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# Dumping Dirty Diesels in Latin America:
## Reducing Black Carbon and Air Pollution from Diesel Engines in Latin American Countries

**A Report to the Natural Resources Defense Council**


***Prepared by***
**Gladstein, Neandross & Associates**



GLADSTEIN, NEANDROSS & ASSOCIATES

**ACKNOWLEDGEMENTS**
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NRDC and GNA wish to express their gratitude to Renzo Mendoza Castro, whose research was fundamental to this report.

This report presents the latest research on black carbon, consolidated and analyzed by NRDC and GNA over the past year. The key findings are:

- Short-lived climate pollutants (SLCPs) such as black carbon are an increasingly important component of local, national, and international efforts to reduce the impacts of climate change. Recent research has concluded that black carbon is the second most important global warming pollutant after carbon dioxide.
- In addition to its global warming impacts, black carbon emissions have been linked to serious heart, lung, and other impacts, including premature deaths.
- Research about the climate impacts and public health impacts of black carbon in Latin America is currently sparse. Much more study needs to be done on both topics to understand the effects that growing black carbon emissions in Latin America are having on people and the environment.
- Transportation is one of the largest sources of black carbon emissions in Latin America and globally, with diesel vehicles leading the way in Latin America.
- As the number of diesel vehicles in Latin America continues to grow, and more and more people move to cities, millions of people will be increasingly exposed to the negative impacts of these emissions. Yet air quality monitoring systems in the region do not adequately detect fine particulate matter or black carbon.
- Introducing ultra-low sulfur diesel fuel, emission standards for new diesel vehicles that lead to the widespread use of diesel particulate filters, and complementary programs to reduce diesel emissions from today's fleet of diesel engines in a "systems approach" will be a highly effective—and cost-effective—approach to reducing black carbon emissions from diesel engines in Latin America and worldwide.

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# GLOSSARY OF ACRONYMS

**Companies and Organizations**

| | |
|---|---|
| CCAC: | Climate and Clean Air Coalition |
| CMMCh: | Centro Mario Molina Chile |
| GNA: | Gladstein, Neandross & Associates |
| IPCC: | Intergovernmental Panel on Climate Change |
| NCDC: | National Clean Diesel Campaign |
| NOC: | National Oil Company |
| NRDC: | Natural Resources Defense Council |
| PDVSA: | Petróleos de Venezuela |
| Pemex / PEMEX: | Petróleos Mexicanos |
| Petrobras: | Petróleo Brasileiro S.A. |
| Petroecuador: | Empresa Estatal Petróleos del Ecuador |
| TfL: | Transport for London |
| U.S. EIA: | United States Energy Information Administration |
| U.S. EPA: | United States Environmental Protection Agency |
| UN: | United Nations |
| UNEP: | United Nations Environment Programme |
| WHO: | World Health Organization |
| WMO: | World Meteorological Organization |

**Emissions**

| | |
|---|---|
| BC: | Black carbon |
| $CO_2$: | Carbon Dioxide |
| Gg: | Gigagram (unit of measure roughly equivalent to 1,102 short tons) |
| HFC: | Hydrofluorocarbons |
| Kt: | Kiloton |
| MM: | Million |
| $NO_x$: | Oxides of nitrogen |
| $PM_{2.5}$: | Particulate matter that is 2.5 micrometers in diameter and smaller, also known as "fine PM" |
| $PM_{10}$: | Particulate matter that is between 2.5 and 10 micrometers in diameter |
| Ppm: | Parts per million |
| SLCP: | Short-lived climate pollutant |
| $SO_x$: | Oxides of sulfur |

**Equipment, Technology and Programs**

| | |
|---|---|
| BRT: | Bus Rapid Transit program |
| DPF: | Diesel Particulate Filter |
| GVWR: | Gross Vehicle Weight Rating |
| HDV: | Heavy-Duty Vehicle |
| LDV: | Light-Duty Vehicle |
| LEZ: | Low Emission Zone |

# EXECUTIVE SUMMARY

Efforts to reduce black carbon emissions have become an increasingly important component of national and international efforts to fight global warming, particularly as recent studies have concluded that black carbon is the second most powerful climate warming pollutant after carbon dioxide ($CO_2$).[1,2] Black carbon is one of four major Short-Lived Climate Pollutants (SLCPs) that live in the atmosphere for a relatively short period of time compared to other greenhouse gases, such as $CO_2$. The others are methane, tropospheric ozone, and hydrofluorocarbons. Because these SLCPs stay in the atmosphere only briefly, reducing their emissions provides quick climate benefits.

Among the SLCPs, black carbon has the shortest lifetime—staying in the atmosphere for only days or weeks. Thus, reducing black carbon emissions provides benefits almost immediately.[3]

***Although black carbon is emitted from a wide variety of combustion sources including open biomass burning, domestic cookstoves and industry, the transportation sector is the largest source of anthropogenic (human-generated) black carbon emissions in Latin America.***[4,5]

More specifically, high-emitting diesel vehicles are the largest source of transportation-related black carbon emissions. This is a function of two factors: (1) the high concentration of black carbon within the carbon core of a typical diesel particle and (2) the increasing number of diesel vehicles. Open biomass burning is the leading source of black carbon emissions globally, but its combustion produces great quantities of organic matter, offsetting the warming potential of its black carbon emissions.[6]

## BLACK CARBON'S CLIMATE IMPACTS

Although research into the specific environmental and climate impacts of black carbon emissions continues, there is an emerging consensus that, globally, black carbon emissions accelerate the melting of glaciers, snow and ice, and impact temperature and weather patterns in the Arctic and many alpine regions. In addition, black carbon emissions may also affect photosynthesis when deposited on leaves, reduce the quantity or quality of water available for agriculture, and reduce visibility due to suspended particles.[7, 8, 9]

Research about the local climate impacts of black carbon emissions in Latin America reflects the global trends. For example, the surface area of the Andean glaciers has significantly reduced over the past three decades. Compared to 1964–1975, the loss of glacial surface area has nearly quadrupled in scale through 2010.[10, 11] This drastic decline in glacial ice impacts the 85 million people who live in the Andean regions of Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela.[12] Of these people, 20 million rely on Andean glaciers for drinking water and agriculture.[13] Shrinking glaciers are also a major concern for hydroelectric power generation in the region. In addition, black carbon emissions have a warming effect on the climate that reduces evaporation rates and atmospheric moisture, leading to continually decreasing rainfall throughout the Amazon Basin and surrounding areas.[14, 15, 16]

Although these major trends have been established, research and data on the specific environmental impacts of black carbon in Latin America are scant. More focused and localized studies are needed to discern the full extent and implications of these emissions. Nevertheless, we know that the problem is serious, that cost-effective solutions exist, and that governments have the policy tools to implement those solutions now.

## BLACK CARBON'S PUBLIC HEALTH IMPACTS

Reducing diesel pollution is an important tactic to improve human health. Black carbon is a component of particulate matter (PM), a complex mixture of extremely small particles and liquid droplets in the atmosphere. The most common source of transportation-related PM is incomplete combustion from diesel engines.[17] The core of a diesel particle is typically comprised of black carbon, so the most common source of transportation-related black carbon is also incomplete combustion from diesel engines. Thus, transportation strategies designed to reduce black carbon will also reduce PM.*

Health experts have found links between black carbon exposure and decreased vascular and respiratory functioning, including thrombosis, acute respiratory symptoms, aggravated asthma symptoms, decreased lung function, and lung inflammation.[18] Moreover, the World Health Organization

*It is worth noting that some PM reduction strategies will reduce black carbon, but not all. For example, reducing sulfur levels in diesel fuel to no more than 50 parts per million (ppm) and installing diesel PM filters will reduce both PM and black carbon. In contrast, reducing sulfur levels in diesel fuel from 5,000 ppm to 500 ppm will reduce PM levels, but will not reduce black carbon at all.

(WHO) has determined that outdoor air pollution, diesel exhaust and particulate matter cause cancer.[19, 20]

Although there have been some studies (e.g., in Santiago, Chile), there is not enough information regarding black carbon's specific health impacts in Latin America. Such studies should be a priority for policymakers, since the expanding use of diesel fuels and vehicles in Latin America as a whole, coupled with the incredibly high rates of urbanization in the region, mean that more and more Latin Americans are being exposed to harmful fumes that damage their health and environment. One study has shown that, by implementing specific measures to reduce black carbon and methane emissions, the Andean region could avoid 27,000 premature deaths annually.[21] But more information is needed; the more we know about the local impacts of black carbon emissions, the better we can mitigate them.

Policy efforts to reduce diesel emissions to very low levels, therefore, represent a promising strategy to combat climate change and a range of public health issues.

## REDUCING BLACK CARBON EMISSIONS IN LATIN AMERICA WITH A "SYSTEMS APPROACH" TO THE TRANSPORT SECTOR

The evidence clearly indicates that black carbon has widespread and dramatic impacts on Latin America: glacial melting in the Andes and Patagonia, declining moisture in the Amazon Basin, and illness and premature deaths from outdoor air pollution. Although additional black carbon-focused and health and climate studies are needed in Latin America to expand our understanding of these impacts, we know enough to strongly recommend that policymakers take action now.

Because black carbon is emitted as a component of PM, many tactics that can be used to reduce diesel PM in Latin America will be effective in reducing black carbon emissions as well, providing significant human health and environmental benefits at the local and global levels.

**Figure 1: Map of Latin American countries with corresponding fuel sulfur levels[22]**

Taken together, the following strategies comprise a "systems approach" that has successfully reduced diesel PM and black carbon emissions in the United States, Canada, Europe, and elsewhere. There are three main components of this systems approach, as follows:

- **Clean fuels:** The top priority for Latin America is to ensure widespread adoption of fuel standards that reduce sulfur levels to ultra-low levels (below 50 ppm). Reaching ultra-low sulfur levels will reduce PM emissions from all vehicles and enable the use of advanced vehicle emission control technologies that can eliminate more than 90 percent of black carbon emissions, compared to engines that are not equipped with these technologies. Currently, Chile is the only country to both adopt and implement ULSD standards. Mexico, despite adoption in 2009, has yet to implement its standards, though the country has signaled its intention to revise its fuel regulations this year, and to implement an ultra-low sulfur requirement in the near future. Chile is the only country to both adopt and implement ULSD standards to sub-15 ppm levels. Colombia and Uruguay have 50 ppm sulfur standards.

- **Stringent emissions standards for new vehicles:** Once ultra-low sulfur fuels are in place, Latin American countries can adopt vehicle emission standards for new vehicles that require the use of diesel particulate filters (DPFs) or comparably effective alternative fuels or advanced vehicle technologies that are emerging in markets around the world (e.g., vehicles powered by natural gas, hybrid-electric or electric power). Because DPFs and other advanced emission controls are damaged or destroyed by high-sulfur fuels, adopting ultra-low sulfur diesel fuels is the necessary precursor to these new standards. Several countries have already made progress. By requiring urban buses to meet U.S. Environmental Protection Agency's (EPA) 2007 standards, Chile is leading the way. Mexico has also signaled its intention to publish a rule in 2014 that would implement these (or even more protective) standards in the near future. Argentina and Brazil have Euro V standards for heavy duty vehicles (HDVs) and others have Euro IV in place as well

- **Complementary programs to reduce in-use emissions from existing vehicles:** Because so many older, high-emitting vehicles will remain on the road for years to come, countries should consider complementary measures to reduce in-use emissions from their existing diesel fleets. The most successful of these programs has targeted urban fleets, which focus on high-emitting, centrally fueled fleets. For example, in Santiago, Chile, more than 2,000 city buses have been *retrofitted* with DPFs.[23] *Low-Emissions Zones*, which restrict a vehicle's access to urban centers according to its emissions level, have proven successful in Europe through the establishment of incentives for cleaner vehicles.[24] Small *scrappage programs* are being implemented in Mexico, Colombia and Chile, under which owners of the oldest, dirtiest trucks receive financial incentives to retire them and replace them with newer, cleaner, more fuel-efficient models.[25] More than 45 Latin American cities have implemented new *Bus Rapid Transit* routes that have created new public transit options that use clean buses to replace aging, high-emitting buses.[26] Finally, in-use *emissions monitoring* helps ensure and improve fuel quality and supports in-use emissions maintenance programs.

In addition to the policy recommendations above, Latin America will benefit from more extensive air quality monitoring. Currently, only eight of the 15 countries surveyed in this analysis monitor for fine particulate matter ($PM_{2.5}$), and most monitoring activities take place only in major cities. With improved air quality monitoring, public education and communications campaigns can educate the public about the link between diesel pollution, public health and climate change, and thereby help to catalyze progress towards better government policies.

This report summarizes the latest research on black carbon and its role in global warming, and consolidates research Natural Resources Defense Council (NRDC) and Gladstein, Neandross and Associates (GNA) conducted over the past year. The report and its appendices include country-specific research for Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Paraguay, Peru, Uruguay and Venezuela, as well as case studies of successful programs in Chile, Mexico, China and the United States. Some of the most pertinent information is summarized in Table 1.

If policy makers follow the systems approach we describe, which relies on proven fuels, technologies and strategies, black carbon emissions will be significantly reduced in Latin America, providing important climate, public health and other environmental benefits to hundreds of millions of people throughout the region, as well as globally.

