Chapter 8

Mitigation Approaches for Mobile Sources

8.1 Summary of Key Messages

- In the United States, mobile sources accounted for 52% of total BC emissions in 2005, approximately 93% of which came from diesel vehicles or engines. On a global basis, mobile sources are responsible for approximately 19% of BC emissions, with total mobile source emissions and the percentage attributable to mobile sources both significantly lower in developing countries.

- In the United States, new engine requirements have resulted in a 32% reduction in BC emissions from mobile sources between 1990 and 2005. As vehicles and engines meeting new regulations are phased into the fleet, a further 86% reduction in BC emissions from mobile sources is projected from 2005 to 2030, leading to a total decline of 90% in BC emissions between 1990 and 2030. Such regulations have been effective in reducing emissions of BC from on-road vehicles (mainly diesel trucks), and nonroad diesel engines, locomotives, and commercial marine vessels.

  - Most of these reductions are concentrated in the diesel fleet, and can be achieved via application of diesel particulate filters (DPFs) combined with ultra low sulfur diesel fuel. DPFs typically eliminate more than 90% of diesel PM and can reduce BC by as much as 99%.

  - The cost of controlling $PM_{2.5}$ from most types of diesel engines is about $14,000/ton (2010$) based on prior EPA rulemakings.

- Mobile source BC emissions in other developed countries have been declining rapidly since the 1990s due to regulations on PM emissions from new engines, mainly diesel trucks, and substantial further emissions reductions are expected by 2030 and beyond. Internationally, other developed countries have and are continuing to adopt emission standards (including those for diesel engines with ultra low sulfur fuel) similar to EPA emission standards, which also results in harmonization of standards. However, standards for new engines lag behind in some regions.

- Of the on-highway and nonroad diesel engines currently in operation in the United States, many of which will remain in operation for the next 20 to 30 years, there are approximately 11 million legacy fleet engines that are emitting PM at elevated levels compared to new engines.

- For policymakers seeking additional BC emissions reductions beyond those that will be achieved as a result of the new engine regulations already in place, there are currently available, cost-effective diesel retrofit strategies that can reduce harmful emissions from in-use engines substantially.

  - DPFs in a retrofit program for in-use vehicles can reduce PM emissions by up to 99%, at a cost of $8,000 to $15,000 for passive DPFs, and $20,000 to $50,000 for active DPF systems. However, not all engines are good candidates for DPFs because of old age or poor maintenance. Other cleaner engine strategies include engine repowers, engine upgrades, and replacement of the engine (sometimes including the vehicle or piece of equipment). EPA's National Clean Diesel Campaign has provided grant funds to support diesel engine retrofits, repowers, and replacements.

  - Other strategies to reduce emissions from existing engines include improved fleet maintenance practices, idle reduction programs, advanced aerodynamics, more fuel efficient tires and more efficient supply chain management strategies, including shifts in mode of transportation. EPA's SmartWay Transport Partnership is designed to encourage industry to adopt these best practices for reducing emissions and improving fuel economy.

  - Internationally, retrofit programs present significant financial and logistical challenges. This is particularly true in developing countries, where infrastructure is lacking to assist with vehicle registration, inspection and maintenance programs, technology certification/verification programs, and application of readily available technologies. Vehicles in these regions tend to be older and less well-maintained than in developed countries, and the availability of low-sulfur diesel fuel is limited. In addition, the costs of DPFs may be prohibitive for some countries.

8.2 Introduction

A number of $PM_{2.5}$ control strategies have proven successful in reducing BC emissions from mobile sources, which represent one of the most important categories of BC[1] emissions globally, especially within developed countries (see Chapter 4). The two principal strategies include: (1) emissions standards for new vehicles and engines, with emissions reductions occurring as the vehicle and engine fleet turns over, and (2) controls or strategies that reduce emissions from existing in-use engines, such as diesel retrofits. In this chapter, these two major strategies are explored, with emphasis on describing the anticipated impact of these approaches on emissions by 2030. It is important to note that these strategies are complementary, and can be employed simultaneously. The joint application of new engine standards and controls on in-use engines has been very successful in both the United States and Europe in reducing direct PM emissions—including BC—from mobile sources.[2]

Existing programs provide important insights into achievable emissions reductions, costs, and implementation challenges for new and existing vehicles/engines in the mobile sector. Emphasis is placed on programs and strategies which have proven successful in the United States, including both new vehicle/engine standards and programs addressing in-use diesels such as EPA's National Clean Diesel Campaign (NCDC), the SmartWay Transport Partnership Program, and California's mandatory diesel retrofit program. The chapter discusses the impact of these approaches on current and anticipated future emissions levels, and describes the specific control technologies and strategies involved, along with the cost of these approaches. A close examination of such strategies may offer insights into applicability of such strategies elsewhere.

The main technology for reducing black carbon emissions from diesel engines is the catalyzed diesel particulate filter (DPF) discussed later in this section. It is important to note that since DPFs are made inoperable by fuels with high sulfur content, mitigation of mobile source BC emissions depends on the availability and widespread use of ultra low-sulfur fuels (15 ppm sulfur). Typically, the low-sulfur diesel fuel is in the marketplace about the same time that the DPFs are introduced, although some countries, particularly in the developing world, may introduce low-sulfur fuel before adopting stringent PM emission standards. The timing of ultra low-sulfur fuel availability in different world regions is discussed in this section, and in further detail in Appendix 4.

8.3 Emissions Trajectories for Mobile Sources

As discussed in Chapter 4, mobile sources remain the dominant emitters of BC in developed countries. In the United States, for example, mobile sources were responsible for about 52% of BC emissions in 2005, almost all of which (93%) came from diesel vehicles or engines. If wildfire emissions are excluded, then mobile sources account for 69% of the 2005 domestic inventory. On a global basis, mobile sources are responsible for approximately 19% of the BC (Bond et al., 2004) with total emissions and percentage attributable to mobile sources both significantly lower in developing countries. A number of studies have projected that these emissions are likely to increase globally in the future, largely due to growth in the transportation sector in developing countries (Streets et al., 2004; Jacobson and Streets, 2009) (see Chapter 7). However, mobile source BC emissions in developed countries have been declining rapidly since the 1990s. Regulations on (PM) emissions from new engines, particularly in the United States and Europe, have been effective in reducing emissions of BC from on-road vehicles (mainly diesel trucks), and nonroad diesel engines, locomotives, and commercial marine vessels, although Europe has not currently adopted stringent locomotive and commercial marine standards as the United States has. Substantial emissions reductions are expected over the next two decades and beyond.

[1] As mentioned in Chapter 5, optical measurements of BC are limited and vary depending on measurement technique. Measurements of elemental carbon (EC) by thermal optical methods are more widespread and consistent; mobile source emissions inventories and information about control strategies for mobile sources usually involve EC measurements. To ensure consistency in this report, however, the term BC is used throughout.

[2] Roughly 98% of the exhaust PM emitted from mobile sources is 2.5 microns or smaller in size. This is true for both diesel and gasoline vehicles/engines. All exhaust particulate from mobile diesel sources is commonly referred to as "diesel PM" and this convention is used in this chapter. These emissions do not include secondary PM (SOA, nitrates, sulfates) formed from mobile source emissions in the atmosphere or tire and brake wear emissions.

In the United States, new engine requirements have resulted in a 32% reduction in BC emissions from mobile sources between 1990 and 2005. As vehicles and engines meeting new regulations are phased into the fleet, a further 86% reduction in BC emissions from mobile sources is projected from 2005 to 2030, leading to a total decline of 90% in BC emissions between 1990 and 2030 as shown in Table 8-1. Most of these reductions are concentrated in the diesel fleet. For example, from 1990-2005, there was a 30% decline in BC emissions from diesel trucks. Due to new regulations, a further 95% decline is projected in diesel truck BC emissions by 2030 (97% total decline since 1990). Other categories of diesel engines, such as nonroad diesels (e.g., agricultural, construction equipment), commercial marine diesels (excluding ocean going vessels), and locomotives are also projected to have major declines (75-92%) in BC emissions from 2005 to 2030 in the United States. BC emissions from gasoline vehicles and nonroad gasoline engines, which are much smaller sources of BC, are projected to decline by 80% during 1990-2030 time period, with a 23% reduction occurring from 2005-2030. Most of that reduction will come from on-road gasoline vehicles due to the use of catalysts that decrease PM.[3,4]

Considering only the emissions from U.S. mobile sources occurring north of the 40th parallel in 2005, EPA estimates there will be a substantial decline of approximately 85% in these emissions by 2030 as well. As discussed in Chapter 4, emissions from sources in northern latitudes are of particular interest, due to the proximity of these emissions to the Arctic and the greater likelihood of transport to that sensitive region. However, the projected decline in mobile source emissions north of the 40th parallel does not reflect potential future increases in emissions from marine freight transport that may occur under future climate scenarios. The total or seasonal loss of Arctic sea ice may result in new marine trade routes through the Arctic. Such developments could potentially result in greater emissions in the Arctic, with greater potential for deposition on remaining ice. U.S. emissions inventories currently contain no projections of these potential future emissions in the Arctic area. However, some studies have been done of emissions from shipping and aircraft in the Arctic area (Corbett et al., 2010; Wilkerson et al., 2010).

Table 8-1 shows the emissions reductions in BC (as well as $PM_{2.5}$ and OC) going from 1990 through 2030 for various mobile source sectors which are discussed in the following sections. The basis for the emissions inventories here is discussed in the mobile source section of Appendix 2. The numbers are based largely on the MOVES and NONROAD models, which represent EPA's projections for emissions reductions that will occur as a result of the engine and tailpipe emissions regulations already promulgated by EPA, but do not include any additional emissions reductions that would occur as a result of engine retrofits or replacements. Also, Figure 8-1 shows the reductions in BC graphically from 1990 through 2030.

8.4 New Engine Standards in the United States

In the United States, PM emissions standards for new mobile source engines are being phased in across different sectors between 2007 and 2020, mostly for diesel engines. These standards will lead to the large reductions in mobile source emissions of BC illustrated in Table 8-1.[5] The realized reductions depend on the rate of fleet turnover—i.e., the rate at which older vehicles and engines are replaced with new vehicles that comply with the latest emissions standards. The rate of fleet turnover depends heavily on the type of vehicle or engine, with on-road engines such as passenger cars and light-duty trucks being replaced more frequently than some other types of mobile sources, such as nonroad equipment. The state of California has its own diesel PM standards as promulgated by the California Air Resources Board (CARB). These standards are, in general, similar if not identical to the Federal standards. CARB also has its own gasoline PM standards. A detailed list of the mobile source PM standards is contained in Appendix 5.

