THE STATE OF CLEAN TRANSPORT POLICY

A 2014 SYNTHESIS OF VEHICLE AND FUEL POLICY DEVELOPMENTS

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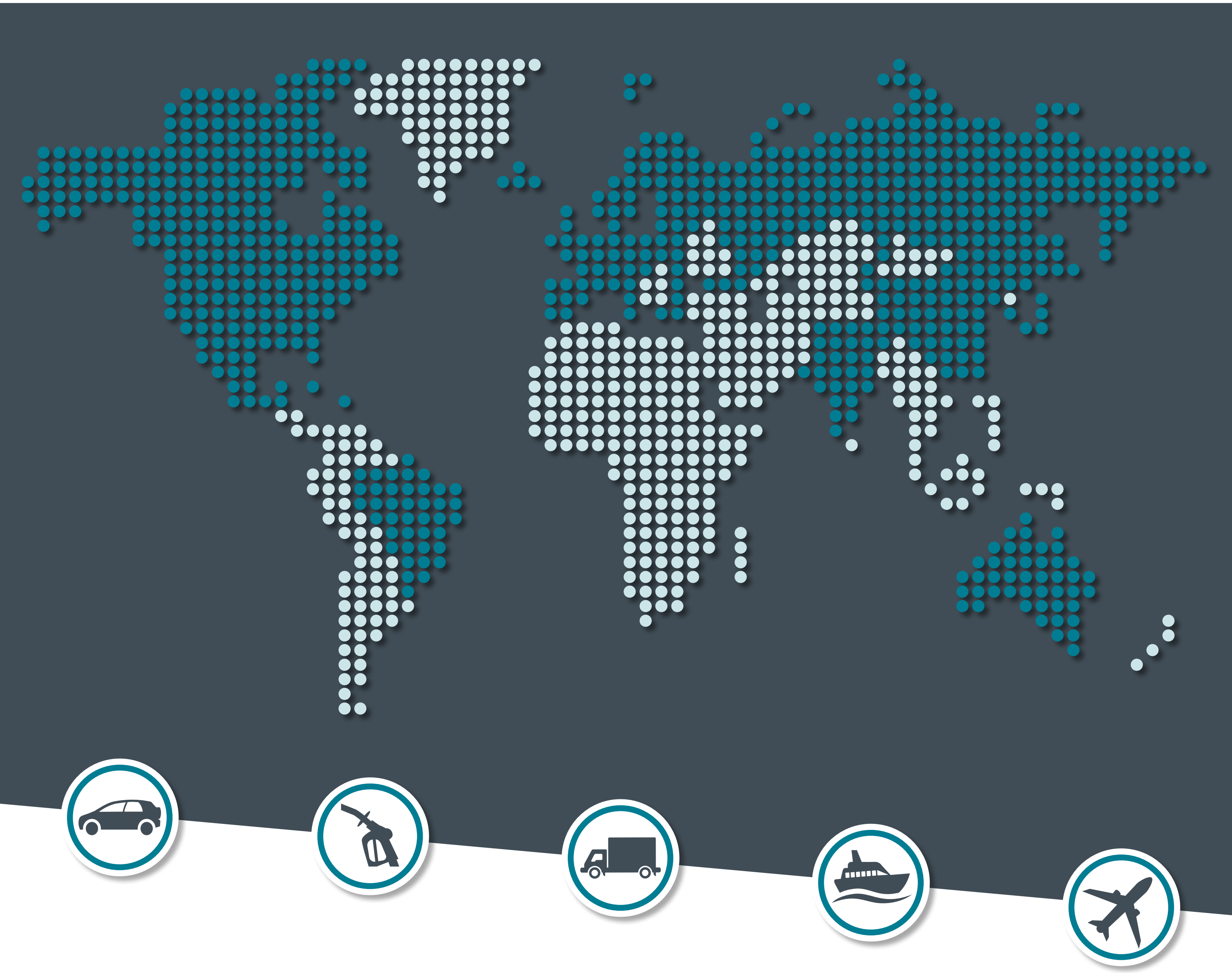

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ACKNOWLEDGEMENTS

Funding for this work was generously provided by the William and Flora Hewlett Foundation and the ClimateWorks Foundation. This work builds off the International Council on Clean Transportation's technical research and regulatory support on clean vehicle, ship, plane, and fuel policies around the world, as well as the TransportPolicy.net web portal. Special thanks to Nic Lutsey for providing review at multiple stages and contributing inputs regarding low-carbon fuels, electric-drive vehicles, and the conclusions of the report, and to Drew Kodjak for his contributions to the executive summary. The authors thank the ICCT staff who contributed to the accuracy of this report through careful review, including Anup Bandivadekar, Chris Malins, Dan Rutherford, Rachel Muncrief, Ben Sharpe, Ray Minjares, Vicente Franco, Zifei Yang, Stephanie Searle, and Sebastian Galarza. Additionally, several ICCT staff contributed toward the development of the report: Alyson Azzara and Haifeng Wang (marine), Anastasia Kharina and Irene Kwan (aviation), Zhenying Shao (ongoing validation of the Roadmap model), and Sarah Chambliss (development of health impact methods). The authors also thank Drew Kodjak, Fanta Kamakaté, and Joe Schultz for their critical reviews.

The authors would like to thank the ICCT Council Members who have generously contributed their time and insight in reviewing and commenting on the draft version of this report. We particularly thank:

Alberto Ayala, California Air Resources Board
Krishan Dhawan, Shakti Sustainable Energy Foundation, India
Vadim Donchenko, Scientific and Research Institute of Motor Transport (NIIAT), Russia
Axel Friedrich, Umweltbundesamt (retired), Germany
Hal Harvey, Energy Innovation: Policy and Technology LLC, U.S.
Youngil Jeong, Korea Institute of Machinery and Materials (KIMM)
Li Kunsheng, Beijing Environmental Protection Bureau, China
Patricia Monahan, Energy Foundation, U.S.
Philip Owen, European Commission DG Climate Action
Margarita Parra, William and Flora Hewlett Foundation, U.S.
Sanjivi Sundar, The Energy and Resources Institute (TERI), India
Dagang Tang, Chinese Research Academy of Environmental Sciences (CRAES), China
Catherine Witherspoon, ClimateWorks Foundation, U.S.
Ding Yan, Vehicle Emission Control Center, Ministry of Environmental Protection, China

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EXECUTIVE SUMMARY

This inaugural *State of Clean Transport Policy* report compiles advancements in national and international regulations to reduce energy use, mitigate climate change, and control air pollution from motor vehicles and fuels across eleven major vehicle markets from January 2013 through August 2014. These eleven vehicle markets—China, the United States (US), the European Union (EU), Japan, Brazil, India, Russia, Canada, South Korea, Australia, and Mexico—represented 85% of total vehicle sales in 2013.

This report quantifies the benefits associated with environmental policies for light- and heavy-duty vehicles, marine vessels, aircraft, and fuels in terms of reduced greenhouse gas (GHG) emissions and local air pollution, fuel savings, and benefits to public health. Where opportunities are identified, the report also estimates the potential for additional benefits associated with the adoption of best-practice policies. The scope of this report excludes motorcycles, locomotives, and off-road vehicles. Future editions may expand to include other modes of transport, additional markets, or regulations for mobile refrigerants. Also excluded from this report are policies aimed at reducing transport activity and shifting people and goods to more environmentally-friendly modes, although such actions are also important to meet global environmental goals.

CLIMATE IMPACTS AND ENERGY USE

In 2010, the global transport sector was responsible for almost a quarter of all anthropogenic carbon dioxide (CO_2) emissions, resulting in the release of 8.8 billion metric tons (Gt) of CO_2 into the atmosphere and consuming 47 million barrels per day of oil (mbd). By 2030, transport emissions are expected to increase by roughly two-thirds to 15 $GtCO_2$ and 78 mbd of oil. Based on this assessment of adopted policies in major markets, total reductions from these policies will lower projected baseline emissions by 2.2 $GtCO_2$ and fuel consumption by 11 mbd, equivalent to about a 13% reduction. An expansion of best practices could reduce another 4.4 $GtCO_2$ and 21 mbd in 2030 (Figure ES-1), equivalent to a 30% and 27% reduction, respectively, in 2030.

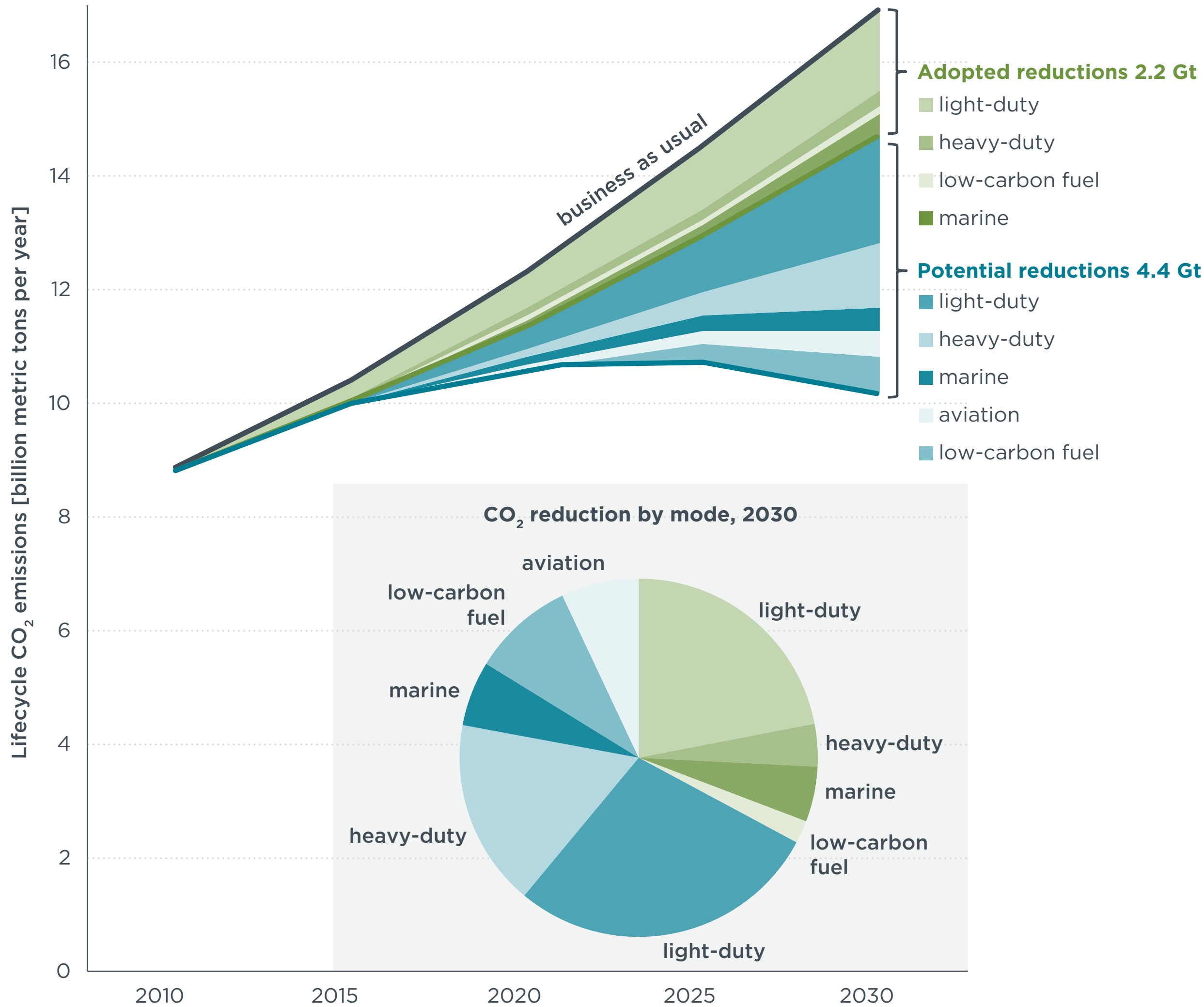


Figure ES-1. Global CO_2 emissions from transport, 2010-2030

The following findings reflect the state of vehicle efficiency and low-carbon fuel standards in the eleven selected markets as of August 2014.

» *Light-Duty Vehicles*. Nine regions have adopted policies requiring vehicle manufacturers to improve the energy efficiency of new light-duty vehicles (LDV); in 2013, over 80% of global new passenger car sales were subject to such regulations. Recently adopted policies are projected to reduce GHG emissions by almost 1.5 $GtCO_2$, or 8.2 mbd in 2030. The US and Canada are implementing LDV GHG standards that have established the global benchmark for long-term phase-in periods to 2025. Another 1.1 $GtCO_2$, or 5.8 mbd, could be achieved if existing programs in the US, Canada, China, EU, Japan, Brazil, India, South Korea and Mexico were extended to 2030, and these nations were joined with new programs in Russia and Australia. Combined, these policies could reduce emissions from the light-duty sector by 37% in 2030.

