppm diesel cut in half (to HK\$ 0.56/L (USD 0.07/L)) as compared with 50 ppm 	<ul style="list-style-type: none"> Became the first region to introduce 50 ppm sulfur diesel in Asia Exclusive availability of 10 ppm sulfur diesel by 2008
	United Kingdom	<ul style="list-style-type: none"> 1997-1999: Accelerate 200 → 50 ppm transition 	<ul style="list-style-type: none"> 1997-1999: Differential tax of 1-3 pence/L levied (USD 0.016-0.048/L) 	<ul style="list-style-type: none"> Rapid transition to full 50 ppm diesel market in 1999 Full conversion to 50 ppm six years ahead of most other EU member states
	Germany	<ul style="list-style-type: none"> 2001-2002: Accelerate 350 → 50 ppm transition 2003-2004: Accelerate 50 → 10 ppm transition 	<ul style="list-style-type: none"> 2001-2002: 3 pfennigs/L (USD 0.015/L) tax on >50 ppm diesel 2003-2004: 1.5 pfennigs/L (USD 0.03/L) tax break for ≤10 ppm diesel 	<ul style="list-style-type: none"> Rapid shift to 50 ppm and 10 ppm diesel
Tax incentive for refiners	Japan (national)	<ul style="list-style-type: none"> 1990-1997: Accelerate 5,000 → 500 ppm transition 	<ul style="list-style-type: none"> 7% deduction in corporate tax, or a 30% accelerated depreciation on equipment purchase 	<ul style="list-style-type: none"> Nationwide diesel supply desulfurized from 5,000 ppm to 2,000 ppm by 1992, and further to 500 ppm by 1997
	United States	<ul style="list-style-type: none"> 2003-2009: Accelerate 500 → 15 ppm transition for small refiners 	<ul style="list-style-type: none"> Tax credit of 5 cents per gallon of 15 ppm diesel provided to small refiners 	<ul style="list-style-type: none"> Complete shift to 15 ppm diesel in 2009
Direct government subsidy to refiners	Tokyo	<ul style="list-style-type: none"> 2001-2003: Accelerate 500 → 50 ppm transition 2003-2005: Accelerate 50 → 10 ppm transition 	<ul style="list-style-type: none"> 10 yen/L (USD 0.13/L) subsidy to refiners 	<ul style="list-style-type: none"> 500 ppm → 50 ppm (2003) → 10 ppm (2005) transition completed 21 months and two years, respectively, ahead of national regulatory schedule

For alternative-fuel vehicles, differential pricing can promote fuel switching and generate adequate demand to justify investments in fueling infrastructure. For

example, in Brazil, where most light-duty passenger cars are flex-fuel vehicles that can use gasoline-ethanol blends that are from 20% ethanol (i.e., E20) up to pure ethanol, the state levies a differential tax on ethanol and gasoline that is designed to promote consumption of ethanol by these vehicles.

4. Implement an effective compliance program.

Because of the negative effects of certain fuel characteristics (especially sulfur level) on emissions, the introduction of low- and ultra-low-sulfur fuel requires a strong policy framework that includes mandatory standards, regular testing, and strong penalties for non-compliance. In regions where two fuels are supplied in parallel (e.g. on-highway and off-highway diesel fuel), a clear system such as color marking may be necessary to prevent misfueling.

The U.S. EPA uses a system of presumptive liability to maintain fuel quality. That is, when noncompliant fuels are discovered, all stakeholders upstream of where the violation is discovered are presumed liable unless they can positively establish their innocence. This system creates a strong financial incentive for all parties involved in the supply chain to track and test their products, and to assist in investigations of potential evaders. Once discovered, in an effective program liability for violations of fuel quality will extend to repairs to or replacement of emissions control devices damaged by exposure to sulfur.

An alternative to a liability-based system is to have suppliers cross-checking each other's fuel quality, as is done in Japan, when policymakers do not have the ability to check all fuels. Under this system, competitors take on some of the analytical burden and call policymakers' attention to potential violations. Creating an incentive for the industry to help police itself can help ensure acceptable fuel quality, especially in fragmented markets with a large number of private suppliers.

An effective compliance program will also help prevent fuel adulteration. Aftermarket adulteration (for example, the mixing of diesel or gasoline with lower-cost fuels such as naphtha, natural gas liquids, kerosene, waste solvents, byproduct petroleum stream, etc.) can affect vehicles in a variety of ways, including increasing emissions and reducing durability. One example program of note is in Tokyo (see description in box). Similar programs were subsequently adopted by other urban areas in Japan, such as Kobe and Nagoya.

Fuel adulteration in Japan

Aftermarket fuel adulteration has been a serious problem in Japan. Typically this involves aftermarket mixing of untaxed Heavy Oil “A” with kerosene or diesel fuel, which is taxed at a rate of 32.1 yen per liter (\$1.50 per gallon). Since diesel fuel taxes are collected by local authorities in Japan, fuel adulteration was historically viewed as a fiscal, rather than environmental, problem that did not concern the national government. National fuel quality standards are geared to limiting the distribution and sale of noncompliant fuels, rather than on end-use fuel quality, so technically fuel adulteration is not illegal under national law. Local governments, which hold limited authority over fuel quality, repeatedly petitioned the central government to ban the practice, with limited effects.

In September 2000, the Tokyo Metropolitan Government (TMG) began Operation No Diesel, a local campaign to reduce particulate emission from in-use diesel vehicles. Fuel adulteration, which increases fuel sulfur content and therefore impacts the viability of PM retrofits, quickly became an issue. TMG adopted a ban on illicit diesel fuel use by local ordinance, and began cracking down on its use through more 11,000 roadside and onsite inspections, worked with 13 other prefectures to identify and eliminate manufacturing bases and distribution pipelines, and engaged end users to voluntarily eliminate fuel use. Of particular use in identifying manufacturing operations was active monitoring of sulfur “pitch,” a hazardous byproduct that is created when chemicals are added to heavy oil and kerosene to remove the fuel marker coumarin.

Efforts to eliminate illegal fuel mixing met with considerable success. As a result of these efforts, illicit diesel fuel in Tokyo fell from an estimated 14% of the fuel supply in FY 2000 to only 1% in 2002.

5. Use captive fleets to create demand for cleaner fuels.

Where national requirements are delayed, local authorities may consider using public fleets to create early market pull for clean fuels. In some cases, public fleets may make up a large enough fraction of total diesel use to create enough initial demand to justify the cost of refinery upgrades—for example, diesel fuel purchased for Tokyo metro buses in 2001 and 2002 equaled 8% of local diesel sales (Rutherford, 2006). In Tanzania, the whole country went to 50ppm diesel because of the introduction of a Bus Rapid Transit (BRT) system requiring the fuel in the capital Dar es Salaam. Furthermore, public fleets tend to be centrally fueled, minimizing investments in delivery infrastructure and reducing the risk of misfueling vehicles that can occur when more than one kind of diesel fuel is made available to private fleets at a given station.

Ensuring adequate access to alternative fuels for private fleets can be even trickier given the need for substantial infrastructure investments to cover even a modest geographic area. For this reason, municipal fleets under common management and operating over predictable routes or in fixed areas are prime candidates for certain alternative fuels, as they can be refueled regularly at a limited number of stations.

Providing private vehicles with access to these public fueling facilities can help ensure at least a minimal fueling infrastructure in early years of adoption, when the alternative-fuel vehicle population remains very low. For example, the South Coast Air Quality Management District has a dedicated CNG refueling station at its headquarters in Diamond Bar, Calif., which private consumers are also allowed to use.

Key take-home points from Chapter 3 on cleaner fuels

- The use of higher quality conventional fuels or certain alternative fuels may directly reduce emissions as well as facilitate the introduction of advanced emission control technologies.
- The reduction of diesel sulfur content is crucial for controlling in-use emissions from conventional diesel vehicles.
- The targeted deployment of alternative fuel vehicles—including those fueled with biofuels, gaseous fuels, or electricity—could result in reductions of conventional pollutant and greenhouse gas emissions, although policymakers may need to carefully balance multiple factors and weigh the advantages and disadvantages of the use of these fuels prior to launching such a program.

Chapter 4: Scrap and replace old vehicles

Older, high-emitting HDVs meeting less stringent emission standards and with degraded pollution control equipment often emit a disproportionately high share of total emissions. Accordingly, controlling NO_x and particulate emissions from these vehicles is an important part of any comprehensive in-use control strategy. The following two chapters describe programs directly addressing these vehicles. This chapter introduces scrappage programs designed to eliminate older vehicles from the fleet altogether, while Chapter 5 describes retrofit programs to clean up those vehicles so that they can continue to be operated.

The most direct method of controlling older, high-emitting vehicles is to eliminate them from the fleet altogether through mandatory or heavily subsidized voluntary scrappage. For HDVs, scrappage programs typically address conventional pollutant emissions only, while in many countries light-duty scrappage programs have targeted both conventional pollutants and GHGs. In many cases, scrappage programs accomplish the dual goals of reducing emissions and stimulating economic growth; for example, scrappage subsidies may be offered on the condition that the vehicle owner simultaneously purchase a new (or newer used) vehicle. The additional demand created by an aggressive scrappage program can also help ensure demand for new vehicles as part of a transition to a newer, more stringent national emission standard.

One challenge typically encountered in the implementation of scrappage programs relates to the fact that owner/operators of older vehicles are typically economically disadvantaged. Accordingly, fiscal policies, carefully tailored to ensure proper balance between environmental goals and economic fairness, are important to successful programs.