The emission standards and/or control technology cited below to reduce PM (and thus BC) emissions do not include programs such as increased use of

[3] Unlike the reductions for diesels, the reductions in BC from gasoline engines occurred due to regulation of other pollutants (such as hydrocarbons [HC], carbon monoxide [CO], and oxides of nitrogen [NO_x]) rather than regulation of PM itself. The use of catalysts on these vehicles to decrease HC, CO, and NO_x also results in substantial PM and BC reductions. In general, BC emissions from gasoline vehicles and engines have been less studied than those from diesel engines.

[4] Tire and brake wear are also considered to be mobile sources. Emissions from these categories in the United States increased from 1990 to 2030 due to increases in vehicle miles traveled (VMT). Tire and brake wear are relatively minor sources of BC compared to exhaust emissions (i.e., less than 1% of the total in 1990 but 4% in 2030) although they are larger from a PM standpoint. Importantly, BC accounts for 22% of PM emissions from tire wear. At present, there are no EPA emission standards for either tire or brake wear PM emissions.

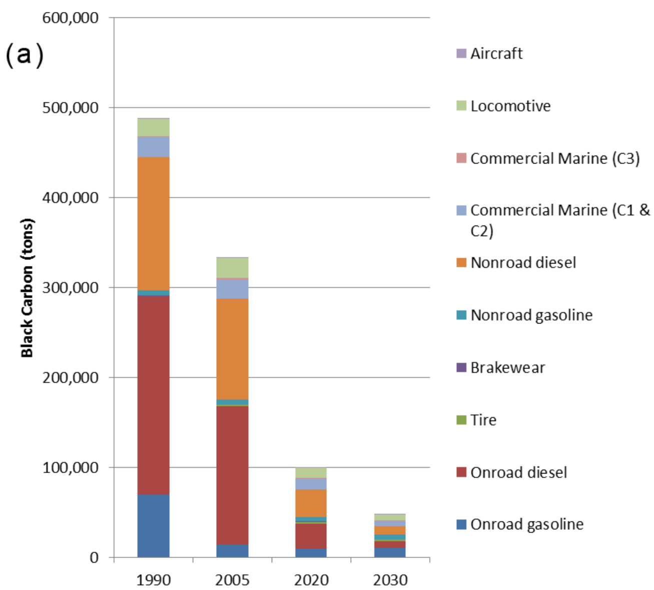
[5] EPA models the cumulative reductions for each category of mobile sources attributable to all past and current standards promulgated for that category rather than modeling the reduction for a particular standard.

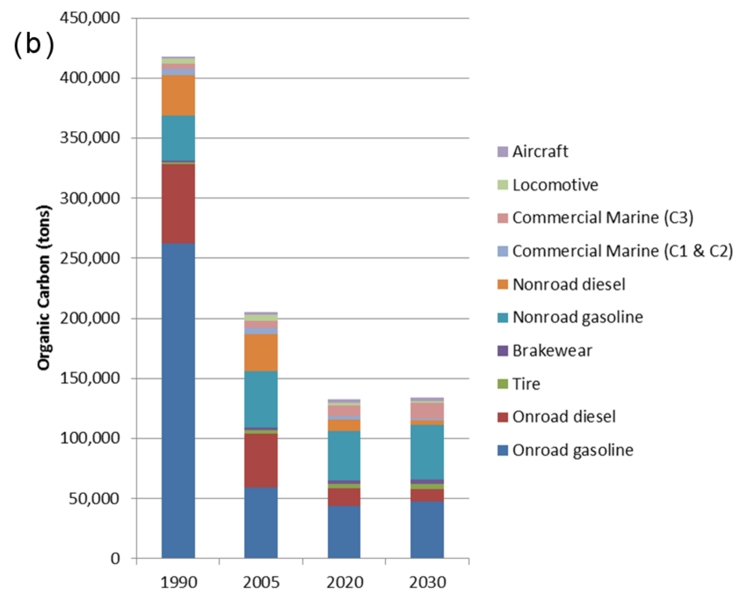
Table 8-1. Mobile Source BC, OC, and $PM_{2.5}$ Emissions 1990-2030 (short tons). (Source: U.S. EPA)

Source Category	Year				% Change	
BLACK (ELEMENTAL) CARBON	**1990**	**2005**	**2020**	**2030**	**1990→2005**	**2005→2030**
Onroad gasoline	69,629	14,510	9,538	10,027	-79%	-31%
Onroad diesel	219,958	153,477	28,175	7,615	-30%	-95%
Tire	809	1,198	1,435	1,720	48%	44%
Brakewear	290	475	569	682	64%	44%
Nonroad gasoline	5,420	5,444	4,702	5,174	0%	-5%
Nonroad diesel	148,537	112,058	31,254	9,356	-25%	-92%
Commercial Marine (C1 & C2)	22,122	21,652	11,595	5,440	-2%	-75%
Commercial Marine (C3)	1,262	1,681	864	1,306	33%	-22%
Locomotive	19,317	22,495	11,349	5,684	16%	-75%
Aircraft[a]	283	410	457	553	45%	35%
Total BC Emissions (Mobile)	**487,628**	**333,400**	**99,940**	**47,557**	**-32%**	**-86%**
ORGANIC CARBON						
Onroad gasoline	262,065	59,657	43,711	47,421	-77%	-21%
Onroad diesel	66,056	44,423	14,883	10,580	-33%	-76%
Tire	1,734	3,060	3,678	4,407	76%	44%
Brakewear	1,191	2,321	2,790	3,343	95%	44%
Nonroad gasoline	37,613	46,734	41,137	45,424	24%	-3%
Nonroad diesel	33,872	30,618	9,759	3,891	-10%	-87%
Commercial Marine (C1 & C2)	5,045	4,937	2,772	1,710	-2%	-65%
Commercial Marine (C3)	4,734	6,303	8,644	13,060	33%	107%
Locomotive	4,405	5,130	2,659	1,507	16%	-71%
Aircraft[a]	1,372	1,988	2,217	2,682	45%	35%
Total OC Emissions (Mobile)	**418,088**	**205,172**	**132,252**	**134,025**	**-51%**	**-35%**
DIRECT $PM_{2.5}$						
Onroad gasoline	335,205	75,924	54,682	59,106	-77%	-22%
Onroad diesel	290,478	208,473	43,698	18,765	-28%	-91%
Tire	3,678	5,325	6,450	7,727	45%	45%
Brakewear	11,129	17,801	21,559	25,830	60%	45%
Nonroad gasoline	54,198	55,834	49,000	54,078	3%	-3%
Nonroad diesel	192,905	145,289	46,310	18,463	-25%	-87%
Commercial Marine (C1 & C2)	28,730	28,119	15,789	9,741	-2%	-65%
Commercial Marine (C3)	42,082	56,028	14,407	21,767	33%	-61%
Locomotive	25,087	30,910	15,145	8,584	23%	-72%
Aircraft[a]	2,178	3,156	3,519	4,257	45%	35%
Total $PM_{2.5}$ Emissions (Mobile)	**985,671**	**626,859**	**270,559**	**228,318**	**-36%**	**-64%**

[a] Non landing and take-off (LTO) emissions not included; also, planned technology and operations improvements that require funding for implementation are not included in the forecast.

electrification (either for light-duty vehicles using hybrids or electric vehicles or, more importantly, truck stop electrification which reduces idling of the diesel truck engine and use of auxiliary power units on heavy-duty trucks which are typically small diesel engines). They do not include benefits from reduced idle programs or other transportation control measures (such as reduced commuting, increased





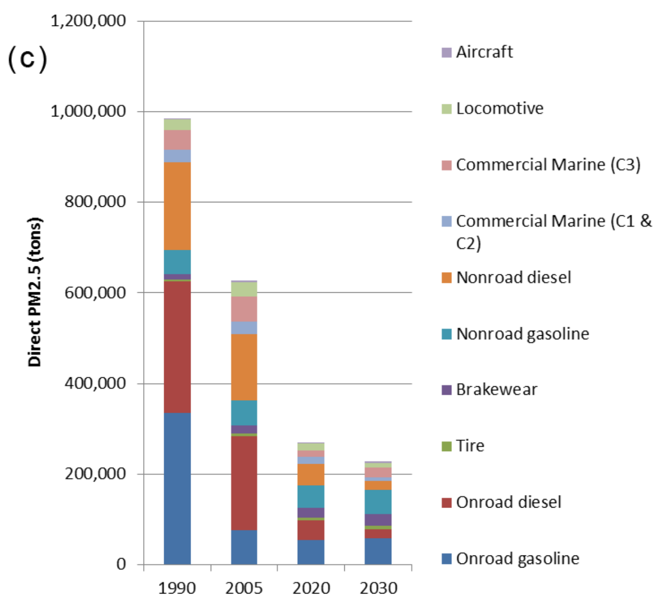


Figure 8-1. Estimated Changes in Emissions of (a) BC, (b) OC, and (c) Direct $PM_{2.5}$ from Mobile Sources in the United States, 1990-2030. Estimates of the number of tons of emissions reduced from each mobile source category are reported in Table 8-1. (Source: U.S. EPA)

use of mass transportation, increased bicycling/ walking). These types of programs are discussed more generally in a later section of this chapter.

The reductions in BC also do not consider how BC would be affected by future fuel economy standards such as those for light-duty vehicles (which are mostly gasoline-powered and thus a smaller source of BC emissions) and diesel vehicles (which are mostly heavy-duty trucks and a larger source of BC emissions). EPA has issued light-duty vehicle fuel economy standards effective for the 2012-2016 model years. EPA also just issued final rulemaking for heavy-duty vehicle fuel economy standards for the 2014-2018 model years. Additional fuel economy improvements for light-duty vehicles for model years 2017-2025 have recently been proposed.[6] Basically, these standards will not increase BC emissions.