» *Heavy-Duty Vehicles*. Four regions—Japan, US, Canada, and China—have adopted GHG or efficiency standards for heavy-duty vehicles (HDVs). Such policies are projected to reduce GHG emissions by 0.26 $GtCO_2$ in 2030, or 1.4 mbd. Expansion of HDV GHG and efficiency standards to the rest of the world could reduce another

0.65 $GtCO_2$ (3.4 mbd) in 2030, and essentially stabilize global HDV emissions after 2025. Combined, these policies could reduce GHG emissions and fuel use from the heavy-duty vehicle sector by 26% in 2030.

- *Low Carbon Fuels.* Three regions (California, US, and EU) have adopted low-carbon fuel regulations, with projected GHG emission reductions of 0.22 $GtCO_2$ in 2020. Expanded adoption of fuel policies—including those that accelerate the deployment of low-carbon fuels and electric drive and also curb high-carbon fossil fuels—that are consistent with a 10% reduction in the carbon intensity of on-road fuel by 2030 could mitigate another 1.1 $GtCO_2$ in 2030.
- *International Marine*. The International Maritime Organization (IMO) has adopted efficiency standards for new international marine vessels that are expected to reduce carbon dioxide emissions by 0.34 $GtCO_2$ and fuel use by 1.8 mbd in 2030. Strengthening the efficiency requirements for new ships and implementing a mandatory program to improve operational efficiency could save 0.4 $GtCO_2$ and over 2.1 mbd in 2030. Together these policies could reduce emissions from the international marine sector by 30% in 2030.
- *International Aviation*. The International Civil Aviation Organization (ICAO) has not yet adopted energy efficiency standards for aircraft. New CO_2 emission standards for aircraft engines and airframes, combined with market-based measures for commercial airlines, have the potential to reduce GHG emissions by 0.48 $GtCO_2$ and oil use by 2.6 mbd in 2030—representing a 23% reduction from business-as-usual trends in the aviation sector.

AIR POLLUTANT EMISSIONS AND PUBLIC HEALTH

Exposure to outdoor air pollution resulted in 3.2 million early deaths worldwide in 2010 and ranks among the top ten health risks. Motorized transport is a major contributor to outdoor air pollution, particularly near major roadways and in urban areas with a high concentration of vehicle activity. The vast majority of health impacts from vehicle activity occur in India, China, Brazil, Mexico, and the countries in the Asia-Pacific, Latin America, Middle East, and Africa. As shown in Figure ES-2, implementing world-class vehicle emissions standards would reduce transport air pollution-related mortality from approximately 270,000 deaths to 71,000 deaths in 2030 globally, with benefits that are greatly concentrated in major cities. These estimates are limited strictly to exhaust emissions of fine particulate matter ($PM_{2.5}$) from light- and heavy-duty on-road vehicles in urban areas and thus represent a conservative estimate of health impacts from transport.

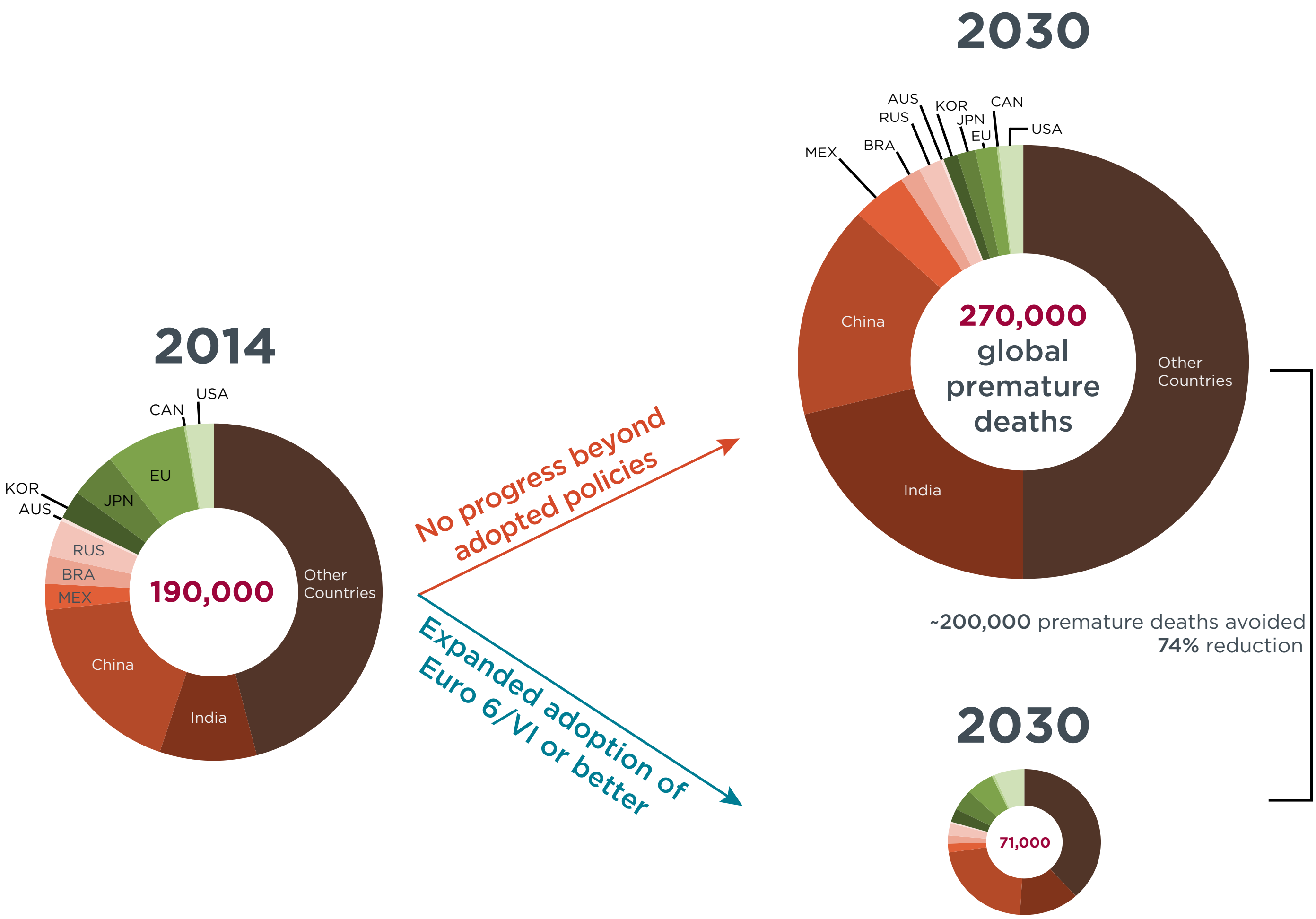


Figure ES-2. Global premature deaths from light- and heavy-duty vehicle exhaust $PM_{2.5}$

The following findings reflect the state of vehicle air pollutant emissions and ultralow-sulfur fuel standards in the eleven selected markets as of August 2014.

» *Light-Duty Vehicles.* Six markets have adopted world-class emission standards (US, Canada, EU, Japan, South Korea, and Australia). In 2013, 43% of global new passenger car sales were subject to world-class emission standards, and this share could increase to over 80% if such standards are adopted in China, Brazil, India, Russia, and Mexico.

» *Heavy-Duty Vehicles*. Five markets have implemented or adopted world-class heavy-duty vehicle emissions standards (US, Canada, EU, Japan, and South Korea) and have ultralow-sulfur diesel fuel available. Another four major markets—China, India, Brazil and Russia—could adopt world-class standards within the next several years.

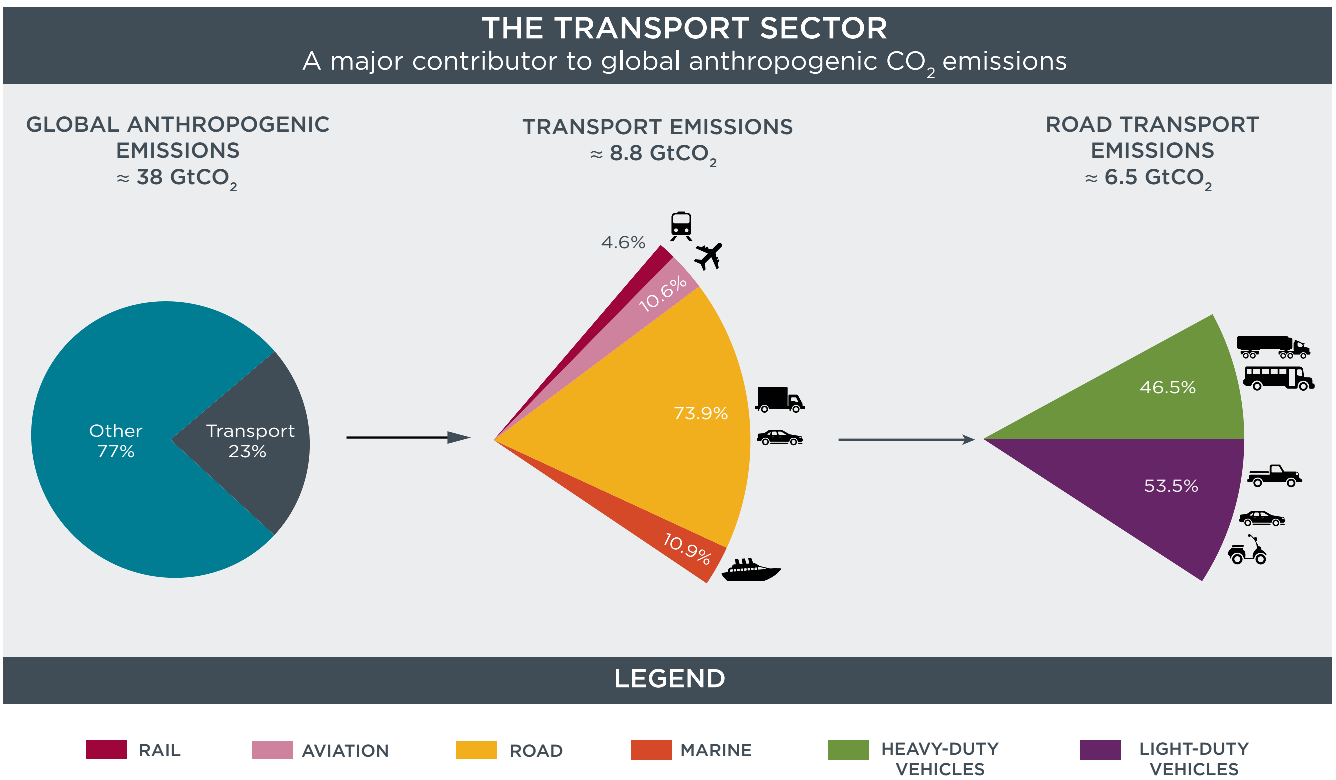
» *Ultralow-Sulfur Fuel*. A key requirement to world-class vehicle standards, and thus cleaner vehicles, is the availability of ultralow-sulfur fuels, including gasoline with fewer than 30 parts per million (ppm) sulfur content and diesel with fewer than 15 ppm. As of August 2014, only five of the eleven markets (US, Canada, EU, Japan, and South Korea), representing 50-60% of the global consumption of on-road gasoline and diesel, have such fuels ubiquitously available (Australia also has ultralow-sulfur diesel available).

- *International Marine*. The IMO is responsible for setting emission standards for international vessels, and has to date regulated emissions of nitrogen oxides (NO_x) and the sulfur content of bunker fuels, with more stringent limits applied to Emission Control Areas (ECAs). Marine bunker fuel sulfur levels start very high (up to 35,000 ppm) but are required to decline globally to 5,000 ppm in 2020, and regionally to 1,000 ppm for ships operating in the North Sea, Baltic Sea, North American waters, and the Caribbean Sea in 2015. More-stringent standards could reduce international marine emissions of NO_x by 23%, and PM and sulfur oxides (SO_x) by more than 80%, in 2030 from business-as-usual levels.
- *International Aviation.* In 2010, ICAO established stringent, but non-binding, NO_x reduction targets that are equivalent to a 45% reduction by 2016, and a 60% reduction by 2026. Making these non-binding targets mandatory would ensure that the intended benefits are realized. In addition, ICAO has an opportunity to reduce the impacts of ultrafine PM on air quality, human health, and global climate if it adopts a non-volatile particulate matter standard by 2016 that is in line with ICAO's previous announcements.

CHAPTER 1. INTRODUCTION

The transport sector has seen substantial global growth in the past two decades, in the form of increased vehicle ownership, passenger and freight activity, and energy use across all transport modes. Despite the evident economic benefits from increased mobility and freight trade, such activity has negative consequences such as increased petroleum use and associated climate and health impacts. Driven largely by transport sector growth, world oil use, including its unconventional oil and other fossil replacements, is expected to surpass 100 million barrels of oil per day (mbd) in the 2020-2025 timeframe (IEA, 2013). To help mitigate the associated environmental effects, many governments have developed transport sector policies to improve the environmental and energy performance of vehicles and fuels.