There is international precedent for both mandatory and voluntary scrappage programs. Mandatory programs force retirement of vehicles regardless of whether they have useful life remaining. Mandatory scrappage regulations can be based upon age, mileage, or vehicle vocation (e.g., use as a taxi). In China, all classes of vehicles have mandatory age or mileage limits, although the limits on private passenger cars are currently under review (Huo and Wang, 2011). In Egypt, bus, taxi, and other passenger transit vehicles are prohibited from renewing their licenses if the vehicle is more than 20 years old (World Bank, 2011). Strict, mandatory vehicle scrappage programs are not very common and, without additional fiscal or other policy incentives, may be difficult to enforce.

More commonly, scrappage programs are voluntary and supported by some form of fiscal incentive, such as direct subsidies or fees to discourage older vehicle use. Voluntary programs are sometimes linked to retrofit or repowering programs, providing flexibility to vehicle owners to reduce emissions in the most economical way possible for a given vehicle and duty cycle.

China is currently implementing one of the world's most aggressive voluntary scrappage programs. The Ministry of Environmental Protection in China aims to

retire approximately 10 million “yellow-label” vehicles (diesel vehicles not meeting the Euro 3/III standard and gasoline vehicles not meeting the Euro 1/I standard) by the end of 2015, although this extremely aggressive goal is not likely to be achieved. Both national and local subsidies have been implemented to support these goals. National subsidies of 3,000 to 6,000 renminbi (\$460 to \$920) proved to be insufficient when offered in 2009, and were raised to 6,000 to 18,000 renminbi (\$920 to \$2,800) in 2010 (MOF, 2009; MOF and MOC, 2010). In addition, these national subsidies are often matched or exceeded at the local level in China. To date, Beijing has been the most successful city to encourage voluntary early retirement of yellow-label vehicles. Beginning in 2008, Beijing offered additional subsidies, graduated by vehicle age and ranging from 1,000 to 5,500 renminbi (\$150 to \$850) per vehicle, for the scrappage of the oldest yellow-label vehicles. Subsidy levels have been revised twice and are now as high as 17,200 renminbi (\$2,650) per vehicle (Beijing EPB, 2011). Beijing reports that the program eliminated more than 150,000 vehicles, reducing NO_x emission by 32 tons per day, and that officials have vowed to retire an additional 400,000 vehicles by the end of 2015. However, since Beijing’s program does not require verification of vehicle retirement in order to qualify for subsidies, it is unclear how many of these vehicles were transferred outside of the city limits and continue to pollute other areas of the country. The Chinese program and some other recent examples of scrappage programs are summarized below in Table 6. Many of the programs were carried out in the 2009–2011 time frame and were utilized as both an economic and vehicle technology stimulus.

Table 6: Summary of scrappage programs

Scrappage program	Type	Subsidy / Incentive	Attribute targeted	Scrappage verification	Complementary policies used	Retrofits also funded?
California: Carl Moyer Program	Replacement	80% of new vehicle cost for fleets up to five units; 50% for fleets greater than five units	NO _x , PM	Only certified scrap yards		Yes
China	Scrappage		Conventional pollutants		Labeling	No
Germany: Umweltprämie	Replacement	About \$3,000 on average	Vehicle age	No, many exported		No
U.S. EPA: National Clean Diesel Campaign	Replacement, demonstration	\$10,000 - \$60,000				Yes
United States: Car Allowance Rebate System (“Cash for Clunkers”)	Replacement	About \$4,000 on average	Fuel economy (miles per gallon)	Engines disabled, under legal requirement by dealer	Indexed to U.S. EPA label fuel economy	No

Best practices in accelerated retirement of high-emitting vehicles

Based on efforts around the world to accelerate the retirement of high-emitting vehicles, the following are several best practices for the design and implementation of successful scrappage programs.

1. Ensure that replacement vehicles meet advanced emission standards and truly achieve lower real-world emissions.

A scrappage program will only reduce emissions if replacement vehicles are indeed cleaner than those they replace, as ensured by the establishment of stringent new vehicle emission standards that effectively control real-world NO_x and particle emissions over the full range of operating conditions encountered by the vehicle during its useful life. Ideally, replacement vehicles should be certified to state-of-the-art emission standards (e.g., U.S. 2010 or Euro VI); in regions where those standards have not yet been implemented, policymakers may need to consider other approaches to make sure that in-use emissions from the replacement vehicles are adequately controlled.

For example, research in Europe and China has shown that real-world NO_x emissions from buses and trucks operating in low-speed, urban environments have not decreased even with the successive introduction of emission standards through Euro V (Lowell and Kamakaté, 2012). Some local authorities have reacted by employing supplemental or alternative test procedures for replacement buses. For example, Transport for London (TfL), as part of a program to replace all Euro II buses with Euro V buses by 2015, is requiring that replacement vehicles demonstrate proper NO_x controls on a supplemental London bus-specific drive cycle. Similarly, the Beijing Environmental Protection Bureau has proposed supplemental testing requirement for new HD diesel vehicles sold and registered in Beijing.

The only current technology that controls ultrafine (<100 nm) particulate emissions is the diesel particulate filter (DPF), which is not required for new vehicles below U.S. 2010 or Euro VI standards. Policymakers who wish to achieve ultrafine particle emissions reductions in regions where those standards have not yet been implemented may consider supplementary requirements to existing standards (e.g., Euro III/IV/V) for replacement vehicles. For example, in Santiago, Chile, all new buses are required to meet the Euro III emission standard, but must also be fitted with a DPF; by December, 2010, 40% of the urban bus fleet met this custom “Euro III + DPF” standard (TransSantiago, 2012). Alternatively, a mass-based particulate limit—for example the 0.01 g-PM/bhp-hr standard enforced under California’s 2005 “Fleet Rule” for public and utility fleets— that achieves similarly low emission results to DPFs may be adopted.

2. Ensure that replacement vehicles are similar in power and operation to the scrapped vehicles.

The benefits of a scrappage/replacement program could be much smaller than anticipated if the new vehicles are used or driven considerably more than the scrapped vehicles would have been, or if the new vehicles have substantially more power than

the replaced vehicles. A robust program establishes clear requirements both for scrappage eligibility and for performance and operation of the replacement vehicle.

The California Air Resources Board's Carl Moyer Grant Program requires that applicants for scrappage subsidies demonstrate that the vehicle to be scrapped is in "operational condition" via a visual inspection and submit detailed records of the vehicle's past two years of operation (e.g., vehicle kilometers traveled or VKT, fuel records, maintenance records, etc.). The replacement vehicle must operate in the same vocation as the scrapped vehicle, subject to detailed limits for exceeding the operation of the scrapped vehicle (e.g., the new vehicle's mileage cannot exceed 150% of the estimated project mileage, the replacement vehicle engine's horsepower cannot exceed the scrapped one by more than 120%, and so on) (CARB, 2008).

3. Verify that the high-emitting vehicles are indeed scrapped (as opposed to being transferred to another region).

Because vehicles eligible for scrappage typically can still be operated, successful programs will ensure the vehicles are actually removed from operation as opposed to transferred to another region where they may continue to pollute. CARB's Carl Moyer program requires that strict protocols for scrappage be followed—vehicles to be scrapped may only be taken to certified salvage yards, whose staff destroy the engine and chassis and send photographic proof to policymakers (CARB, 2008). The United States' "Cash for Clunkers" program required that the engines of scrapped passenger vehicles be destroyed by running them for a short time with sodium silicate solution in place of oil, a cheap and environmentally benign means of ensuring that the vehicle is never operated again (NHTSA, 2009).

In contrast, a 2009 German scrappage program for light-duty vehicles required only that owners deliver their cars to a scrap yard, with no other proof of deactivation required; as a result, up to 50,000 vehicles received subsidies but were subsequently sold to other auto markets in Eastern Europe or Africa (Dougherty, 2009).

4. Improve the cost-effectiveness of programs by giving incentives based upon competitive bidding.

In most scrappage programs, the demand for subsidies is higher than the available funds. To prioritize which projects are funded, policymakers may consider awarding grants based on a cost-effectiveness metric per ton of pollution reduced.

In the Carl Moyer program, applicants must estimate in detail the expected emission reductions resulting from each replaced vehicle based upon standardized emission factors and verified estimations of VKT. The cost-effectiveness of the project is then calculated based on the cost of the new vehicle purchase and a weighted estimation of surplus reductions of NO_x, reactive organic gases, and PM₁₀. Grants are awarded competitively, with a cap on cost-effectiveness (CARB, 2008). Individual districts within California may set stricter cost-effectiveness caps.

California's Carl Moyer Grant Program

California's Carl Moyer Grant Program, established in 1998, is a voluntary subsidy program to encourage the early replacement or retrofitting of higher emitting diesel engines by covering the incremental cost of emission reduction technologies for vehicle and equipment owners. Grants are made by the California Air Resources Board to individual air districts, which in turn distribute funds to local public and private entities to cover new purchases, fleet modernization (scrappage and replacement), repowers, and retrofits for both on-road and off-road vehicles. The majority of grants for on-road HD trucks go towards replacement of older vehicles with cleaner ones ("fleet modernization"), and allow for funding of up to 80% of the cost of a new vehicle, contingent on the cost-effectiveness cap.

The program affords a fair amount of flexibility to local air districts in determining how to allocate funds. Individual grant levels are determined in various ways, including project type and, especially, cost effectiveness. Program evaluations regularly estimate the cost per ton of emissions reduced for each project, and there is a cap on cost effectiveness as evaluated in cost per weighted ton of pollution reduced (CARB, 2008). Other guiding principles include ensuring that the emissions reductions are "surplus" (that is, they would not have occurred under existing federal or state regulations), quantifiable, and enforceable.