These rulemakings and other forces in general will result in changes in vehicle technology. The introduction of and increased use of electric vehicles is certainly already occurring. There have been several studies (Jacobson and Delucchi, 2011; Delucchi and Jacobson, 2011) examining alternative energy sources including one on providing worldwide energy (for electric power, transportation, heat/cooling) by wind, water, and sunlight on a widespread basis in the 2030-2050 time frame. These alternative power sources could

[6] See *http://www.epa.gov/otaq/climate/regulations.htm*.

greatly reduce emissions of PM and BC. Also, it will be important to determine the effect from increased use of biofuels on BC emissions, which is currently an area of significant uncertainty.

8.4.1 On-road and Nonroad Diesel Engines

Diesel PM, as it exits the engine, is 70-80% BC for the pre-2007 model year diesel trucks and current diesel nonroad engines (excluding commercial marine oceangoing vessels which are discussed separately). The main source of diesel PM has traditionally been heavy-duty diesel trucks with gross vehicle weights from 8,501 to 80,000 lbs. The first standards controlling diesel PM for on-road engines were standards for visible smoke (which has some correlation with PM) effective with the 1970 model year followed by increasingly stringent PM mass standards starting with the 1988 model year. For the 2007 vehicle (engine) model year, stringent emission standards of 0.01 g/BHP-hr (grams per brakehorsepower/hour – a standard unit for emissions from heavy-duty mobile source engines) became effective for heavy-duty diesel engines, which represents over 99% control from a pre-control diesel engine in the 1970 time frame.[7]

As a result of these standards, BC emissions have been dramatically or even preferentially reduced as the major PM constituent.[8] To meet these stringent PM standards, virtually all new on-highway diesel trucks in the United States, beginning with the 2007 model year, have been equipped with DPFs. DPFs typically eliminate more than 90% of diesel PM and can reduce BC by as much as 99%. The type of DPFs typically used on new model year vehicles are called "wall flow" filters with a catalyst coated on a ceramic monolith with the exhaust flowing through the filter walls trapping the PM and allowing the exhaust gases to flow through. The trapped PM is then oxidized by reaction with compounds such as oxygen and nitrogen dioxide on the catalyst surface. This technology preferentially removes solid particles such as BC. BC emissions from the heavy-duty diesel truck fleet have been reduced by 30% from 1990-2005, and EPA projects that the application of DPFs will result in a further 95% reduction by 2030, from 153,477 tons to 7,615 tons. EPA's earlier rulemakings concluded that use of DPFs separate from the overall emission control system could result in a minimal fuel economy penalty (~1%) due to additional pumping work to force the exhaust gases through the DPF at high engine loads, but that the overall fuel economy impact would be neutral due to optimization of the complete emission control system. This was one of the primary reasons the Agency took such a systems approach. Now that the heavy-duty on-highway program is fully phased-in, some manufacturers are claiming a 5-6 percent fuel economy improvement through the use of integrated emission control systems. Additionally EPA and NHTSA projected that these overall optimized emission control systems could be further improved as part of the technology packages engine manufacturers are projected to use to comply with the Agencies' recently finalized Heavy-Duty Fuel Efficiency and Greenhouse gas rulemaking.

Corresponding national PM emissions standards of 0.01 g/mile took effect for U.S. passenger cars (and light-duty trucks) from 2004-2006. These "Tier 2" standards apply to both gasoline and diesel light-duty vehicles, although there are very few diesel passenger cars in the United States (unlike in Europe where diesel passenger vehicles are used extensively).

Nonroad diesel engines also emit a significant amount of BC. EPA's first emission standards for PM for these engines began in 1996. Recent rules issued in 2004, to be effective with the 2012 calendar year for newly manufactured engines, will result in widespread use of DPFs with dramatic reductions (~ 99% from a pre-control engine) in PM and BC. These standards will be fully phased in around 2015 for new model year nonroad diesel engines but will be phased into the fleet some years later with fleet turnover. EPA's latest version of the NONROAD model calculates the effect of all of these regulations, including those resulting in use of DPFs. EPA calculates a 92% decrease in emissions between 2005 and 2030, from 112,058 tons of BC in 2005 to 9,356 tons in 2030, despite substantial expected growth in use of these engines over this time period. Cumulatively, this will be a 94% decrease from 1990 to 2030.

A general note is that the recent down turn in the economy (not accounted for in these projections) can result in lower fleet turn-over than seen historically for on-road light-duty vehicles and

[7] EPA's emissions standards for heavy-duty diesel trucks have always been engine standards since the same engine can be used in a wide variety of truck chassis bodies with many of these bodies manufactured by companies different from those who manufacture the engines. For light-duty vehicles and trucks (trucks up to 8,500 lbs gross vehicle weight), the emission standards in g/mile apply to the car/truck itself.

[8] Ultrafine particles (generally those smaller than about 0.10 microns in size) from pre-2007 diesel engines generally comprise primarily BC, OC, metals, and sulfates. DPFs preferentially reduce BC, OC, and metals. Also, the use of ultra low sulfur diesel fuel reduces total sulfate emissions (and emissions of ultrafine sulfate PM). Recent work shows that DPFs reduce particle number (an indicator of ultrafines or nanoparticles) by up to 90-99% based on emissions characterization with four 2007 heavy duty diesel engines. See Khalek et al. (2009).

trucks. This can also be an issue with nonroad engines. These changes by themselves would increase emissions since increased numbers of older vehicles or engine are being used. Also, a shift in travel patterns and freight movement can occur, such as altered use of intermodal freight facilities. Economic downturns may also reduce total usage for both on-road and nonroad vehicles, which would reduce total emissions. Similarly, increases in fuel prices and land-use patterns will affect transportation patterns. Also, any shift in travel patterns and freight movement such as altered use of intermodal freight facilities would affect BC emissions. Finally, it is important to note that the total emissions reductions achieved will depend on the extent to which older vehicles/engines officially retired from service are still utilized for limited purposes in the United States or are exported to other countries (especially in Central and South America) for continued use.

As mentioned briefly in the introduction to this chapter, an important prerequisite for the application of DPFs is a switch to low-sulfur fuel. Low-sulfur fuel is needed, and has been required in the United States by regulation, to preserve catalytic activity of the emission control system, which is poisoned by sulfur. In issuing diesel PM regulations for on-road heavy-duty vehicles, nonroad diesels, and commercial marine (categories 1 and 2)/ locomotives, EPA determined that the emission standards being required could be met only with use of ultra low sulfur diesel fuel. Specifically, sulfur interferes with the ability of the DPF to passively regenerate. For NO_x control with urea selective catalytic reduction (SCR), sulfur compromises low-exhaust temperature NO_x reduction performance. Fuel sulfur also results in sulfate PM due to catalytic oxidation of sulfur oxides over the DPF, which increases PM. Noncatalytic diesel particulate filters that would be compatible with higher sulfur diesel fuels are harder to regenerate (i.e., removal of accumulated diesel particulate in the filter) and are not as effective for PM control. They also do not control the organic fraction of PM as effectively and, thus, do not meet stringent PM standards (U.S. EPA, 2001). Such filters though could be among possible control technologies for larger commercial marine diesels (category 3) which use heavy fuel oil instead of conventional diesel fuel; these engines are discussed later.

EPA first regulated sulfur content in on-road diesel fuel to 500 ppm in 1993, resulting in typical fuel sulfur levels of about 300 ppm. Prior to that, the sulfur level in on-road diesel fuel was about 2,000 ppm. In 2006, the sulfur level was limited to 15 ppm for on-road diesel fuel and has been reduced gradually in nonroad diesel fuel, first to 500 ppm in 2007 for all categories except ocean-going vessels, and, starting in 2010, to 15 ppm for most categories. In the case of locomotive and marine diesel fuel (for categories 1 and 2 marine diesel), this second step will occur in 2012. Thus, all highway diesel vehicles and nonroad engines in the United States must now or will soon operate on "ultra-low sulfur diesel" (ULSD). Typical in-use fuel sulfur levels are about 7 ppm. Of course, as discussed later, fuel for the larger C3 marine (such as heavy fuel oil, HFO) diesel (ocean-going) engines has significantly higher sulfur levels and would not be suitable for diesel particulate filters.

It is important to note that the net climate impact of the application of DPFs will be offset somewhat by the necessary co-emissions reductions in sulfate, which is reflecting (cooling).[9] Also, while diesel PM from pre-2007 engines has a high level of BC in PM, it also has some OC (about 22%), which is also greatly reduced by the DPF in later model years. The net climate impact of the application of DPFs will be affected by these reductions in OC emissions. Still, given the predominance of BC in diesel exhaust (70-80%), emissions reductions from this source category have a strong likelihood of providing climate benefits.

The EPA nonroad diesel rule[10] issued in 2004 provides an aggregate cost estimate for controlling PM emissions using DPFs on new engines of about $14,000 per ton ($2010). This cost figure includes the additional cost of ULSD fuel, engine costs, any changes in maintenance costs, and equipment costs. As shown in Table 8-2, similar cost estimates were developed in 2001 for the Heavy-Duty Diesel Rule

[9] The 15 ppm sulfur limit greatly reduces SO_x emissions, some of which convert to sulfate in the ambient air. For exhaust emissions of sulfates, the situation is more complicated since a typical conversion rate of SO_2 to sulfate for diesel engines without DPFs is about 2% but increases to about 50% for vehicles/engines with DPFs. Due to the dramatic reduction in diesel fuel sulfur, there is still some reduction in sulfate emissions from vehicles/engines with DPFs and 7 ppm diesel fuel sulfur versus vehicles/engines without DPFs using fuel meeting the 500 ppm limit, which results in a typical sulfur level of 200-300 ppm. A 50% conversion of SO_x to sulfate with the typical 7 ppm fuel sulfur level results in less exhaust sulfate (about 35% less) than from an older pre-trap diesel using fuel with the 200-300 ppm sulfur levels.

[10] *Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel*. Federal Register: June 29, 2004 (Volume 69, Number 124). See specifically, *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines, EPA420-R-04-007*, Chapter 8, Table 8.7.1, page 33, May 2004 (*http://www.epa.gov/nonroaddiesel/2004fr.htm#ria*).