In 2010, the global transport sector was responsible for almost a quarter of all anthropogenic CO_2 emissions, resulting in the release of 8.8 $GtCO_2$ into the atmosphere and consuming 47 mbd (Figure 1). Within the transport sector, on-road vehicles accounted for about three-quarters of fuel consumption (35 mbd) and CO_2 emissions (6.5 $GtCO_2$) (see Box 1).



Notes:
Global anthropogenic CO_2 emissions in 2010 based on IPCC (2014).
Transport CO_2 emissions in 2010 estimated by ICCT (2014) include the full fuel lifecycle, including direct emissions from combustion & upstream emissions from extraction, refining, & distribution of fuels.
Sources:
ICCT (2014). Global Transportation Roadmap Model. Available from http://www.theicct.org/global-transportation-roadmap-model
IPCC (2014). Summary for Policymakers. Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Figure 1. Global transport sector lifecycle CO_2 emissions, 2010

BOX 1. FUEL CONSUMPTION AND CO_2 METRICS

While the vast majority of transport fuel is derived from fossil fuels, a small but growing share consists of biofuels, as well as electricity and hydrogen derived from renewable energy sources. Throughout this report, estimates of fuel consumption are given in **million barrels of oil equivalent per day**, abbreviated as **mbd**.

Many sources estimate direct CO_2 emissions from fuel combustion, also known as tank-to-wheel (TTW) emissions; however, it is also important to consider the upstream, or well-to-tank (WTT) emissions that are generated from the extraction, refining, and distribution of transport fuels. The estimates in this report consider the full fuel lifecycle, or well-to-wheel (WTW) and include both combustion and upstream emissions; these are given in **million** or **billion metric tons per year**, abbreviated as **$MtCO_2$** and **$GtCO_2$**, respectively. These estimates do not include emissions from the manufacture or scrappage of vehicles, ships, or planes, or emissions associated with transport infrastructure.

Motorized transport is a major contributor to outdoor air pollution, particularly near major roadways and in urban areas with a high concentration of vehicle activity. Exposure to outdoor air pollution resulted in 3.2 million early deaths in 2010 and ranks among the top ten health risks worldwide (Lim et al., 2012). Figure 2 compares the annual average $PM_{2.5}$ concentration in 2010 of cities worldwide with over 100,000 inhabitants against the levels recommended by the World Health Organization (WHO). Most cities worldwide have serious air quality problems, in particular those in the Asia-Pacific region. Particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$) is among the most harmful vehicle pollutants with a range of associated health impacts including cardiovascular and respiratory diseases, lung cancer, and infant mortality. In response to the serious health impacts of vehicle emissions, state-of-the-art emission control technologies have been developed, which are capable of reducing emissions of particulate matter (PM) and nitrogen oxides (NO_X) by over 97% from unregulated levels (Johnson, 2012). Advancing to world-class vehicle emission standards (with stringency equivalent to Euro 6/VI or better) paired with requirements for ultralow-sulfur fuel can dramatically reduce emissions of local air pollutants and associated health impacts, even amid growth in vehicle activity.

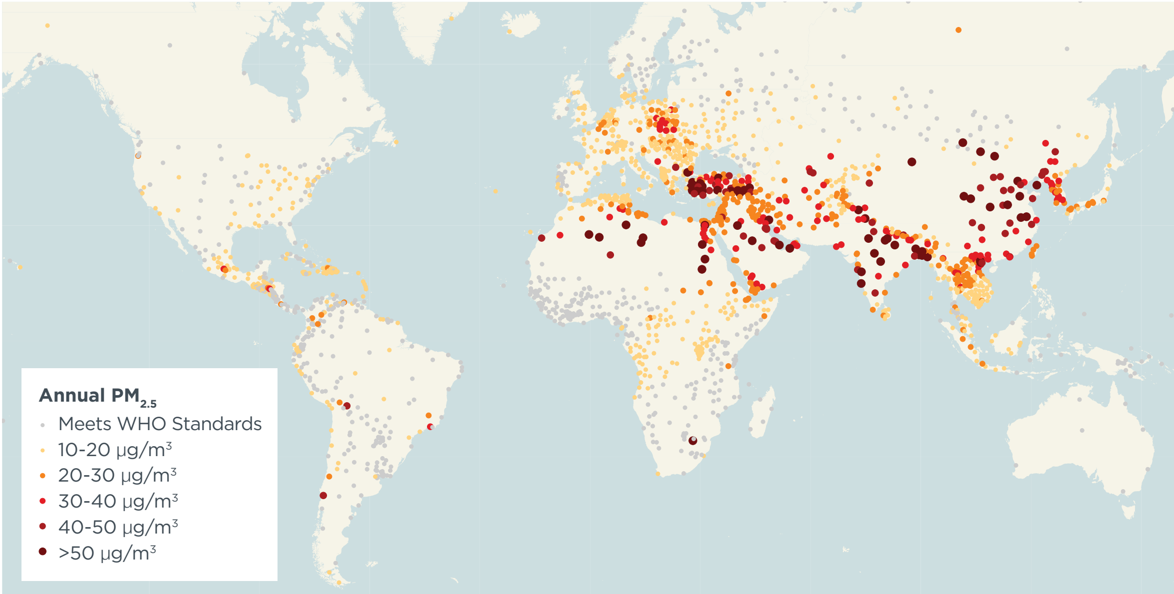


Figure 2. Annual average $PM_{2.5}$ concentrations relative to WHO guidelines in 2010 (adapted from Brauer et al., 2012 and WHO, 2014)

Includes monitoring data from WHO (2014) and modeled concentrations from Brauer et al. (2012) for 2010 where monitoring data was not available.

This report covers eleven of the top vehicle markets that represented 85% of total vehicle sales in 2013 (Figure 3). These markets include China, US, EU, Japan, Brazil, India, Russia, Canada, South Korea, Australia, and Mexico. These regions are collectively referred to as "selected markets" in this report. While this edition focuses on eleven selected vehicle markets, future editions may expand the scope to include regulatory developments in growing vehicle markets such as Thailand, Indonesia, Argentina, Turkey, Saudi Arabia, Iran, Malaysia, and South Africa—each of which had over half a million new vehicle sales in 2013.

The scope of this report is limited to on-road vehicles, marine, and aviation, and excludes motorcycles, locomotives, and off-road vehicles. Future editions may expand the scope to provide better coverage of national policies; for example, motorcycles are an especially important sub-sector in India and in the Asia-Pacific region. The scope of policies covered includes national-level vehicle efficiency and GHG standards, tailpipe emission standards for local air pollutants, and low-sulfur fuel standards, as well as international regulations for marine vessels and aircraft. Regulations targeting F-gases and refrigerants are outside the scope of this analysis but may be covered in future editions. Policies that aim to reduce transport activity and shift people and goods to more environmentally-friendly modes are also beyond the scope of this work, but we recognize their critical role in meeting global climate targets as described in a previous analysis (Façanha et al., 2012).

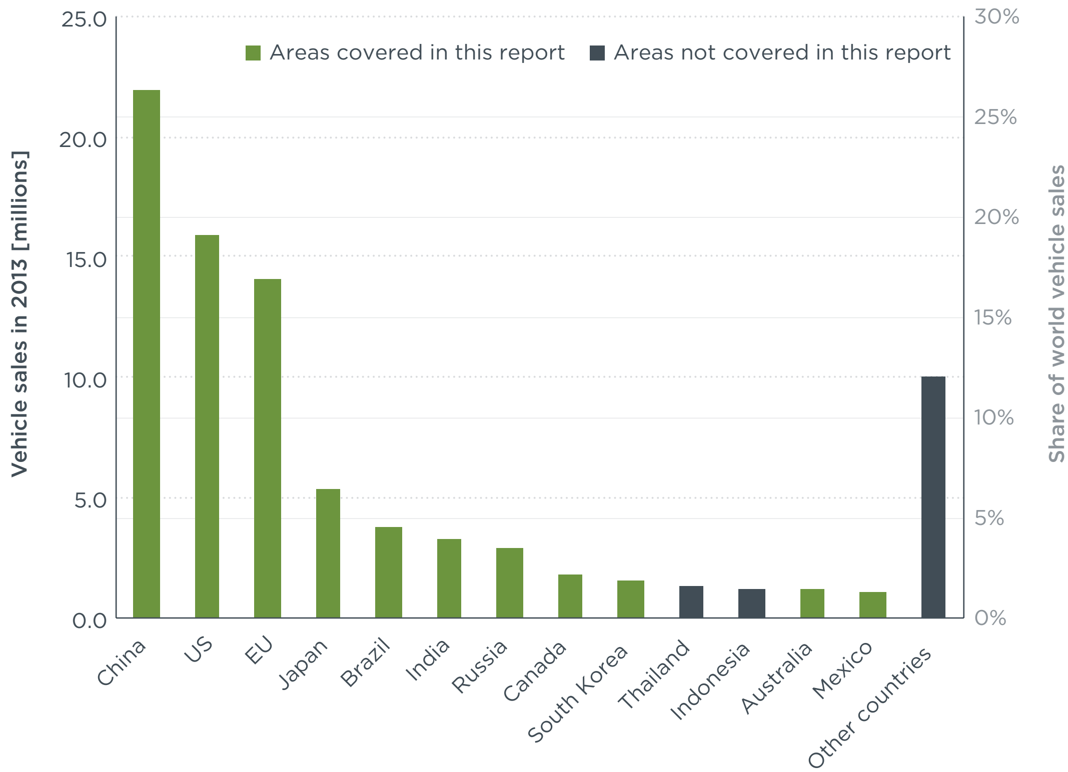


Figure 3. Sales of light- and heavy-duty vehicles by region in 2013 (based on OICA, 2014)

Clean vehicle and fuel policies are an essential part of local, national, and international efforts to reduce energy consumption, mitigate climate change, and ensure adequate air quality. Such findings are demonstrated in wide ranging studies by the IPCC, IEA, and UNEP, among many others (An et al., 2011; GFEI, 2014; IEA, 2012; IPCC, 2014; Shindell et al., 2011; UNEP, 2011). Two previous ICCT studies have contributed to recent international modeling work and policy studies by assessing the direct effects of adopted national-level clean vehicle and fuel policies on emissions of GHGs and local air pollutants, and evaluating the benefits of actionable timelines for new policies to reduce energy consumption and mitigate impacts of vehicle emissions on climate, air quality, and health (Façanha et al., 2012; Chambliss et al., 2013).

This report builds upon previous work to create a novel synthesis of information and analysis on clean transport policy, bringing together the following elements: (1) Summary of the state of clean vehicle and fuel policies; (2) Update of recent regulatory developments in major markets; (3) Quantification of the impacts of recently adopted policies on climate, energy, and health; (4) Evaluation of the benefits of strengthening and expanding international best practices. The report aims to accomplish these elements by synthesizing technical and regulatory work and providing novel analysis. This work relies heavily on TransportPolicy.net, a collaborative effort between the ICCT and DieselNet that provides accurate, up-to-date, referenceable, and comprehensive information on regulatory policies for clean vehicles and fuels (ICCT & DieselNet, 2014) (see Box 2). This study also relies on ICCT's validated methods for emissions quantification, including our publicly-available Roadmap model that evaluates the impacts of transport policies on energy, GHGs, emissions of local air pollutants, and health (see Façanha et al., 2012; Chambliss et al., 2013; ICCT, 2014).

BOX 2. HYPERLINK REFERENCES TO TRANPORTPOLICY.NET

In addition to the standard referencing to technical and government reports, this report contains hyperlinks to pages on the TransportPolicy.net website. This site is maintained by the ICCT as a public repository and reference site for technical and implementation details of fuel quality, vehicle, marine, and aviation policies described herein.

This first edition of the *State of Clean Transport Policy* seeks to summarize, track, and quantify the impacts of such vehicle and fuel standards—with an aim to provide annual updates as transport policies and systems evolve. The remainder of the document is organized as follows. Chapter 2 provides an update of regulatory policies for clean vehicles and fuels that were proposed, adopted, or first implemented from January 2013 through August 2014. Chapter 3 evaluates the effects of clean transport policies adopted to date on energy consumption, transport emissions, and health impacts, and quantifies the benefits of strengthening and expanding the adoption of international best practices. Finally, chapter 4 summarizes the key conclusions and recommendations for future policy action based on recent progress and current policy developments.