Over the first seven years of the program, 7,500 engines were cleaned up with \$170 million in total funding, yielding estimated total daily NO_x and PM emissions reductions of 24 tons and 1 ton, respectively (CARB, 2008). This implies an average grant per engine of more than \$20,000, and an overall cost effectiveness of around \$2,800 per ton of NO_x reduced and \$67,000 per ton of PM reduced. Since 2004, program funding from California's base budget and smog check, tire, and motor registration fees has averaged \$141 million per year. This level of funding is expected to continue through 2015.

5. Allocate funding to local-level policymakers to make individual grant determinations and implement projects.

Initially, a large-scale scrappage program may need to be established and funded by a central authority. For example, in the United States, the EPA directs the National Clean Diesel Campaign, and CARB oversees the Carl Moyer program. China's scrappage/replacement program was launched as a national-scale program by multiple ministries and commissions. However, ideally program implementation via individual project grants is handled by local-level policymakers with a more detailed understanding of local needs and the ability to follow up to ensure the vehicles are properly retired. In some cases, local regions will fund their own programs (or supplement existing national ones). For example, Beijing's vehicle scrappage program predated and has surpassed China's national programs in terms of effectiveness. In California, the South Coast Air Quality Management District administers multiple scrappage programs funded above and beyond the statewide CARB programs. In

addition to, or as a funding mechanism for, providing scrappage subsidies, policy-makers may further incentivize scrappage through the use of complementary policies such as targeted urban low-emission zones or vehicle emission-indexed taxes. For example, Beijing's scrappage program was supplemented by the creation of a low-emission zone, whereby yellow-label vehicles are not permitted to drive inside the Sixth Ring Road. These measures are described further in Chapter 6.

Key take-home points from Chapter 4 on accelerated vehicle retirement programs

- Mandatory or incentivized voluntary programs to scrap older, high-emitting vehicles can significantly reduce emissions.
- Programs must be designed carefully to ensure that real-world emissions reductions are achieved, and that older vehicles are actually scrapped.
- Effective programs may also fund retrofits and other types of emission control programs in addition to scrappage.

Chapter 5: Retrofit high-emitting vehicles

Pollution control retrofits help reduce emissions for vehicles with remaining useful life, but for which scrappage and replacement is not cost-effective. Retrofits will not be appropriate to all vehicles due to cost, space/mounting constraints, and duty cycle diversity. Vehicle retrofits may target either conventional pollutants or GHGs. Conventional pollutant retrofits are typically diesel aftertreatment devices; for GHGs, they may include aerodynamic, rolling resistance, or idling reduction technologies.⁴

In this chapter, the primary retrofit technologies are briefly introduced, followed by descriptions of retrofit program types and international best practices. As highlighted below, technology certification is a key component of a successful retrofit program. For this reason, only technologies that have been certified by one of the main international certification bodies (including CARB, U.S. EPA, Tokyo's Retrofit Verification Program, and through the VERT Association of Switzerland) are described here.

Retrofit types

In the most common type of retrofit, conventional pollutant emissions are controlled by installing either a diesel oxidation catalyst (DOC) or DPF onto the vehicle's exhaust system. Most retrofits target particulate matter emissions, although a limited number of projects promote advanced retrofit technologies that control both PM and NO_x. Much less experience exists for promoting independent NO_x reduction retrofits due to the relative complexity and significant mounting space required for those systems. In addition to PM- and NO_x-related retrofits, there is also some potential for CO₂-related retrofits. The retrofit types are described below.

There are four primary PM exhaust aftertreatment technologies: crankcase filters, diesel oxidation catalysts, partial-flow filters (PFFs, also known as partial oxidation catalysts or flow-through filters), and DPFs. All four may be used in both new and retrofit application. Of these, DPFs are considered the best available control technology for HD diesel PM control, and are the only one of the four that significantly reduces ultrafine particulates and black carbon. To date, DPFs have been retrofitted on more than 250,000 vehicles globally (MECA, 2012).

The particular choice of retrofit technology depends on numerous factors, including what level of emissions reductions are desired, the level of public and private investment available, the application and duty cycles of targeted vehicles, and diesel fuel quality. In particular, the sulfur content of diesel fuel is an important constraint because catalyzed particulate filters require low-sulfur fuel to enable periodic "regeneration," under which accumulated particulate matter is oxidized to

⁴ Many diesel emission reduction programs in the United States, including CARB's Carl Moyer program and the U.S. EPA's National Clean Diesel Campaign, also fund repowering, the replacement of a vehicle's engine with a newer engine or one burning a cleaner fuel such as CNG. In general, repowering is only cost-effective for specialized vehicles containing high-value equipment (e.g., pumps, cranes or specialized construction devices), non-road applications such as locomotives and ships, and select on-road vehicles such as refuse trucks, dump trucks, fire trucks, and school buses. Repowering is relatively rare, and beyond the scope of this paper.

return the filter back to its clean condition and function. Insufficient regeneration leads to backpressure problems, fuel economy penalties, and, in certain cases, fires that may damage the filter and/or vehicle.

For fleets or regions lacking access to low-sulfur (<50 ppm) diesel fuel, retrofit options may be limited to a small number of actively regenerating particulate filters, PFFs, DOCs, or crankcase filters. Each of these systems has drawbacks relative to a catalyzed DPF. Actively regenerated filters require some secondary means of burning off accumulated particulate matter, such as applying an electric current to heat the filter while installed on the vehicle or periodic removal and baking of the filter in a specialized oven. This level of maintenance may not be accepted by operators, who may choose instead to deactivate or remove the retrofit, as discussed further below. PFFs and DOCs, in contrast, primarily reduce PM mass and are largely ineffective in cutting the fine and ultrafine particulate emissions that are generally understood to have the greatest impact on human health and the climate.

The vast majority of HD retrofit programs to date have targeted particulate matter reductions alone; retrofitting NO_x control devices is much less common. The most common NO_x reduction tailpipe emission control system, selective catalytic reduction (SCR), is complex and expensive in retrofit applications because it requires the precise dosing of a urea reductant. To be effective, SCR retrofits must be carefully matched to the engine, application, and duty-cycle characteristics of individual vehicles. This high level of customization increases the retrofit cost compared to that of a new vehicle. SCR systems also typically require large-volume catalyst beds and tanks for urea storage, making them difficult to mount on smaller vehicles. However, there are a few precedents to including NO_x emissions under a retrofit program by promoting a combined DPF-SCR system, although these systems generally require access to diesel fuel with sulfur content below 15 ppm (MECA, 2010).

Retrofit technologies to reduce GHG emissions from HDVs include technologies to reduce aerodynamic drag, tire rolling resistance, and idling. Aerodynamic retrofits are typically truck or trailer attachments (e.g., trailer gap reducers, trailer boat tails, trailer side skirts, and trailer end fairings) that reduce the aerodynamic drag of the vehicle. Aerodynamic drag reduction retrofits can reduce fuel consumption by 5% or more on vehicles operating at highway speeds (e.g., long-distance trucks traveling on highways). When properly installed, tire retrofits utilizing verified low rolling resistance tires, retreads, and/or pressure monitors to remind drivers to keep tires properly inflated can reduce NO_x emissions and fuel use by 3% or more compared to the best selling models. Idling reduction technologies save fuel and prevent criteria pollutant emissions by reducing unnecessary engine operation, typically through the use of auxiliary clean power sources or automatic shutoffs.

Like conventional pollutant retrofits, GHG retrofits require careful monitoring to ensure efficacy and will be most effective when certified or verified by policy-makers for use on certain vehicles and applications. Unlike conventional pollutant reduction retrofits, GHG retrofits often “pay for themselves” over a certain operating period in the form of reduced fuel costs. However, because GHG retrofits require initial capital investment, a financing program—either state-sponsored or

private-sector—that provides loans to owners with limited access to capital may be important to support adoption.

The U.S. EPA's SmartWay Technology program is the global leader in verification and certification of GHG reduction technologies. The program structure and technologies supported have been shown to be effective in the United States and multiple regions around the world, including developing countries.

Voluntary and mandatory retrofit programs

There are two basic types of retrofit programs: voluntary programs under which participation is encouraged through financial incentives, and, less frequently, mandatory programs where retrofits are required of all vehicles of a certain type.

The most common retrofit programs are voluntary and often small in scale, sometimes involving only tens or hundreds of vehicles. If conducted by local authorities in developing countries, they often draw upon international expertise and funding for initiation. While offering more modest benefits relative to mandates, voluntary programs are easier to implement due to their small scale, limited need for enforcement, and the reduced burden of verifying devices to cover the large breadth of vehicle types and duty cycles covered by mandatory schemes. Per-vehicle costs can also be lower, owing to the fact that vehicles for which retrofits are cost-effective can be specifically targeted under the programs. Subsidies for participation are particularly important for voluntary programs because, in contrast to replacement, retrofits provide no direct benefit to operators, and may in fact increase operating costs due to the need for routine maintenance and increased fuel costs.

Less commonly, retrofits of diesel pollution control equipment can be mandated, generally by a local authority for public fleets or as a precondition for operation within its jurisdiction. Mandatory programs may be more costly to implement than voluntary programs, because of the larger number and diversity of vehicles covered. Recognizing that retrofits are not appropriate for all vehicles, mandatory programs are typically enforced as an in-use emission standard that operators can comply with by retrofit or vehicle replacement. Mandatory programs offer the largest potential air quality benefits, but can be politically challenging to implement because of their impact on economically vulnerable groups with limited access to investment capital. Examples of mandatory retrofit programs include the fleet rules adopted under California's Diesel Risk Reduction Plan, the Tokyo Retrofit Program, and certain low-emission zones in Europe.