Table 8-2. Cost Estimates for Particulate Matter Controls on New Diesel Engines (2010$), based on Recent U.S. EPA rulemakings. These costs include the additional cost of requiring Ultra Low Sulfur Diesel Fuel. (Source: U.S. EPA)

Rule	Estimated Cost (2010$) Per Ton $PM_{2.5}$ Reduced	
	NPV, 3% rate	NPV, 7% rate
Heavy-Duty Diesel Rule (2001)	$16,652	$19,216
Nonroad Diesel Rule (2004)	$13,762	$14,461
Locomotive/Marine Rule (2008)	$8,579	$9,778

for on-road[11] and the 2008 rule controlling emissions from locomotive and marine diesel engines.[12] It is important to note that the values reported in Table 8-2 are adjusted from the original values developed by EPA to 2010$ as a function of GDP to ensure consistency with other costs presented in this Report. A large fraction of the cost is due to the requirements for ultra low sulfur diesel fuel.

It is important to note that the controls applied under these regulations affect multiple pollutants, not just BC. At this time, there is no methodology to allocate these costs specifically to BC or other PM components but it is useful to note that for these diesels the BC is the largest PM component. Furthermore, the analyses conducted during the 2001-2008 time frame utilized the best cost information available at that time, as well as emissions reductions (total tons reduced) based on EPA's then-current emissions models. Since then, the emissions models have changed so that the reductions estimated in the earlier rulemaking analyses would be somewhat different today. The magnitude of the reductions was determined doing emissions inventory estimates for given years both with and without the standard being considered in effect. One cannot obtain the tons reduced by given standard just from emissions inventory data for a given year compared to another year since the total reduction reflected in the inventory from one year to another is the result of all the standards in place (and vehicle/engine turn over) for all mobile sources rather than just a single standard for a particular category. Also, the inventory and cost numbers used in these calculations have not been updated since they were obtained. In the absence of new analysis, the $14,000 cost/ton (the average costs in Table 8-2) is the best available EPA information for control of diesel PM from newly manufactured on-road vehicles and nonroad engines meeting EPA emission standards. The total costs and benefits of these regulations are discussed separately in Chapter 6. As an aside, EPA cost estimates made in rulemakings tend to be higher than the actual cost due to improvements in technology to meet the standard that were not considered when the rule was issued (Anderson and Sherwood, 2002).

8.4.2 On-road and Nonroad Gasoline Engines

On-road gasoline PM emissions have decreased dramatically over the years, especially with the use of catalysts and unleaded gasoline starting with the 1975 model year vehicles. For example, PM emissions for a typical car using leaded gasoline in 1970 were about 0.3 g/mile compared to emissions from current vehicles with unleaded fuel of about 0.001 g/mile, a reduction of over 99% (Coordinating Research Council, 2008). While BC emissions were not usually measured in the PM from cars in the 1970s, some limited measurements suggest that BC made up about 10-20% of the PM at that time, compared to about 20% of PM mass in 2005. Thus, the per-vehicle PM reductions since 1970 have resulted in a substantial reduction in BC emissions. Most of this BC comes under "rich" operating conditions (where there is insufficient air for full combustion, such as during cold-start or high load conditions). EPA's most recent modeling indicates that BC emissions from on-road gasoline engines have declined 79% since 1990, from 69,629 in 1990 tons to 14,510 tons BC in 2005, and will decline a further 31% by 2030 (to 10,027 tons).

[11] *Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, Final Rule.* Federal Register: January 18, 2001 (Volume 66, Number 12). This rule applies to 2007 and later model-year heavy duty diesel on-road engines. See specifically, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*; Chapter VI, Table VI F-4, page VI-19, January 2001 (http://www.epa.gov/otaq/highway-diesel/regs/ria-vi.pdf).

[12] *Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder; Republication*. Federal Register: June 30, 2008 (Volume 73, Number 126). See specifically, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder*; Chapter 5, Table 5-67, page 5-98, June 2008 (*http://www.epa.gov/oms/regs/nonroad/420r08001a.pdf*).

Under the Tier 2 exhaust regulations mentioned above for light duty vehicles (passenger cars and light-duty trucks), EPA set a PM emissions standard for both gasoline and diesel vehicles at 0.01 g/mile starting in 2004, with full phase-in for all light-duty vehicles (including light-duty trucks) in model year 2009. When the Tier 2 rules were promulgated, EPA estimated that a total of 36,000 tons of $PM_{2.5}$ would be reduced in the year 2030 from these standards (versus not having these standards) using the emissions models available at that time (U.S. Environmental Protection Agency, 1999). Prior exhaust standards from the 1990s and earlier also have helped reduce PM. While these regulations do not limit PM directly, they resulted in better control of air/fuel ratio and improved catalyst formulations to meet HC, CO, and NO_x emissions standards, all of which affected PM emissions levels. Because the regulations were targeted at other pollutants, however, EPA has not calculated a cost for the resulting PM reductions specifically.

It should be noted that most current technology vehicles now emit below the Tier 2 PM standard by a significant margin. However, a relatively new technology, gasoline direct injection (GDI), is being utilized for a number of reasons such as improved fuel economy and performance. GDI engines differ from conventional fuel injected engines in that the fuel is injected directly into the cylinder (like in a diesel engine) rather than at the intake port. GDI vehicles are expected to constitute a major part of the new vehicle fleet in the coming years and may be 90% of new vehicle sales in model year 2016. The specific technology for injecting and guiding the gasoline spray into the engine coupled with the catalyst may have an impact on the magnitude of the PM emissions. Recent studies performed by EPA determined that some “wall guided” GDI engines perform slightly worse than currently produced “port fuel injection” (PFI) engines with respect to PM but that “spray guided” GDI engines perform on par with PFI engines. Indications are that most manufacturers utilizing GDI technology will be migrating to “spray guided” designs, but regardless EPA anticipates future GDI designs will perform on par with or better than current technology.

CARB has issued a preliminary discussion paper discussing the option of tightening the PM mass standard effective for the 2015 model year (California Air Resources Board, 2010). The present CARB PM standard (LEV II) is 0.01 g/mile, which is also the EPA emission standard. The possible standard presented in the discussion paper is 0.003 g/mile starting in 2017. A 0.001 g/mile standard is being considered starting for the 2025 model year. CARB had also considered a standard specifically for BC, but announced at its November 2010 LEV III (Low Emission Vehicle) workshop that it would not set such a standard.

Nonroad gasoline engines are either 2-stroke engines (where lubricating oil is mixed into and burned with the gasoline) or 4-stroke engines. The 2-stroke engines are smaller engines and tend to be used more in lawn and garden equipment, such as handheld string trimmers; they have also been used in lawn mowers and snow blowers. They can also be used in recreational marine, although most engines there are now 4-stroke engines. The 4 stroke engine is used in equipment such as lawn mowers, small generator sets, industrial equipment, and recreational equipment such as marine engines. These engines emit significant PM mass, especially the 2-stroke engines, where the PM has a large contribution from the lubricating oil. They can also be used in larger equipment such as farm and construction equipment although, here, the dominant engine type is diesel. EPA estimates that BC emissions from nonroad gasoline engines will decline approximately 5% (from 5,444 tons to 5,174 tons) between 2005 and 2030, largely due to changes needed to meet standards for volatile organic compounds (VOC), CO, and NO_x emissions standards being applied to several categories of nonroad gasoline engines, which will also reduce PM. Current information, which needs to be updated, used in EPA air quality modeling suggests that BC is approximately 10% of PM mass with the same number being used for both 2-stroke and 4-stroke engines even though 2-stroke engines have oil added to gasoline. PM emissions from nonroad gasoline engines, particularly the 2-stroke engines, have been characterized far less thoroughly than emissions from on-road gasoline vehicles, and EPA’s estimates of BC emissions are highly uncertain. EPA places a high priority on obtaining better BC emissions data from both 2-stroke and 4-stroke nonroad gasoline engines.

8.4.3 Other Mobile Sources – Commercial Marine Vessels, Locomotives, and Aircraft

Locomotives have used diesel (diesel electric) engines (both 2-stroke and 4-stroke engines) predominantly since the 1950s. EPA has implemented several tiers of emission standards for PM for these engines with the most recent set of standards to be effective in 2015. These newest standards will result in the use of DPFs on new locomotives which preferentially reduce BC. In addition, national emission standards require that older locomotives that are remanufactured must be certified to more stringent emission standards than their prior certification level.

Commercial marine vessels are classified as C1, C2, and C3 based on engine size. C1 marine engines are similar in size (less than 5 l/cylinder or for some categories less than 7 l/cylinder) to those used in construction/farm equipment. C2 marine engines (between 5 or 7 and 30 l/cylinder) are similar to locomotive diesels. The C3 engines (greater than 30 l/cylinder vessels) are similar to those used in some power plants and are used in ocean-going vessels. The most recent set of emission standards for these engines will result in most new C1 and C2 commercial marine engines having DPFs starting in 2014. Ultra low sulfur diesel fuel is being required for these engines. For these engines, there will be a dramatic drop in PM emissions and an even more dramatic drop in BC emissions. Like locomotives, older marine diesel engines must be certified to more stringent emission standards upon remanufacturing, compared to their previous certification level. The level of the standards to which these remanufactured engines must be certified varies depending on engine type and year of manufacture for the original engine.

PM emissions from C3 engines comprise mainly sulfate (about 75%) and relatively little BC (can be less than 1% although as discussed in Appendix 2 this percentage can vary significantly). Due to recent work with the International Maritime Organization (IMO), there will be large reductions in the higher sulfur level of the fuel (largely bunker diesel fuel composed of especially high molecular weight, even solid, hydrocarbon compounds) used in these engines (see Appendix 4). As this sulfur level is reduced, PM will be greatly reduced but BC levels are expected to stay roughly the same on a per-vessel basis and will constitute a larger percentage of the PM emissions. There is some increase in BC emissions from 2005 due to an increase in usage of these vessels. Though C3 marine is responsible for less than 1,000 tons of BC emissions for the entire United States, there is some concern that emissions from these vessels could have disproportionate impact on the Arctic, especially if Arctic marine traffic increases as shipping lanes open due to ice melt in the region. Additional BC emissions data and modeling/deposition studies are needed to clarify the impact of C3 marine vessels.

C3 marine usually uses heavy fuel oil (HFO), which can be solid at room temperature (and is heated before going into the engine), rather than the conventional distillate diesel fuel used by C1/C2 commercial marine and other nonroad diesels. HFO contains higher molecular weight hydrocarbon compounds than conventional distillate diesel fuel. This affects the characteristics of the PM emissions. As is also discussed in Appendix 4, HFO contains higher fuel sulfur levels and cannot be used with DPFs.

There has been limited research into the BC emissions from aircraft. Additional characterization of aircraft emissions would help to improve understanding of BC emissions from aircraft, although there is sufficient information to develop a PM inventory and an initial BC and OC inventory.