CHAPTER 2. NEW NATIONAL AND INTERNATIONAL REGULATIONS, 2013-2014

This chapter provides an update of regulatory policies for clean vehicles and fuels that were proposed, adopted, or first implemented from January 2013 through August 2014. Each of the following sections contains a table that summarizes recent regulatory developments, provides a measure of each regulation's stringency, estimates the reduction in annual CO_2 emissions in 2030 (for efficiency policies), and hyperlinks to more information. Technical information is linked to TransportPolicy.net, a site maintained by the ICCT and DieselNet which provides comprehensive, up-to-date, and sourced information on energy and environmental regulations in the transport sector worldwide, with a focus on vehicles and fuels. Policy updates are linked to the ICCT's website (theicct.org), which provides additional publications regarding international best practices and technical analyses of the costs, benefits, energy and environmental impacts of such regulations. Key terms related to the status of regulations are summarized in Box 3. While many of the regions covered in this publication are considering new standards for vehicle efficiency, emissions and fuels, this comparison purposefully considers only those standards that have been formally notified as government proposals or adopted into law. Future editions will give credit to new policies as they are notified as proposals, adopted, and subsequently implemented.

BOX 3. KEY TERMS RELATED TO REGULATORY STATUS

While the processes that regulations undergo from consideration to implementation vary by region and policy type, the terms used in this report are defined as follows unless otherwise indicated:

Proposal—refers to a published regulatory proposal that has not yet been adopted

Adoption—indicates that a regulation has been finalized, with established dates for phase-in and implementation of the regulatory requirements

Entry into force—refers to the date at which an international regulation becomes legally binding upon Governments that have ratified it; in the EU, this corresponds to implementation

Delay—indicates when a regulation has been formally adopted, but one or more implementation dates have been set back

Implementation begun—indicates when new vehicle type approvals are first subject to a new regulation; for fuel sulfur standards, corresponds to availability of fuel meeting requirements

Current implementation—indicates all sales and registrations of new vehicles are subject to the regulation

2.1. EFFICIENCY OF LIGHT- AND HEAVY-DUTY VEHICLES

Through August 2014, all selected markets except Australia and Russia have adopted fuel efficiency and GHG regulations or equivalent fiscal measures for light-duty vehicles (LDVs). In contrast, only China, the US, Canada, and Japan have adopted similar regulations for heavy-duty trucks and buses (Table 1). The latest phase of LDV standards requires reductions in CO_2 emission rates of new vehicles (in grams per vehicle-km) between 9% and 35%, compared to 11% to 14% for the first phase of HDV standards. For both light- and heavy-duty efficiency standards, strong compliance programs such as conformity of production and in-use verification requirements are needed to ensure that regulatory requirements translate to real-world emissions reductions and fuel savings; such requirements have been included in US programs but have yet to be adopted across all countries with vehicle efficiency standards (He, 2014).

Table 1. Comparison of the latest adopted regulations for light- and heavy-duty efficiency in selected regions

		Light-duty vehicles			Heavy-duty vehicles		
Region[a]	Percent of world vehicle sales, 2013	Baseline model year[b]	Implementation period (model year)	Reduction in average CO_2 rate (grams/vehicle-km)	Baseline model year	Implementation period (model year)	Reduction in average CO_2 rate (grams/vehicle-km)
China[c]	25%	2011	**2012-2015**	9%	2012	**2014-2015**	11%
EU	19%	2015	**2020-2021**	27%			0%
US	17%	2017	**2017-2025**	35%	2011	**2014-2018**	14%
Japan	6%	2015	**2020**	16%	2006	**2015**	12%
Brazil[d]	4%	2013	**2013-2017**	12%			0%
India	4%	2012	**2017-2021**	17%			0%
Russia	3%			0%			0%
Canada[e]	2%	2011	**2011-2016**	20%	2011	**2014-2018**	14%
South Korea	2%	2011	**2012-2015**	9%			0%
Australia	1%			0%			0%
Mexico	1%	2012	**2014-2016**	13%			0%

Adopted or newly implemented between Jan. 2013 and Aug. 2014 | **Adopted or implemented prior to Jan. 2013**

[a] Includes eleven major vehicle markets
[b] Percent reduction in new fleet fuel consumption estimated from a baseline year (determined by expert judgment rather than regulatory requirement) to the final model year covered by the regulation. Reductions for HDVs are activity-weighted by vehicle type.
[c] China has adopted separate standards for passenger cars and light commercial vehicles. The latest adopted standard for passenger cars (Phase 3) is summarized here.
[d] Brazil's Inovar-Auto program requires a 12.1% improvement for manufacturers to qualify for a 30% reduction in vehicle sales tax.
[e] Canada has announced intention to harmonize with the US 2017-2025 GHG standards; however formal adoption has not occurred as of August 2014.

The following tables summarize recent developments in regulations to reduce the fuel consumption and GHG emissions of LDVs and HDVs. Since the beginning of 2013, five of the selected markets—China, EU, Brazil, India, and Mexico—have formally proposed, adopted or implemented regulations or equivalent fiscal measures to improve LDV efficiency (Table 2). This progress occurred after the adoption in 2012 of new LDV efficiency standards in the US, which extend the benefits of improved vehicle efficiency from 2017 to 2025. LDV regulation stringency is summarized by the new fleet target in grams CO_2 per vehicle-km, which ranges from 95 to 169 gCO_2/km, demonstrating significant potential for further benefits by reducing the disparities among countries with LDV efficiency standards in place. As shown in Table 2, recent regulatory developments are expected to avoid an estimated 420 $MtCO_2$ in 2030.

Table 2. Regulatory developments in light-duty vehicle efficiency in 2013-2014

Status	Regulatory development	New fleet target (grams CO_2 per km)[a]	CO_2 reduced in 2030 (Mt per year)[b]	More information
Implemented	**Brazil** implemented Inovar-Auto in 2013, a fiscal instrument that incentivizes makers of passenger cars and light commercial vehicles to improve new fleet efficiency by 12-19% between 2013 and 2017.	–[c]	**19**	Technical Policy update (Façanha, 2012)
Implemented	**China** released rules for calculating corporate average fuel consumption of passenger cars to support enforcement of Phase 3 efficiency standards, which target a fleet average fuel consumption of 6.9L/100km in 2015.	2015: **161**	**-**	Technical Policy update (He & Yang, 2014a)
Adopted	**China** renewed and tightened subsidies for energy-efficient vehicles, tightening fuel consumption requirements by 2-14% and offering market incentives for early compliance with China 5 emission standards on vehicles with engines less than 1.6L.	**-**	**-**	Policy update (He, 2013)
Adopted	**EU** adopted 95 gCO_2/km standards for passenger cars with full compliance in 2021, and 147 gCO_2/km standards for light commercial vehicles with compliance in 2020.	2020: **95 / 147**	**140**	Technical Policy update (Mock, 2014)
Adopted	**India** adopted the country's first passenger car efficiency standards, which take effect in 2017 and set a target of 113 gCO_2/km by 2021.	2021: **113**	**50**	Technical
Adopted	**Mexico** adopted CO_2 standards for cars, pickups, and sport utility vehicles (SUV) from model years 2014-2016, setting a fleet average target of 14.6 km/L in 2016.	2016: **169**	**17**	Technical Policy update (Blumberg, 2013)
Proposed	**China** released a proposal for Phase 4 fuel consumption standards that set a target of 5L/100km by 2020.	2020: **117**	**190**	Technical Policy update (He & Yang, 2014b)
	TOTAL		**420 $MtCO_2$**	

Implemented Adopted Proposed Delayed implementation

[a] All values adjusted to New European Driving Cycle (NEDC) test cycle. Source: He & Yang (2014c).
[b] Estimates are rounded to two significant digits. Source: ICCT (2014).
[c] *"–" indicates not applicable or no estimate is available.*

Compared to regulations for LDV efficiency, HDVs have a relatively short regulatory history, with 2014-2015 a landmark period of implementation for all four mandatory HDV efficiency standards. The lead times between adoption and implementation of HDV efficiency standards are progressively shortening: Japan's Phase 1 standard was adopted in 2006, and financial incentives for early compliance came into effect several years before full implementation, which is scheduled for 2015. Such regulations were subsequently adopted in the US (2011) and Canada (2013) and applied to model year 2014 vehicles. In contrast, China's Phase 2 standard was finalized in February 2014 and applied to new type approvals only a few months later, starting in July 2014. Other regions, however, have yet to adopt such standards. For example, the EU has adopted standards for light commercial vehicles[1] (LCVs) through 2020 but has not adopted standards for heavier vehicles, which account for a greater share of energy consumption. In Table 3, the associated stringency of HDV standards is compared according to the expected reduction in new vehicle fleet

1 Light commercial vehicles include light trucks and vans. Such vehicles weighing less than 3500 kg gross vehicle weight rating (GVWR) are considered light-duty vehicles. In North America, the definition extends to vehicles weighing up to 3863 kg.

fuel consumption over the timeframe of the regulation, weighted by the activity of each vehicle type (e.g., vocational, straight truck, and tractor-trailers). As shown in the table, these regulations will avoid an estimated 210 MtCO_2 in 2030.

Table 3. Regulatory developments in heavy-duty vehicle efficiency in 2013-2014

Status	Regulatory development	Percent reduction in new fleet fuel consumption[a]	CO_2 reduced in 2030 (Mt per year)[b]	More information
Implemented	**Canada's** Phase 1 standards were adopted in March 2013 and applied starting with model year 2014 vehicles. These standards, which are closely aligned with the US rules, require CO_2 emission reductions of 6-23% and will be fully phased in by 2018.	14%	12	Technical Policy update (Sharpe, 2013)
Implemented	**Japan's** financial incentives for early compliance with the Phase 1 standard are in effect; the standard becomes fully enforceable in 2015.[c]	12%	12	Technical
Implemented	**US** Phase 1 standards came into effect starting with model year 2014 vehicles. The standards require CO_2 emission reductions of 6-23% and will be fully phased in by 2018.	14%	**76** [d]	Technical Policy update (Sharpe, 2011)
Implemented	**China** adopted Phase 2 fuel consumption standards in February 2014. The standard applied to new type approvals only a few months later, in July 2014; the standard is expected to reduce new fleet average fuel consumption 11% by July 2015.	11%	110	Technical Policy update (He & Tu, 2014)
	TOTAL		**210 MtCO_2**	

Implemented Adopted Proposed Delayed implementation

[a] Vehicle activity-weighted reduction in new fleet fuel consumption over the timeframe of the regulation.
[b] Estimates are rounded to two significant digits. Source: Façanha et al. (2012).
[c] MLIT (2012).
[d] CO_2-equivalent estimate. Source: US EPA (2011).

2.2. AIR POLLUTANT EMISSIONS OF LIGHT- AND HEAVY-DUTY VEHICLES

Light-duty vehicles (LDVs) are significant contributors to urban air quality issues, especially for pollutants that form in the atmosphere such as ozone and secondary PM. In countries that allow diesel LDVs to be sold, the light-duty fleet can also be a major source of direct PM emissions. The most stringent emission standards currently in effect are US Tier 2, Japan's New Post Long-Term Standards, and Euro 6. The US Environmental Protection Agency's (EPA) Tier 3 standards require significant improvements from the emission standards currently in force and could push the next generation of LDV emission controls. While heavy-duty vehicles (HDVs) in most countries constitute only a small share of the total vehicle fleet, they contribute more than two-thirds of exhaust PM and NO_X emissions from on-road vehicles. The most stringent emission standards for HDVs that have already been adopted are US 2010, Japan's New Post Long-Term Standards, and Euro VI. Most countries follow the pathway of emission standards developed in Europe, although many countries are up to a decade or more behind. In this publication, the stringent emission standards for LDVs and HDVs most recently adopted in the EU, US, and Japan are collectively referred to as Euro 6/VI-equivalent or better.

BOX 4. REGULATIONS FOR VEHICLE POLLUTION AND FUEL SULFUR CONTENT

The regulatory approaches for vehicle emissions and fuel quality developed in the US and EU provide a pathway that other countries can follow to improve the environmental performance of their vehicle fleets. Regulations for LDVs in the EU progress from Euro 1 to Euro 6 using Arabic numerals, and in the US include Tier 1, Tier 2, and Tier 3. US Tier 3 standards are largely harmonized with California's LEV III program, which sets the most stringent PM emission limits (1 mg/mi in 2025) of any LDV regulation in the world (the Tier 3 limit is slightly higher, at 3 mg/mi). HDV regulations in the EU progress from Euro I to Euro VI using Roman numerals, and in the US include EPA 2004, 2007, and 2010 standards. While the latest HDV standards effectively eliminate PM from diesel vehicles, there is still significant potential for advanced low-NO_X technologies. California has approved an optional program to certify HDV engines at up to 90% below the NO_X limits of the 2010 standards; such a program could be a precursor to the next generation of HDV emissions standards.