Best practices in vehicle retrofit programs

Retrofitting a vehicle with supplemental pollution control equipment is a complex, engineering-intensive procedure that must be performed carefully to ensure efficacy and durability and to prevent damage to the vehicle or the retrofit equipment. The case studies outlined in this chapter point toward the following general principles that are critical in any retrofit project:

1. *Establish rigorous verification systems to ensure effectiveness.*

Maximum real-world emissions reductions will be achieved only when technologies whose efficacies have been verified/certified by the environmental protection authority of a country or region are approved for use in a retrofit application. Typically, a specific retrofit model is matched to a given engine or engine family, application, and, in some cases, duty cycle to ensure proper functionality (including regeneration in the case of DPFs). This maximizes the likelihood that the retrofit will effectively reduce emissions over a reasonable operating lifetime. Countries or regions that do not yet have the capacity to certify technologies may consider adopting one of several existing international certification schemes, summarized in Table 7.

Table 7: International retrofit technology certification schemes

Type	Certification	Description and notes	Link
Conventional pollutant reduction retrofits	U.S. EPA Verified Technologies List	Retrofit technologies certified for PM, NO _x , HC, and CO reduction efficiency and durability	http://epa.gov/cleandiesel/verification/verif-list.htm
	CARB verified retrofit technologies	Retrofit technologies certified for PM and NO _x reductions for specific applications	http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm
	Tokyo Retrofit Verification Program	DPF and DOC verified for compliance with Tokyo program	http://www.kankyo.metro.tokyo.jp/vehicle/attachement/ichiran.pdf (Japanese only)
	Swiss Government / VERT	PM technologies certified by particle number reduction efficiency and durability; secondary emissions also tested	http://www.vert-certification.eu/
GHG reduction retrofits	SmartWay	Technologies certified include idle reduction, aerodynamic, low rolling resistance tires, and retrofits (same as U.S. EPA Verified Technologies List)	http://www.epa.gov/smartway/technology/index.htm

The primary purpose of a retrofit verification program is to characterize the reduction efficacy of candidate retrofit technologies, and to match those technologies with engines, applications, and duty cycles that will ensure proper functioning. For particulate filters, a proper match of retrofit to operating conditions will both allow for regular passive regeneration and minimize regular maintenance. Retrofits are generally categorized at different levels of reduction (e.g., 10-30%, 30-50%, etc.) and in terms of the chemical species affected (e.g. PM only, or PM plus NO_x). Attempts to credit pollution control retrofits without formal verification systems may encounter serious difficulties in implementation due to the emergence of ineffective pollution control retrofits, such as engine magnets purported to reduce emissions under Japan's NO_x Control Law in the mid-1990s (Rutherford, 2006). The largest verification program in the United States has been implemented by CARB as part of its Diesel Risk Reduction Plan, summarized below.

California's Diesel Risk Reduction Strategy

In August 1998, after a 10-year review of relevant health studies, the California Air Resources Board identified diesel PM as a toxic air contaminant. The designation triggered the creation of a comprehensive plan for reducing diesel PM exposure throughout the state. The plan, known as the Diesel Risk Reduction Plan, was subsequently approved in September 2000, and laid the foundations for CARB's diesel emission control efforts for the following decade (CARB, 2000).

The Diesel Risk Reduction Plan addresses virtually all new and existing diesel engines operating in the state. For new vehicles, the plan calls for the introduction of stringent emission standards requiring the use of DPFs; for existing vehicles, the plan calls for the retrofitting of engines wherever feasible. To support the expected widespread use of DPFs, the plan also calls for the introduction of ultra-low-sulfur diesel fuel with sulfur content <15ppm. The plan even specifies actions needed by the federal government in instances where CARB does not have adequate legal authority (e.g., locomotive and marine emission control programs). The overall goals of the plan are to reduce diesel health risks in the state by 75% by 2010 and 85% by 2020, from the baseline in 2000.

Responding to the plan's goal for widespread retrofits in the state, CARB immediately began developing a set of verification guidelines to ensure the efficacy and durability of any adopted retrofit technologies. In 2002, CARB issued a detailed verification procedure regulation calling for specific requirements for retrofits used in multiple applications including on- and off-road, stationary, marine, and locomotives (CARB, 2011). The regulation, last updated in 2011, establishes a formal test procedure for verifying emissions reductions of PM and NO_x, sets durability and warranty requirements, and establishes classes of retrofits that can be used in specific applications. All verified technologies, and their approved applications, are listed on CARB's website (<http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm>) and presented in a searchable database by engine type (<http://www.arb.ca.gov/diesel/verdev/vdb/vdb.php>).

2. Conduct pilot projects to build capacity and test the suitability of off-the-shelf technologies for local conditions.

Whether a local authority is considering a voluntary or mandatory retrofit program, smaller scale pilot projects can be an important first step toward an effective program. Pilot projects help educate stakeholders of the key issues associated with installing and monitoring the performance of retrofit technologies, while providing a means to determine whether off-the-shelf technologies are appropriate to local conditions. If not, an effective pilot project provides an opportunity for an early course correction. Vehicles for demonstration projects are typically drawn from captive public or privately contracted fleets that offer decentralized procurement, maintenance, and fueling systems.

3. *Domestic supply must match local demand.*

While the technical assistance of foreign equipment providers can be crucial to launching a new retrofit program, international experience suggests that the majority of retrofits adopted under a new program will ultimately be purchased from domestic manufacturers, particularly when public subsidies are available. Government agencies interested in promoting vehicle retrofits may therefore need to directly foster domestic manufacturing capacity by coordinating symposia on retrofit technologies, actively engaging local manufacturers, etc. In most cases, this role is best played by the national regulatory authority that oversees vehicle manufacturing, although in certain cases large prefectural/state governments such as California and the Tokyo Metropolitan Government have effectively fostered a local manufacturing base for PM retrofits.

Retrofits under Tokyo's In-Use Emission Standard

Beginning in October 2003, the Tokyo Metropolitan Government (TMG), in conjunction with three neighboring prefectures, banned the operation of HD diesel vehicles failing to meet a local in-use particulate emission standard from Tokyo streets. Vehicles were brought into compliance with the standard through either purchasing a newer diesel vehicle compliant with the standard, by retrofitting their vehicles with a verified DPF or DOC, or by shifting to a gasoline or alternative fuel vehicle. TMG estimated that approximately 200,000 diesel trucks and buses registered in Tokyo would be affected by the regulation. Of those, approximately three-quarters were either replaced, registered in other parts of Japan, or exported, with the remaining vehicles retrofit with either a DOC (40,000) or DPF (10,000).

While an early demonstration project on Tokyo's bus fleet was conducted using DPFs from foreign manufacturers, ultimately the majority of retrofits sold under TMG's program were manufactured by domestic companies, sometimes under foreign licensing agreements. A pilot project found that off-the-shelf, continuously regenerating DPFs needed to be modified for use in Japan because of the unique exhaust NO_x/PM balance created by Japan's HD emission standards (Rutherford 2006).

While TMG established a rigorous DOC and DPF verification program, the program was marred by one significant scandal linked to the ability of companies to submit their own testing data for verification. Mitsui, one of Japan's largest general trading companies, revealed that DPFs it sold were underperforming because employees of a subsidiary company had falsified emissions data on three separate occasions during verification, including once in front of TMG staff visiting to company's factory.

Despite these difficulties, Tokyo's in-use emission standard led to significant improvements in local air quality in Tokyo: suspended particulate matter (SPM) concentrations at roadside monitoring stations fell by more than 20% between 2002 and 2004, with the percentage of stations complying with national ambient air quality standards jumping from 0 to 97%. Tokyo's program was also instrumental in prompting the central government to tighten its outdated HD standards, bringing them up to international standards in 2005 (Rutherford, 2006).

4. Retrofit subsidies may be necessary, both to ensure participation in voluntary schemes but also to lessen the impact of mandatory programs on economically vulnerable populations.

As with scrappage and replacement programs, complementary fiscal incentives for retrofitting may increase program participation. Incentives are particularly important for retrofits because, in contrast to vehicle replacement, the driver gains no real benefit for installing the equipment other than the continued right to use the vehicle under mandatory systems. Incentives may take the form of direct subsidies, tax breaks, or low-interest loans for equipment purchase, and will be particularly important in securing the participation of capital-constrained owner-operators in retrofit voluntary programs and limiting the adverse economic effects of mandatory systems on those stakeholders. For example, over a two-year period leading up to the enforcement of its mandatory system, the Tokyo Metropolitan Government dispersed more than 8.9 billion yen (\$80 million) in subsidies, or 200,000 to 400,000 yen (\$1,800 to \$3,600) for DOCs and DPFs, respectively.

5. Improve fuel quality to facilitate use of best available retrofit technologies.

Fuel sulfur levels will determine the range of retrofit technologies that can be deployed in a given region. For fleets or regions lacking access to low sulfur fuel, retrofit options may be limited to actively regenerating particulate filters, PFFs, or diesel oxidation catalysts. While DOCs are a well-established technology for reducing particulate mass associated with unburned fuel in diesel exhaust, they do not reduce emissions of fine or ultrafine particulate emissions. Actively regenerated DPFs and PFFs, by contrast, offer some control of small particulates but at a cost of regular or semi-regular maintenance. This, in turn, may lead some operators to deactivate or remove retrofit equipment, with negative consequences for program effectiveness.