**Table 1. Summary table of key indicators for the countries surveyed in this report**

| COUNTRY | National Annual $PM_{10}$ and $PM_{2.5}$ Standards[27,*] | Maximum Sulfur Level in Diesel Fuel | Road Sector Diesel Use (kilotons of oil equivalent by year) | Number of Registered Vehicles[28] | Emissions Standards for New Vehicles[29,**] |
|---|---|---|---|---|---|
| Argentina[30] | $PM_{10}$: None<br>$PM_{2.5}$: None | 1,500 ppm (500 in Buenos Aires, Rosario, Mar del Plata, and Bahía Blanca) | 7,212 (2008) | 11 MM (2011) | LDV, HDV, and Buses: Euro V[31] |
| Bolivia[32] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: None | 5,000 ppm | 1,058 (2010) | 1.1 MM (2011) | Buses: Euro III (La Paz)[33] |
| Brazil | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: None | 1,800 ppm (Between 50 and 500 in major cities)[34] | 28,732 (2009)[35] | 64.8 MM (2010)[36] | LDV: Euro IV<br>HDV: Euro V |
| Chile | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 20 µg/m³ | 15 ppm[37] | 3,534 (2010)[38] | 3.4 MM (2010)[41] | LDV and MDV: Euro V<br>HDV: Euro V (from Sept. 2014)<br>Buses: U.S. 2004 NOx / U.S. 2007 PM[40] |
| Colombia[41] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 25 µg/m³ | 50 ppm[42] | 3,754 (2010) | 7.2 MM (2011) | LDV: Euro IV<br>HDV: Euro IV (from 2015)<br>Buses: Euro II |
| Ecuador[43] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 15 µg/m³ | 5,000 ppm (500 in Quito and Cuenca)[44] | 2,415 (2010) | 1.4 MM (2011) | LDV: Euro I / U.S. 1987<br>HDV: Euro II / U.S. 1994 |
| El Salvador[45] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 15 µg/m³ | 5,000 ppm | Levels unknown | 0.7 MM (2012) | LDV: Euro I / U.S. 1987 |
| Guatemala[46] | $PM_{10}$: None<br>$PM_{2.5}$: None | 5,000 ppm | Levels unknown | 2.1 MM (2010) | None |
| Honduras[47] | $PM_{10}$: None<br>$PM_{2.5}$: None | 5,000 ppm | Levels unknown | 1.2MM (2012) | None |
| Mexico | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 15 µg/m³ | 15 ppm, but most diesel is 300 ppm[48] | 13,767 (2009)[49] | 30.2 MM (2011) | All: Euro IV / U.S. 2004 |
| Nicaragua[50] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: None | 5,000 ppm | Levels unknown | 0.6 MM (2012) | None |
| Paraguay[51] | $PM_{10}$: None<br>$PM_{2.5}$: None | 2,500 ppm | 1,039 (2010) | 1.15 MM (2013) | None enforced |
| Peru[52] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 25 µg/m³ | 5,000 ppm (15 in Lima and Callao) | 3,426 (2010) | 2.6 MM (2011) | LDV and HDV: Euro III<br>Buses: Euro IV (Lima) |
| Uruguay[53] | $PM_{10}$: None<br>$PM_{2.5}$: None | 50 ppm[54] | 582 (2010) | 1.6MM (2011) | All: Euro III |
| Venezuela | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: None | 2,000 ppm[55] | 2,909 (2010)[56] | 4.4 MM (2011) | HDV: Euro I / U.S. 1991[57] |

*Some countries have adopted more stringent PM10 and/or PM2.5 standards for their major cities. For example, La Paz, Bolivia, has adopted WHO-equivalent annual PM10 and PM2.5 standards of 20 and 10 µg/m3, respectively. Also, Montevideo, Uruguay has adopted an annual PM10 standard of 60 µg/m3.

**This column lists the types of regulations—using the U.S. or European systems—that are already in place for light duty vehicles (LDV), heavy duty vehicles (HDV) and/or buses in each country. For further information, see Appendix 3: U.S. and E.U. Heavy-Duty Diesel Engines Emission Standards."

# I. INTRODUCTION

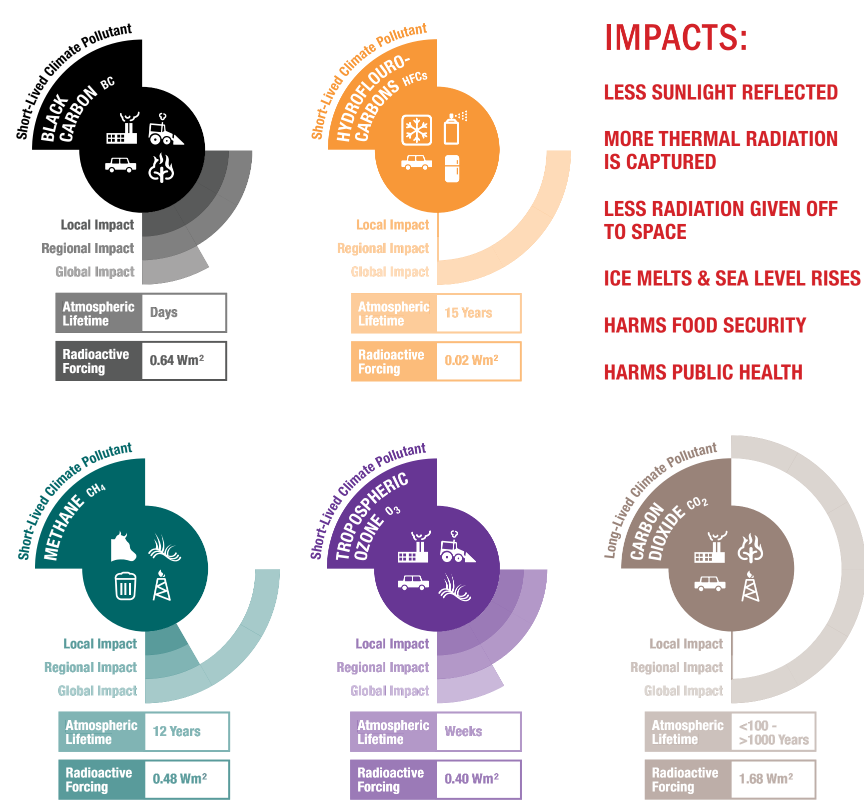
Reducing Short-Lived Climate Pollutants (SLCPs) like black carbon, methane, tropospheric ozone, and hydrofluorocarbons (HFCs) is becoming an increasingly important component of national and international efforts to fight global warming. As shown in Figure 2, because these SLCPs have atmospheric lifetimes of days, weeks, or, in some cases, years, reducing these emissions can have climate benefits that are felt almost immediately. As a result, institutions and organizations such as the United Nations (UN), the World Bank, the World Health Organization (WHO), and the Climate and Clean Air Coalition (CCAC)* are devoting significant resources and time to reducing SLCP emissions. Recent studies have concluded that black carbon is the second most powerful climate-warming pollutant after carbon dioxide ($CO_2$).[58, 59] Unlike greenhouse gases such as $CO_2$ that persist in the atmosphere for decades or even centuries, black carbon lasts in the atmosphere for days, making its reduction especially beneficial for the short and long term.

The transportation sector is the largest source of anthropogenic (or human-generated) black carbon emissions in Latin America. Within Latin America's transportation sector, diesel engines are the largest source of black carbon emissions. (Globally, diesel emissions contribute roughly 20 percent of total black carbon). In Latin America, policy efforts to reduce diesel emissions should be an important component of any comprehensive strategy to combat climate change.

Cutting Black carbon emissions can also have significant public health benefits. Black carbon is generally emitted as a component of particulate matter (PM), which itself is a significant part of the exhaust from diesel vehicles.[60]

***The WHO has officially categorized diesel engine exhaust, PM, and general outdoor air pollution as carcinogens—i.e., pollutants that can cause cancer in humans.***[61]

**Figure 2: Explanation of short-lived climate pollutants (SLCPs)**[62]




Source: Climate and Clean Air Coalition and the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report

*NRDC is a member of the CCAC.

**Figure 3: Diesel buses in Bogotá spewing particulate matter and black carbon emissions[63]**


In addition, diesel exhaust has been linked to respiratory and cardiovascular disease, chronic bronchitis, acute respiratory symptoms, aggravated asthma symptoms, decreased lung function, lung inflammation, emphysema cancer, and premature death.[64] Strategies to clean up diesel vehicles by reducing black carbon and PM emissions will, therefore, bring health benefits to millions of people who regularly breathe diesel exhaust.

The Natural Resources Defense Council (NRDC) and and Gladstein, Neandross and Associates (GNA) have been working together for years to reduce pollution in the transportation sector and develop strategies that mitigate emissions of SLCPs, such as black carbon. This work began in the United States, but quickly expanded to other countries, such as China and Mexico, where growing diesel vehicle fleets were fast becoming important health, environmental and public policy issues.

In Latin America, the expanding use of diesel fuels and vehicles, coupled with the incredibly high rates of urbanization, mean that more people are being exposed to pollution that harms their health and environment. For that reason, we decided to look at the current status of black carbon and PM emissions, vehicle fleets, air quality monitoring efforts, and fuel and vehicle regulations in Latin America to identify patterns and steps to reduce these emissions.

This report summarizes the latest research on black carbon, its role in global warming and its public health impacts at both the global and regional levels, and consolidates country-specific research NRDC and GNA conducted since August 2013. The report and its appendices include information about Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Paraguay, Peru, Uruguay and Venezuela, as well as case studies of successful programs in Chile, Mexico, and the United States.

We conclude with a series of recommendations for policymakers based on successful examples from countries around the world. Each of these steps relies on proven fuels, technologies and strategies. If policymakers follow these steps, black carbon emissions will be significantly reduced in Latin America, providing important climate, public health, and other environmental benefits to hundreds of millions of people throughout the region and the world.

# II. THE IMPORTANCE OF REDUCING BLACK CARBON

## A. BLACK CARBON AND GLOBAL CLIMATE CHANGE

Along with methane, tropospheric ozone, and hydrofluorocarbons (HFCs), black carbon is one of the four main short-lived climate pollutants (SLCPs), shown above in Figure 2.[65] Compared to carbon dioxide, these substances have both a relatively short lifetime in the atmosphere and a warming effect on the climate, known as radiative forcing.

**Table 2: Atmospheric lifetime and radiative forcing of four main short-lived climate pollutants[66]**

| SLCP | Lifetime in Atmosphere | Current Radiative Forcing* |
|---|---|---|
| Black Carbon | Days | 0.64 W/m$^2$ |
| Methane | 12 years | 0.48 W/m$^2$ |
| Tropospheric Ozone | Weeks | 0.40 W/m$^2$ |
| Hydrofluorocarbons | 15 years (averaged by weight) | 0.02 W/m$^2$ |
| Carbon Dioxide[67] | 30 – 1,000 years | 1.68 W/m$^2$ |

*Radiative forcing is measured as the change in the energy balance between incoming solar radiation and exiting infrared radiation, typically measured in watts per square meter (W/m2). The SLCPs shown here have positive radiative forcing, which means they tend towarm the surface of the Earth.

Source: Climate and Clean Air Coalition and the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report

Black carbon is emitted as a component of PM during the incomplete combustion of fossil fuels or biomass.[68] This dark-colored pollutant absorbs light and then radiates it as heat.[69] Although research on the specific impacts of black carbon emissions continues, there is an emerging consensus that the dark surface of black carbon emissions accelerates the melting of glaciers, snow, and ice when it is deposited on their surface (see a more detailed explanation below in Section B), and that black carbon can affect temperature and weather patterns. Globally, the accelerated melting of Arctic and Antarctic ice is of great concern, especially because of the connection between melting ice and rising global sea levels.[70] In Latin America, evidence of increasing melting glaciers and snow in the Andes creates more localized concerns related to water supply, agricultural impacts, and other environmental changes.[71]

In 2013, the scientific understanding of the importance of reducing black carbon emissions increased significantly. The Intergovernmental Panel on Climate Change (IPCC) issued its Fifth Assessment, which included data that suggests that black carbon has a much stronger impact on global climate change than previously thought.[72] Additional research concluded that black carbon has a climate impact twice the direct climate impact reported in previous assessments, and that black carbon ranks "as the second most important individual climate-warming agent after carbon dioxide."[73] This study also found that cleaning up diesel engines and some wood and coal combustion could slow the pace of warming almost immediately.[74]

In addition to the impacts listed above, black carbon emissions have other environmental impacts that have been difficult to quantify with precision. These impacts include the effects on photosynthesis when black carbon is deposited on leaves, changes in glacial melting, changes in the quantity or quality of water available for agriculture, and reduced visibility from suspended particles.[75, 76, 77] For a more detailed review of black carbon's climatic impacts, including radiative forcing, aerosol speciation and global warming potential, see Appendix A in the World Bank's "Reducing Black Carbon Emissions from Diesel Vehicles: Impacts, Control Strategies and Cost-Benefit Analysis."[78]

## B. BLACK CARBON'S CLIMATE IMPACTS IN LATIN AMERICA

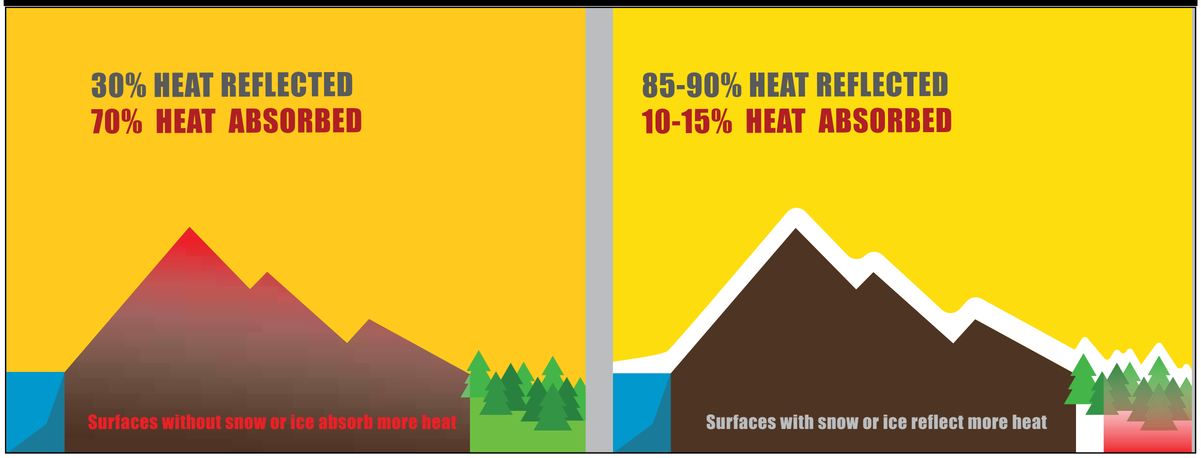
While most attention to black carbon has focused on its impacts on polar ice melting, black carbon is also having significant effects in Latin America. These impacts are felt mostly in the Amazon Basin and in the Andean glaciers.

Black carbon plays a major role in the accelerating melting of South America's Andean glaciers. This accelerated melting is due to changes in the surface albedo of the snow and ice. Light-colored surfaces, such as snow and ice, reflect a significant amount of solar radiation. Such surfaces are described as having a "high albedo." When these surfaces are darkened by black carbon deposited on the snow or ice, their albedo decreases. In other words, as snow or ice on the ground absorb more solar radiation, the surface gets warmer and melting accelerates.[79] This leads to more dark surfaces (i.e., water), further accelerating melting. Figure 4 portrays the varying rates of absorption and reflection for different surfaces.

The surface area of the Andean glaciers has been significantly reduced over the past three decades. Compared to 1964–1975, the loss of glacial surface area has nearly quadrupled in scale through 2010.[80, 81] Glaciers in Peru's Cordillera Blanca—home to Peru's highest peak and roughly 260 glaciers—have lost 27 percent of their surface area since the 1960s, decreasing from 723 km$^2$ to 527 km$^2$.[82]

This drastic decline in glacial ice impacts the 85 million people who live in the Andean countries of Argentina, Bolivia, Chile,

**Figure 4: The albedo affects different impacts on surfaces with or without snow and ice**




Source: adapted from the Climate and Clean Air Coalition (2014).