Regulations for LDVs require new vehicles to meet emission limits based on distance traveled, while those for HDVs tend to limit new vehicle emissions based on engine work done. Both standards tend to apply first to all new type approvals, followed by application to all new sales and registrations up to a year or so later. The timelines in this report refer to standards by the date of application to all new sales and registrations. The impact of these standards on fleetwide emissions depends on the rate of fleet turnover, which averages significantly longer for HDVs than for LDVs. In addition to setting stringent emission limits, the latest generation of emission standards also include requirements for on-board diagnostic (OBD) systems, extended engine durability periods, and in-use emissions testing to promote compliance over the lifetime of the vehicle. The latest standards for gasoline vehicles also include limits on evaporative emissions of hydrocarbons.

In the US, EU, and Japan, vehicle emissions regulations have accelerated the commercialization of advanced emission control technologies. Because many of these technologies require cleaner fuels to function optimally, vehicle regulations have been paired with fuel quality regulations that allow the proper function of emission controls as well as reduce emissions from the legacy fleet. Such regulations have proven to be a highly cost-effective means of controlling vehicle emissions, with the most recent Tier 3 LDV regulations in the US yielding 4.5 to 13 dollars of benefits for every dollar spent on cleaner vehicles and fuel (US EPA, 2014a). Today, the technologies for clean vehicles and fuels necessary to meet the latest regulations in the US, EU, and Japan are commercially available and can be transferred to other countries that adopt such regulations. For additional background on vehicle emissions standards, see Chambliss et al. (2013).

While this publication focuses on national-level policies, we recognize that several sub-national regions have routinely implemented more-stringent regulations than those currently in place at the national level. Such regions include California, Beijing, Tokyo, and others.

Six of eleven selected markets have yet to adopt Euro 6/VI-equivalent standards across LDVs, HDVs, and fuels, and some lag by two or more levels of emission standards. The implications of this lag are particularly severe for diesel vehicles, which effectively require the latest emission control technologies (e.g., diesel particulate filters) only starting at Euro 5 for LDVs and Euro VI for HDVs. Table 4 summarizes the vehicle emissions and fuel standards that are currently in effect for all sales and registrations in selected regions; where applicable, adopted regulations that have yet to be implemented are indicated as "Adopted."

Table 4. Light- and heavy-duty vehicle emissions and fuel sulfur standards in selected regions

Region	Percent of world vehicle sales 2013	Emission standards				Fuel sulfur standards			
		Light-duty		Heavy-duty		Gasoline		Diesel	
		Current[a]	Adopted	Current	Adopted	Current	Adopted	Current	Adopted
China	25%	China 4[b]	China 5	China IV		50 (10)[c]	10	350 (50, 10)	10
US	19%	Tier 2	Tier 3	US 2010		30	10	15	
EU	17%	Euro 5b	Euro 6	Euro VI		10		10	
Japan	6%	PNLT		PNLTES		10		10	
Brazil	4%	L-6		P-7		50		500 (10)	
India	4%	Bharat III	[d]	Bharat III		150		350 (50)	
Russia	3%	Euro 4	Euro 5	Euro IV	Euro V	150	10	350	10
Canada	2%	Tier 2	[e]	US 2010		30		15	
South Korea	2%	Euro 6		Euro V	Euro VI	10		10	
Australia	1%	'Core' Euro 5	Euro 6	Euro V / US07/JE05		150 (50)		10	
Mexico	1%	Tier 1 / Euro 3[f]		US 2004 / Euro IV		150 (30)		500 (15)	
Other countries	15%								

Euro-equivalent[g]

Euro 3/III	Euro 4/IV	Euro 5/V	Euro 6/VI	Post Euro 6/VI

[a] "Current" indicates standards apply to all vehicle sales and registrations. "Adopted" indicates standards that do not yet apply to all vehicle sales and registrations. Source: TransportPolicy.net.

[b] China 4 for light-duty vehicles applies to gasoline-fueled vehicles only. China 5 has been implemented in Beijing and Shanghai.

[c] Values in parentheses indicate higher quality fuel is available sub-nationally, but not required nationwide.

[d] As of April 2014, Bharat IV standards were in effect in 33 cities including the national capital region; however, a nationwide implementation date has yet to be formally adopted. In 2014, the Auto Fuel Policy Committee published recommendations for a nationwide roadmap to Bharat VI standards for vehicles and fuels; however, as of August 2014, these recommendations have yet to be officially notified as a government proposal.

[e] Canada has announced intention to harmonize with the US Tier 3 regulation; however, formal adoption had not occurred as of August 2014.

[f] Mexico is planning to revise its existing standards for diesel heavy-duty vehicles; however, as of August 2014, these revisions had yet to be officially notified as a government proposal.

[g] Euro-equivalent emission standards based on limit values.

From January 2013 through August 2014, several of the selected vehicle markets implemented new standards for LDVs and HDVs (Table 5); notably, Brazil and Russia began type approvals for light-duty standards based on Euro 5, while the EU and South Korea began type approvals for heavy-duty Euro VI standards. After several years of delay citing unavailability of high quality fuel, China has begun implementation of China IV standards. For reference, Table 5 summarizes the average reduction in limit values for PM and NO_x compared to the previous standards in each region. While the real-world reductions in emissions depend on a number of factors, such as the specific emission control technologies utilized, the success of compliance and enforcement programs, and the duty cycle of the vehicle, the regulatory developments since 2013 set a course for significantly improved air quality in over half of selected markets.

Table 5. Regulatory developments for light- and heavy-duty vehicle emissions in 2013-2014

Status	Regulatory development	Percent reduction in emissions[a]	More information
Light-duty vehicles			
Implemented	**Brazil** began type approvals for L-6 standards in January 2014. The standard will apply to all sales and registrations in January 2015. While based on Euro 5, L-6 does not include the particulate filter-forcing mass and number emission standards.	PM: **50%** NO_x: **50%**	Technical
Implemented	**Russia** began type approvals for Euro 5 vehicles starting in 2014. The standard will apply to all sales and registrations in January 2016.	PM: **80%** NO_x: **25-28%**	Technical
Adopted	**US** adopted Tier 3 emission standards, to be phased in from MY 2017 and fully implemented by 2025. The federal standards are largely harmonized with California's LEV III standards, which were adopted in 2012 and will be phased in starting MY 2015. Both Tier 3 and LEV III emission limits are significantly lower than those of Euro 6 (though LEV III requires a 90% reduction in PM, compared to 70% for Tier 3).	PM: **70%** NO_x: **80%**	Technical Policy update (German, 2014)
Heavy-duty vehicles			
Implemented	**China** implemented China IV standards for all sales and registrations in July 2013. China IV standards are closely aligned with Euro IV requirements.	PM: **80%** NO_x: **30%**	Technical
Implemented	**EU** implemented Euro VI standards for all sales and registrations in January 2014.	PM: **50%** NO_x: **80%**	Technical
Implemented	**South Korea** began type approvals for Euro VI standards in January 2014. The standard will apply to all sales and registrations in January 2015.	PM: **50-65%** NO_x: **77-80%**	Technical
Implemented	**Russia** began type approvals for Euro V standards in January 2014. The standard will apply to all sales and registrations in January 2016.	NO_x: **43%**	Technical

Implemented Adopted Proposed Delayed implementation

[a] Percent reductions in PM and NO_x emissions are estimated based on the limit values of the new standard compared to the previously implemented standard in that region. Source: TransportPolicy.net.

2.3. SULFUR CONTENT OF GASOLINE AND DIESEL ON-ROAD FUELS

Fuel quality, most notably the sulfur content of gasoline and diesel, is key to the implementation of advanced vehicle emission controls. For optimal function of emission controls, Euro 3/III vehicles generally require a maximum sulfur content of approximately 350 parts per million (ppm) for diesel and 150 ppm for gasoline, and Euro 6/VI-equivalent vehicles require fuel as low as 10 ppm sulfur. Limiting the sulfur content of fuels also reduces emissions from legacy fleets (Blumberg et al., 2003), and previous research indicates that can be done at less than a few cents per liter (Hart Energy & MathPro Inc. 2012). In fuel importing countries, comprehensive fuel quality regulations can have immediate effects without changes to fueling infrastructure; in fuel producing countries, refinery upgrades can be required or incentivized through relaxed fuel price controls, direct subsidies, or tax incentives.

Progress in reducing sulfur levels in on-road fuels around the world has been significant but uneven since 2001. Currently, only six of the selected vehicle markets limit diesel sulfur content to 15 ppm or less nationwide, with China committing to do so by 2018. And while eight of the selected vehicle markets limit gasoline sulfur content to fewer than 50 ppm nationwide, only six have committed to tighten this limit to 10 ppm, the level recommended for world-class vehicle emission controls.

Table 6. Regulatory developments in nationwide fuel quality in 2013-2014

Status	Regulatory development	Fuel sulfur content (ppm)	More information
	Gasoline		
Implemented	**Brazil** phased out 1,000 ppm gasoline in favor of 50 ppm nationwide as of January 2014.	**50**	Technical
Adopted	**China** issued a regulation in accordance with a 2013 State Council mandate requiring China V gasoline below 10 ppm sulfur nationwide by 2018.	**10**	Technical Policy update (Wagner & Yang, 2014)
Adopted	**US** adopted Tier 3 emission standards which will reduce gasoline sulfur content from an average of below 30 ppm to below 10 ppm by 2017.	**10**	Technical Policy update (German, 2014)
	Diesel		
Implemented	**Brazil** phased out 1,800 ppm diesel in favor of 500 ppm nationwide; as of January 2013, 10 ppm diesel is available in major cities and select stations to fuel P-7 trucks.	Nationwide: **500** Major cities: **10**	Technical
Adopted	**China** issued two regulations in accordance with a 2013 State Council mandate requiring nationwide China IV diesel (50 ppm) by 2015, and China V diesel (10 ppm) by 2018.	2015: **50** 2018: **10**	Technical Policy update (Wagner & Yang, 2014)

Implemented   Adopted   Proposed   Delayed implementation

2.4. INTERNATIONAL MARINE VESSELS

Emissions of CO_2, sulfur oxides (SO_x), and NO_x from international marine vessels are regulated by the International Maritime Organization (IMO). Two newly adopted—and one delayed—marine emission reduction policies are summarized in Table 7. In 2013, the Energy Efficiency, Design Index (EEDI) entered into force, becoming the first regulation to establish CO_2 emission standards across a global sector. EEDI essentially requires new ships to be progressively more efficient from 2015 through 2025, as compared against the average 2000-2010 ships of the same type. For non-CO_2 pollutants, 2014 saw the successful implementation of the newest emission control area (ECA), the US Caribbean Sea ECA, to regulate NO_x and SO_x emissions. ECAs are sea areas that are specially designated by the IMO for enhanced mandatory measures to control air pollution from ships, including maximum fuel sulfur content and exhaust NO_x emission levels (IMO, 2014). Today, ships traveling in ECAs must meet stricter fuel sulfur requirements than elsewhere; and in 2016, new ships will be required to meet special NO_x emission standards (Tier 3) when traveling within ECAs. Following Russia's proposal to delay the implementation of Tier 3 NO_x standards in ECAs, the IMO upheld the 2016 implementation date for existing ECAs (including the US Caribbean ECA), but delayed this date for NO_x ECAs entering into force in later years.

Table 7. Regulatory developments in international marine in 2013-2014

	Regulatory development	Effect of policy	More information
	Efficiency		
● (Implemented)	Adopted by the **IMO** in 2011, the EEDI entered into force in 2013, applying to all global ships over 400 gross tonnage. EEDI requires new build ships to be 10% more efficient by 2015, from a baseline representing the average efficiency for ships built between 2000 and 2010.	New build ship efficiency improvement in 2015: **10%** 2020: **20%** 2025: **30%**	Technical
		340 $MtCO_2$ in 2030 (lifecycle)	Publication (Wang & Lutsey, 2013)
	Emissions		
● (Implemented)	The **US Caribbean Sea ECA** became enforceable in January 2014, reducing fuel sulfur content from 3.5% to 1%. This limit tightens to 0.1% sulfur in 2015, and Tier 3 NO_x standards become enforceable in 2016.	Reduction in fuel sulfur: 2014: **71%** 2015: **90%** NO_x reduction with Tier 3: 2016: **74-76%**	Technical
● (Delayed implementation)	After a **Russian** proposal to delay the implementation of Tier 3 NO_x standards to 2021, IMO reached a compromise that upholds implementation in existing ECAs in 2016; Tier 3 in future ECAs will be determined by the date of application approval.	NO_x reduction with Tier 3 in existing ECAs 2016: **74-76%** Tier 3 NO_x in future new ECAs: **delayed**	Blog (Rutherford, 2014)

● Implemented ● Adopted ● Proposed ● Delayed implementation

2.5. INTERNATIONAL AVIATION

Although no new regulations for international aviation emissions have been proposed, adopted, or implemented in the study period, two policy developments at the Ninth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP) merit mention. The first is a new CO_2 certification requirement for new aircraft, which will serve as a key building block for the CO_2 standard under development by ICAO by 2016 (Rutherford, 2013). The second is a revised "Chapter 14" noise standard for new aircraft, which will take effect in 2017 and aim to address existing noise problems at airports, notably in Europe (Dickson, 2013).