6. Enforcement and follow-up is important.

Continued outreach with operators and manufacturers may be necessary to verify that the retrofits remain installed and continue to work properly throughout the vehicle's lifetime. While it is likely not feasible to test the actual emissions of vehicles once they are in service, periodic visual inspection on-road, on-site, or at areas where HDVs typically congregate (truck stops, regional distribution centers, etc.) may offer clues as to whether retrofits are installed and maintained properly. Manufacturers are typically required to demonstrate durability over a given useful life as a precondition for verification, and to provide purchasers with a warranty covering typical operation, particularly when a retrofit is publicly financed. Implementing authorities may also require that manufacturers with verified technologies provide periodic summaries of the number and types of warranty claims against their equipment as a way to verify that durability claims have been met.

Key take-home points from Chapter 5 on vehicle retrofit programs

- PM reduction retrofits may be a cost-effective means of reducing emissions from HDVs with expensive, customized chassis and/or vehicles with long useful lifetimes.
- Retrofits will not be appropriate to all vehicles due to cost, space/mounting constraints, and duty cycle diversity. For smaller vehicles with shorter useful lives, vehicle replacement/scrappage may be preferable.
- Robust verification programs, which match emission control devices to engine type, application, and duty cycle, are crucial to ensuring that retrofits reduce emissions through the remainder of a vehicle's useful life. Retrofit malfunction, accidents, and even fraud can be expected if verification is not designed and policed effectively.
- Retrofit pilot projects may be necessary to ensure that existing technologies are appropriate to a given locality's fleet and transportation conditions. Captive public or privately contracted fleets are well-suited for conducting these projects. Successful pilots can be important showcases of benefits to trigger more aggressive action at the broader city or national level.

Chapter 6: Use complementary or enabling strategies

Many of the in-use emission control strategies described in Chapters 3, 4, and 5 of this report target vehicle emissions through engine, vehicle, or fuel modifications. This section introduces measures that policymakers can use to complement these strategies. These complementary or enabling measures include restricting older vehicle operation in certain regions; applying fiscal disincentives to high-emission vehicles, programs and policies to reduce emissions through behavioral changes; and other indirect, non-vehicle specific programs such as road improvements and inter-modal shifting.

Low-emission zones

A low-emission zone (LEZ) is an area in which certain vehicles are prohibited from operating. An LEZ can be an important tool for preventing local emissions, encouraging vehicle owners to purchase cleaner vehicles, incentivizing modal shift to lower-polluting transport modes, and reducing congestion and noise. Local air pollution and congestion are typically the primary drivers of the creation of an LEZ, although greenhouse gas emission reduction may be an important co-benefit.

LEZs take different forms around the world, including bans on certain categories of vehicles (e.g., motorcycles), restrictions on vehicles not meeting a minimum emission standard, or bans on vehicles during certain times of the day or week. In some cases, an LEZ imposes a fee on some or all motor vehicles instead of an outright ban. For example, drivers who wish to enter Milan's city center must pay a base fee plus a tax levied according to the vehicle's certified emission standard.

Table 8 introduces some prominent examples of LEZs around the world. Europe, which has been the world's most enthusiastic adopter of the concept, has hundreds of different LEZs of various types (EU, 2012).

Table 8: Examples of low emission zones around the world

LEZ Type	Sub-type	Example	Notes / Details	Enforcement
Ban on certain types of vehicles only	Ban by tailpipe emission standard	Berlin, Germany	Not permitted in the Environmental Zone: Pre-Euro 1 gasoline, Pre-Euro IV diesel vehicles	Manual enforcement by color-coded windshield sticker
		Amsterdam, Netherlands	Not permitted in the city center: pre-Euro IV heavy diesel trucks; Euro III permitted if retrofitted with a diesel particulate filter	Automatic enforcement by cameras recording license plates
		Beijing, China	Not permitted inside the Sixth Ring Road: Pre-China I (Euro 1) gasoline vehicles, pre-China III (Euro III) diesel vehicles	Manual enforcement by color-coded windshield sticker
	Ban by vehicle type	Guangzhou, China	All motorcycles banned in urban area	Manual enforcement
Ban on certain types of vehicles only during certain periods	Ban by time of day	Beijing, China	HD trucks banned inside the Fourth Ring Road between 6 a.m. and 11 p.m.	Manual enforcement
	Ban by day of the week	Beijing, China; Mexico City, Mexico	Passenger cars banned for selected days during week according to license plate number	Manual enforcement supplemented by cameras recording license plates

Most LEZs aimed at reducing local air pollution restrict vehicles based on their certified tailpipe emission standard. In some cases, for example in Amsterdam, vehicles meeting an older standard (e.g. Euro III) may be permitted in the LEZ if they have been retrofitted with a particulate filter. LEZs can be strengthened over time as tighter standards are applied to new vehicles—in combination, these two policies help ensure that low-emission technologies are adopted in a timely manner in urban areas.

Enforcing an LEZ can be challenging. Most of them rely on some sort of vehicle marking system (e.g., windshield stickers) indicating the certification standard of a given vehicle. In areas where inspection and maintenance programs are a routine part of emission-control policy, these markings may be recertified at the time of each inspection. In many areas, cameras are used to record vehicle information (e.g., license plates), check for appropriate markings, and assess noncompliance.

Local governments are generally responsible for designing and implementing LEZs, which are most effective when tailored to local conditions. To meet pollution reduction goals, policymakers may consider which vehicles are restricted and at what times, charges levied, method of enforcement, exemptions granted (e.g., alternative fuel vehicles, emergency vehicles, etc.) penalties for noncompliance, and other factors.

National governments can enable LEZs by setting nationally applicable minimum standards on which LEZ criteria are based, standardizing certification and marking systems used to identify vehicles, and other steps.

LEZs may face strong political and societal opposition, typically on the grounds that they are overly burdensome to economically disadvantaged operators of older vehicles. This opposition may be overcome by the introduction of retrofit or replacement subsidies for noncompliant vehicles in parallel with the implementation of the LEZ.

Pollution taxing

Direct taxation based on a vehicle's emissions can be a straightforward way to promote low-emitting vehicles. For example, both Germany and Switzerland levy differentiated taxes on HD trucks based on their certified emission standard. In Switzerland, a performance-related heavy vehicle fee (HVF) is levied on all HD trucks traveling on public highways in the country. The fee is calculated based on the total weight of the vehicle, the number of kilometers driven, and the tailpipe emission standard. The tax rates by emission standard are divided into three categories; the highest taxation rate per kilometer is levied on Euro 0, I, and II vehicles, the middle rate is levied on Euro III vehicles, and the lowest tax rate is on heavy vehicles certified to Euro IV or higher standards. Enforcement is achieved through the use of installed recording devices or electronic identification cards carried by drivers that contain information on the vehicle's distance traveled and certified emission standard (FDF, 2011).

The taxation by tailpipe emission standard may be politically challenging because it is a regressive tax, insofar as low-income people are more likely to own older, high-emitting vehicles. Pairing a pollution-taxing program with funding programs to offset the cost of equipment upgrades for low-income vehicle owners may help overcome opposition.

Other complementary measures

Many more measures are used to directly or in complementary indirect ways aid in the abovementioned in-use emission reduction actions. Other such complementary programs, which are briefly mentioned below, include anti-idling programs for trucks, driver training programs to instill less emission-intensive driving behavior, and broader travel demand management and mode-shifting policies.

Anti-idling regulations may be an effective way to improve local air quality and to reduce fuel consumption and CO₂ emissions in urban environments. In the United States, where drivers idle climate-controlled trucks overnight to sleep, the EPA estimates that truck and locomotive engine idling is responsible for 200,000 tons of NO_x, 5,000 tons of particulate matter, and 11 million tons of CO₂ per year, in addition to other harmful pollutants (U.S. EPA, 2011). Although the United States has no national anti-idling laws, numerous states and counties have implemented restrictions on the amount of time that diesel truck drivers can idle their engines (ATRI, 2012). Stringent anti-idling laws are commonly adopted under State Implementation Plans (SIPs) for meeting U.S. federal ambient air quality targets. For example, New York City prohibit idling for more than three minutes (one minute if near a school), and California restricts

the idling of HD diesel commercial vehicles to less than five minutes throughout the entire state (CARB, 2008). Tokyo, Hong Kong, Canadian cities, and cities in Sweden and other European countries have adopted similar requirements.

Although operators are generally held responsible for ensuring that their vehicles do not violate anti-idling laws, technologies such as truck stop electrification, auxiliary power units, fuel operated heaters, battery air conditioners, thermal storage systems, and automatic shutdown/startup systems can also be used to reduce or automatically limit idling. Many of these technologies have been verified under the U.S. EPA's SmartWay program (U.S. EPA, 2011).

Another measure that is being explored in a number of places, primarily for CO₂ and fuel use reductions, is driver training to optimize vehicle efficiency. Training programs can teach HDV drivers how to improve fuel economy through a variety of strategies, including using cruise control at optimal speeds, idling less, driving with the engine operating at lower rpm, optimizing shifting patterns, accelerating less aggressively, and optimizing routes. US EPA reports that driver training and monitoring can improve fuel economy and reduce CO₂ emissions by 5% or more (U.S. EPA, 2010). Driver training programs are typically implemented by trucking companies as a fuel saving strategy.

The primary challenge in driver training programs is sustaining the benefits initially achieved. To help maintain performance, electronic monitors may be used to track driver performance over time. In some companies, improved fuel economy due to improvements in driving style may be rewarded via incentive programs.

Most of the strategies described in this report have related directly to vehicles, fuels, or vehicle owners/operators. However, additional, significant pollutant emissions reductions from in-use vehicles may be attained through transportation network optimization, including infrastructure improvement, traffic flow optimization, and intermodal shifting.