Colombia, Ecuador, Peru and Venezuela.[83] Of these people, 20 million rely on Andean glaciers for drinking water and agriculture.[84] Shrinking glaciers are also a major concern for power generation, as Andean hydropower supplies 81 percent of Peru's electricity, 73 percent of Colombia's electricity, 72 percent of Ecuador's, and 50 percent of Bolivia's.[85]

In Patagonia, home to the largest ice fields in the southern hemisphere besides Antarctica, the most recent rate of glacial melting is up to 100 times faster than at any time in the past 350 years.[86] The pace of Patagonian melting outpaces any other glacial region in the world.[87, 88, 89] This rapid melting, confirmed by satellite observations, suggests that the Patagonian ice fields' contribution to global sea-level rise has increased by 50 percent and accounts for two percent of annual sea-level rise since 1998.[90, 91]

In the Amazon Basin, black carbon emissions are also creating significant radiative forcing that adds to local global warming impacts. It does this by changing the convective process that mixes different air temperature layers in the atmosphere. This process is an important component of cloud formation in the region.[92]

During the region's dry season from June through December, logging and farming operations generate high emissions from biomass burning and incomplete combustion. The resultant smoke plumes are rich with black carbon and organic carbon (OC) that can reduce atmospheric convection.[93] When atmospheric convection is hindered by black carbon emissions, rain-bearing clouds do not form as prevalently. This, in turn, reduces atmospheric moisture and precipitation levels. Furthermore, the presence of black carbon-rich smoke from biomass burning reduces the ability of solar radiation to penetrate the atmosphere. The result of these changes can be seen in reduced evaporation rates and atmospheric moisture, leading to continually decreasing rainfall throughout the surrounding areas.[94, 95] Glacial melting in the Andes and Patagonia and declining moisture levels over the Amazon Basin are just two of black carbon's climate impacts in Latin America.

***However, at the time of this report's publication, data on the specific climate impacts of black carbon throughout Latin America is few and far between. More focused and localized studies are needed to discern the full extent and implications of these impacts in the region.***

## C. REDUCING DIESEL PARTICULATE MATTER REDUCES BLACK CARBON

In order to understand the mechanisms for reducing black carbon, it is important to understand its role as a component of particulate matter. Because of the relationship between black carbon and PM, transportation strategies to reduce black carbon will also reduce PM. Many (but not all) PM reduction strategies will reduce black carbon.

**Figure 5: Different sizes of particulate matter with reference points**[96]

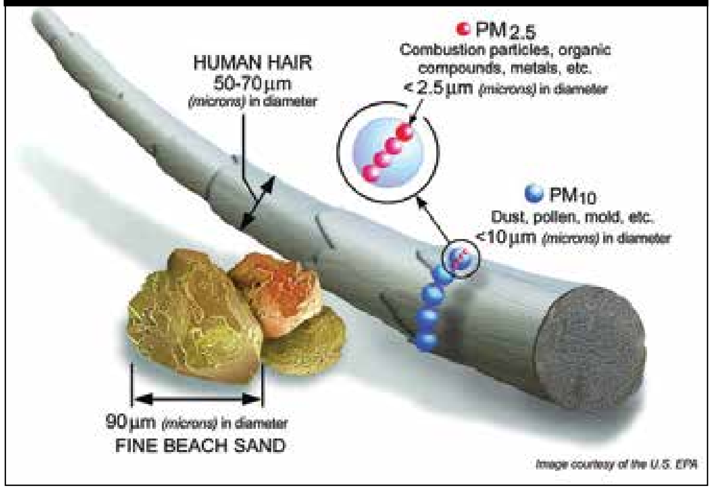
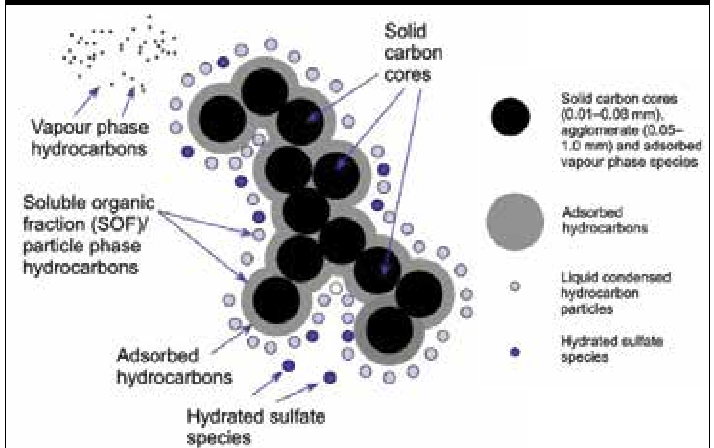



**Figure 6: Different sizes of particulate matter with reference points**[100]




Source: Twigg and Phillips (2009).

PM is a complex mixture of extremely small particles and liquid droplets that are suspended in the atmosphere.[97] PM is made up of a number of components, including acids (e.g., nitrates and sulfates), organic chemicals, metals and soil or dust particles. PM is typically regulated by size, which ranges from microscopic ultrafine particles to larger particles like dust or sand. Most countries regulate engine emissions and ambient air at the $PM_{10}$ level (i.e., particles that are smaller than 10 microns in diameter). A number of countries (including Australia, Canada, China, the European Union, India, Japan, and the United States) regulate ambient air quality at the $PM_{2.5}$ level (i.e., particles that are smaller than 2.5 microns in diameter, sometimes called fine particulate matter).[98] Figure 5 shows these two sizes of PM, along with fine beach sand and an average human hair for reference. More than 90 percent of diesel particles are less than one micron in diameter. These are often described as "ultrafine" particles.[99]

In order to use PM strategies to reduce black carbon, one must first understand the carbon core of a PM particle. PM emissions are composed of two forms of carbon: organic and elemental. Organic carbon includes any compound with carbon bound to other elements (such as hydrogen and oxygen) and generally reflects light rather than absorbing energy.[101] Black carbon originates as solid spheres of mainly pure, so-called elemental carbon.[102] These smaller particles, on a scale of 0.001 to 0.005 micrometers (µm), can aggregate to form larger particles (0.1 to 1 µm).[103]

Diesel PM emissions contain a black carbon core, along with a number of other co-pollutants (nitrogen oxides, hydrocarbons, organic carbon, and carbon monoxide). As shown in Figure 6, the black carbon core of a diesel particle is typically surrounded by organic carbons, hydrocarbons, and hydrated sulfates, which are adsorbed or attached to the solid carbon core of the diesel particle.[104]

To meet the latest EPA, California, and European diesel standards (see Appendix 3), PM filters are the *de facto* required emission control technology for diesel engines.** These filters have been shown to be at least as effective at reducing black carbon as they are at reducing overall PM mass.

***In fact, EPA has reported that diesel PM filters reduce diesel PM by at least 90 percent, but can reduce black carbon by as much as 99 percent.***[105]

However, less stringent emission standards that do not require PM filters typically lead to the use of oxidation catalysts and engine combustion controls that do not reduce black carbon. These strategies tend to reduce the gaseous or soluble hydrocarbons adsorbed or attached to the particle, rather than the black carbon core (see Figure 6). Thus, the long-term approach to reducing both diesel black carbon and PM would be to implement diesel PM standards that are stringent enough to require PM filter technology in all diesel engines.

**It is worth noting that natural gas engines or electric vehicles meet these standards without filters (although the use of electric vehicles may produce upstream power plant emissions that emit black carbon). These benefits of alternative fuels and advanced vehicle technologies are worth exploring, but are beyond the scope of this report.

It is worth noting that not all combustion yields particles that follow this pattern. Particles from burning biomass contain much larger quantities of organic carbon, which has a cooling effect. As a result, reducing biomass burning will not yield as many black carbon benefits as reducing diesel PM. Because particles emitted from the transportation sector have the lowest ratio of organic carbon to black carbon of any major source, targeting these sources will deliver the greatest benefits, as illustrated in Table 3.

**Table 3: Ratio* of Organic Carbon (OC) to Black Carbon (BC) for a variety of emissions sources**

| Source Type | OC / BC Ratio |
|---|---|
| Transportation / Diesel Engines[106] | 1–2 |
| Industry[107] | 2 |
| Domestic / Residential[108] | 4 |
| Energy / Power[109] | 7 |
| Open Biomass Burning[110] | 9 |

*The lower the OC/BC ratio, the greater the warming effect the source has.

In sum, emissions reduction and mitigation strategies that focus on black carbon-rich sources like diesel engines will be most effective.[111]

## D. BLACK CARBON'S PUBLIC HEALTH IMPACTS

As noted above, strategies that reduce black carbon also reduce diesel PM, and the most effective strategies to reduce diesel PM also reduce black carbon. As a result, an effective black carbon reduction strategy will capture the health-related benefits of reducing diesel PM. This is of the utmost importance, since health experts, as noted earlier, have linked black carbon and PM to serious health risks.[112] What's more, the WHO has determined that outdoor air pollution, diesel exhaust, and particulate matter cause cancer.[113,114] This helps explain why outdoor PM is now the eighth leading cause of premature mortality in the world.[115] According to the WHO, 3.7 million people die prematurely from outdoor air pollution annually. Almost all of these premature deaths are attributable to PM.[116]

The WHO recently also studied the specific health effects of black carbon and found "sufficient evidence" of an association between black carbon exposure and negative health impacts.[117] The review of short-term epidemiological studies and long-term cohort studies showed that these health effects ranged from cardiopulmonary hospital admissions to cardiovascular mortality. The review states "that black carbon may not be a major directly toxic component of fine PM, but it may operate as a universal carrier of a wide variety of chemicals of varying toxicity to the lungs, the body's major defense cells and possibly the systemic blood circulation."[118] The report found that a "reduction in exposure to $PM_{2.5}$ containing black carbon and other-combustion-related PM material for which black carbon is an indirect indicator should lead to a reduction in the health effects associated with PM."[119] Additional studies are needed to further understand black carbon's role as a carrier of toxins, the types of toxins it carries, and the mechanisms by which these toxins are absorbed into the bloodstream and other parts of the human body.

## E. BLACK CARBON'S PUBLIC HEALTH IMPACTS IN LATIN AMERICA

There is insufficient information regarding black carbon's specific impacts in Latin America. However, the World Bank, in partnership with the International Cryosphere Climate Initiative, recently conducted a modeling study to determine the global impacts (such as sea level-rise) and health and crop benefits of reducing black carbon emissions.[120] The study targeted five cryospheres, one of which was the Andes, including portions of Argentina, Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela. To model the potential impacts of emissions reductions, the study used the modeled reduction measures outlined in Table 5.

**Table 4: Country-level Avoided Premature Mortality by Diesel Scenario[121]**

| COUNTRY | On-road Diesel (Euro-6/VI) | Off-road Diesel (Euro-6/VI) |
|---|---|---|
| Argentina | 700 | 300 |
| Bolivia | 0 | 0 |
| Brazil | 2,800 | 700 |
| Chile | 300 | 0 |
| Colombia | 200 | 100 |
| Ecuador | 100 | 0 |
| El Salvador | 100 | 0 |
| Guatemala | 300 | 0 |
| Honduras | 0 | 0 |
| Mexico | 2,100 | 1,000 |
| Nicaragua | 0 | 0 |
| Paraguay | 0 | 0 |
| Peru | 300 | 200 |
| Uruguay | 0 | 0 |
| Venezuela | 200 | 0 |

**Table 5: Modeled reduction measures for black carbon and methane emissions, based on the World Bank and the International Cryosphere Climate Initiative[122]**

| Emission | Source | Modeled Reduction Measure |
|---|---|---|
| **BLACK CARBON** | On-road Diesel | Diesel road vehicles comply with Euro 6/VI standards (including particle filters) |
| | Off-road Diesel | Diesel off-road vehicles comply with Euro 6/VI standards (including particle filters) |
| | Heating Biofuel | Replacing current residential wood burning stoves and boilers with pellet stoves and boilers |
| | Heating Coal | Replacing chunk coal with coal briquettes for residential household heating |
| | Cookstoves | Replacing current biofuel cookstoves with forced draft (fan-assisted) stoves or<br><br>Replacing current biofuel cookstoves with stoves using biogas or liquefied petroleum gas (LPG) |
| | Open Burning–<br>50 percent Biomass Burning | Reducing all open burning worldwide by 50% |
| | Flaring | Reducing black carbon emissions from gas flaring at oil fields to best practice levels |
| **METHANE** | Mining | Capturing methane or degasification prior to the mining process |
| | Oil and Gas Production | Capturing or re-injecting fugitive methane emissions, where feasible with re-use |
| | Oil and Gas Pipelines | Reduced leakage through improved monitoring and repair |
| | Landfills | Recycling, composting, and anaerobic digestion and methane capture for re-use |
| | Wastewater | Upgrade of treatment to include methane gas capture and overflow control |
| | Livestock | Anaerobic digesting and capturing methane |
| | Rice Paddies | Intermittent aeration: fields remain continuously flooded with only occasional exposure to air |

The modeled reduction measures for diesel engines—which assumed compliance with Euro 6/VI standards (see Appendix 3) as well as the use of DPFs—are most relevant.[123] By implementing these measures (outlined in Table 5) to reduce black carbon and methane emissions, the Andean region could avoid 27,000 premature deaths annually by reducing ambient outdoor air pollution. The country-specific benefits of the diesel scenarios are identified in Table 4. For all of South America, implementing these measures could increase its staple crops (wheat, rice, maize, and soybeans) by 2.6 metric tons annually.[124] To give a sense of scale, Brazil's soybean crop in the 2013–2014 growing season was 85 million metric tons.[125] Though the increase in staple crops would certainly generate benefits, they would not be as dramatic as the reduction in premature deaths. The World Bank's report recommends that observational studies be conducted in the Andean region to define the amount of black carbon reaching the glaciers and snow pack.[126]

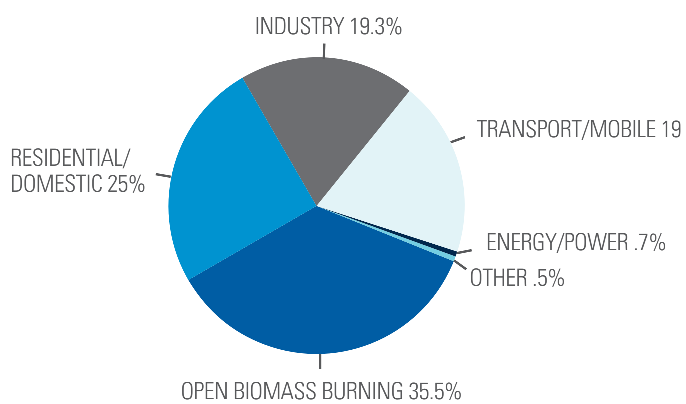
Santiago, Chile, has been the site for multiple black carbon emissions studies. Cakmak et al. conducted two different studies that found links between black carbon and all non-accidental respiratory admissions, respiratory mortality, cardiac mortality, and total mortality.[127, 128] The two studies identified that particulate air pollution from "motor vehicle exhaust had the greatest observed effect on mortality" and that "traffic combustion-related particulates had the strongest association with emergency department visits."[129, 130] The link between black carbon emissions and their sources—especially transportation—will be discussed in the following sections.