In general, therefore, additional emissions information for commercial vessels, locomotives and aircraft would improve characterization of BC, since present data are limited, and it is difficult to determine how much BC will be reduced by the PM standards affecting these sources.

8.5 New Engine Standards Internationally

Heavy-duty on-road diesel vehicles represent the predominant mobile source of BC in most areas of the world, although nonroad diesel (and locomotives and commercial marine) can also be significant. Given the importance of diesel engines internationally, use of DPFs to reduce $PM_{2.5}$ will also result in large reductions in BC from the global mobile source sector. Some countries have already made significant progress in this area and have introduced diesel PM standards (mainly for on-road vehicles) which effectively reduce BC. While broad-scale application of DPFs is an attractive option to reduce global emissions, this is dependent on simultaneous use of ULSD fuel. Many other developed countries in Europe and Asia have already adopted low-sulfur fuel requirements. As a result, BC emissions from mobile sources are declining in many regions, especially in Europe and Japan. However, many developing countries have not yet switched to low-sulfur fuel, and PM emissions controls are less common. Each of these issues is discussed further, below. In general, the U.S. experience controlling diesel PM and, thus, BC provides a good template for international control programs.

8.5.1 International Regulations of Diesel Fuel Sulfur Levels

As noted above, the availability and widespread use of low-sulfur fuels is a critical prerequisite to effective BC control from mobile sources. Like the United States, Canada, Japan, and the European Union have adopted strict controls on on-road diesel fuel sulfur levels. Many countries have also adopted regulatory standards for reducing sulfur levels in on-road diesel fuel to levels needed to enable low-emission vehicle technologies. In other regions, however, reductions in the sulfur content of fuel lag behind. This effectively constrains BC emissions reductions in these countries, since higher sulfur fuels would prevent DPFs from functioning properly, even if they were applied.

The United Nations Environment Programme's (UNEP) Partnership for Clean Fuels and Vehicles (PCFV), founded at the World Summit on Sustainable Development in 2002, promotes low sulfur fuels and cleaner vehicle standards and technologies. This partnership has over 100 members from the oil and gas industry, engine and retrofit manufacturers, government agencies, and environmental NGOs. Currently, the PCFV is conducting a low sulfur campaign with a call for global adoption of 50 ppm sulfur gasoline and diesel. The implementation of 50 ppm sulfur programs would allow countries to begin to deploy DPFs, which would produce significant reductions in $PM_{2.5}$ and BC. However, the U.S. EPA believes a further reduction to sulfur levels at or below 15 ppm is needed for DPFs to function for their intended lifetime. Further detail on the diesel sulfur reduction activities of countries outside the United States, Canada, Japan, and the European Union is provided in Appendix 4. Most of the actions underway in other countries focus on fuels for on-road vehicles. Sulfur limits for nonroad diesel fuel are also needed on an international basis to facilitate BC control. It is important to note that the cost to provide the ULSD fuel will vary from one country to another depending on fuel supplies and refinery capabilities. Thus, while the benefits of low sulfur fuels and advanced emission control technologies far outweigh the costs, the often substantial upfront costs of upgrading existing refineries presents a challenge for many governments.

The global community has also been working to reduce the sulfur content of fuels used in marine vessels. Currently, the IMO has established requirements for the sulfur content of bunker type fuel used in C3 marine vessels on both a global basis and for an Emission Control Area (ECA) in specific target years (U.S. EPA, 2010g). However, these requirements are designed to reduce sulfate emissions, rather than to enable use of DPFs, and even the cleanest fuel on this schedule (1,000 ppm sulfur within the ECA by 2015) would not enable use of DPFs (see Appendix 4).

8.5.2 Standards for New Engines Outside the United States

Many other countries have adopted PM emission standards for new engines. Most of these standards affect on-road engines, and the rigor of these standards and the time for phase-in of new engine requirements differ significantly among countries. In general, developed countries have adopted standards sooner and have mandated more rapid phase-in schedules than developing countries. Canada generally adopts U.S. motor vehicle standards directly following U.S. implementation. Thus, similar percentage reductions in BC can be expected from similar engine categories in Canada. European and Japanese diesel PM standards have been reducing PM steadily over the last decade and are achieving BC reductions similar to those in the United States. In the next few years, the level of the standards will be such that DPFs will be used on almost all new on-road European and Japanese diesel engines.

In Europe, DPFs were first applied to light-duty diesels; these requirements are relatively recent, with the latest standards, known as Euro 5, becoming effective in 2009. Nonroad diesels will start to phase in DPFs starting with what are termed Stage IIIB standards in 2011. The nonroad reductions will be followed by Euro 6 on-road heavy-duty diesel standards which will require DPFs on all new trucks starting in 2013. Likewise some locomotive engines will have DPFs by 2011 although commercial marine diesels are not regulated.[13]

Other countries have adopted or proposed heavy-duty engine emission standards equivalent to earlier U.S. or Euro emission standards. In the Americas, these countries include Argentina, Brazil, Chile, Mexico, and Peru. In the western Pacific and Asia, these countries include China, India, the Republic of Korea, Singapore, and Thailand. China is following the European emission standard progression with some time lag; however, China has not yet implemented low sulfur fuel nationwide to enable widespread use of DPFs. In Europe outside of the European Union, Russia and Turkey have adopted earlier Euro standards. These countries are making progress in reducing BC emissions from heavy-duty vehicles. In addressing the future impact of possible standards, it is important to account for both the vehicle/engine standards and growth in the number of vehicles/engines as well as increases in usage (such as vehicle miles traveled).

[13] The European standards use the PMP (particle measurement program) methodology with thermal treatment (catalytic oxidation) to remove volatile particles before the PM is measured which removes much of the organic PM and, thus, PM as measured by the European test procedure has less organics than that measured by the U.S. test procedure. With the PMP it is important to distinguish between particle mass and particle number where organics, which tend to be small in size, make a contribution. The treatment of organics is an important distinction for PM control and may affect the control technology used, which could affect BC reductions.

Relatively little is known about the costs of DPFs in other countries. However, it is expected that the costs for DPFs should not differ greatly from costs in the United States. More details on diesel PM emission standards in other countries are discussed in Appendix 6. It is important to note that few countries have pursued standards for nonroad diesels such as construction and farm equipment, locomotives, and commercial marine vessels (categories 1 and 2). Such standards, which already exist in the United States, may offer a mitigation opportunity internationally.

For control of BC from C3 marine internationally, EPA is working with the IMO, the Arctic Council, and others to recommend what can be done to better define and reduce BC from C3 engines in international waters. Such work would include developing a definition for BC emissions from international shipping. It would also include considering measurement methods for BC and identifying the most appropriate method for measuring BC emissions from international shipping. It would also include investigating appropriate control measures to reduce the impact of BC emissions from international shipping in the Arctic. Control measures that can be evaluated include speed reductions, improved routing/logistics, vessel, propeller and engine modifications, DPFs (such as non-catalytic ones that could be used with higher sulfur fuel), water-in-fuel emulsification, use of slide-valves, and possibly alternative fuels (MEPC, 2010; UNEP and WMO, 2011a). Some of these measures have been discussed in a recent research article (Corbett et al., 2010) and an earlier Arctic Council report (Arctic Council, 2009). Finally, the effect of using a distillate diesel fuel (similar to what is used for diesel trucks and nonroad diesels) versus HFO on BC emissions should be investigated. Use of a distillate fuel is expected to result in less organic emissions and could increase the BC/PM ratio although the total mass of BC emitted might decrease.

8.6 Mitigation Approaches for In-use Mobile Sources in the United States

Though emissions standards for new engines will reduce emissions over time, existing engines can remain in use for a long time (20 to 30 years) (U.S. Census Bureau, 2004). Opportunities to control BC emissions from in-use vehicles center almost exclusively on diesel engines. Despite EPA's diesel engine and fuel standards taking effect over the next decade for new engines, in-use diesel engines will continue to emit large amounts of PM and BC, as well as other pollutants such as NO_x, before they are replaced. For this reason, strategies to reduce emissions from in-use engines have received a great deal of attention, particularly because communities near freight corridors and other large concentrations of diesel-powered engines are disproportionately affected by the pollution. EPA's NCDC estimates that Diesel Emission Reduction Act (DERA) funding could be used to apply in-use mitigation strategies to 11 million of the on-highway and nonroad engines now in the U.S. diesel fleet.

A variety of strategies are available to reduce substantially harmful emissions from in-use vehicles, and many of these strategies are cost-effective given the health benefits associated with reducing PM emissions. As used by EPA, the term diesel retrofit includes any technology or system that achieves emissions reductions beyond that required by the EPA regulations at the time of new engine certification. Diesel retrofit projects include the replacement of high-emitting vehicles/equipment with cleaner vehicles/equipment, repowering or engine replacement, rebuilding the engine to a cleaner standard, installation of advanced emissions control after-treatment technologies such as DPFs, or the use of a cleaner fuel (U.S. EPA, 2006a).

The BC mitigation potential of diesel retrofits applied to existing engines depends on several factors, including engine application (vehicle or equipment type), engine age, engine size, engine condition (maintenance) and remaining engine life. One or more of these factors will dictate the suitability of a mitigation strategy. Some engines, whether because of old age, poor maintenance or duty cycle, are not able to be retrofitted with DPFs. Engines with limited remaining life or low usage rates are not good candidates for retrofits when cost-effectiveness is considered. It can also be technically infeasible to replace an old engine with a new one in many cases because of insufficient space in the original vehicle or piece of equipment. For some of these vehicles, truck replacement, with scrappage of the original vehicle, may be the only viable option to reduce BC emissions. It is also possible for 10%-15% of the vehicles in a typical fleet to emit 50% or more of each major exhaust pollutant due to malfunctioning engine parts (National Academies Press, 2001). This is one of a variety of important considerations in developing mitigation strategies.

The NCDC and the SmartWay Transport Partnership Program are EPA's two primary programs responsible for reducing emissions from in-use diesel vehicles and equipment. These programs support the testing and deployment of numerous technologies and strategies to reduce emissions from in-use diesel engines, including BC, and can provide immediate reductions. These programs are described in more detail below, following a discussion of key retrofit technologies and approaches for reducing emissions from in-use vehicles and engines.