Many network improvement projects, which can be readily implemented by local actors, provide both economic and environmental benefits. For example, paving heavily worn roads may reduce fuel consumption and CO₂ emissions by several percent, while also reducing overall vehicle repair and maintenance costs (Chatti and Zabar, 2012). Synchronizing traffic signals to reduce stop-and-go activity and idling could reduce the pollution load for an individual segment by 20% (CPCB, 2011), while also curbing congestion. In China, temporary traffic restrictions during mega-events such as the Beijing Olympics have shown dramatically reduced emissions. A recent China-based study indicates that properly flowing traffic can reduce local air pollution from vehicles by 20–50% (Liu and He, 2012).

Although not discussed in this report, intermodal shifting for freight is also an important strategy that could result in significant emissions reductions. Policies at the national and economy-wide scales encouraging shifting to lower-emitting modes (for example, from trucks to rail or inland marine) can achieve significant improvements in emissions intensity per ton-kilometer traveled (Winebrake et al, 2008). Intermodal shifting can also help to reduce the total activity of high-emitting vehicles. Intermodal optimization is likely guided by national-level policy, including overall goals, infrastructure development, and pricing.

Best practices in complementary measures for in-use emission control

This chapter briefly introduced several examples of complementary measures that can be used to help reduce in-use vehicle emissions. Two broad best practices are identified here for complementary fiscal mechanisms.

1. When existing policies are in place, utilize them to promote better in-use truck operations and vehicle technology purchasing.

Many existing policies can be used to promote decisions by truck fleet operators to better facilitate in-use measures described in this report. For example, many urban areas have restrictions on vehicle use in low-emission zones—these can be used for the promotion of vehicles that have demonstrated very low emission levels (e.g., certified over given model years, appropriate inspection and maintenance approval, particular retrofit technology, running on advanced clean fuels, etc). Annual vehicle registration fees or fuel taxation can similarly be linked to technologies and/or exemplary low emission levels, and these fees could be indexed to emission performance to provide a market-based mechanism to help drive clean technologies.

2. Utilize fuel taxation to promote use of low-sulfur and low-carbon fuels.

The near universal existence of fuel taxation at some level allows a mechanism that can be considered for use in promoting fuels that have inherently lower NO_x, PM, and CO₂ emissions capabilities. Offering preferential (i.e., lower) taxation on a per-energy-unit basis for such fuels promotes the use of the fuel directly at the consumer level. In addition, establishing such differential taxation rates for low-sulfur and low-carbon fuels over the long term improves the value proposition for vehicle purchasing decisions for these emerging low-emission alternative fuel technology vehicles.

Key take-home points from Chapter 6 on complementary programs

- In addition to direct vehicle or technology-based emission reduction strategies, policymakers may consider a variety of complementary measures to reduce emissions from in-use vehicles.
- Complementary fiscal measures, such as vehicle- or fuel-related taxation that is linked to emission control technology and/or cleaner fuels, can serve as either a funding mechanism for other in-use emission control programs or a way to better align the environmental outcomes with market practices.
- Such measures include preventing vehicle operation in certain regions, fiscal disincentives to operating high-emission vehicles, programs and policies to reduce emissions through behavioral changes, use of idling reduction technologies, transportation optimization through inter-modal shifting, improving traffic flow, and more.

Chapter 7: Conclusions and policymaker roles for in-use vehicle emission reduction

This report introduced ways to reduce HDV pollution's effects on local air quality and the global climate that go well beyond waiting for advanced technologies in the new vehicle market to slowly supplant older, higher-emission vehicles. With cleaner fuels, improved exhaust emission control technologies, aftermarket aerodynamic and tire technologies, use of idling reduction technologies, and other strategies, it could be possible to dramatically reduce the emissions of all the HDVs that are on the road today. This report summarized how to best understand a fleet's emissions and allocate resources effectively under a strong in-use emission reduction plan for HDVs, which despite their limited numbers have a disproportionate impact on urban air quality and global warming.

The report discussed how the initial steps to control in-use emissions involve establishing an emission inventory, ideally updated continually with real-world data, to characterize fleet emissions. A key step is to establish a basic regulatory framework for certification of vehicle emissions, and to gradually incorporate requirements for manufacturers to assume responsibility that the vehicles they produce remain clean throughout their entire useful lives. As emission levels become better characterized, information is generated to more optimally devote efforts and resources toward the high-pollution-emitting vehicles through inspection and maintenance programs and effectively deploying retrofit emission control technology. Central to this approach is for national and local authorities to improve fuel quality, in particular by lowering fuel sulfur content. Improved fuel quality directly reduces emissions and enables advanced emission control technologies for very low NO_x and PM emissions.

This work highlighted a number of national, regional, and local emission control programs that characterize international best practices. Based on how legal authority is generally distributed in most nations, several concluding remarks are made here regarding the relative roles that national and local decision-makers can play in controlling in-use emissions. In the tables on the following two pages, summary actions for policymakers are itemized.

National level roles

Table 9 summarizes actions to reduce in-use HDV emissions that can be taken by decision-makers at the national level. Major federal actions generally concern industry-wide regulations for engine and vehicle manufacturers and for fuel providers. Although federal engine and vehicle emission regulations directly pertain to new vehicles and new equipment, establishing strong regulatory foundations for in-use compliance testing, durability, and appropriate full useful life requirements are critical in the long term to control in-use emissions. Federal entities—typically environment, energy, and transport agencies—have a critical role in establishing consistent analytical models for categorizing emissions, as well as providing guidelines for evaluation and guidance on in-use, remote sensing, fuel inspection, scrappage, and other programs that many

localities may independently implement. Federal guidance and evaluation in such areas ensures that various local authorities are learning from efforts already undertaken elsewhere. National decision-making agencies can gain greatly from strong technical and data exchange with local actors, leading to better understanding of how local circumstances influence priority setting and policy outcomes. Many complementary fiscal programs (e.g., fuel taxation, vehicle taxation, technology subsidies) would especially benefit from joint national-local decision-making that link the fiscal policies to in-use emission control policies.

Table 9: National actions to reduce in-use heavy-duty diesel emissions

Area	Program(s)	Roles for national (or regional) decision-makers
Identify and prevent high-emitting vehicles	Inventory modeling	<ul style="list-style-type: none"> Characterize vehicle population, activity, in emission inventory model to quantify mobile pollution sources. Develop emissions inventory model structure for national and local use to quantify mobile pollution sources. Issue guidance and defaults for use of the inventory model.
	Prevent gross emitters	<ul style="list-style-type: none"> Establish national regulatory provisions for appropriate full useful life vehicle emission compliance and for in-use compliance testing. Provide inspection and maintenance (I/M) and remote sensing program guidance and evaluation.
Cleaner fuels	Low-sulfur fuels	<ul style="list-style-type: none"> Set minimum fuel quality requirements, and, if necessary, provide fiscal or other policy support to refineries to begin producing higher-quality fuels. Establish and oversee fuel quality inspection programs.
	Alternative fuels	<ul style="list-style-type: none"> Establish national-level alternative fuel use requirements or targets with clear guidelines for fuels' lifecycle emission performance.
Accelerated retirement of high-emitting vehicles	Voluntary or mandatory scrappage	<ul style="list-style-type: none"> Design overall program or implementation guidance that links scrappage program to highest-emitting vehicles and emission reduction results. Determine metrics for calculating emissions reductions. Provide national subsidies to support local programs with demonstrated need.
Vehicle retrofits for emission control	NO _x , PM emission control	<ul style="list-style-type: none"> Consider developing retrofit technology verification guidelines to target highest-emitting vehicles. Work to ensure supply of low-sulfur fuels to enable a broad spectrum of retrofit technology options. Consider policies/measures to foster domestic retrofit device manufacturing capabilities.
	Fuel efficiency and CO ₂ improvement	<ul style="list-style-type: none"> Establish guidelines, publish information resources, utilize voluntary programs to disseminate best technology practices for in-use fuel efficiency technologies (e.g., aerodynamics, low rolling resistance tires). Consider pilot and research programs with public funding to measure and demonstrate real-world benefits of aftermarket technologies.
Complementary strategies	Vehicle and fuel taxation	<ul style="list-style-type: none"> Issue standardized guidelines for low-emission vehicle zones for local implementation, including linkage to national vehicle environmental labeling and regulatory policy as applicable. Promulgate progressive tax policy discouraging the use of high emission vehicles.

	Demand, mode shifting	<ul style="list-style-type: none"> • Implement national programs to encourage freight and transit shift to lower emission modes.
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Local level roles

Table 10 shows actions to reduce in-use HDV emissions that are generally implemented by local decision-makers. The actions tend to be closely connected with those highlighted above for national actors. However, in many cases, the local authorities will have the critical on-the-ground role. Developing robust emissions inventories that reflect the local vehicle population, activity, and real-world emissions factors typically require local involvement. Regularly collecting additional information (via inspection, spotting of gross emitters, vehicle compliance testing, available fuel quality, weigh stations for overloading, etc.) on high emitters is a fundamental responsibility of local authorities, typically in urban areas. In addition to these factors, local control programs provide critical resources for the design of optimal pollution control strategies that reflect that technical capabilities of local equipment vendors and fleets. Ultimately, local policymakers benefit by coordinating their efforts with federal actions mentioned above to implement a series of cost-effective pollution control policies that carefully target the highest emitting sources and leverage the most directly relevant technology.