There is significant uncertainty surrounding the extent of health impacts from black carbon emissions in Latin America. This uncertainty stems from the lack of adequate and consistent data, illustrating the need for additional monitoring and study of black carbon emissions levels and their local and regional health impacts.

## F. SOURCES OF GLOBAL BLACK CARBON EMISSIONS

In 2000, almost 20 percent of global black carbon emissions came from the transportation sector, mostly from diesel engines, according to a 2010 global black carbon inventory created by Jean-Francois Lamarque and his colleagues at the National Center for Atmospheric Research.[131, 132] The Lamarque study was the first to provide a consistent methodology for comparing black carbon emissions in different regions of the world.[133, 134]

**Figure 7: Global BC emissions in 2000, by source[135]**




Source: adapted from Lamarque, J.F. et al. (2010)

In 2000, total global black carbon emissions were estimated at 7,600 gigagrams (about 8.4 million tons).[136] Figure 7 shows the breakout of these emissions by source.[137] Open biomass burning (including agricultural burning, prescribed burning, and wildfires) accounts for more than 35 percent of global black carbon emissions. However, this burning is not the most significant source of black carbon-related global warming, since the cooling effect from the large quantities of organic carbon released from open biomass burning offsets the warming effect of its black carbon emissions. Residential and domestic sources of black carbon (emitted from stoves that burn biomass, dung, or coal) accounted for more than a quarter of black carbon emissions.[138] These emissions are primarily associated with developing countries. Nearly two-thirds of the total black carbon emissions from residential and domestic sources are generated in China, India, and Western Africa (including Nigeria, Ivory Coast, and Ghana).[139] In Latin America, black carbon emissions from residential and domestic sources account for only 9 percent of total black carbon emissions.

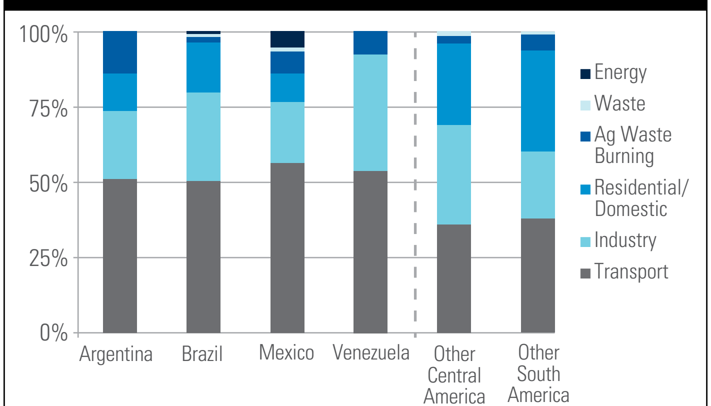
Diesel and other transportation sources, including on-highway and off-road vehicles, trains, ships and planes, emit high levels of black carbon with little to no organic carbon, resulting in a higher global warming potential than open biomass burning. In addition, transportation sources contribute significantly higher black carbon emissions than residential and domestic sources in developed countries. Thus, focusing on high-emitting diesel engines presents a very promising strategy to combat climate change while also addressing public health concerns.

## G. SOURCES OF BLACK CARBON EMISSIONS IN LATIN AMERICA

Latin American countries emit 12 percent of the world's black carbon emissions.[140] The Lamarque inventory analyzed four major Latin American countries (Argentina, Brazil, Mexico, and Venezuela) and consolidated the remaining nations into Central and South America. As illustrated in Figure 8, they found that transportation is the predominant source of anthropogenic black carbon emissions in Latin America, although there is some variation among the contributions of sources from country to country.[141, 142] Despite these variations, transportation is consistently higher than all other sectors—more than half of all black carbon emissions in the four profiled countries and roughly 37 percent in most of the other Central and South American countries.

Unfortunately, as Table 6 shows, this data set is likely to be incomplete, because Latin America lacks a uniform system of air quality monitoring.[143]

**Figure 8: Anthropogenic sources of black carbon emissions in Latin America in 2000[144]**




Source: adapted from Lamarque, J.F. et al. (2010).

## H. THE ROLE OF AIR QUALITY MONITORING

Developing the ability to effectively measure $PM_{2.5}$ and black carbon emissions is crucial to understanding the benefits of any emissions reduction strategy. Such a monitoring system is important to identify the source and type of emissions, to develop effective emissions reductions strategies and to quantify the emissions reductions and air quality benefits of any such strategies that are implemented.

For the most part, Latin American cities and countries do not have the level of monitoring infrastructure commonly found in the United States or Europe. At the time of our research, 10 of the 15 Latin American countries surveyed had monitors for $PM_{10}$. Only nine monitor for $PM_{2.5}$ emissions.[145, 146] In most cases, PM monitoring is limited to the capitals and/or the largest urban centers. There is also significant variability among the cities that monitor $PM_{2.5}$ both in the number of monitors and the extent of the monitoring.

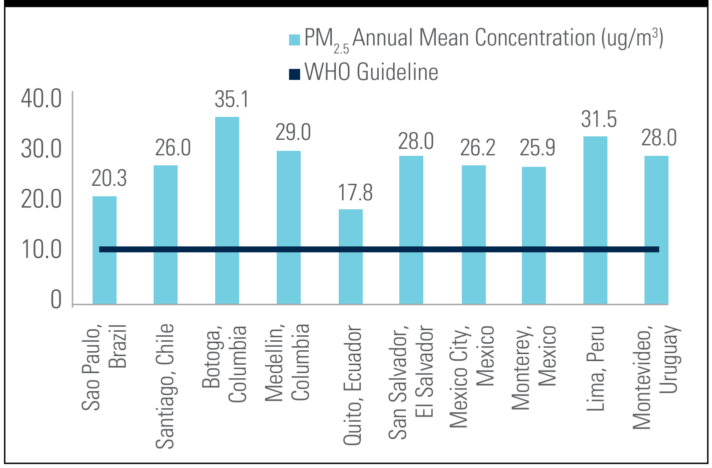
**Table 6: Air quality monitoring and geographic coverage in Latin American countries[147]**

| COUNTRY | Air Quality Monitors | Geographic Coverage |
|---|---|---|
| Argentina | $PM_{10}$ | Buenos Aires |
| Bolivia | $PM_{10}$ | 10 large cities |
| Brazil | $PM_{2.5}$ / $PM_{10}$ | Sao Paulo |
| Chile[112] | $PM_{2.5}$ / $PM_{10}$ | Santiago / Nationwide |
| Colombia | $PM_{2.5}$ / $PM_{10}$ | Nationwide (limited) |
| Ecuador | $PM_{2.5}$ / $PM_{10}$ | Quito and Cuenca |
| El Salvador | $PM_{2.5}$ / $PM_{10}$ | San Salvador |
| Guatemala | $PM_{2.5}$ | Nationwide (limited) |
| Honduras | None | None |
| Mexico | $PM_{2.5}$ / $PM_{10}$ | Mexico City and Monterrey ($PM_{2.5}$) / Nationwide ($PM_{10}$) |
| Nicaragua | None | None |
| Paraguay | None | None |
| Peru | $PM_{2.5}$, $PM_{10}$ and BC | Lima-Callao |
| Uruguay | $PM_{2.5}$ / $PM_{10}$ | Montevideo |
| Venezuela | Unknown | Unknown |

At the municipal level, Lima, Peru was the first city to monitor black carbon emissions. This project helped set the stage for a new generation of air quality monitoring that measures local black carbon emissions. Also, it is worth noting a recent study by the CCAC and the Centro Mario Molina Chile (CMMCh) that measured black carbon emissions from diesel engines used in public transportation and trucks in Santiago. The team found that Santiago could reduce black carbon emissions from public transit buses by as much as 70 percent by switching to an alternative fuel like natural gas.[148] They also found that Santiago could reduce black carbon emissions from its large fleet of heavy-duty trucks by 26 percent by using DPFs and replacing the oldest vehicles.[149]

The WHO guideline for $PM_{2.5}$ exposure is an annual mean concentration of 10 µg/m³.[150] Latin American $PM_{2.5}$ exposure data is limited to the major cities. As Figure 9 shows, each of the ten cities with available data had annual $PM_{2.5}$ concentrations well above the WHO guidelines.[151] The situation is especially critical in Bogotá and Lima, where the annual mean $PM_{2.5}$ concentrations are more than three times higher than the WHO guidelines.

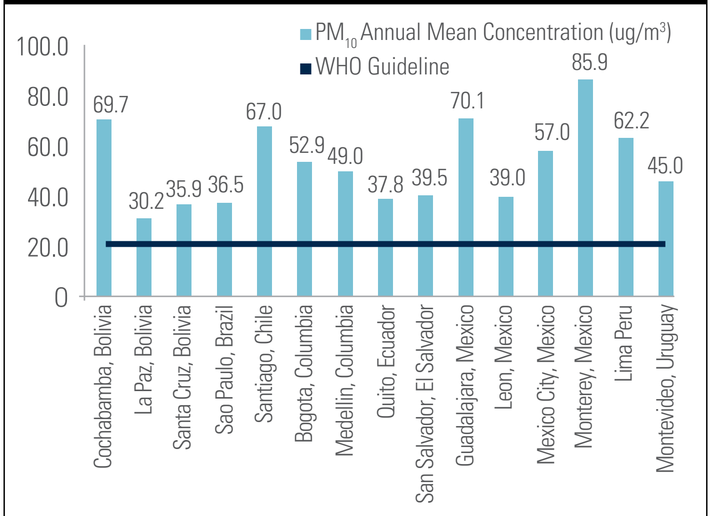
**Figure 9: $PM_{2.5}$ annual mean concentration levels (µg/m3) in select Latin American cities[152, 153, 154]**




For $PM_{10}$, the WHO has established an annual mean concentration guideline of 20 µg/m³.[155] As shown in Figure 10, in the 9 countries with available data, 15 cities exceeded the WHO guidelines.[156] Of greatest concern are the cities that exceed the WHO guideline by roughly threefold or more: Monterey, Mexico (85.9 µg/m³); Guadalajara, Mexico (70.1 µg/m³); Cochababma, Bolivia (69.7 µg/m³); Santiago (67.0 µg/m³); Lima (62.2 µg/m³); and Mexico City (57.0 µg/m³).

Although it is different from Latin America in many ways, China provides a potential guide for air quality monitoring in Latin America. China's air quality policies have benefited greatly from improved air quality monitoring. A simple PM monitor, installed in 2008 on the roof of the U.S. Embassy in Beijing, catalyzed a nationwide urban movement for

**Figure 10: $PM_{10}$ annual mean concentration levels (μg/m3) in select Latin American cities[157, 158]**




greater air pollution monitoring in China.[159, 160] Prior to this movement, only 119 county-level cities*** had monitoring capabilities, and there was very little publicly available data.[161] However, by the end of 2014, each of China's 338 cities will have air quality monitoring systems that generate publicly available data to be released hourly.[162]

This movement also led to the development of China's 2013 "Action Plan for Air Pollution Prevention and Control."[163] The Action Plan established an ambitious set of air pollution monitoring and control goals to be accomplished in the next five years. While the plan will improve air quality nationwide, it also pays special attention to the key regions of greater Beijing, the Yangtze River Delta (including Shanghai), and the Pearl River Delta (including Hong Kong, Guangzhou, and Shenzhen). Specifically, the plan sets forth to:

- Reduce the level of fine particulate matter ($PM_{2.5}$) in Beijing-Tianjin-Hebei Province, the Yangtze River Delta, and the Pearl River Delta by 25 percent, 20 percent, and 15 percent, respectively (against 2012 baseline)
- Reduce the annual concentration of fine particulate matter ($PM_{2.5}$) in Beijing to 60 μg/$m^3$
- Reduce the level of inhalable particulate matter in 338 cities by at least 10 percent (against 2012 baseline)[164]

To accomplish these goals, China's Action Plan outlines 10 measures, several of which are related to vehicle emissions control. One of China's first steps was to target "yellow label" vehicles, which fail to meet the Euro I standard (see Appendix 3), which was adopted in China in 1992.[165] China has committed to phasing out all "yellow label" vehicles registered prior to 2006 in the three key regions by 2015. By 2017, all "yellow label" vehicles will be phased out nationwide.[166] Along with targeting the oldest, dirtiest vehicles on the road, China is also focusing on reducing sulfur levels in its fuels and adopting advanced emissions standards, as shown in Table 7.

**Table 7: China's clean fuels and vehicles roadmap[167, 168]**

| YEAR | China Action Plan Fuel Quality Goal | Maximum Fuel Sulfur Level (ppm) |
|---|---|---|
| 2013 | China IV Gasoline adopted nationwide | 50 |
| 2014 | China IV Diesel adopted nationwide | 50 |
| 2015 | China V Gasoline and Diesel adopted in three key regions | 10 (ULSD) |
| 2017 | China V Gasoline and Diesel adopted nationwide | 10 (ULSD) |
| 2018+ | China VI++ to be adopted in three key regions | 10 (ULSD) |

***"County-level cities" are administrative units in China made up of large cities and the surrounding rural areas
++ The China VI standard for heavy-duty diesel engines will require the use of particulate filters, dramatically reducing black carbon emissions. (Source: ICCT, March 2013).

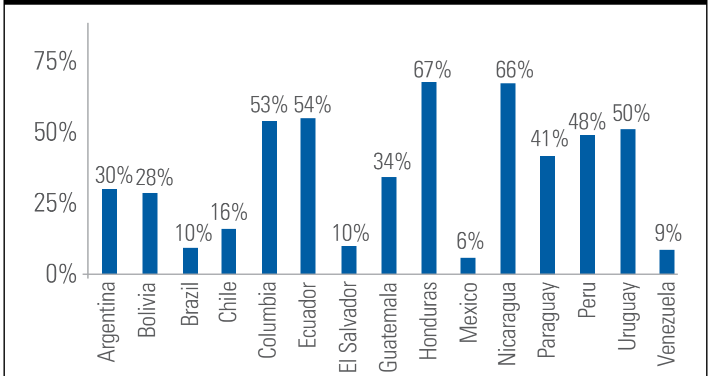
# III. USING A SYSTEMS APPROACH TO REDUCE BLACK CARBON AND DIESEL EMISSIONS IN LATIN AMERICA

## A. SUMMARY OF THE LATIN AMERICAN VEHICLE FLEET

The Latin American vehicle fleet was comprised of nearly 130 million registered vehicles in 2012.[169] In contrast, there were more than 250 million registered vehicles in the United States for the same year.[170] Almost half of the vehicles in Latin America are in Brazil (64 million), but Mexico (30 million) and Argentina (10 million) also have sizable vehicle fleets. Together, these countries are home to 80 percent of the vehicles in Latin America, suggesting that effective diesel black carbon strategies could focus on these three countries to have the maximum impact.