2.6. LOW-CARBON FUELS

There have been a number of significant low-carbon fuel policy developments in 2013 and early 2014. Table 8 summarizes the low-carbon fuel policies that have recently seen proposed revisions (and are already being implemented) to promote increased deployment of low-carbon fuels. The California Low Carbon Fuel Standard (LCFS) was originally proposed in 2009 and has been implemented since 2010. The LCFS is a fuel-neutral performance standard that would reduce average road transport fuel carbon intensity, measured in grams CO_2e per megajoule of fuel, 10% by 2020 by requiring fuel providers to increasingly mix in lower carbon fuels to displace conventional gasoline and diesel fuels. This regulation will require increasing use of biofuels, natural gas, and electricity with documented low lifecycle GHG characteristics in vehicles through 2020. The LCFS has withstood several legal questions through 2014, is being implemented, and is expected to adopt several revisions in the 2014-2015 timeframe. The US EPA's Renewable Fuel Standard (RFS) has established various requirements for increasing the volume of biofuels (and other eligible renewable natural gas and electricity sources) up to 36 billion gallons through 2022. These include minimum requirements of fuels within given categories, which have associated minimum required GHG reductions (i.e., of 20%, 50%, and 60%) compared to gasoline and diesel fuels. The US RFS has added many eligible low-GHG fuel pathways in 2013 and early 2014, and has continued to revise the biofuel volume targets within each fuel category from year to year (see US EPA, 2014b).

Table 8. Regulatory developments in low-carbon fuel policy in 2013-2014

Status	Regulatory development	Effect of policy	More information
Implemented	**California** is implementing its Low Carbon Fuel Standard, which requires increasingly stringent road transport fuel GHG intensity (gCO_2e/MJ fuel) reductions from 2011 through 2020. New low-carbon fuel pathways were proposed and adopted in 2014.[b] The adopted 2020 goal would require an average 10% reduction by 2020.	**23** $MtCO_2e$ in 2020[a]	Technical Policy update (Baral, 2010)
Implemented	The **US** adopted and implemented new 2013 requirements, proposed revised biofuel volume requirements for 2014-2015, and adopted new eligible low-carbon fuel pathways in its Renewable Fuel Standard.[c]	**138** $MtCO_2e$ in 2022[d]	Technical Policy update (Baral, 2011)
Proposed	In June 2014, the EU's Energy Council reached a political agreement on proposed revisions for GHG accounting in its Fuel Quality Directive, which requires fuel suppliers to reduce road transport fuel carbon intensity 6% by 2020. Additionally, the EU proposed caps for particular fuel types and added incentives for cellulosic biofuels in its Renewable Energy Directive, which requires 10% renewable energy content in the road transport fuel pool by 2020.[e]	**62** $MtCO_2$ in 2020	Technical Policy update (Malins, 2014)
	TOTAL	**223** $MtCO_2$	

Implemented   Adopted   Proposed   Delayed implementation

[a] Policy effect refers to the LCFS as a whole as opposed to the new low-carbon fuel pathways (CARB, 2009).
[b] Green Car Congress (2014)
[c] US EPA (2014b)
[d] US EPA (2010)
[e] Both the FQS and RED were adopted in 2009. The proposed revisions for GHG accounting, also referred to as the "iLUC proposal", would amend the FQD if passed. For additional details, see Malins (2014).

We note that there are a number of other fuel-carbon-related policies that are actively being developed, revised, and implemented. Most prominently, the EU's Fuel Quality Directive (FQD) and Renewable Energy Directive (RED) would require that road transport fuel GHG intensity be reduced by 6% (up to 10%) and that 10% of transport is fueled by renewable sources by 2020 (European Union, 2009a; European Union, 2009b). The EU's FQD has seen a number of proposed revisions, including those related to its inclusion of indirect land use change in the lifecycle GHG accounting and the capping of food- and feed-based fuels (Malins and Searle, 2012; Malins, 2014). There are also a number of underlying efforts in EU member states, Canadian provinces, and other US states. Other biofuel targets and policies without specific GHG reduction criteria are also being implemented, and these are discussed further in Section 3.3.

CHAPTER 3. IMPACT ASSESSMENT OF CLEAN TRANSPORT POLICIES

This chapter provides additional background on regulations in each transport sub-sector, compares regulatory progress among selected vehicle markets, and quantitatively assesses the impacts of adopted and potential policies on climate, energy, emissions, and health. Each quantitative comparison purposefully considers only those standards that have been formally adopted into law by national governments as the "Adopted" policies case. Other policies that have been proposed or are under discussion could capture a portion of the potential benefits if successfully implemented. Although there are no regulatory updates in international aviation from January 2013 through August 2014, this chapter includes upcoming regulatory opportunities for a global CO_2 standard and market-based measures.

While policies are broadly categorized as targeting either energy consumption and GHGs or local air pollutants and health, we acknowledge that there are significant co-benefits in each category. In particular, black carbon (BC) is the second most important climate pollutant after CO_2 in terms of its climate forcing impacts, and Euro VI-equivalent emissions standards for diesel vehicles are capable of cutting BC emissions from the new vehicle fleet on the order of 99%. The climate co-benefits of local air pollutant emissions standards are examined in Chambliss et al. (2013).

3.1. ENERGY CONSUMPTION OF LIGHT-DUTY VEHICLES

Fuel efficiency and GHG standards for light-duty vehicles (LDV) have a strong record of success in reducing fuel consumption and GHG emissions of passenger cars, light trucks, and sport utility vehicles (SUV). Fuel economy regulations were first implemented in the US in the 1970s to reduce vulnerability to the price volatility of oil imports. After initial gains, LDV efficiency in the US stalled as technology improvements were offset by increases in vehicle size and performance. Other regions such as Japan and the EU pursued a combination of high fuel taxes and fiscal measures to encourage the sale of more efficient vehicles. In recent years, many of the largest markets have adopted or implemented mandatory fuel efficiency and GHG standards to ensure that new vehicle fleets become progressively more efficient and utilize available and emerging cost-effective technologies.

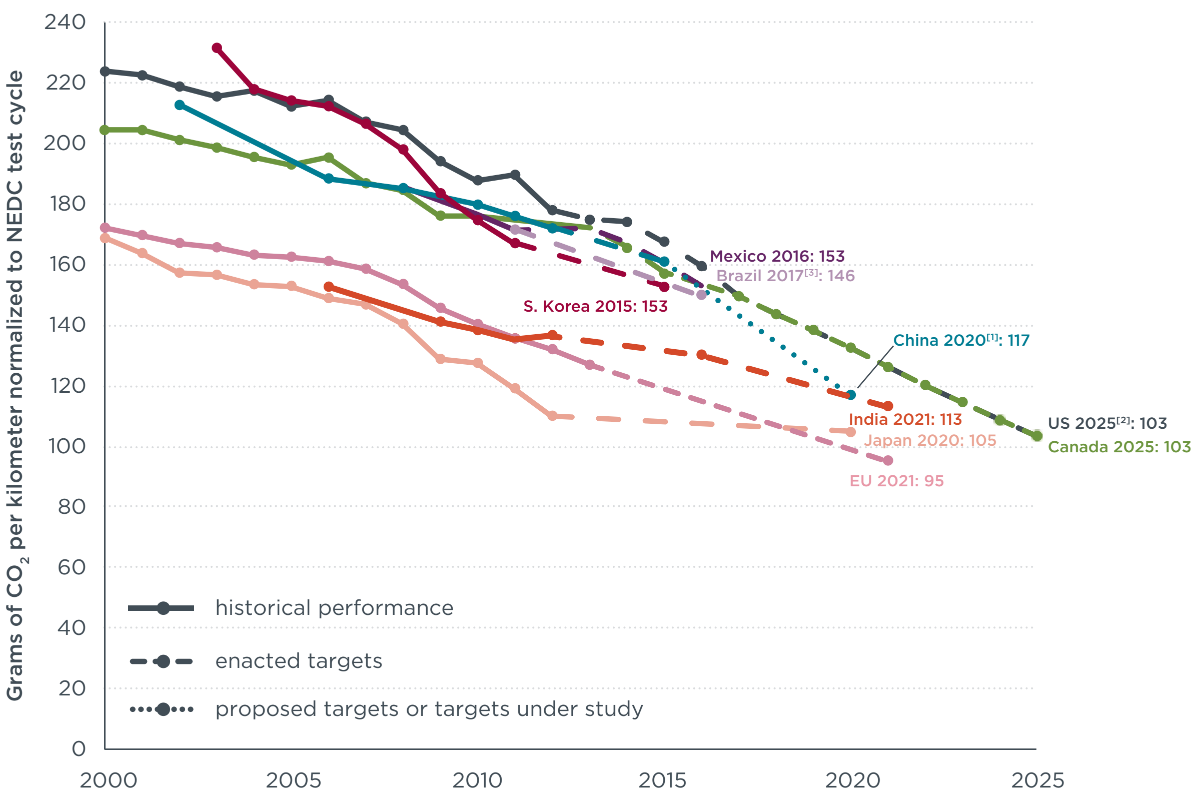
Context

Most of the world's top vehicle markets have adopted regulations requiring vehicle manufacturers to improve the energy efficiency of new LDVs. Such standards set targets for new vehicle fleets based on CO_2, GHG emissions, fuel consumption, or fuel economy (see Box 4); these vehicle efficiency standards are differentiated from vehicle emission standards, which limit emissions of local air pollutants from vehicles.

BOX 4. METRICS FOR VEHICLE EFFICIENCY AND GHG STANDARDS

Depending on the regulatory authority and objectives of the standard-setting agency, some regulations set targets for fuel consumption (e.g., MJ/km, L/100km) or fuel economy (e.g., mpg, km/L), while others directly target CO_2 or GHG emissions (e.g., grams CO_2 / km, grams CO_2e/mile); still others include targets for both. For ease of comparison, these policies are collectively referred to as "efficiency standards" throughout this report.

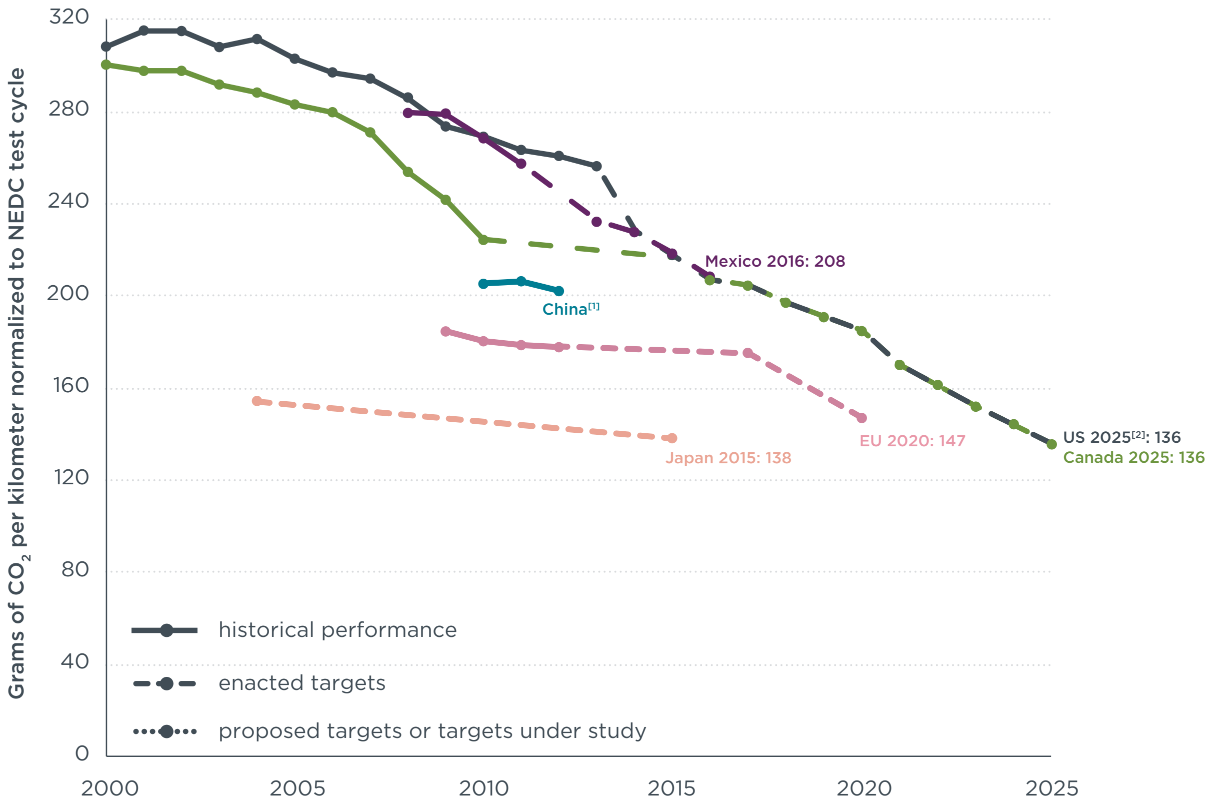
Efficiency standards for LDVs have proven to be a highly cost-effective means of cutting CO_2 emissions: recent regulations in the US, EU, and China have resulted in fuel savings that pay off the incremental vehicle costs within one to five years (Federal Register, 2010; Façanha et al., 2012). The ICCT compares corporate average vehicle efficiency requirements for the new fleet across countries that have adopted efficiency standards or comparable fiscal instruments (Figure 4 & Figure 5). We also note that North American standards include passenger cars, light trucks, and SUVs, while the EU addresses passenger cars and light commercial vehicles in separate regulations. To date, the US has adopted the longest regulatory timeline for LDV GHG standards, out to 2025, and Canada is expected to harmonize with the US regulations. For China, the EU, Japan, and India, the stringency of standards for the 2021-2025 period could determine the global leader in LDV efficiency. In Brazil, South Korea, and Mexico, the next several years are a critical period to determine whether they will keep pace with other top vehicle markets.