8.6.1 Available Retrofit Technologies and Strategies for In-use Engines

8.6.1.1 Diesel Exhaust After-treatment Devices

Typically, after-treatment diesel retrofit involves the installation of an emission control device to remove emissions from the engine exhaust. This type of retrofit can be very effective at reducing PM emissions, eliminating up to 99% of BC in some cases. Of the diesel retrofit devices currently available, DPFs most effectively reduce BC. For the sake of completeness, various diesel retrofits are covered below.[14] Further information is available from NCDC, including a table of emissions reductions and typical costs for various diesel retrofits.[15] EPA and CARB adhere to rigorous verification processes to evaluate the performance and reliability of available retrofit technologies. These processes evaluate the emission reduction performance of retrofit technologies, including their durability, and identify engine operating criteria and conditions that must exist for these technologies to achieve those reductions. Federal funding under the NCDC requires recipients to use EPA or CARB-verified diesel retrofit technologies for clean diesel projects.

As previously mentioned, DPFs are wall-flow exhaust after-treatment devices that are effective at significantly reducing diesel PM emissions by 85% to 90% and BC emissions by up to 99%. Because BC exits the engine in solid particle form, DPFs can reduce BC up to 99%. The small amount of PM that does penetrate a DPF is composed of mainly sulfate and OC. DPFs typically use a porous ceramic, cordierite substrate, or metallic filter to physically trap PM and remove it from the exhaust stream. The collected PM is oxidized primarily to CO_2 and water vapor during filter regeneration. Regeneration can be passive (via a catalyst) or active (via a heat source) and is necessary to keep the filter from plugging and rendering the engine inoperative. Regular engine maintenance is essential to DPF performance.

Passive regeneration occurs when exhaust gas temperatures are high enough to initiate combustion of the accumulated PM in the DPF, usually in the presence of a catalyst, but without added fuel, heat, or driver action. Active regeneration may require driver action and/or sources of fuel or heat to raise the DPF temperature sufficiently to combust accumulated PM. Active DPFs may be necessary for lower engine temperature applications, such as lower speed urban and suburban driving; otherwise the DPF may become plugged due to an accumulation of PM.

For large, on-highway trucks, retrofitting passive DPFs generally costs between $8,000 to $15,000, including installation, depending on engine size, filter technology and installation requirements. Active DPF systems can cost $20,000 for a heavy duty diesel truck and up to $50,000 for a large piece of nonroad equipment. Vehicle inspection, data logging, and backpressure monitoring systems are required with each installation; these costs along with installation of the device, are typically included in the cost of the DPF (U.S. EPA, 2010a). However, operating costs incurred due to application of DPFs are not included in the estimates above. Operating costs could include the differential cost for using ULSD, fuel economy impacts related to increased exhaust backpressure, or changes to maintenance practices related to the use of retrofit technologies. There is no increased cost for use of ULSD in the United States because ULSD is now the predominant diesel fuel used in both highway and nonroad applications. In addition, data from existing retrofits show no significant difference in fuel economy for fleets with and without these retrofit technologies.[16,17]

Some diesel retrofit technologies were designed to reduce other pollutants, such as NO_x and hydrocarbons, and do not significantly impact BC emissions. Such technologies include:

- Partial Diesel Particulate Filters (PDPFs) provide moderate (around 30% to 50%) reduction of PM from diesel exhaust. However, while limited test data exists on the effectiveness of PDPFs to reduce BC, it is likely that these devices result in minimal BC reductions (UNEP and WMO, 2011). PDPFs typically employ structures to briefly retain particles for oxidation, structures to promote air turbulence and particle impaction, and catalysts to oxidize diesel particles. Partial flow filters are capable of oxidizing the soluble organic

[14] See *http://www.meca.org/cs/root/diesel_retrofit_subsite/what_is_retrofit/what_is_retrofit*.

[15] See *http://www.epa.gov/cleandiesel/technologies/retrofits.htm*.

[16] These cost estimates are from NCDC's Cost-Effectiveness Paper 2006, updated to 2010 dollars.

[17] NREL Ralph's Grocery study at: *http://www.nrel.gov/docs/fy03osti/31363.pdf* and/or Clean Air Task Force (2009b). The carbon dioxide-equivalent benefits of reducing black carbon emissions from U.S. Class 8 trucks using diesel particulate filters: a preliminary analysis. Available on the Internet at *http://www.catf.us/resources/publications/view/100*.

fraction of diesel exhaust and likely some BC. As of October 2010, only three PDPF technologies were verified by CARB (none by EPA), and these were only verified for transport refrigeration units (TRU). These devices cost about $4,000-$8,000 per unit.

- Diesel oxidation catalysts (DOCs) provide minimal BC reductions. DOCs are exhaust after-treatment devices that reduce PM, HC and CO emissions from diesel engines and are widely used as a retrofit technology because of their simplicity, relative low cost, and limited maintenance requirements. DOCs verified by EPA and CARB are typically effective at reducing PM by 20 to 40%, though the PM removed by DOCs is composed largely of OC that comes from unburned fuel and oil. DOCs are not an effective mitigation strategy for BC reductions.

- Closed Crankcase Ventilation Systems (CCVS) provide negligible BC reductions. In many diesel engines, crankcase emissions or "blow-by" emissions are released directly into the atmosphere through the "road draft tube." Closed Crankcase Ventilation (CCV) devices capture and return the oil in blow-by gas to the crankcase, directing HC and toxics to the intake system for re-combustion instead of emitting them into the air.

- Selective Catalytic Reduction (SCR) systems inject a reducing agent such as diesel exhaust fluid (DEF), a urea solution, into the exhaust stream where it reacts with a catalyst to reduce NO_x emissions. Most 2010 and newer on-road diesel engines come equipped with an SCR system and SCRs are also available as after-treatment retrofits. SCR systems require periodic refilling of the reductant and may also be used with a catalyzed DPF to reduce PM emissions. Coupling engine design techniques that lead to a reduction of BC through a low PM engine strategy with a NO_x after-treatment control device such as an SCR has been an approach used in Europe. SCR systems, which are effective in reducing NO_x by 60 to 80%, can provide potential BC reductions when the engine fuel injection timing is changed for lower PM and higher NO_x emissions.

8.6.1.2 Cleaner Engine Strategies

Engine Repower: Significant emissions reductions can be achieved by repowering, upgrading, or "reflashing" a diesel engine. Engine repowering (i.e., replacing the engine, but not the entire vehicle) is straightforward, and the benefits are easily quantified. For example, when an uncontrolled engine is taken out of service and replaced with a new engine, the emissions benefits are determined from the difference in emissions levels of each engine. The cost of replacing a vehicle or piece of equipment is much higher than replacing just the engine. However, not all vehicles/equipment can be repowered. New engines are not always compatible with the original vehicle/equipment.

Engine Upgrade: An alternative to vehicle/equipment replacement and engine repower is "engine upgrade." An engine upgrade is the process by which parts of an in-use engine are replaced with newer components, resulting in lower emissions. Engine upgrades are normally sold as kits from an engine manufacturer and include newer mechanical parts, and, for electronically controlled engines, changes to the computer program that controls the engine. Reprogramming the computer that controls an engine is known as *reflash*, and it can change the mix of pollutants in the exhaust stream (e.g., by changing the injection timing). Engine upgrades, including "reflashes," are generally less expensive than replacing an entire engine, but they are only available for specific engines. Thus, implementation is limited by the number of upgradable engines currently in service.

Vehicle/Equipment Replacement: When no diesel retrofit solutions can be cost-effectively implemented for a particular vehicle or piece of equipment, the option exists to retire the vehicle/equipment from service before the end of its useful life and replace it with a newer model. While this is typically the most expensive method of reducing emissions, this can be the most feasible strategy for a particular vehicle or piece of equipment. For example, significant emissions reductions can be achieved by scrapping older model drayage trucks at ports and replacing them with newer, clean diesel trucks. One benefit to replacing an entire vehicle or piece of equipment is that newer models often have improved non-engine systems and parts that are preferred by operators.

8.6.1.3 Other Emissions Reduction Strategies

A variety of other strategies can also reduce emissions from in-use vehicles. While the precise impact of such strategies on BC emissions can be more difficult to quantify than application of an after-treatment device, these strategies may substantially reduce emissions, while improving fuel economy and extending engine life.

Improved Fleet Maintenance Practices: Since a small percentage of vehicles in a given fleet may be responsible for a majority of the fleet's emissions,

Local Retrofit Projects in the United States

Agricultural Vehicle Repowers

The Air Pollution Control District in San Joaquin Valley received $2 million to repower 33 pieces of agricultural equipment with new engines that meet or exceed EPA's Tier 3 diesel emission standards. Using ARRA funds, EPA awarded this project because of its long-term economic and immediate health benefits for the community. The repowered engines are expected to reduce emissions of NO_x by over 160 tons and PM by nearly 6 tons.

Locomotive Repower

The Railroad Research Foundation was awarded $2.9 million to repower 4 locomotives that operate as switchers in rail yards in Baton Rouge, Louisiana. The original locomotives were built with 3,500 horsepower engines in 1985 and 1986, and the new engines meet or exceed EPA Tier 2 locomotive engine emission standards. Tier 2 locomotive emissions are one-third those from Tier 0 locomotives.

Shore Power

Massachusetts Port Authority was awarded $400,000 to install shore-side electric power to ships, with a 9-unit shore connection system serving 18 berths in South Boston. Most vessels dock at the pier 100 to 300 days per year, and typically run diesel generators for 10 to 14 hours to provide cabin heat, generate power to unload fish, and supply electricity for other needs. The new on-shore power hook-ups are projected to reduce PM emissions by 96%.

Construction Retrofits

New Jersey Department of Environmental Protection (NJDEP) was awarded $1.73 million to pay for the cost and installation of pollution control devices on various construction equipment used in New Jersey. Funding under this program has allowed NJDEP to implement Phase 2 of its existing New Jersey Clean Construction Program to retrofit non-road equipment used on publicly funded construction projects. The retrofits are projected to reduce PM by 3.8 tons annually.

one of the first steps for reducing emissions is to take an inventory and inspect vehicles and equipment. This information may be used to identify vehicles in need of repair and find candidates for other mitigation options. Repair of poorly operating engines typically decreases emissions and improves fuel economy. Furthermore, regularly performed maintenance will extend the life of vehicles and equipment (Partnership for Clean Fuels and Vehicles, 2009). For example, many manufacturers prescribe that engines be rebuilt after accumulating a set number of hours of use. An engine rebuild involves replacing some old parts and restoring durable parts to original factory specifications. In some cases, an after-treatment technology could be installed at the time of engine rebuild. This would save time since the vehicle or equipment would not need to be removed from service any longer than prescribed for normal maintenance.