The Latin American fleet will certainly grow in the future if it continues the growth rate seen in recent years, as shown in Figure 11. This growth has been fastest in countries with smaller fleets—Honduras grew from 731,257 vehicles in 2007 to 1,219,453 vehicles in 2012 (a 67 percent increase) and Nicaragua grew from 360,961 vehicles in 2007 to approximately 600,000 vehicles in 2012 (a 66 percent increase).[171,172, 173, 174] These growth rates are especially impressive in comparison to the United States, which has seen a minimal growth rate of 3 percent in vehicles between 2007 and 2012.[175, 176]

**Figure 11: Growth rate of vehicle fleets in select Latin American countries[177, 178]**

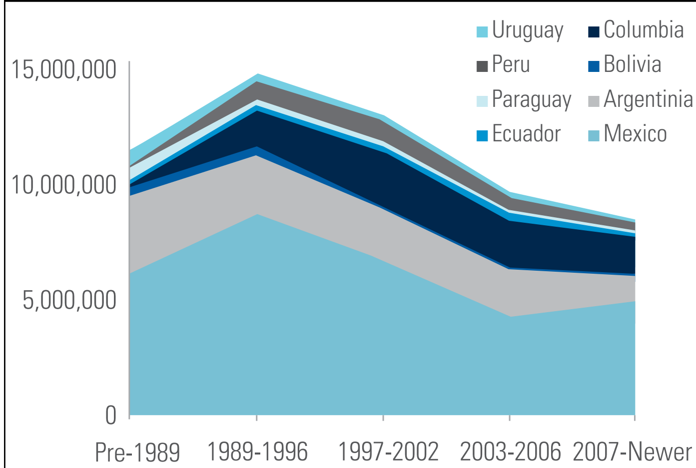



Sources: "Estadísticas Vehiculares" (2014), "Perfil de la Caracterización del Parque Vehicular de Guatemala Año Base 2010" (2014), and Mendoza Castro, R. (2013).

* Data was not available for all countries in all years for the 2007 to 2012 time period.

The increase of vehicles is partially the result of an increasing number of new vehicles, but it is also due to older vehicles remaining in service, as seen in Figure 12. This is especially true with heavy-duty diesel vehicles (e.g., trucks and buses), which often operate for 20 years or more.[179] Argentina, which has the third largest fleet in Latin America (behind Brazil and Mexico), has an extremely old fleet—in 2008, nearly 30 percent of its vehicles were more than 20 years old.[180, 181] Mexico's fleet shows a similar age distribution as nearly a quarter of registered vehicles are older than 20 years.[182]

**Figure 12: Number of vehicles by model year in select Latin American countries[183, 184, 185]**



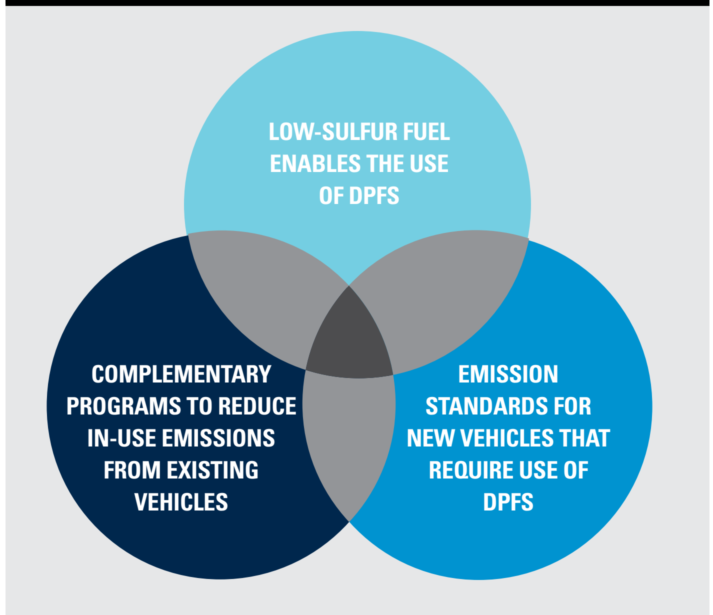

However, as the number of vehicles increases with economic development, more and more new vehicles will take up market share. Argentina's most recent estimates from 2012 show that 31 percent of its fleet is now less than five years old. This has been helped by an import ban on used vehicles, which allows only new vehicles to be imported to Argentina.[186] In Mexico, only 16 percent of the fleet is comprised of model year 2007 vehicles or newer. The lack of a similar import ban is likely the main reason for this difference.[187]

## B. OVERVIEW OF A SYSTEMS APPROACH TO REDUCE DIESEL AND BLACK CARBON EMISSIONS

The United States, Europe, and other countries have used a "systems approach" to dramatically reduce vehicle emissions in recent years. As shown in Figure 13, a systems approach involves a series of complementary strategies to rapidly and significantly reduce emissions. In a diesel-based systems approach, cleaner, low-sulfur fuels are introduced first, thereby enabling more effective emission control technologies that cannot be used with dirtier, high-sulfur fuels. Because these technologies are generally installed on new vehicles only (and perhaps a limited number of retrofitted vehicles), additional policies and programs to reduce in-use emissions from the existing fleet can be adopted to accelerate the entire fleet's emission reductions. A systems approach represents a quicker, broader, and more cost-effective way to reduce emissions than any one of the three prongs of the systems approach in isolation.[188, 189, 190]

The systems approach has been used to successfully reduce emissions from gasoline and diesel vehicles. For example, in the 1970s, countries began removing lead from gasoline, which enabled the use of catalytic converters, dramatically reducing carbon monoxide, hydrocarbon, and other toxic emissions.[191] The health benefits of this move were substantial. In the United States, the introduction of unleaded gasoline yielded a 77 percent decrease in blood lead levels, which led to $10 in health savings for every $1 invested.[192] Moreover, the introduction of the three-way catalytic converter (made possible with the introduction of unleaded gasoline) was critical to eliminating chronic carbon monoxide problems in high-traffic urban areas.

**Figure 13: The systems approach to reducing diesel emissions**




The systems approach has been used to reduce diesel emissions successfully in the United States, Europe, Japan, and other countries. In this diesel example, reducing sulfur levels in diesel fuel is the first step. Reducing sulfur to ultra-low levels (so-called ultra-low sulfur diesel [ULSD], which has been capped at 10 ppm and 15 ppm in Europe and the United States, respectively) enables the use of diesel PM filters, which reduce diesel PM and black carbon emissions by more than 90 percent. ULSD is a critical first step, because sulfur damages the catalytic material in the substrate of the diesel PM filter that is critical to its successful emissions reductions. It is important for policymakers to understand that ULSD must be in place before the filters are introduced.

In the United States, the EPA required the nationwide introduction of ULSD fuel (capped at 15 ppm) for highway diesel use in late 2006, followed by stringent vehicle emissions standards for new diesel engines in 2007 and 2010.[193] Similar rules were then implemented for construction, agricultural, and industrial diesel engines, as well as locomotives and marine diesel engines.[194] The EPA and several states then adopted complementary strategies for the existing vehicles to accelerate overall emissions reductions. These strategies included federal and state funding for new diesel engine purchases, retrofits of older engines, and incentive programs that targeted the oldest and dirtiest diesel trucks and buses in specific sectors for scrappage or retrofits (e.g., port drayage fleets, school buses, and public transit buses).

In the United States, implementing this systems approach will eliminate 380,000 tons of PM, 7 million tons of NOx, and 51,300 premature deaths annually by 2030.[195, 196, 197, 198] The health and other cost savings are dramatic—more than $290 billion dollars saved annually by 2030.[199] Indeed, these programs were found to be the most cost-effective transportation programs of the past 20 years—every dollar spent to upgrade refineries, develop and manufacture new emission control technologies, and otherwise implement these rules will yield at least $19 in health benefits.[200] The black carbon benefits of these regulations will be similarly impressive. By 2030, these regulations are projected to decrease mobile source black carbon emissions by 86 percent.[201]

The EU has followed a comparable pathway toward establishing a systems approach to reduce emissions from diesel vehicles. From 1996 to 2009, a series of EU Directives ratcheted down the sulfur levels in diesel fuel from 500 ppm to 10 ppm for highway vehicles.[202] By 2011, nonroad vehicles were required to use the 10 ppm sulfur fuel.[203] The EU has also instituted emissions standards regulating cars and light trucks, heavy-duty truck and bus engines, and nonroad diesel engines. These standards, discussed more completely in Appendix 3, have resulted in NOx reductions of 95–98 percent and PM reductions of 97–98 percent for new heavy-duty diesel engines. Finally, the EU has implemented a series of programs targeting the emissions from its existing vehicle fleets, including Low Emissions Zones (see Section III.C.iii ), diesel retrofit programs, and green freight programs.[204, 205]

## C. APPLYING THE SYSTEMS APPROACH IN LATIN AMERICA

To reduce Latin America's black carbon emissions while dramatically reducing PM emissions from the transportation sector, Latin American countries can implement a systems approach to reduce diesel emissions. In short, by switching to ultra-low sulfur diesel fuels, countries could introduce diesel particulate filters to eliminate more than 90 percent of the PM and black carbon from today's diesel engines. Because these filters would be used mostly in new vehicles, countries could accelerate their emissions reductions by adopting additional strategies to reduce emissions from all in-use vehicles.

### i. Cleaner, Ultra-Low Sulfur Diesel Fuels

As mentioned above, the availability and widespread use of ultra-low sulfur fuel is a critical prerequisite to control black carbon emissions from transportation in Latin America.[206] As seen in Figure 14, reducing sulfur levels in diesel fuel reduces the sulfate portion of PM emissions—from all vehicles—in direct proportion to the sulfur reduction in the fuel. However, unless sulfur levels are reduced to ultra-low levels (i.e., below 50 ppm) and diesel particulate filters are used, black carbon emissions will not be reduced at the same time.

Figure 14, originally developed to show PM reductions at different sulfur levels by the International Council on Clean Transportation (ICCT), illustrates the role of reducing fuel sulfur in reducing both PM and black carbon emissions. At roughly 500 ppm, diesel oxidation catalysts become widely available. These catalysts reduce PM by 15–30 percent, but do not reduce black carbon because they reduce only the adsorbed or gaseous (i.e., "vapor-phase") hydrocarbon component of the particle. In order to reduce black carbon from diesel combustion, ULSD levels that enable diesel PM filters are necessary. It bears repeating that particulate filters will *only* work with ULSD fuel. With sulfur levels of roughly 50 ppm, filters can be used to reduce black carbon and particulate by approximately 75 percent. When sulfur levels are reduced to the 10–15 ppm levels, PM and black carbon

**Figure 14: Potential PM and black carbon reductions at different fuel sulfur levels (Graphic provided by ICCT)**

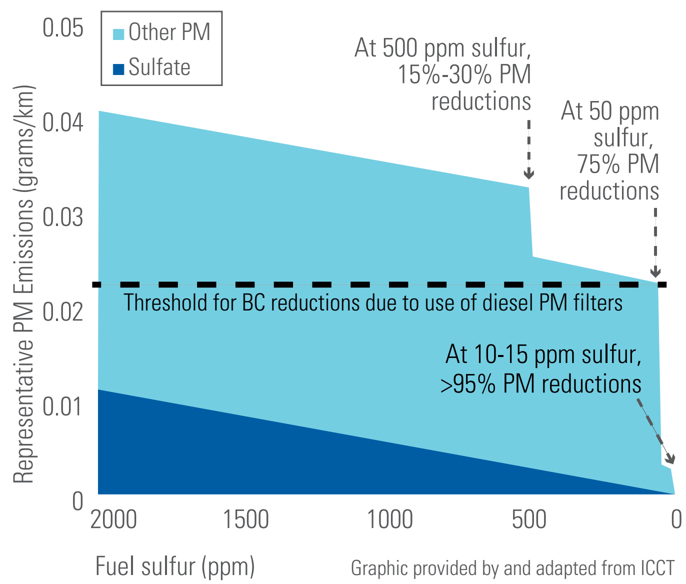
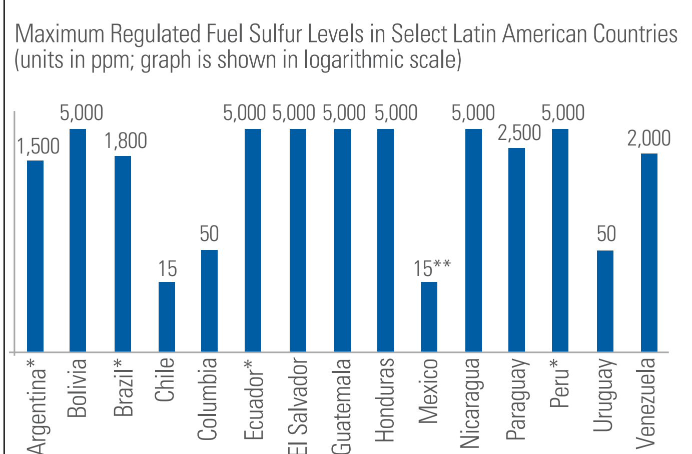



**Figure 15: Maximum sulfur levels in diesel fuel[207, 208]**




* Some cities within this country have lower fuel sulfur levels, as shown in Table 6 below. For instance, Ecuador's Quito and Cuenca have limits of 500 ppm.

Note: Although Mexico adopted a ULSD requirement in 2006, PEMEX has not implemented the necessary refinery upgrades to comply. At present, ULSD is available only in Mexico City, Guadalajara, Monterrey and the U.S./Mexico border zone.

Source: Mendoza Castro, R. (2013) and UNEP (2014) emissions can be reduced by more than 90 percent.[209] In sum, achieving ultra-low sulfur levels is the critical step to achieving the black carbon emissions reductions benefits of the systems approach.

As shown in Figure 15, allowable sulfur levels in diesel fuel vary greatly across Latin America.[210] Chile, Colombia, Mexico, and Uruguay have each taken significant steps to reduce their sulfur levels to ULSD levels. However, many countries continue to use diesel fuel that contains more than 1,500 ppm or even more than 5,000 ppm.[211] In a number of countries, the largest cities have lower-sulfur fuels than the rest of the country, as shown in Table 8. Cities in Brazil, Mexico, and Peru that have implemented ULSD programs can begin to implement clean bus and other local programs to reduce diesel PM and black carbon simultaneously.