[1] China's target shown here reflects gasoline vehicles only. The target will be more stringent after new energy vehicles are considered.
[2] US values reflect fuel economy standards set by NHTSA and exclude the credits for low-GWP refrigerants established under the GHG standards set by EPA.
[3] Gasoline in Brazil contains 22% ethanol (E22); all data in the chart have been converted to gasoline (E00) equivalent.

Figure 4. Global comparison of passenger car efficiency standards (He & Yang, 2014c).

For supporting data, see www.theicct.org/info-tools/global-passenger-vehicle-standards.

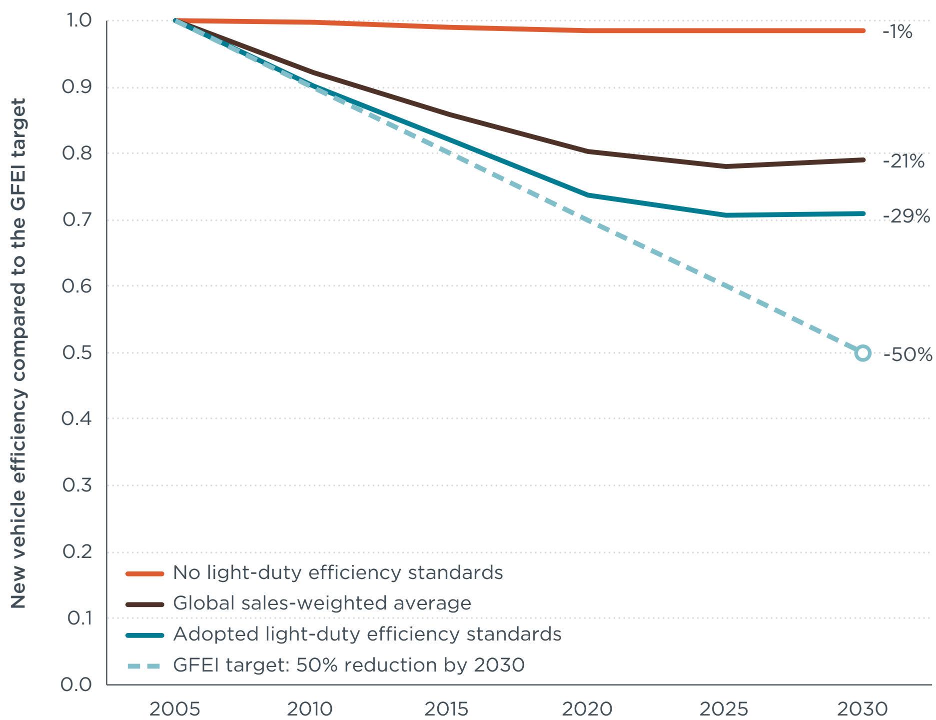


[1] China's target shown here reflects gasoline vehicles only. The target will be more stringent after new energy vehicles are considered.
[2] US values reflect fuel economy standards set by NHTSA and exclude the credits for low-GWP refrigerants established under the GHG standards set by EPA.

Figure 5. Global comparison of light commercial vehicle efficiency standards (He & Yang, 2014c). *For supporting data, see* www.theicct.org/info-tools/global-passenger-vehicle-standards.

Outlook and projections

Recent progress in light-duty efficiency regulations highlights the potential for further improvements in the selected regions, as well as opportunities for expansion to other vehicle markets. The ICCT is a partner of the Global Fuel Economy Initiative (GFEI), a consortium that aims to halve the fuel consumption of new LDVs from 2005 to 2030 by strengthening and expanding the adoption of LDV efficiency standards (GFEI, 2014). Figure 6 compares progress under LDV efficiency standards adopted to date with the 2030 GFEI target. Some countries are on track to meet the GFEI target with their adopted standards: the US 2017-2025 rule is expected to achieve this target five years early; Japan and the EU could achieve the GFEI target by adopting 2025 standards. China's adopted Phase 3 standards will achieve about one-third of the targeted improvement; while Phase 4 will push progress further, follow-up 2025 standards would be needed to reach the GFEI target. Mexico and Canada could get close to the GFEI target by harmonizing with the US through 2025; South Korea and Brazil would have to move relatively quickly to meet the target, likely with two phases of standards. Russia and Australia have yet to adopt efficiency standards and would likely need several consecutive phases of standards to reach such a target. Most countries outside of the selected markets have yet to adopt vehicle efficiency standards; developing such standards in these markets would result in significant benefits in addition to those achievable through future phases of existing standards.



Status	Region	Projected share of global light-duty vehicle sales in 2030	Reduction in new light-duty vehicle fuel consumption with adopted standards, 2005-2030
Adopted light-duty efficiency standards	**China**	27%	15%
	EU	14%	40%
	US	15%	50%
	India	7%	26%
	Japan	2%	38%
	Brazil	2%	12%
	Canada	1%	24%
	Mexico	3%	19%
	South Korea	2%	24%
	Total	**74%**	**29%**
No light-duty efficiency standards	**Russia**	4%	0%
	Australia*	1%	17%
	Other countries	21%	0%
	Total	**26%**	**1%**
Global sales-weighted average		**100%**	**21%**

Figure 6. Progress of adopted light-duty efficiency standards toward the 2030 GFEI target

** While Australia has not adopted mandatory standards, its substantial improvement in vehicle fuel economy is due to an effective labeling program and voluntary CO_2 reduction commitments from industry.*

Sales-weighted averages include projected sales of passenger cars and light commercial vehicles through 2030 (ICCT, 2014). Includes only policies that have been formally adopted; proposals such as China Phase 4 are not counted here.

Figure 7 compares projected LDV CO_2 emissions under three scenarios. Compared to business-as-usual trends, standards adopted to date will reduce annual lifecycle emissions by 1.5 $GtCO_2$, equivalent to 8.2 mbd, in 2030. Another 1.1 $GtCO_2$, or 5.8 mbd, could be achieved if existing programs in the US, Canada, China, EU, Japan, Brazil, India, South Korea, and Mexico were extended to 2030, and these programs were joined by new programs in Russia and Australia. Combined, these policies could reduce emissions from the LDV sector by 37% in 2030. Some regions are already considering policies that would exceed the 50% reduction in new vehicle fuel consumption targeted by the GFEI: for example, California has called for 5% annual improvements in light- and heavy-duty vehicle efficiency through 2025 and beyond (CARB, 2014a).

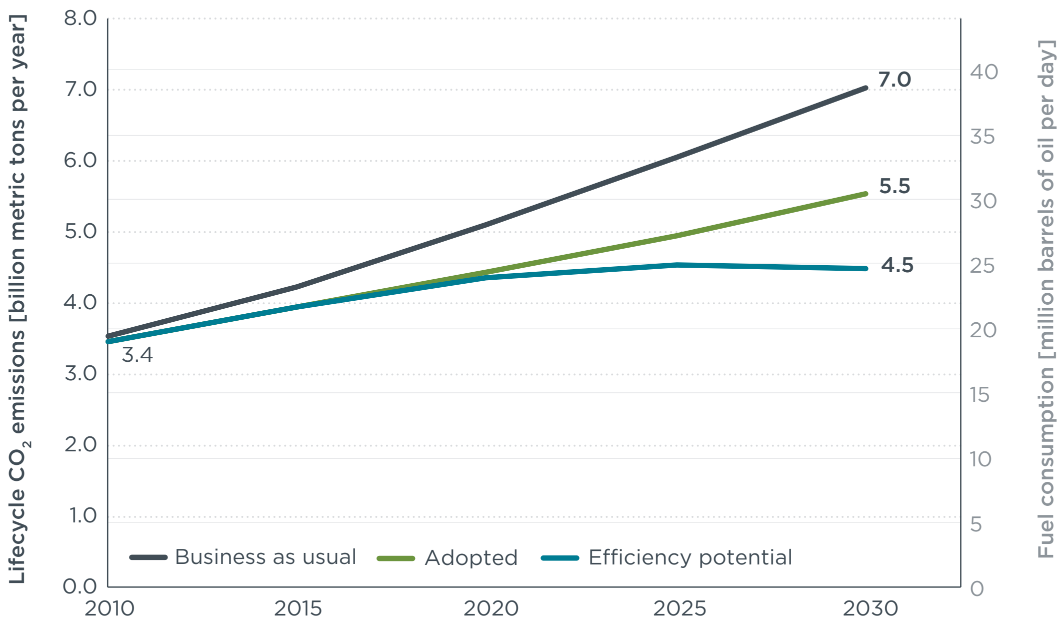


Figure 7. Impact of light-duty efficiency standards on global lifecycle CO_2 emissions

Estimated using ICCT's Global Transportation Roadmap model (ICCT, 2014). ***Business as usual*** *= vehicle efficiency remains at 2005 levels.* ***Adopted*** *= currently adopted policies.* ***Efficiency potential*** *= eleven of the top vehicle markets adopt standards that reduce the average fuel consumption of new vehicles by 4% per year from 2021 to 2030; other markets adopt such standards from 2026 to 2030. Such policies are broadly consistent with GFEI's target to reduce new fleet average fuel consumption by 50% compared to 2005 levels by 2030 (GFEI, 2014).*

Electric-drive vehicles

As vehicle emissions and efficiency standards become increasingly stringent, they help to encourage the integration of advanced technologies, lightweight materials, and zero-tailpipe emission electric-drive technologies. Electric-drive vehicles, including plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs), are becoming increasingly competitive with conventional internal combustion engine vehicles with respect to range, performance, and cost. Electric vehicles still account for a small share of overall passenger car sales—less than one percent in most of the top vehicle markets in 2013, with higher shares in the US (1.3% nationwide, and 4% in California), the Netherlands (5.6%), and Norway (6.1%) (Mock & Yang, 2014). However, there has been rapid growth in the number of models available, for example, from nine in 2012 to seventeen in 2013 in the US (InsideEVs, 2014). Moreover, total sales of BEVs and PHEVs have increased rapidly since 2009, doubling year-over-year from 2011 to 2012, and again from 2012 to 2013 (Figure 8) (Mock & Yang, 2014).

While the bulk of these sales have occurred in the US, EU, Japan, and China, numerous regions have adopted tax exemptions, direct subsidies, and other non-fiscal incentives to encourage the sale of electric-drive vehicles. Besides various forms of incentives, perhaps the most significant electric-drive vehicle policy to date is California's Zero Emission Vehicle (ZEV) program, which requires manufacturers to meet an increasing share of vehicle sales with PHEV, BEV, and FCEV technologies. California Air Resources Board (CARB) analysts have forecast electric-drive vehicles to account for 15% of model year 2025 vehicles sold in California as a result of the ZEV program (CARB, 2012). California has also implemented policies to promote ZEV buses such as the "Transit Fleet Rule", which requires transit operators to reduce fleetwide PM and NO_X emissions with alternative fuels, advanced technologies, or retrofits (CARB, 2014b). Such policies highlight the potential of ZEV technologies to simultaneously mitigate climate and health impacts of transportation. Replacing conventional technologies with zero-tailpipe-emission BEVs and FCEVs could be especially beneficial for air quality in densely populated urban areas and near major roadways.

In addition to direct incentives, many adopted efficiency standards provide credits to accelerate the development and commercialization of advanced technologies, including electric-drive vehicles. These vehicles will become increasingly important to achieve long-term decarbonization of on-road transport; as such, achieving this potential will benefit from early policy action on multiple fronts, including light-duty efficiency standards, direct incentives, and supporting infrastructure investments.