Table 10: Local actions to reduce in-use heavy-duty diesel emissions

Area	Program(s)	Roles for local decision-makers
Identify and prevent high-emitting vehicles	Inventory modeling	<ul style="list-style-type: none"> • Develop and utilize standard emission inventory models. • Gather local data for inventory models, run the models, and report the result to national authorities. • Conduct in-use testing to develop real-world emission factors.
	Prevent gross emitters	<ul style="list-style-type: none"> • Design and implement inspection and maintenance (I/M), remote sensing, and spotter programs consistent with national guidance. • Issue and enforce anti-overloading regulations.
Cleaner fuels	Low-sulfur fuels	<ul style="list-style-type: none"> • When national fuel quality requirements are insufficient for local air quality needs, implement local-level fuel quality requirements. • Support and participate in fuel quality inspection programs.
	Alternative fuels	<ul style="list-style-type: none"> • Deploy local fleets of alternative fuel vehicles. • Provide incentives (parking, lane access, etc.) for very-low-emission vehicles with advanced alternative fuel technology.
Accelerated retirement of high-emitting vehicles	Voluntary or mandatory scrappage	<ul style="list-style-type: none"> • Award subsidies based on competitive bid process and cost-effectiveness. • Implement program, including scrappage verification. • Implement supplemental subsidies and/or complementary policies to increase incentives and maximize effectiveness of program.
Vehicle retrofits for emission control	NO _x , PM emission control	<ul style="list-style-type: none"> • Carefully implement retrofit programs that match a given device to vehicle/engine type, vocation, duty cycle, etc., to ensure effectiveness of the program. Carefully police systems to make sure that requirements are being met. • Develop incentive programs for retrofits, with a focus on fostering the participation of capital-constrained owner/operators. • Establish retrofit demonstration projects using public and/or publicly contracted captive fleets to determine the appropriateness of existing technologies. • Enforce mandatory retrofit programs.
	Fuel efficiency and CO ₂ improvement	<ul style="list-style-type: none"> • Establish guidelines, publish information resources, utilize voluntary programs to disseminate best technology practices for in-use fuel efficiency technologies (e.g., aerodynamics, low rolling resistance tires). • Consider pilot and research programs with public funding to measure and demonstrate real-world benefits of aftermarket technologies.
Complementary strategies	Vehicle and fuel taxation	<ul style="list-style-type: none"> • Designate and enforce low-emission zones that restrict high-emission vehicles and encourage advanced very-low-emission vehicles. • Conduct driver training programs.
	Use of idling reduction technologies	<ul style="list-style-type: none"> • Issue and enforce anti-idling regulations that encourage operators to use technologies such as truck stop electrification, auxiliary power units, fuel operated heaters, battery air conditioners, thermal storage systems, and automatic shutdown/startup systems to reduce idling of the main propulsion engine.
	Demand, mode shifting	<ul style="list-style-type: none"> • Optimize traffic patterns to resolve congestion and reduce emissions. • Implement local programs to encourage modal shift to lower emission modes.

References

- Andersson, J. (2011). *Summary report on Module 1 – Biofuel effects on diesel performance, emissions and economy in conventional and advanced technologies*. Retrieved September 2, 2012 from <http://assets.dft.gov.uk/publications/biofuels/biofuel-effects-on-diesel-performance.pdf>.
- American Transportation Research Institute (2012). *Compendium of idling regulations*. Retrieved September 2, 2012, from http://www.atri-online.org/research/idling/ATRI_Idling_Compendium.pdf.
- Asian Development Bank (2008). *A road map for cleaner fuels and vehicles in Asia*. Retrieved September 11, 2012, from http://cleanairinitiative.org/portal/sites/default/files/attach/Fuel_roadmap.pdf.
- Beijing Environmental Protection Bureau (2011). *Municipal government issues new policy encouraging scrappage of older vehicles* (in Chinese). Retrieved December 8, 2012, from <http://www.bjepb.gov.cn/portal0/tab189/info6306.htm>.
- Cai, F., Han, G., Wang, Z. (2004). The effects of overloading on fuel consumption and emission of motor vehicles (in Chinese). *Journal of Highway and Transportation Research and Development*. 21(9): September.
- California Air Resources Board (1998). *Findings of the scientific panel on the report on diesel exhaust*. Retrieved September 2, 2012, from <http://www.arb.ca.gov/toxics/dieseltac/de-fnds.htm>.
- California Air Resources Board (2000). *Risk reduction plan to reduce particulate matter emissions from diesel-fueled engines and vehicles*. Retrieved September 11, 2012, from <http://www.arb.ca.gov/diesel/documents/rrpFinal.pdf>.
- California Air Resources Board (2008). *The Carl Moyer program guidelines*. Retrieved September 2, 2012, from http://www.arb.ca.gov/msprog/moyer/guidelines/cmp_guidelines_part1_2.pdf.
- California Air Resources Board (2009). *Emissions inventory data*. Retrieved September 2, 2012, from <http://www.arb.ca.gov/ei/emissiondata.htm>.
- California Air Resources Board (2011). Final Regulation Order California Code of Regulations, Title 13, Division 3, Chapter 14. *Verification procedure, warranty and in-use compliance requirements for in-use strategies to control emissions from diesel engines*. Retrieved September 11, 2012, from http://www.arb.ca.gov/diesel/verdev/reg/procedure_march2011.pdf.
- Central Pollution Control Board (2011). *Air quality monitoring, emission inventory and source apportionment study for Indian cities: National summary report*, Ministry of Environment and Forests. Retrieved September 2, 2012, from http://cpcb.nic.in/Source_Apportionment_Studies.php.
- Cheng, J., (2010). The smog squad of Hong Kong has truckers on the run. *Wall Street Journal*. Retrieved September 2, 2012, from <http://online.wsj.com/article/SB10001424052748704025304575284460465232720.html>.

- Chatti, K. and Zabar, I. (2012). *Estimating the effects of pavement condition on vehicle operating costs* (National Cooperative Highway Research Program Report 720). Retrieved from http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_720.pdf.
- Dougherty, C. (2009). Driving out of Germany, to pollute another day. *New York Times*. Retrieved September 2, 2012, from <http://www.nytimes.com/2009/08/08/world/europe/08germany.html>.
- Europa (2012). *Promotion of the use of energy from renewable sources*. Retrieved September 2, 2012, from http://europa.eu/legislation_summaries/energy/renewable_energy/en0009_en.htm.
- European Union (EU), 2012. *Low emission zones in Europe: Europe-wide information on LEZs*. Retrieved September 2, 2012, from <http://www.lowemissionzones.eu>.
- Switzerland Federal Department of Finance (2011). *Performance-related heavy vehicle fee: HVF - overview, 2011 edition*. Retrieved September 2, 2012, from http://www.ezv.admin.ch/zollinfo_firmen/steuern_abgaben/00379/index.html?lang=en.
- Fung, F., Hui, H., Sharpe, B., Kamakate, F., and Blumberg, K. (2011). *Overview of China's vehicle emission control program*. Retrieved September 2, 2012, from <http://theicct.org/node/6>.
- Gehr, P. (2010). *Health effects due to inhaled engine emitted solid nanoparticles*. Presented at the Technical Workshop on DPF Retrofits, Beijing, October 27, 2010. Retrieved from http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=40627.
- Hart Energy and MathPro, Inc. (2012). *Technical and economic analysis of the transition to ultra-low sulfur fuels in Brazil, China, India, and Mexico*. Prepared for the International Council on Clean Transportation. Retrieved December 8, 2012, from <http://www.theicct.org/technical-and-economic-analysis-transition-ultra-low-sulfur-fuels-brazil-china-india-and-mexico>.
- Hong Kong Environmental Protection Department (2007). *Press release: Emissions from LPG taxis*. Retrieved September 2, 2012, from http://www.info.gov.hk/gia/general/200711/21/P200711210199_print.htm.
- Hong Kong Environmental Protection Department (2009). *Smoky vehicle control programme and spotter training*. Retrieved September 2, 2012, from http://www.epd.gov.hk/epd/english/how_help/report_pollution/spotter_training.html.
- Huo, H. and Wang, M. (2011). Modeling future vehicle sales and stock in China. *Energy Policy*: Volume 43, April 2012, Pages 17-29.
- International Agency for Research on Cancer (2012). IARC: Diesel Engine Exhaust Carcinogenic. Press Release No. 213, June 2012. Retrieved July 23, 2013, from http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf.
- Kagawa, J. (2002). Health effects of diesel exhaust emissions - a mixture of air pollutants of worldwide concern. *Toxicology*: 181-182 (2002): 349-353.