It is worth noting that Mexico adopted an ultra-low sulfur diesel rule in 2006 that should have led to the national use of ULSD by 2009. To date, Petróleos Mexicanos (PEMEX) has not made the necessary refinery investments to implement this rule. Mexico City, Guadalajara, Monterrey, and the United States/Mexico border zone have ULSD, but the rest of the country continues to use 300 to 500 ppm sulfur diesel fuel. Mexico's Peña Nieto government has signaled its desire to update this rule in 2014, which would lead to a national roll-out of ULSD in the next few years. Nevertheless, no proposal has been released to the public at the time of this report.

Many national oil companies are hesitant to invest in the refinery upgrades necessary to desulfurize their fuels because of cost issues. In some cases, public-private partnerships have helped create a shared commitment to an integrated fuels and vehicles program at the municipal level. Peru provides a good case study for this phenomenon. In Lima and Callao, public-private partnerships have been used to successfully implement ULSD fuel, more stringent local emission standards for public fleets (Euro IV instead of the national standard of Euro III, see Appendix 3), and a robust air quality monitoring program that measures black carbon, $PM_{2.5}$, and $PM_{10}$ (see Appendix 4). At the national level, though, Peru continues to rely on diesel fuels with sulfur levels as high as 5,000 ppm fuel sulfur levels due to the lack of widespread availability of ULSD. This has been largely attributable to the role of the national oil company, PeruPetro, which has only recently begun to invest in updating the country's refining capabilities, including a recent project to upgrade the Talara refinery to produce 50 ppm fuel.[212]

**Table 8: Maximum sulfur levels in diesel fuel in selected cities[213]**

| COUNTRY | Cities / Programs | Maximum Sulfur Levels (ppm) |
|---|---|---|
| Argentina | Buenos Aires, Rosario, Mar del Plata and Bahía Blanca | 500 |
| Brazil | Metropolitan areas<br>Public Transport Buses | 500<br>50 |
| Ecuador | Quito and Cuenca | 500 |
| Mexico | Mexico City, Guadalajara and Monterrey | 15 |
| Peru | Lima and Callao | 15 |

### *The Role of Fuel Imports and Domestic Refineries on Reducing Sulfur Levels in Latin American Fuels*

A country's fuel source can play an important role in reducing sulfur levels in its diesel fuel. Generally, countries have two options: import ULSD fuel from other countries that produce it, or ensure that a domestic refinery is able to produce ULSD, often through upgrading existing refineries or building a new refinery altogether. Of the two, it is easier to reduce sulfur levels in diesel fuel in countries that import their fuels. Indeed, one key lesson from the global elimination of leaded gasoline was that countries that imported their fuel switched to unleaded gasoline quickly—because all they had to do was change the type of fuel they purchased.

In contrast, countries that refined their own fuels had to upgrade their refineries before switching to unleaded fuels, an expensive and time-consuming process. In countries with domestic refining capacity, state-owned, national oil companies (NOCs) were among the last to remove lead from gasoline, in part because they were typically insulated from public pressure. They were also less efficiently operated, generated poorer financial performance, and had less interest in competing in international markets than publicly-owned oil companies. Indeed, because of their governmental ownership, NOCs typically have to meet many policy, labor, and other objectives well beyond merely producing and selling petroleum products.

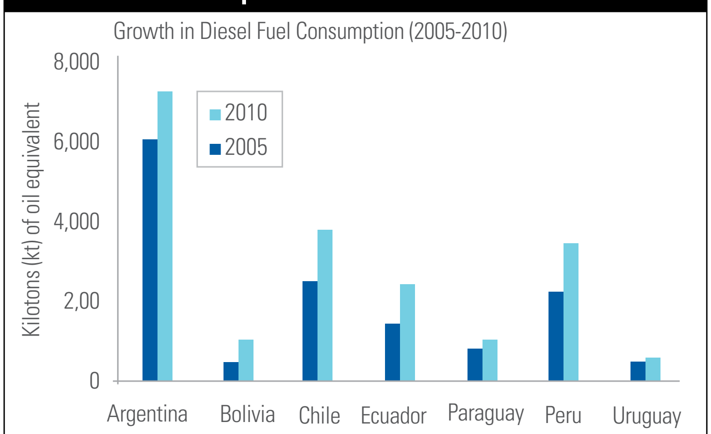
Countries with NOCs that want to reduce their sulfur levels are likely to have the same experience, and will have to develop strong regulatory or incentive programs to ensure the desulfurization of their domestic refineries and fuel supplies. In Latin America, many countries have large NOCs, including Brazil's Petrobras, Mexico's PEMEX, Venezuela's

PDVSA, and Colombia's Ecopetrol.[214] Relative to private oil companies, NOCs in Latin America generally have lower labor and capital efficiency, less profitability, and a much smaller percentage of upstream reserves than comparable publicly-owned or private oil companies.[215] This has led to significant delays in upgrades and planning in the NOC refineries of Colombia, Ecuador, Mexico, Nicaragua, Peru, and Uruguay.[216, 217, 218]

Importing low-sulfur diesel from the United States[§] or other countries may provide a temporary pathway for Latin American countries to meet low-sulfur or ultra-low sulfur fuel demand. This has been the case in Mexico, where PEMEX imports ULSD from the United States for sale and use in Mexico City, Guadalajara, Monterey, and the United States/Mexico border region.[219]

Indeed, many Latin American countries import diesel fuel for internal consumption. One reason imports are needed is because demand for diesel fuel has grown considerably in the last decade, as seen in Figure 16. In these countries, local production has been unable to keep up with demand even though they may have their own refineries. Several countries, including Argentina, Colombia, Ecuador, Mexico, Peru, and Uruguay, have plans for new refineries or refinery upgrades to enable low sulfur diesel production and expand diesel production capacity overall.[220]

**Figure 16: Diesel fuel's increasing demand from road consumption in Latin America[221, 222]**




Source: Mendoza Castro, R. (2013) and The World Bank (2014)

These refinery upgrade projects can be a cost-effective opportunity to install the necessary equipment and infrastructure to produce ULSD. This is because many costs of the desulfurization projects can be shared with the larger ongoing capital projects. Ecuador's largest refinery, Esmereldas, is receiving a new catalyzer that will enable the production of 250 ppm fuels,[223] and a new desulfurization plant at Peru's Talara refinery will allow for production of 50 ppm sulfur fuels.[224] In each case, these desulfurization investments are part of a larger refinery upgrade and should create more cost-effective ways to reduce sulfur than stand-alone investments.

Changing international markets for fuel plays a key role in this issue. Venezuela, once the primary source of diesel across the entire Latin American region, is still the leading provider for Bolivia, Ecuador, Nicaragua, Paraguay, and Uruguay.[225] The United States has gained market share and now plays a leading role in El Salvador, Guatemala, and Honduras, while gaining ground in Argentina and Colombia.[226] This shift towards American imports creates an opportunity for these countries to secure ultra-low or low sulfur diesel fuel because the United States already produces it in large quantities while Venezuela does not. Colombia is already importing low-sulfur fuel from the United States.[227] This is an ever-changing situation that should be watched.

### ii. Emissions Standards that Effectively Require Diesel Particulate Filters

Once ultra-low sulfur fuels are in place (i.e., capping sulfur at no more than 50 ppm, but ideally at no more than 10-15 ppm), emissions standards stringent enough to effectively require the use of diesel particulate filters (DPFs) become feasible. Indeed, the stringent emissions standards used in the United States and elsewhere effectively require the use of DPFs or alternative fuels like natural gas—both of which emit virtually no black carbon.

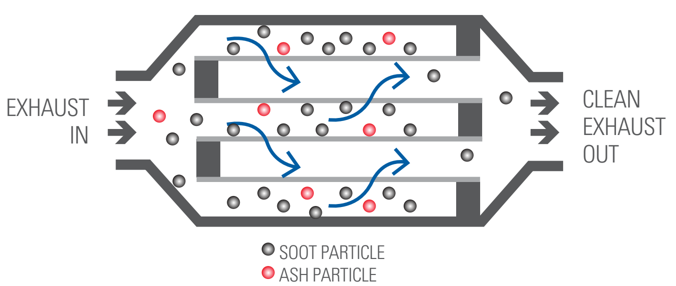
When matched with ULSD, DPFs can reduce PM by more than 90 percent. Because DPFs physically filter the particles, they trap diesel particles of any size effectively. Thus, using DPFs reduces black carbon from diesel exhaust as effectively as they reduce overall PM. It is important to note that DPFs only operate efficiently and effectively when ULSD is used—higher sulfur fuels will reduce the DPF's efficiency and eventually clog and disable it.

More specifically, DPFs operate by filtering the exhaust exiting the engine through a porous filter, as shown in Figure 17.[228] (In contrast, other vehicle emission control technologies use catalysts, which reduce vehicle emissions

[§] We specifically suggest the United States as an option solely due to its proximity to many Latin America countries.

through a series of chemical reactions in the exhaust, rather than by physical filtration.) Because black carbon exits the engine in solid particle form, DPFs trap black carbon emissions as they approach the tailpipe. In fact, the most effective DPFs reduce black carbon by up to 99 percent when combined with ULSD.

**Figure 17: Schematic of a diesel particulate filter (DPF)[229]**




Source: adapted from Lamarque, J.F. et al. (2010).

In order to ensure that DPFs are used, governments should set vehicle emissions standards at the levels of the U.S. EPA's 2007 or 2010 U.S. standards, or follow Europe's approach of combining its Euro VI standard and its newly-implemented particle number limit (which limits the number of ultrafine particles and was implemented in January 2013; see Appendix 3). Either of these approaches would lead engine companies to sell diesel engines equipped with DPFs or comparably effective equipment. It could also lead to increased use of natural gas-fueled engines, because natural gas-fueled engines meet all of these standards and limits without a DPF. These standards are shown in Figure 18.

As shown in Table 9, diesel engine emissions standards in Latin America lag far behind those in the United States or Europe. Guatemala and Honduras lack emissions standards altogether, Nicaragua has pending regulations, and Paraguay fails to enforce its emissions standards.[230] As such, these countries lack any enforceable plans or programs to reduce diesel PM or black carbon emissions in the near term.

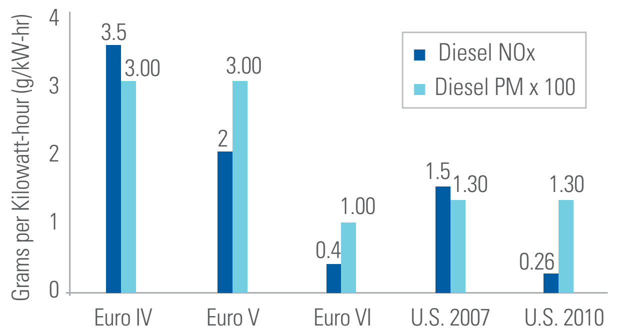
Several countries have implemented stringent emissions standards, but none currently require DPFs or comparable equipment. Adopted in 2008, Brazil's PROCONVE P-7 standards are based on Euro V regulations and were implemented nationwide in 2012 for all new heavy-duty engines.[231] This standard reduced PM emissions from heavy-duty engines by more than 90 percent, as compared to the PROCONVE P-3 standards, but will not require DPFs.

Mexico requires heavy-duty engines to meet standards that are comparable to the EPA 2004 or Euro IV standards and has signaled its intention to adopt and implement the latest EPA or Euro standards. However, this is a debate that has continued in Mexico since it adopted a ULSD standard in 2006. Argentina and Chile require that all new light and heavy-duty vehicles comply with Euro V standards as of October 2014. Some countries, such as Bolivia, Colombia, and Peru, have not established stringent national emissions standards, but are home to municipal programs that are reducing emissions from their public transit fleets. Nevertheless, only Santiago's urban bus program will require DPFs or natural gas to be used.

**Table 9: Emissions standards for new vehicles in Latin America**

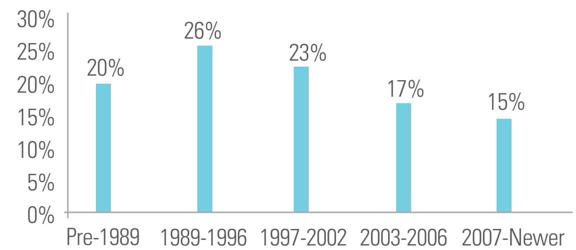
| COUNTRY | Emissions Standards for New Vehicles[232] |
|---|---|
| Argentina | LDV, HDV and Buses: Euro V[233] |
| Bolivia | Buses: Euro III (La Paz)[234] |
| Brazil[235] | LDV: Euro IV<br>HDV: Euro V |
| Chile[236] | LDV and MDV: Euro V<br>HDV: Euro V (from Sept. 2014)<br>Buses: U.S. 2004 NOx / U.S. 2007 PM |
| Colombia | LDV: Euro IV<br>HDV: Euro IV (from 2015)<br>Buses: Euro II |
| Ecuador | LDV: Euro I / U.S. 1987<br>HDV: Euro II / U.S. 1994 |
| El Salvador | LDV: Euro I / U.S. 1987 |
| Guatemala | None |
| Honduras | None |
| Mexico[237] | All: Euro IV / U.S. 2004 |
| Nicaragua | None |
| Paraguay | None enforced |
| Peru | LDV and HDV: Euro III<br>Buses: Euro IV (Lima) |
| Uruguay | All: Euro III |
| Venezuela | HDV: Euro I / U.S. 1991[238] |

**Figure 18: European and EPA heavy-duty engine emission standards (transient cycle)**




As of 1/1/2013, Euro VI also includes a 6.0 x $10^{11}$ particle number limit

**Figure 19: Age distribution of vehicles in Argentina, Bolivia, Colombia, Ecuador, Mexico, Paraguay, Peru, and Uruguay (2010)[242, 243]**




Source: Mendoza Castro, R. (2013) and Davis / Khan, UC Berkeley (2010)

### iii. Complementary Programs to Reduce Emissions from the Existing Fleet of Diesel Vehicles

There are many programs for existing fleets that can complement the clean fuels and vehicle emission standards components of the systems approach. Some complementary programs focus on retrofitting DPFs onto existing fleets of vehicles, while others focus on accelerating the retirement of the oldest and dirtiest of vehicles (also known as "scrappage") or incentives to use the cleanest vehicles (e.g., the Low-Emission Zones of Europe). Still others focus on reducing the overall amount of driving through better transit systems.

Diesel engines have long lifetimes and can remain in use for decades. Because older diesel vehicles do not have advanced emission controls, they can generate high levels of dirty emissions for many years. By taking steps to either retrofit or retire these older engines, or reduce their use, policymakers can reduce emissions from the dirtiest diesels in their midst.