Cleaner fuels can lead to BC reductions via multiple pathways. As previously stated, ULSD fuel is necessary for diesel particulate filters and other after-treatment technologies to be effective. Fuel options such as compressed natural gas (CNG), liquefied natural gas (LNG), ethanol, and hydrogen can yield substantial reductions in PM and BC. However, this requires installation of engines and fuel systems compatible with these fuels as well as infrastructure to facilitate storage and delivery of the fuels. Many U.S. urban fleets of heavy-duty vehicles have shifted their diesel-fueled vehicles to those fueled with CNG or LNG. Transit buses and solid waste collection vehicles are among those fueled with CNG. Recently, a number of drayage trucks in Southern California's Port of Los Angeles and Port of Long Beach have been converted from diesel to LNG. As previously stated, it will also be important to determine the effect from increased use of biofuels such as biodiesel on BC emissions.

Another form of fuel switching is electrification. As previously stated in this report, power plant supplied electricity has extremely low emissions of BC in the United States. If mobile sources can be powered by electricity, BC emissions can be reduced. One example of this is cold-ironing (shore power) at seaports, which allows marine vessels to shut down their engines and run normal operations by plugging into electrical connections at docks. When a vessel is at berth, it typically runs its auxiliary diesel engines to provide power for normal operations (referred to as hotelling). For example, CARB has estimated that 1.8 tons per day of diesel

PM was emitted by approximately 2,000 hotelling ocean-going vessels in California in 2006 (Regional Planning Organization, 2006). Hotelling emissions can be dramatically reduced if the vessel uses "shore power" electricity while at port. It should be noted that emissions of pollutants from other sources should be considered when pursuing this and other alternative fuels/energy sources. For example, electrification shifts the emissions from the mobile source to the power plant.

Fuel economy improvements may yield reductions in BC. Some fuel savings devices, such as low-rolling-resistance tires and aerodynamic technologies (e.g., trailer gap reducers, trailer boat tails, and trailer side skirts) reduce fuel use with little change to engine operation. These fuel saving devices likely result in PM reductions; however, additional research is needed to quantify the emission reductions. Hybrid vehicles are potential technologies for CO_2 reductions, but further research is necessary to determine the extent of PM or BC reductions.

Idle reduction: Long-duration idling of truck and locomotive engines consumes an estimated 1 billion gallons of diesel fuel annually, resulting in thousands of tons of PM, a significant fraction of which is BC (i.e., 15-40%) (Gaines et al., 2006; Lim, 2002). It is important to consider that while BC is a significant fraction of overall diesel PM, BC/PM ratios differ during idling. The reduction in PM due to idling has definite health benefits, and the reduction in fuel use results in reduced CO_2 emissions and, in turn, climate benefits. However, the net climate benefit due to reduction in idling PM is less understood. Furthermore, idling increases fuel and engine maintenance costs, shortens engine life, increases driver exposure to air pollution, and creates elevated noise levels. Idle reduction programs and technologies are already prevalent in the US. They serve as one of the simplest and lowest cost methods to reduce emissions from engines. Because reducing idling reduces engine operation, emissions of all pollutants are lower. Strategies for reducing idling include both operational and technological methods. Examples of on-board truck technologies include:

- Automatic engine shut-off devices programmed to shut down the engine after a preset time limit
- Direct-fired heaters to eliminate idling used to heat the cab
- Auxiliary power units (APU) or generators to provide power for cab comfort at rest stops and eliminate the need to run the truck engine
- Battery or alternatively powered heating and air conditioning units.

Off-board technologies include truck stop electrification, which provides conditioned air and electricity to truck cabs for accessory loads while at a truck stop. These systems also may provide telephone, cable TV, and internet access. A majority of U.S. states and many municipalities have anti-idling regulation in place to limit idling of vehicles (American Transportation Research Institute, 2011).

Transportation modal shift: Transportation of certain goods can be altered to reduce BC emissions and increase efficiency. Specifically, a shift from trucks to rail or to sea and inland waterways can reduce diesel truck PM emissions and alleviate traffic congestion (Barth and Tadi, 1998; Winebrake et al., 2008). It is important to note that modal shifts can result in localized increases in emissions where goods movement is concentrated, such as ports and rail yards. While the percentage of BC in total locomotive PM emissions is roughly equal to that of diesel trucks (72-78%), diesel engines under idle or low load, such as occur in intermodal freight terminals, emit PM with a smaller fraction of BC (approximately 15-40%). In addition, ship emissions can exhibit very different characteristics from truck or locomotive engines, particularly emissions from slow-speed engines used in ocean-going vessels (Category 3) burning residual (bunker) fuel. As described in Chapter 4 on inventories, recent studies have reported BC to be a minor fraction of PM from Category 3 marine engines. However, these data are limited to a few studies. Further research is needed in order to better characterize ship emissions and to better understand the effects of modal shifts on BC emissions.

8.6.2 Cost-Effectiveness of Retrofits

In 2006, EPA published a report on the cost-effectiveness of heavy-duty diesel engine retrofits (U.S. EPA, 2006a). The analysis presented in that report, which was based on data collected from 2004-2005, estimated the cost-effectiveness of installing a passive DPF (one that regenerates removing built-up diesel PM on its own) on a Class 8 truck to be \$12,100-\$44,100 per ton of $PM_{2.5}$ reduced. Model year 1994 and newer class 8 trucks employed in long-haul operation are generally good candidates for DPFs.

In 2009, EPA published a Report to Congress, *Highlights of the Diesel Emission Reduction Program*, which provides information on the overall cost-effectiveness of various diesel emissions reduction strategies funded under the Diesel Emissions

Reduction Act. The Report estimates that the average cost-effectiveness of the DERA projects funded in 2008 ranged from $9,000 to $27,700 per ton of $PM_{2.5}$. According to this analysis, which is currently being updated, diesel retrofit strategies compare favorably with other emissions reduction strategies used to attain national ambient air quality standards that range from $1,000 to $20,000 and as high as $100,000 per ton of $PM_{2.5}$ on an annualized basis. However, most diesel retrofit strategies are less cost-effective than regulatory programs designed to set PM emissions standards for new diesel engines, such as the emissions standards for 2007 and later model year heavy-duty highway engines.

8.6.3 Applicability of Diesel Retrofits

The ability to install diesel retrofits on different diesel vehicles and equipment depends on a number of factors. Not all engine types are equally well suited to retrofit strategies; for others (e.g., bulldozers), long engine lifetime may make retrofits the only feasible option. The on-highway diesel vehicles in the United States are mostly heavy-duty trucks. The 2002 Census indicated that most trucking companies are small businesses that own only one to three trucks. Smaller businesses are less able than large businesses to absorb capital costs associated with emissions reductions from diesel engines.

The nonroad engine and vehicle category includes a diverse range of equipment from lawnmowers to marine and locomotive engines to construction machinery. Each category has specific needs and challenges. Construction equipment, for example, is often much more expensive with longer useful life than on-highway vehicles. This adds complexity when considering mitigation. Vehicle replacement is difficult for large construction equipment due to their high costs. In addition, repower options are only available for certain types of construction machines due to space limitations in the engine compartment.

Currently, PM mitigation strategies for marine and locomotive engines are limited. No DPFs are verified or certified by federal or state agencies for these engines. Therefore, upgrading/replacing engines and fuel switching are currently the two most viable mitigation strategies for these engines. Fuel switching could also include the use of shore power for larger marine vessels, which eliminates local PM emissions while ships are at port. New emissions reduction technologies are being developed to reduce locomotive and marine emissions. For example, marine engine upgrade kits have been implemented with funding support from the EPA Emerging Technologies Program.[18]

8.6.4 Experience with Diesel Emissions Reduction Programs in the United States

Federal, State, and local agencies have demonstrated substantial capacity to develop and implement diesel emissions reduction programs. Collectively, these agencies, in partnership with environmental and industry stakeholders, have built a strong foundation for the testing, verification and implementation of new technologies and strategies. Many of these programs provide funding or other incentives for voluntary diesel retrofits, engine replacements, or idle reductions. These programs include EPA's NCDC and the SmartWay Transport Partnership; FHWA's Congestion Mitigation and Air Quality (CMAQ) Improvement Program; the Texas Emissions Reduction Plan (TERP), and California's Carl Moyer Memorial Air Quality Standards Attainment Program.

8.6.4.1 National Clean Diesel Campaign (NCDC)

The National Clean Diesel Campaign (NCDC) is a partnership that aims to accelerate the implementation of emissions control strategies in the existing fleet through approaches such as retrofitting, repairing, replacing, repowering, and scrappage of diesel vehicles and equipment; reducing idling; and switching to cleaner fuels. This ten-year effort by EPA to bring together industry, environmental groups, local and State governments and Federal programs has resulted in significant experience with various fleet types and technologies and reduced emissions from thousands of engines. Several initiatives through the Campaign have targeted specific sectors, such as Clean School Bus USA and the clean ports program, demonstrating a variety of technologies and strategies on those fleets.

In 2005, a dedicated source of funding was authorized by Congress for implementation of NCDC projects on a wider scale. The Energy Policy Act of 2005[19] provided EPA with grant and loan authority to promote diesel emissions reductions from the existing in-use fleet in the United States and authorized appropriations of up to $200 million per year to the Agency under the DERA provisions for FY2007 through FY2011. The DERA Program may serve as one of the best avenues and foundations for reducing BC emissions in the United States (U.S.

[18] See *http://www.epa.gov/cleandiesel/projects/projects.htm*.

[19] *http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf*

EPA, 2009a). Congress appropriated $169.2 million in funding under this statute in FY 2008 through FY 2010. In addition, the American Recovery and Reinvestment Act of 2009 allotted the NCDC $300 million. The Diesel Emissions Reduction Act of 2010 was signed into law in January 2011. This law authorizes DERA for $100 million per year from FY2012 through FY2016.