- Kopp, R.E., and Mauzerall, D.E. (2010). Assessing the climatic benefits of black carbon mitigation. *Proceedings of the National Academy of Sciences*: 107 (26). 11703-11708.
- Lents, J., Walsh, M., He, K., Davis, N., Osses, M., Tolvett, S., and Liu, H. (2011). *Handbook for Air Quality Management*. Retrieved from <http://www.aqbook.org>.
- Lim, Stephen S, Theo Vos, Abraham D Flaxman, Goodarz Danaei, Kenji Shibuya, Heather Adair-Rohani, Markus Amann, et al. 2012. "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: a Systematic Analysis for the Global Burden of Disease Study 2010." *The Lancet* 380 (9859) (December): 2224–2260. doi:10.1016/S0140-6736(12)61766-8.
- Liu, H., He, K., He, D., Fu, L., Zhou, Y., Walsh, M.P., and Blumber, K.O. (2008). Analysis of the impacts of fuel sulfur on vehicle emissions in China. *Fuel*: Volume 87: 3147–3154.
- Liu, H., and He, K. (2012). Traffic Optimization: A new way for air pollution control in China's urban areas. *Environmental Science & Technology*. 46 (11): 5660–5661. Retrieved from <http://pubs.acs.org/doi/full/10.1021/es301778b>.
- Lowell, D. (2012). Clean diesel versus CNG buses: Cost, air quality, & climate impacts. Retrieved September 2, 2012, from http://www.catf.us/resources/publications/files/20120227-Diesel_vs_CNG_FINAL_MJBA.pdf.
- Lowell, D. and Kamaketé, F. (2012). Urban off-cycle NO_x emissions from Euro IV/V trucks and buses. International Council on Clean Transportation. Retrieved December 8, 2012, from <http://www.theicct.org/urban-cycle-nox-emissions-euro-ivv-trucks-and-buses>.
- McConnell, R., Berhane, K., Yao, L., Jerrett, M., Lurmann, F., Gilliland, F., Kunzli, N., Gauderman, J., Avol, E., Thomas, D., and Peters, J. (2006). Traffic, susceptibility, and childhood asthma. *Environmental Health Perspectives*. Volume 115(5): 766-772. May.
- McCormick, R.L., Graboski, M.S., Alleman, T.L, Alvarez, J.R., and Duleep, K.G., 2003. Quantifying the emission benefits of opacity testing and repair of heavy-duty Diesel Vehicles. *Environmental Science and Technology*. 37(3): 630-637.
- Manufacturers of Emission Controls Association (2010). *Diesel retrofit technology FAQ*. Retrieved September 2, 2012, from <http://www.meca.org/galleries/default-file/diesel%20retrofit%20FAQ%201010.pdf>.
- Manufacturers of Emission Controls Association (2012). Written Statement of the Manufacturers of Emission Control Association on the Proposal to Revise the National Ambient Air Quality Standards for Particulate Matter. Retrieved December 8, 2012, from <http://www.meca.org/galleries/default-file/EPA%20PM%20NAAQS%20testimony%200812.pdf>.
- Mellera, M. and Bignardi, P. (2011). Alternative Fuel Program & Next Generation Transit Vehicles at SFMTA. Retrieved December 8, 2012, from <http://www.apta.com/mc/multimodal/previous/2011/Presentations/Session-6-Hybrid-Buses-and-Trolley-Buses-The-Next-Generation-M-Mellera-P-Bignardi.pdf>.

- Ministry of Environmental Protection of China (2010a). *Vehicle emission control annual report* (in Chinese). Retrieved September 2, 2012, from http://www.mep.gov.cn/gkml/hbb/qt/201011/t20101104_197140.htm.
- Ministry of Environmental Protection (2010b). *Vehicle emission control annual report* (in English). Retrieved September 2, 2012, from http://www.vecc-mep.org.cn/news/e_home_gg/2010engreport.pdf.
- Ministry of Finance et al, (2009). *Notice about issuing of implementation methods for vehicle scrappage and replacement* (in Chinese). Retrieved September 2, 2012, from http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=33844.
- Ministry of Finance and Ministry of Commerce (2010). *Notice about adjusting subsidy standards and related matters for vehicle scrappage and replacement* (in Chinese). Retrieved September 2, 2012, from http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=36388.
- Molina, M., Zaelke, D., Sarma, K., Anderson, S., Ramanathan, V., Kaniaru, D. (2009). Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO₂ emissions. *Proceedings of the National Academy of Sciences*. Retrieved September 2, 2012, from www.pnas.org/cgi/doi/10.1073/pnas.0902568106.
- Ministério do Meio Ambiente (2011). *Primeiro inventário nacional de emissões atmosféricas por veículos automotores rodoviários*. Brazil. Retrieved September 2, 2012, from http://www.mma.gov.br/estruturas/163/_arquivos/inventario_veicular2010_163.pdf.
- National Highway Traffic Safety Administration (2009). *Consumer Assistance to Recycle and Save Act of 2009: Report to the House Committee on Energy and Commerce, the Senate Committee on Commerce, Science, and Transportation and the House and Senate Committees on Appropriations*. Retrieved from <http://www.cars.gov/files/official-information/CARS-Report-to-Congress.pdf>.
- New Jersey Department of Environmental Protection (2012). *Diesel inspection and maintenance: Smoking vehicle*. Retrieved from http://www.nj.gov/dep/bmvim/bmvim_idling.htm#smoking.
- Posada, F. (2009). CNG Bus Emissions Roadmap: from Euro III to Euro VI. International Council on Clean Transportation. Retrieved December 8, 2012, from <http://www.theicct.org/cng-bus-emissions-roadmap>.
- Posada, F., Malins, C., and Baral, A. (2012). Biodiesel carbon intensity, sustainability and effects on vehicles and emissions. International Council on Clean Transportation. Retrieved December 8, 2012, from <http://www.theicct.org/biodiesel-carbon-intensity-sustainability-and-effects-vehicles-and-emissions>.
- Prasad, R., and Bella, V.R. (2010). A review on diesel soot emission, its effect and control. *Bulletin of Chemical Reaction Engineering & Catalysis*. 5(2): 69-86.
- Ramanathan, V., and G. Carmichael. (2008). Global and regional climate changes due to black carbon. *Nature Geoscience*. Vol. 1: 221-227.
- Rutherford, D. (2006). *Policy change in Japan: The Tokyo Metropolitan Government's regulation of diesel emissions*. Dissertation, Stanford University.

- San Francisco Municipal Transportation Agency (2008). *Climate Action Plan, draft for public review, Appendix E*. Retrieved September 2, 2012, from http://www.sf-planning.org/ftp/files/MEA/GHG-Reduction_ApxE.pdf.
- St. Denis, M. and Lindner, J. (2005). Review of light-duty diesel and HD diesel gasoline inspection programs. *Journal of Air and Waste Management Association*. 55:1876-1885.
- Sydbom A., Blomberg A., Parnia S., Stenfors N., Sandström T., Dahlén S.E. (2001). Health effects of diesel exhaust emissions. *European Respiratory Journal*. 17: 733-746.
- Tokyo Metropolitan Government (2003). *The Tokyo Metropolitan Government's diesel control policy: National neglect, local solutions*. Retrieved from http://www.kankyo.metro.tokyo.jp/en/attachement/diesel_vehicle.pdf.
- TransSantiago, 2012. Who are we? (description in English). Retrieved September 2, 2012, from <http://www.transantiago.cl/QUIENESSOMOS/DESCRIPCION/INGLES/index.htm>.
- United States Agency for International Development (2004). *Vehicle inspection and maintenance programs: International experience and best practices*. Retrieved September 2, 2012, from http://cleanairinitiative.org/portal/system/files/articles-59065_paper.pdf.
- U.S. Department of Energy and U.S. Environmental Protection Agency (2012). *Gas mileage tips - keeping your vehicle in shape*. Retrieved September 2, 2012, from <http://www.fueleconomy.gov/feg/maintain.shtml>.
- U.S. Environmental Protection Agency (2006). *North American emissions inventories - Mexico*. Retrieved September 2, 2012, from <http://www.epa.gov/ttnchie1/net/mexico.html>.
- U.S. Environmental Protection Agency (2008). *Case study: Diesel bus retrofit in Beijing, China. 2008. With Southwest Research Institute*. Retrieved September 2, 2012, from <http://www.swri.org/4org/d08/China/busretrofit/pdfs/ReportTranslated.pdf>.
- U.S. Environmental Protection Agency (2008). *EPA finalizes regulations requiring onboard diagnostic systems on 2010 and later heavy-duty engines used in highway applications over 14,000 pounds; revisions to onboard diagnostic requirements for diesel highway heavy-duty applications under 14,000 pounds*. Retrieved from <http://www.epa.gov/obd/regtech/420f08032.pdf>
- U.S. Environmental Protection Agency (2011). *SmartWay technology program: Verified idling reduction technologies*. Retrieved September 2, 2012, from <http://www.epa.gov/smartway/technology/idling.htm>.
- U.S. Environmental Protection Agency (2000). *Regulatory impact analysis: Heavy-duty engine and vehicle standards and highway diesel fuel sulfur control requirements*. EPA420-R-00-026.
- Uslu, A., J. van Stralen (2012). *Sustainable biomass for electricity, heat and transport fuels in the EU27*. Energy Research Center of the Netherlands. Retrieved September 2, 2012, from <http://www.ecn.nl/docs/library/report/2012/e12030.pdf>.

- Wang, M., Huo, H., Johnson, L., He, D. (2006). *Projection of China motor vehicle growth, oil demand, and CO2 emissions through 2050*. Argonne National Laboratory, Energy Systems Division.
- Walsh, M., Kodjak, D., Rutherford, D. (2007). A model regulatory program for reducing exhaust and evaporative emissions from HDVs and engines. International Council on Clean Transportation. Retrieved September 2, 2012, from http://www.theicct.org/sites/default/files/publications/ICCT_HDVmodelrule_2007.pdf.
- Winebrake, J.J., Corbett, J.J., Falzarano, A., Hawker, J.S., Korfmacher, K., Ketha, S., Zilora, S. (2008). Assessing energy, environmental, and economic tradeoffs in inter-modal freight transportation. *Journal of the Air & Waste Management Association* 58(8): 1004-1013.
- World Bank (2011). *Carbon credits help remove old, polluting taxis from the Streets of Cairo*. Retrieved September 2, 2012, from <http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTCARBONFINANCE/0,,contentMDK:22976018~menuPK:5575595~pagePK:64168445~piPK:64168309~sitePK:4125853,00.html>.
- Xinhua News (2010). Authorized for release: Report on the first-ever national pollution source census (in Chinese). Retrieved from http://news.xinhuanet.com/politics/2010-02/09/content_12960555_4.htm.
- Yanowitz, J., McCormick, R., Graboski, M. In-use emissions from HD diesel vehicles, 2000. *Environmental Science and Technology*. 24 (5): 729-740.
- Zhu, Y., Hinds, W.C., Kim, S., Shen, S., Sioutas, C. (2002). Study of ultrafine particles near a major highway with heavy-duty diesel traffic. *Atmospheric Environment*: 36: 4323-4335.



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