Older vehicles have been a significant problem throughout Latin America, as shown in Figure 19. In countries with rapidly growing vehicle fleets, the average age of the vehicle fleet is decreasing—because of the growth in new vehicles, not because of rapid retirements of older vehicles. For example, in 2008, nearly 30 percent of all vehicles in Argentina were more than 20 years old.[239, 240]

By 2012, 31 percent of its fleet was less than 5 years old. A closer analysis shows that the decline in the average age of an Argentine car is due almost entirely to the increased number of new cars and a ban on importing used vehicles.[241]

**Retrofit programs:** Retrofit programs are typically incentive-based and focused on large, centrally fueled and maintained fleets like urban transit buses. These programs have successfully reduced emissions from targeted fleets. In the United States, the National Clean Diesel Campaign (NCDC) and SmartWay® Program have successfully provided financial and other incentives to install emissions control technologies, idle reduction technologies, and aerodynamic devices on vehicles.[244, 245] Several Latin American countries have successfully adapted these models to their cities as well. Mexico's Transporte Limpio is a nationwide, voluntary program initiated in 2010 to increase the efficiency of freight and passenger transport and reduce its cost and emissions.[246] Along with training drivers in economically and environmentally friendly practices, Transporte Limpio offers incentives for emissions control devices and alternative fuel systems. As of December 2013, 148 companies operating 18,722 trucks have participated in the program.[247] A pilot program in Mexico City successfully installed DPFs on city buses, significantly reducing black carbon emissions.[248] This program was a high-altitude demonstration of the scrappage, retrofit, and replacement strategy first demonstrated on a large scale in the New York City Transit fleet from 1995–2006. (The New York City approach is discussed in more detail in Appendix 2.) As discussed above, more than 2,000 of Santiago's city buses have been retrofitted with DPFs, thanks in part to an incentive-based pilot program that grew into a citywide requirement.[249]

**Scrappage programs:** Scrappage programs are designed to incentivize owners of very old vehicles to retire vehicles that are likely to have high emissions. In Colombia, the Programa de Reposición de Vehículos de Carga was implemented in 2004 to retire up to 60,000 trucks and highway tractors, reduce the age of the transport fleet, and avoid the over-population of vehicles.[250] From 2008–2012, the program scrapped nearly 6,000 vehicles and estimates another 2,600 were scrapped in 2013. The Colombian Ministry of Transport, which moderates the program and assigns funding, plans to fund the program with $150 million annually through 2017. This is estimated to fund the scrappage of an additional 20,000 trucks and highway tractors by then.[251]

Chile has also implemented a successful scrappage program, known as "Cambia tu camion."[252] Chile's transport sector accounts for more than one-third of the country's total energy consumption and the country imports diesel fuel as an energy source.[253] The confluence of those two factors created the demand for a cost-effective scrappage program. Beginning as a pilot in 2009, the program was administered by the Chilean Energy Efficiency Agency, a public-private foundation composed of the Ministry of Energy and the Ministry of Economy, Public Works, and Tourism (SERCOTEC).[254] Fleet owners paid between $8,000 and $24,000 for each truck scrapped. (The payments varied according to the size of the truck.) The pilot led to the retirement of more than 300 vehicles before the 2010 earthquake, when its funds were diverted to emergency response measures. In 2013, the program was re-funded, offering $6 million to replace vehicles that are at least 25 years old.[255]

The United States has also experimented with scrappage programs. In 2009, the "Cash-for-Clunkers" program was initiated to replace the oldest, least efficient vehicles with more modern, fuel-efficient vehicles.[256] Unfortunately, studies reported that nearly half of program expenditures went to customers who would have purchased a new vehicle anyway, with or without the program. In essence, the Cash-for-Clunkers program created a short-term effect on purchasing patterns but did not impact long-term car ownership patterns or environmental impacts.[257]

The program generated two important lessons: (1) successful vehicle replacement and scrappage programs need to isolate car owners who do not intend to replace their cars, and (2) programs need to set specific age thresholds to ensure the oldest, dirtiest vehicles are phased out first.[258]

**Bus Rapid Transit (BRT) programs:** Latin American cities have taken the lead in implementing bus rapid transit (BRT) systems. With more than 45 BRT systems, Latin America accounts for 63.6 percent of BRT ridership worldwide.[259]The best of these systems include dedicated bus lanes (usually in the center of the road), off-bus fare payments and bus-level boarding, priorities at intersections, and other features to hasten passenger boarding and disembarking and allow buses to travel quickly through often-congested cities. In Curitiba, Brazil, the world's first BRT system was introduced in 1974 and has led to mixed-use, high-density development

## Case Study:

### Mexico City's Bus Rapid Transit Program

Mexico City's air pollution exceeds national standards for ground-level ozone and particulate matter nearly 10 months out of the year. In the mid-2000s, heavy-duty diesel vehicles contributed more than 50 percent of the fine PM in the air, even though they comprised only 5.5 percent of the entire fleet.

City buses played an especially important role in Mexico City's particulate matter pollution. Until 2005, the city relied heavily on a dispersed system of microbuses, typically operating with older, dirty diesel engines without any emissions reduction equipment. These microbuses were inefficient and unreliable heavy polluters.

To initiate the project, government agencies partnered with private companies and garnered the financial support of the World Bank as well as the Shell, Caterpillar, and Hewlett Foundations. City officials thus successfully inaugurated Mexico City's first "bus rapid transit" (BRT) system, with a dedicated bus lane on the Avenida Insurgentes. Today, the "Metrobus" system is comprised of five lines that travel throughout the city.

Metrobus has reduced pollution and made it easier for millions of Mexico City residents and visitors to move around the chronically congested city. Indeed, average travel times have decreased by 40 percent for the 850,000 riders who use it on a typical day. Because of its cleaner fuels and engines, Metrobus eliminates 2.8 tons of PM every year. Because of the relationship of black carbon and PM, it can be safely assumed that the transition to Metrobuses has significantly reduced the bus sector's black carbon emissions.

Sources: EMBARQ's "Mexico City Metrobus" and Excelsion's "Mancera anuncia apertura de dos líneas del Metrobús"

## KEY LESSONS LEARNED FROM SCRAPPAGE PROGRAMS

To prevent the recycling of the older vehicles back into the vehicle market, the program implementers must take steps to ensure that the older vehicles are actually destroyed before the incentives are paid, and that the incentives will not simply be used to buy a newer vehicle.

Scrappage programs should set specific age thresholds to ensure the oldest, dirtiest vehicles are phased out first.

Transparency regarding payments, administrative processes, and programmatic requirements is critical to building credibility among vehicle owners.

Administrative and documentation requirements should be designed to avoid delaying program implementation, payment verification, or new vehicle delivery. Lack of credit is one of the main reasons applicants cannot qualify for scrappage programs, especially for smaller fleet owners or operators, so steps need to be taken to overcome this barrier.

More robust financing and developed loan guarantees will be required to move any scrappage program from pilot to full-scale implementation.

Sources: Mexico Freight Study (2013), Cash-for-Clunkers (2011)

along the five main corridors. Today, 85 percent of Curitiba's population uses the system and it has inspired transit and urban planners around the world.[260] More recently, Mexico City has adapted the Curitiba model for its BRT system, which operates within Latin America's largest city. Case The Mexico City Case Study on page 27 above discusses Mexico City's successful replacement of its microbuses with a BRT system that attracts an average of 850,000 riders and eliminates 2.8 tons of PM annually.

**Low Emissions Zones:**[261] Low Emission Zones (LEZs) are specific areas, either roadways or urban centers, that deny access to the most polluting vehicles. Since the first LEZ was created in Stockholm in 1996, more than 400 LEZs have been implemented in 13 European countries.[262, 263] Currently, all LEZs apply to vehicles more than 3.5 tons gross vehicle weight (GVW), though an increasing number of areas are targeting both larger buses and coaches (more than 5 tons GVW) as well as smaller vans, cars, and motorcycles.[264] Restrictions are usually based on a vehicle's emissions standard, though certain LEZs only allow heavy-duty vehicles that have DPFs. For example, all German vehicles—both light- and heavy-duty—are required to have particulate filters to operate in an LEZ.[265] Denmark has instituted a national LEZ program that requires that vehicles over 3.5 tons retrofit their engines with a particulate filter or use at least a Euro 4 engine.[266]

London's LEZ is a good example of a successful program. The entire Greater London area was designated as an LEZ in early 2008 and requires that all trucks (above 3.5 tons GVW) and buses (above 5 tons GVW) meet Euro IV standards for PM emissions.[267] Starting in 2015, the LEZ will require that all Transport for London (TfL) buses meet stricter NOx standards through adoption of Euro VI and hybrid buses along with installation of SCR on older, Euro III buses.[268, 269, 270] The LEZ in Greater London is enforced through the use of fixed and mobile cameras, which scan license plates and check them against the registration database. If a vehicle violates LEZ requirements, penalties ranging from £500 to £1000 ($854–$1709) are charged.[271***] TfL has led the effort to purchase the cleanest vehicles available by ordering 1,200 hybrid buses while also phasing out or retrofitting an additional 1,800 buses.[272]

Officials are also planning an LEZ for downtown Santiago, called the "Zona Verde para el Transporte en Santiago." If implemented, this would be the first LEZ in Latin America. The LEZ will cover about 2 square kilometers in the heart of the city and is based on four main strategies: (1) promoting zero and low emission vehicles, (2) using low-carbon buses for public transport, (3) promoting bicycles, and (4) and traffic re-design and management. Project designers expect the plan to reduce $CO_2$ by 13,800 tons in 10 years, and to reduce $PM_{2.5}$ by at least 0.62 tons and NOx by 7.7 tons over the same period. To finance the project, the Chilean government has submitted it as a Nationally Appropriate Mitigation Action (NAMA), making it eligible for international funding. The total projected cost of the LEZ is $17.7 million, with 70 percent coming from NAMA funds and 30 percent coming from Chilean sources.[273]

***Conversions were calculated on July 18, 2014 using the ration 1 British Pound Sterling : 1.71 U.S. Dollar.

# IV. CONCLUSIONS AND RECOMMENDATIONS

Reducing short-lived climate pollutants like black carbon, methane, tropospheric ozone, and hydrofluorocarbons is becoming an increasingly important component of national and international efforts to fight global warming. Because of their short lifetimes, reducing these emissions can have almost immediate climate benefits. Black carbon, a byproduct of incomplete combustion, is one of the most important SLCPs. Recent studies have concluded that black carbon is the second most powerful climate warming pollutant after carbon dioxide.[274, 275]

Transportation—especially diesel vehicles—is one of the largest sources of black carbon emissions in Latin America and globally. This is a function of two factors: (1) the high concentration of black carbon within the carbon core of a typical diesel particle and (2) the large and growing emissions of PM from Latin America's increasing number of diesel vehicles. Indeed, while open biomass burning is the leading source of black carbon emissions globally, its combustion produces great quantities of organic matter, which offsets the warming potential of the black carbon emitted by this burning.[276]

Black carbon may be both toxic itself and a carrier of other toxins. A recent study by the WHO showed an association between black carbon exposure and negative health impacts, ranging from cardiopulmonary hospital admissions to premature mortality.[277] Beyond its toxicity, black carbon may also function as a carrier of toxins, delivering a wide variety of chemicals to the lungs, the body's major defense cells, or the cardiovascular system.[278] Thus, as the WHO report concluded, a "reduction in exposure to $PM_{2.5}$ containing black carbon and other-combustion-related PM material for which black carbon is an indirect indicator should lead to a reduction in the health effects associated with PM."[279]

***Simply put, reducing black carbon in the transport sector is a win-win strategy to address both climate change and public health concerns.***

The evidence clearly indicates that black carbon has widespread and dramatic impacts on Latin America—melting glaciers in the Andes and Patagonia, declining moisture in the Amazon Basin, and premature deaths from outdoor air pollution. Even though additional black carbon-focused health and climate studies are needed in Latin America to deepen our understanding of regional and local climate and health impacts, we know enough to strongly recommend that policymakers act now. Because black carbon is emitted as a component of PM, many strategies to reduce diesel PM in Latin America will effectively reduce black carbon emissions as well. These strategies fall into three main categories:

- **Clean fuels:** The top priority for Latin America is to ensure widespread adoption of fuel standards that reduce sulfur levels to ultra-low levels (below 50 ppm initially, and eventually to 15 ppm or below). Currently, Chile is the only country to both adopt and implement ULSD standards. Mexico, despite adopting a ULSD standard in 2009, has yet to implement the standard nationwide, although the cleaner fuel is available in Mexico City, Guadalajara, Monterrey, and the U.S.-Mexico border zone. Mexico has signaled an intention to revise its fuel regulations by the end 2014 and implement an ultra-low sulfur requirement in the near future. Colombia and Uruguay have adopted 50 ppm sulfur standards. Reaching ultra-low sulfur levels will reduce PM emissions from all vehicles and enable the use of advanced vehicle emission control technologies that can eliminate more than 90 percent of black carbon emissions.

- **Stringent emissions standards for new vehicles:** Once ultra-low sulfur fuels are in place, countries can adopt vehicle emission standards for new vehicles that will require the use of diesel particulate filters (DPFs) or comparably effective alternative fuels or advanced vehicle technologies (e.g., natural gas or electric power). Because DPFs and other advanced emission controls are damaged or destroyed by high-sulfur fuels, adopting ultra-low sulfur diesel fuels is the necessary precursor to these new standards. By requiring urban buses to meet EPA 2007 standards, Chile is the leader here, although Mexico has signaled its intention to publish a rule by the end of 2014 that would implement these (or even more protective) standards in the near-future.

- **Complementary programs to reduce in-use emissions from existing vehicles:** Because so many older, high-emitting vehicles will remain on the road for years to come, countries should consider adopting complementary measures that will reduce emissions from their existing diesel fleets. The most successful of these programs has targeted high-emitting, centrally fueled fleets in the largest cities. For example, in Santiago, more than 2,000 city buses have been retrofitted with DPFs. Low-Emissions Zones have proven successful in Europe by banning the oldest, dirtiest vehicles and providing incentives for cleaner vehicles. One such zone is being proposed in Santiago. Small scrappage programs are being implemented in Mexico, Colombia, and Chile, incentivizing owners of the oldest, dirtiest trucks to replace them with newer, cleaner, more fuel-efficient models. And, more than 45 Latin American cities have implemented new Bus Rapid Transit routes, creating new public transit options that use clean buses to replace aging, high-emitting buses and provide new transit alternatives to single-occupant driving. Finally, in-use emissions monitoring helps ensure and improve fuel quality and supports in-use emissions maintenance programs.

Each recommendation discussed in this report relies on proven fuels, technologies and strategies.