DERA offers a funding vehicle for immediate BC reductions within the in-use fleet. The first year of DERA funding reduced emissions from more than 14,000 diesel-powered highway vehicles and pieces of nonroad equipment. DERA funding supported a wide range of verified technologies, cleaner fuels, and certified engine configurations, such as repowers, replacements, idle-reduction technologies, biodiesel, and retrofit devices such as DPFs. DERA funding also supported diesel programs in state governments.

The diesel emissions reductions resulting from the FY2008 grants for PM will total approximately 2,200 tons by 2031, which translates to 1,540 tons of BC reductions, assuming 70% of PM is BC. The health benefits will range from a net present value of $580 million to $1.4 billion, including an estimated 95 to 240 avoided premature deaths.

From 2008-2010, EPA received applications requesting more than $665 million, which equates to $7 for every $1 available in clean diesel funding. Thus, there remains strong interest in utilizing DERA to reduce diesel emissions. Additionally, a large number of high emitting engines remain currently in use. In moving forward with the program, a few challenges remain. For example, there are too few verified technologies for nonroad and marine engines and older diesel trucks, limiting the extent of achievable emissions reductions. The nonroad sector offers another challenge because of the number and diversity of nonroad engine types, the range of horsepower and the varying usage and duty cycles of the equipment.

Because BC is a regional pollutant, EPA, through the DERA Program, provides assistance to state and local governments in developing their own clean diesel programs. This includes targeting current nonattainment areas where clean diesel strategies can assist in meeting local emissions reduction goals and providing high quality data to states that depend on the performance of diesel emissions reduction strategies in their air quality plans. In addition, EPA conducts in-use testing—confirming the performance of verified technologies in the field—while working cooperatively with industry groups, engine manufacturers, and state agencies to expand the list of clean diesel technology options.

8.6.4.2 SmartWay

In 2004 EPA launched its SmartWay Transport Partnership. SmartWay is an innovative, voluntary partnership between EPA and private industry to reduce fuel use and emissions from goods movement. SmartWay promotes fuel-saving technologies and emission control technologies; some technologies—like idle reduction or newer truck replacements—do both. Since most cargo-hauling large trucks, locomotives, barges, and other freight vehicles use diesel fuel, and these vehicles remain in the legacy fleet for decades, reducing fuel use and emissions from goods movement and the legacy fleet can have a major impact on diesel emissions, including emissions of BC.

SmartWay provides shippers as well as truck carriers with standardized tools and approaches to assess, benchmark, track and reduce fuel use and emissions from goods movement. SmartWay offers technical assistance to enable partners to improve performance. The program offers incentives (SmartWay logo eligibility, SmartWay partner ranking, recognition of top performers) to encourage continual improvement. To enable this improvement, SmartWay helps its shipper and carrier partners identify fuel-saving operational and technical solutions through its technology program. This technology program researches and evaluates fuel-saving technologies, develops standardized protocols for the measurement of technology improvements (e.g., fuel consumption, aerodynamic impacts, long-duration idle reduction), and officially verifies the benefits of certain technology types (i.e., long-duration idle reduction technologies, low rolling resistance tires, and aerodynamic components).

While a wide variety of technologies exist to reduce fuel consumption and costs for trucking companies, many companies lack the up-front investment capital to benefit from them. The SmartWay Finance program, funded by diesel emissions reduction funding, aims to accelerate the deployment of energy efficiency and emissions control technologies by helping vehicle/equipment owners overcome financial obstacles. Since 2008, the SmartWay Finance program has awarded over $30 million to help small trucking companies reduce fuel costs and emissions. These innovative loans help small trucking firms reduce PM emissions, and lower their fuel costs by purchasing newer used trucks equipped with idling and emissions reduction technologies.

Nearly 3,000 companies, from small firms to Fortune 500 companies, belong to SmartWay. To date, these SmartWay partners have saved $6.1 billion dollars by cutting their fuel use by 50 million barrels of oil. This is equivalent to taking 3 million cars off the road for an entire year. Improving supply chain efficiency helps these companies grow the economy, protect and generate jobs, cut imports of foreign oil, contribute to energy security, and be good environmental stewards.

In developing new national standards to bring cleaner, more efficient trucks to market, EPA and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) drew from the SmartWay experience. This experience includes developing test procedures to evaluate trucks and truck components and determining how these features and components perform. While focused on American freight-efficiency, SmartWay has responded to industry demand to recognize the importance of the global supply chain by expanding its tools and building the capacity for SmartWay-based programs in other countries.

8.6.4.3 Congestion Mitigation and Air Quality Improvement Program (U.S. DOT)

The Congestion Mitigation and Air Quality (CMAQ) Improvement Program, jointly administered by the U.S. Department of Transportation's Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA), provides roughly $1.7 billion in annual funding for a variety of emissions reduction projects including transit, traffic signalization, bicycle/pedestrian facilities, demand management, and diesel retrofit projects. According to the most recent data available, between 2005 and 2007, approximately $285 million of CMAQ funds were spent on diesel retrofits. New priority for the funding of diesel retrofit projects was established by Congress with the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in 2005.

The allocation of CMAQ funds is managed by the state DOTs. CMAQ aims to implement projects that will help areas attain or maintain the NAAQS. Diesel retrofits are more cost-effective in reducing PM than other typical CMAQ projects, such as traffic signal optimization (Diesel Technology Forum, 2006, 2007).

8.6.4.4 State Programs

Mandatory retrofits: The state of California has enacted legislation to require in-use heavy duty diesel fleets to meet minimum emission standards. The legislation is implemented through CARB and applies to many sectors, including both on-highway and nonroad diesel engines. Most of the regulations require accelerated fleet turnover, which includes repowering or retiring vehicles, or requiring best available control technology (BACT) to be installed on diesel engines. Almost all on-highway heavy-duty diesel vehicles, including buses, drayage trucks, and class VIII trucks will be required to reduce diesel emissions.

Several states have passed legislation similar to California's. New Jersey has instituted a mandatory retrofit program requiring owners of diesel vehicles to retrofit with best available retrofit technology (BART). The state reimburses vehicle owners/operators for all expenses. New York has also instituted a mandatory retrofit program that applies to all heavy-duty state-owned and contractor vehicles.

Incentive programs: The state of California's Carl Moyer Memorial Air Quality Standards Attainment Program provides incentive grants for cleaner-than-required engines, equipment, and other sources of pollution providing early or extra emission reductions. The program started in 1998 and has funded hundreds of millions of dollars worth of projects since its inception. California voters also passed Proposition 1B in 2006, which allocated $1 billion to reduce air pollutant emissions from freight along California's trade corridors. Both of these incentive funding programs rank applicants based on cost effectiveness (e.g., $/ton). Carl Moyer funds cannot be used to fund compliance with state or federal laws. Thus, funding opportunities are becoming limited due to California's implementation of regulations affecting most categories of mobile sources.

The Texas Emissions Reduction Plan (TERP), a program of the Texas Commission on Environmental Quality (TCEQ) provides financial incentives to eligible individuals, businesses or local governments to reduce emissions from polluting vehicles and equipment in the state of Texas. TERP has provided over $797 million since 2002, affecting over 12,500 diesel engines with engine/vehicle replacement as one of the key clean diesel strategies. Though this incentive program focuses more heavily on NO_x, there is still an opportunity for manufacturers to develop both NO_x and PM combination technology strategies for BC reductions, through the New Technology Research and Development Program (NTRD), which encourages and supports the research, development, and commercialization of technologies that reduce pollution in Texas.[20]

[20] *http://www.tceq.texas.gov/airquality/terp.*

8.7 Mitigation Approaches for In-use Mobile Engines Internationally

There are millions of large diesel-powered vehicles throughout the world, including buses, heavy duty trucks, off-road vehicles, locomotives, and marine vessels. The exact size of the international diesel fleet is not easily characterized. Some countries are similar to the United States in one or more of the following: vehicle registration, inspection and maintenance programs, availability of low-sulfur fuel, technology certification/verification programs, and readily available technologies. However, many (mainly developing) nations have little to none of this infrastructure in place. Furthermore, developing countries tend to have older and less well-maintained engines and vehicles than developed countries, and the availability of low-sulfur diesel fuel is limited. Therefore, many engines in developing countries are not good candidates for tailpipe control strategies like passive DPFs. In addition, the costs of DPFs may be prohibitive for some countries. Most retrofit programs around the world (including in the United States) have relied heavily on government funding, which presents a significant financial challenge.

EPA has often advised other nations and supported international demonstration projects in an effort to transfer information and technologies to those that seek to reduce emissions from mobile sources. Additionally, EPA's diesel retrofit experts have advised and participated in several pilot retrofit projects where diesel trucks and buses were fitted with various exhaust after-treatment devices. Low-sulfur diesel was obtained for the projects in most cases. The projects have shown generally that, if appropriate fuel is provided and engine maintenance is addressed, DPFs are viable options to reduce PM (and thus BC) on some vehicles. Following a relatively small EPA supported pilot project in Beijing in 2006, city authorities went on to retrofit more than 6,000 vehicles with active DPFs prior to the Beijing Olympics. That number is now above 8,000 and growing. EPA has also assisted in retrofit projects in Mexico City, Bangkok, Santiago, and Pune (India).

As noted earlier, the SmartWay program recognizes the importance of the global supply chain and has shared its program and technology expertise with other countries. EPA hosted a SmartWay International Summit in December of 2008 to offer guidance to numerous countries which are also developing freight sustainability programs. As a result of that Summit and other capacity building and information sharing, multiple countries and regions have gone on to implement SmartWay-like programs. Mexico, Canada, France and Australia have each developed and launched freight sustainability programs using SmartWay templates for tools and program design, partnership structures and best practices. Additionally, a consortium of SmartWay Partners and other businesses in the European Union have beta-tested SmartWay tools with the intent of developing a SmartWay platform for implementation throughout the region.

More recently, EPA has collaborated to help China develop multiple freight sustainability projects utilizing SmartWay technologies and program design elements. EPA first provided technical expertise for the Green Truck Pilot in Guangzhou in 2009. The World Bank funded the retrofitting of SmartWay technology on local trucks and demonstrated notable fuel savings. Based on those results, the World Bank secured funding from the Global Environmental Facility for the Guangdong Green Freight Demonstration Program. This $18 million project will implement truck retrofits and upgrades using SmartWay technologies and financing methods, as well as logistical improvements, driver training and capacity building for governmental officials. The Ministry of Transport and the China Sustainable Energy Program are developing a nationwide freight efficiency program, built in part on these pilot projects.