In addition to the policy recommendations above, Latin America will benefit from more extensive air quality monitoring. Currently, only 8 of the 16 countries surveyed in this analysis monitor for $PM_{2.5}$, and most monitoring activities take place only in major cities. With improved air quality monitoring, public education and communications campaigns can explain the links between diesel pollution, public health, and climate change, thereby helping to catalyze progress toward better government policies.

If policymakers follow these steps, black carbon emissions will be significantly reduced in Latin America, providing important public health and environmental benefits to hundreds of millions of people throughout the region and globally.

# APPENDIX 1: BLACK CARBON'S CLIMATE IMPACTS

Black carbon affects the Earth's climate through three distinct mechanisms: direct forcing, cloud effects, and albedo effects.[280]

1) Direct forcing, black carbon's best-quantified climate impact, is the process by which black carbon aerosols absorb solar radiation. This causes the atmosphere to warm, thus reducing the sunlight that reaches the surface and reflecting it back to space.

2) Black carbon appears to impact cloud formation in several respects. By impacting light absorption and reflectivity, black carbon emissions affect the lifetime, stability, and distribution of clouds, although there is uncertainty about how to quantify the global warming impacts of these cloud effects.

3) Black carbon's dark surface changes the amount of solar radiation reflected by surfaces on which black carbon is deposited. This is called the "albedo effect." Light-colored surfaces, such as snow and ice, have a high albedo, meaning they reflect a significant amount of solar radiation. If these surfaces have increasing deposits of dark-colored black carbon, their albedo will decrease. This results in increased absorption of solar radiation and accelerated melting.[281] In other words, when black carbon is deposited on the light surfaces of snow or ice, its dark color accelerates melting. This leads to more dark surfaces (i.e., water), which further accelerates melting.

# APPENDIX 2: REDUCING PARTICULATE MATTER AND BLACK CARBON EMISSIONS IN NEW YORK CITY

Back in the summer of 1995, there was no such thing as a "clean diesel."

That's when NRDC launched its Dump Dirty Diesels Campaign with this ad on the backs of NYC Transit buses:

The New York City Transit story has been told many times before, but it bears repeating:

Just as lead had to be removed from gasoline to enable the use of catalytic converters that would make cars dramatically cleaner, sulfur had to be removed from diesel fuel to enable the use of effective pollution-cutting technologies that would clean up our dirty diesel buses and trucks.

Back then, this approach was untested. There was no such thing as a clean diesel bus.

Ultra-low sulfur diesel fuel (the diesel equivalent of unleaded gasoline) did not exist in the commercial market yet, and nobody knew whether catalysts and filters would work effectively in the rough-and-tumble of New York City's 24/7 transit service.

But the transit authority worked closely with NRDC to create the clean-fuel bus program that would test this approach.

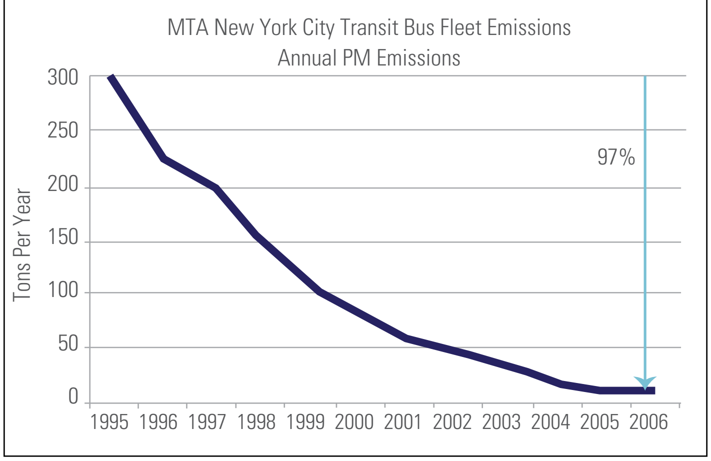
The program included key components that can be easily adapted in Latin America:

- Using ultra-low sulfur diesel fuel
- Accelerating retirement of all older, two-stroke diesel engines
- Retrofitting all remaining four-stroke diesel engines with DPFs
- Purchasing the cleanest possible diesel engines, all equipped with DPFs
- Purchasing and demonstrating promising alternative fuels and advanced vehicle technologies as they emerge, including hundreds of compressed natural gas and hybrid-electric buses

The program worked—and it has become the model for clean fleets in New York City and elsewhere.

**Figure 20: Dump Dirty Diesels ad campaign in New York City**


**Figure 21: Annual PM emissions from NYC transit bus fleet[282]**




In fact, as Figure 21 shows, diesel soot pollution from the NYC Transit fleet was reduced by 97 percent from the start of NRDC's Dump Dirty Diesels Campaign through 2006, when the last two-stroke bus was retired and every diesel bus was equipped with a DPF.

Today, clean buses provide safe, efficient transportation in New York City. Looking ahead, the lessons of New York City Transit may be useful for Latin American cities that introduce ultra-low sulfur diesel fuel.

# APPENDIX 3: U.S. AND E.U. HEAVY-DUTY DIESEL ENGINES EMISSION STANDARDS

The United States and the European Union have set emission standards for heavy-duty diesel engines since 1988 and 1992, respectively. Over the nearly three decades since their inception, these standards have resulted in NOx reductions of 95–98 percent and PM reductions of 97–98 percent for new heavy-duty diesel engines. The tables below show the progression of U.S. and E.U. heavy-duty diesel standards, as well as Latin American countries that employ those standards.

**Table 10: EPA emission standards for heavy-duty diesel engines[283]**

| Year | NOx (g/bhp-hr) | PM (g/bhp-hr) | Particle Number Limit | Latin American Country w/ Comparable Standard |
|---|---|---|---|---|
| 1988 | 10.7 | 0.60 | - | |
| 1990 | 6.0 | 0.60 | - | |
| 1991 | 5.0 | 0.25 | - | |
| 1994 | 5.0 | 0.10 / 0.07* | - | |
| 1998 | 4.0 | 0.10 / 0.05* | - | |
| 2004 | 2.0 | No change | - | Chile (NOx, buses only)[284], Mexico[285] |
| 2007 | 0.20 | 0.01 | - | Chile (PM, buses only)[286] |

* Second number is for urban bus engines only

**Table 11: E.U. emission standards for heavy-duty diesel engines[287]**

| Stage | Year | NOx (g/kWh) | PM (g/kWh) | Particle Number Limit | Latin American Country w/ Comparable Standard |
|---|---|---|---|---|---|
| Euro 1* | 1992 | 8.0 | 0.36 | - | El Salvador[288] |
| Euro II | 1998 | 7.0 | 0.12 | - | Ecuador[289] |
| Euro III | 2000 | 5.0 | 0.10 | - | Bolivia (buses only)[290], Uruguay[291] |
| Euro IV | 2005 | 3.5 | 0.02 | - | Argentina[292], Chile[293], Colombia (public transit only)[294], Mexico[295], Peru (Lima buses only)[296] |
| Euro V | 2008 | 2.0 | 0.02 | - | Brazil[297] |
| Euro VI | 2013 | 0.40 | 0.01 | $6.0 \times 10^{11}$ | |

* For engines greater than 85 kW

# APPENDIX 4: DESCRIPTION OF KEY METRICS FOR EACH LATIN AMERICAN COUNTRY

| Country | National Annual $PM_{10}$ and $PM_{2.5}$ Standards[306,***] | Air Quality Monitoring | Maximum Sulfur Level in Diesel Fuel | Road Sector Diesel Use (kilotons of oil equivalent by year) | Number of Registered Vehicles[307] | Age Distribution | Emissions Standards for New Vehicles[298] |
|---|---|---|---|---|---|---|---|
| Argentina[299] | $PM_{10}$: None<br>$PM_{2.5}$: None | $PM_{10}$: Buenos Aires | 1,500 ppm (500 in Buenos Aires, Rosario, Mar del Plata and Bahía Blanca) | 7,212 (2008) | 11 MM (2011) | As of 2008:<br>Pre-1989: 28.1 percent<br>1989-1993: 10.6 percent<br>1994-1998: 22.6 percent<br>1999-2003: 13.1 percent<br>2004-2008: 25.7 percent | LDV, HDV and Buses: Euro V[300] |
| Bolivia[301] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: None | $PM_{10}$: 10 major cities | 5,000 ppm | 1,058 (2010) | 1.1 MM (2011) | As of 2011:<br>Pre-1969: 1.8 percent<br>1970-1980: 9.0 percent<br>1981-1990: 26.1 percent<br>1991-2000: 49.5 percent<br>2001-2005: 7.9 percent<br>Post-2005: 5.7 percent | Buses: Euro III (La Paz)[302] |
| Brazil | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: None | $PM_{2.5}$ and $PM_{10}$: Sao Paulo[303] | 1,800 ppm (Between 50 and 500 in major cities)[304] | 28,732 (2009)[305] | 64.8 MM (2010)[306] | Unknown | LDV: Euro IV<br>HDV: Euro V |
| Chile | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 20 µg/m³ | $PM_{10}$: Nationwide[307]<br>$PM_{2.5}$: Santiago[308] | 15 ppm[309] | 3,534 (2010)[310] | 3.4 MM (2010)[311] | Unknown | LDV and MDV: Euro V<br>HDV: Euro V (from Sept. 2014)<br>Buses: U.S. 2004 NOx / U.S. 2007 PM[312] |
| Colombia[313] | $PM_{10}$: 50 µg/m³<br>$PM_{2.5}$: 25 µg/m³ | $PM_{10}$ and $PM_{2.5}$: Nationwide[314, 315] | 50 ppm[316] | 3,754 (2010) | 7.2 MM (2011) | As of 2009:<br>16-20 years: 8 percent<br>11-15 years: 21 percent<br>6-10 years: 27 percent<br>0-5 years: 44 percent | LDV: Euro IV<br>HDV: Euro IV (from 2015)<br>Buses: Euro II |

****Some countries have adopted more stringent PM10 and/or PM2.5 standards for their major cities. For example, La Paz, Bolivia, has adopted WHO-equivalent annual PM10 and PM2.5 standards of 20 and 10 µg/m3, respectively. Also, Montevideo, Uruguay has adopted an annual PM10 standard of 60 µg/m3.

| Country | National Annual $PM_{10}$ and $PM_{2.5}$ Standards[306,***] | Air Quality Monitoring | Maximum Sulfur Level in Diesel Fuel | Road Sector Diesel Use (kilotons of oil equivalent by year) | Number of Registered Vehicles[307] | Age Distribution | Emissions Standards for New Vehicles[298] |
|---|---|---|---|---|---|---|---|
| Ecuador[317] | $PM_{10}$: 50 µg/m$^3$<br>$PM_{2.5}$: 15 µg/m$^3$ | $PM_{10}$ and $PM_{2.5}$: Quito and Cuenca[318] | 5,000 ppm (500 in Quito and Cuenca)[319] | 2,415 (2010) | 1.4 MM (2011) | As of 2008:<br>Pre-1983: 12.8 percent<br>1984-1988: 3.3 percent<br>1989-1993: 9.7 percent<br>1994-1998: 16.9 percent<br>1999-2003: 17.0 percent<br>2004-2008: 40.4 percent | LDV: Euro I / U.S. 1987<br>HDV: Euro II / U.S. 1994 |
| El Salvador[320] | $PM_{10}$: 50 µg/m$^3$<br>$PM_{2.5}$: 15 µg/m$^3$ | $PM_{10}$ and $PM_{2.5}$: San Salvador[321] | 5,000 ppm | Levels unknown | 0.7 MM (2012) | Unknown, but expected to have a large share of older vehicles. | LDV: Euro I / U.S. 1987 |
| Guatemala[322] | $PM_{10}$: None<br>$PM_{2.5}$: None | $PM_{10}$: None<br>$PM_{2.5}$: Nationwide | 5,000 ppm | Levels unknown | 2.1 MM (2010) | Unknown, but expected to have a large share of older vehicles. | None |
| Honduras[323] | $PM_{10}$: None<br>$PM_{2.5}$: None | $PM_{10}$: None<br>$PM_{2.5}$: None | 5,000 ppm | Levels unknown | 1.2MM (2012) | Unknown, but expected to have a large share of older vehicles. | None |
| Mexico | $PM_{10}$: 50 µg/m$^3$<br>$PM_{2.5}$: 15 µg/m$^3$ | $PM_{10}$: Nationwide<br>$PM_{2.5}$: Select cities | 15 ppm, but most diesel is 300 ppm[324] | 13,767 (2009)[325] | 30.2 MM (2011) | Unknown | All: Euro IV / U.S. 2004 |
| Nicaragua[326] | $PM_{10}$: 50 µg/m$^3$<br>$PM_{2.5}$: None | $PM_{10}$: None<br>$PM_{2.5}$: None | 5,000 ppm | Levels unknown | 0.6 MM (2012) | Unknown, but expected to have a large share of older vehicles. | None |
| Paraguay[327] | $PM_{10}$: None<br>$PM_{2.5}$: None | $PM_{10}$: None<br>$PM_{2.5}$: None | 2,500 ppm | 1,039 (2010) | 1.15 MM (2013) | As of 2009:<br>11+ years: 60 percent<br>6-10 years: 15 percent<br>0-5 years: 7.6 percent | None enforced |

| Country | National Annual $PM_{10}$ and $PM_{2.5}$ Standards[306,***] | Air Quality Monitoring | Maximum Sulfur Level in Diesel Fuel | Road Sector Diesel Use (kilotons of oil equivalent by year) | Number of Registered Vehicles[307] | Age Distribution | Emissions Standards for New Vehicles[298] |
|---|---|---|---|---|---|---|---|
| Peru[328] | $PM_{10}$: 50 $\mu g/m^3$<br>$PM_{2.5}$: 25 $\mu g/m^3$ | $PM_{2.5}$, $PM_{10}$ and BC: Lima-Callao | 5,000 ppm (15 in Lima and Callao) | 3,426 (2010) | 2.6 MM (2011) | As of 2008:<br>Pre-1991: No data<br>1991-1993: 8.9 percent<br>1994-1998: 34.5 percent<br>1999-2003: 25.8 percent<br>2004-2008: 30.9 percent | LDV and HDV: Euro III<br>Buses: Euro IV (Lima) |
| Uruguay[329] | $PM_{10}$: None<br>$PM_{2.5}$: None | $PM_{10}$ and $PM_{2.5}$: Montevideo[330] | 50 ppm[331] | 582 (2010) | 1.6MM (2011) | Average age is 17 years. Vehicles 10 years and younger is $3_{2.5}$ percent of the fleet. | All: Euro III |
| Venezuela | $PM_{10}$: 50 $\mu g/m^3$<br>$PM_{2.5}$: None | Unknown | 2,000 ppm[332] | 2,909 (2010)[333] | 4.4 MM (2011) | Unknown | HDV: Euro I / U.S. 1991[334] |

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