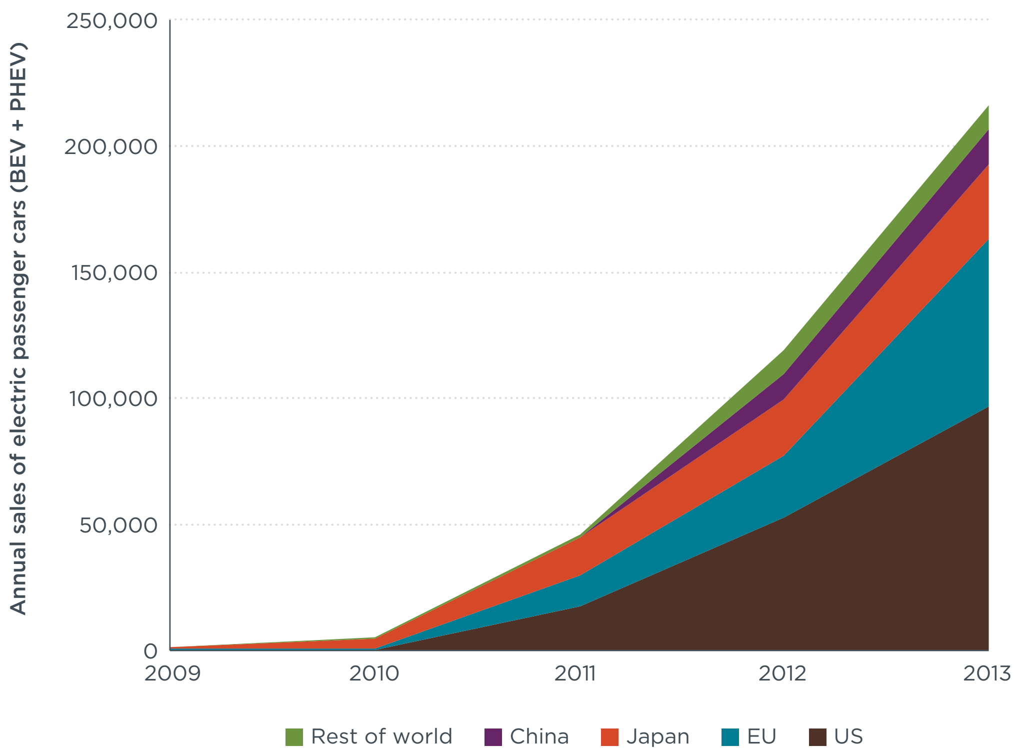


Figure 8. Annual global sales of electric passenger cars, 2009-2013 (Mock & Yang, 2014)

3.2. ENERGY CONSUMPTION OF HEAVY-DUTY VEHICLES

Heavy-duty vehicles (HDVs) encompass a wide range of vehicle types, including large pickups, delivery trucks, long-haul tractors, refuse trucks, urban buses, and coaches. The diversity of heavy-duty fleets—both in vehicle characteristics and duty cycles—makes regulating their fuel consumption and GHG emissions more challenging than for LDVs. Key components of HDV regulations include the metric for efficiency or GHG emissions, vehicle types covered (segmentation), test methods for certification, and means of enforcement.

Context

To date, only four markets have adopted national efficiency regulations for heavy-duty trucks and buses (Japan, the US, Canada, and China). The first HDV GHG regulations in the US and Canada are just now coming into effect. Although Japan adopted its Phase 1 standard as early as 2006, it will not become fully enforceable until 2015, the same year as China's recently adopted Phase 2 regulation. In addition to regulations for new vehicles, California requires in-use long-haul tractors and box-type trailers—the highest fuel-consuming segment of heavy-duty trucks—to retrofit or replace affected vehicles with certified aerodynamic technologies and low rolling resistance tires.

Studies by the National Academy of Sciences (2010) and TIAX (2009) for the US market and AEA-Ricardo (2011) and TIAX (Law et al., 2011) for the European market have found a technical potential to reduce the fuel consumption of most types of HDVs by 40% to 50% from 2009 to 2020. A comparison of the estimated reductions in fuel consumption indicates that Japan, China, the US, and Canada will capture roughly a third of this potential by 2020 with adopted regulations (Figure 9).

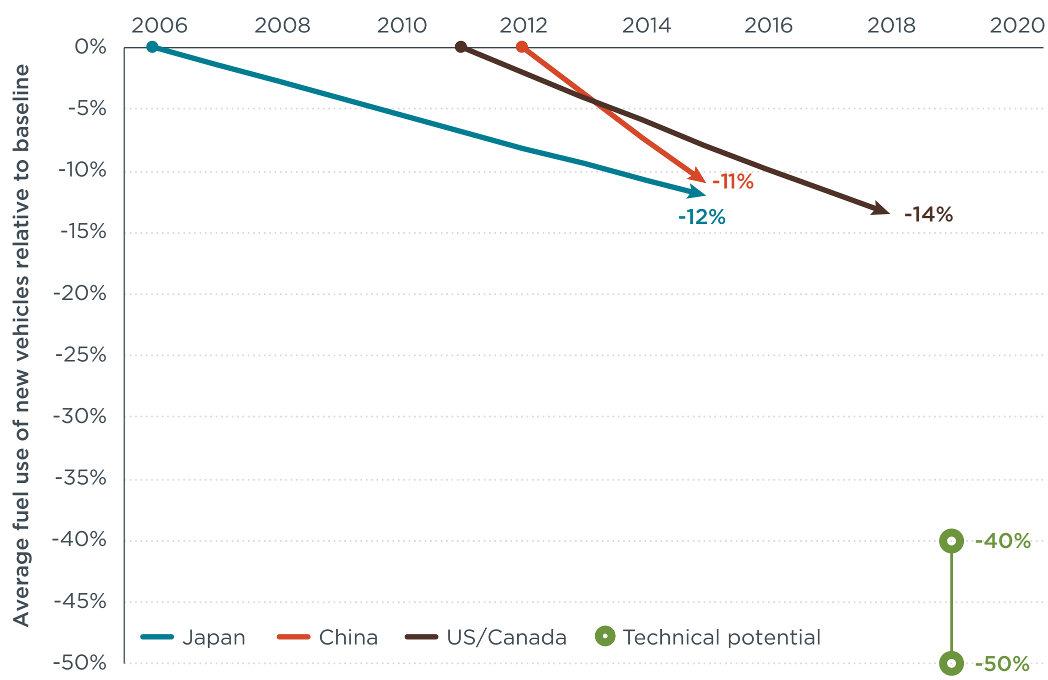


Figure 9. Global comparison of heavy-duty vehicle efficiency standards

Annual reduction in fuel use estimated from vehicle activity-weighted fleet average over the duration of the regulation. Improvements shown beginning in year enacted.

Outlook and projections

Additional heavy-duty efficiency regulations are under consideration in major markets around the world. Beyond the existing four regulated markets (i.e., Japan, US, Canada, and China) there is also activity toward HDV efficiency standards in the EU, India, South Korea, and Mexico. California, the US, and Canada have begun work on Phase 2 efficiency standards, which are anticipated to apply to new 2019 and later models (Lutsey, 2014). While Mexico has harmonized with US light-duty standards with a delay of several years, a recent tripartite commitment with the US and Canada shows promise for harmonization of heavy-duty efficiency and emissions regulations (Blumberg, 2014). China is also working toward its next phase of standards for 2020 and later HDVs, and India has formed a high level committee to formulate an action plan. These markets (China, the US, the EU, Japan, India, Canada, South Korea, and Mexico) accounted for over three-quarters of global heavy-duty freight activity (tonne-km) and energy use in 2010 (ICCT, 2014). In addition, a number of countries around the world are also investigating voluntary green freight programs that would provide in-use fleet efficiency improvements and could serve as building blocks toward future efficiency standards.[2] The policies which are currently under discussion could result in significant fuel savings to owners and operators; while payback periods vary by regulatory design, vehicle type, and region-specific activity patterns, HDV standards in this timeframe typically have payback periods of one to four years.

Figure 10 compares projected CO_2 emissions from the global HDV fleet under three scenarios. Adopted policies are forecast to reduce emissions by 0.26 $GtCO_2$ by 2030, equivalent to 1.4 mbd, as compared to business-as-usual trends in the absence of standards. However, if vehicle activity of buses and trucks continues to grow according to recent trends, HDV efficiency would need to improve at a faster rate going forward to stabilize GHGs and fuel consumption. The *Technical potential* trajectory assumes that new HDV standards improve fuel consumption by 3.5% annually starting in 2020 in the selected vehicle markets, and 2025 in the rest of the world. This level of progress could reduce another 0.65 $GtCO_2$ (3.4 mbd) in 2030, and essentially stabilize global HDV emissions after 2025. Combined, these policies could reduce GHG emissions and fuel use from the heavy-duty vehicle sector by 26% in 2030.

2 Green freight programs are voluntary initiatives that encourage the introduction of efficient technology and implementation of operational measures to improve truck efficiency.

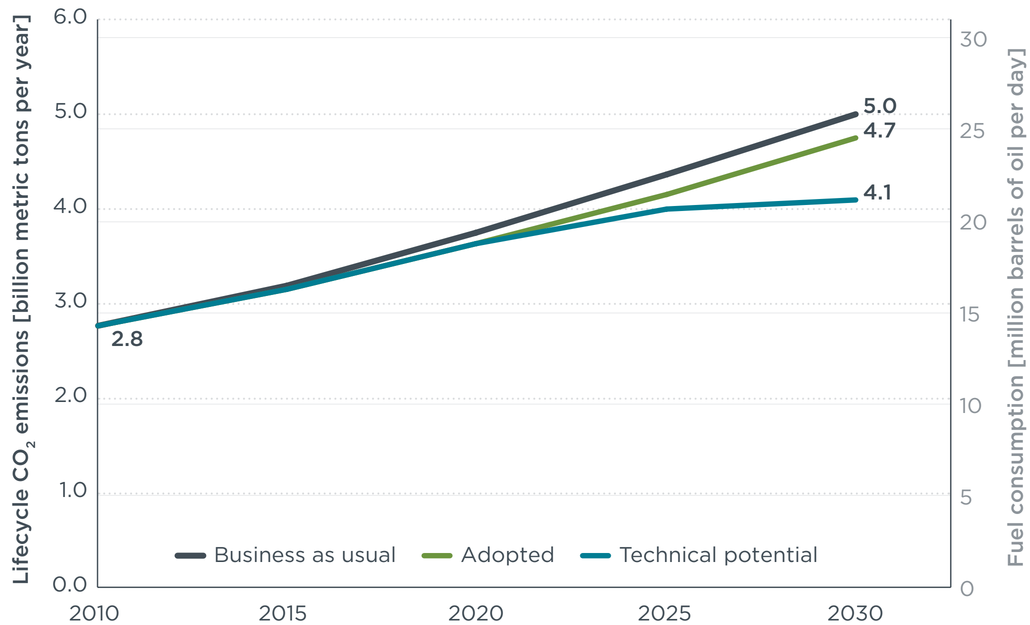


Figure 10. Impact of heavy-duty efficiency standards on global CO_2 emissions

Estimated using ICCT's Global Transportation Roadmap model *(ICCT, 2014).* ***Business as usual*** *= vehicle efficiency remains at 2005 levels.* ***Adopted*** *= currently adopted policies.* ***Technical potential*** *= new HDV standards improve fuel consumption by 3.5% annually starting in 2020 in selected vehicle markets, and 2025 in the rest of the world.*

3.3. CARBON INTENSITY OF ON-ROAD FUELS

Since the mid-2000s, a number of governments have aimed new policies aimed at promoting alternative fuels in the transport sector. Prominent alternative transport fuel sources that governments are encouraging to support their climate mitigation goals include biofuels, lower carbon fossil fuels (e.g., natural gas), and electricity. These policies tend to have a number of objectives, including to increase fuel diversity in the transport sector by displacing oil usage, to reduce the lifecycle carbon intensity of transport fuels, and to increase agricultural economic development. This section considers the use of alternative transport fuel policy to reduce lifecycle GHG emissions.

Context

Table 9 summarizes major efforts over the last ten years to promote alternative fuels. By and large these policy goals are stated in the form of volumetric biofuel targets, with smaller targets of 0.1-1.0 billion gallons per year in countries like Japan and Australia and up to 36 billion gallons per year in the US by 2022. The policies in the US (including California) and the EU include specific regulatory GHG emission and fuel requirements for fuel providers to increasingly mix lower-carbon fuels, including low-GHG biofuels, renewable natural gas, and renewable electricity, into the transport fuel supply.

Table 9. Summary of policies to promote alternative fuels in transport

	Policy name	Biofuel-related targets
EU	Renewable Energy Directive (RED)	10% renewable energy in transport by 2020
	Fuel Quality Directive (FQD)	6% reduction in fuel GHG intensity by 2020
	Deployment of alternative fuels infrastructure Directive	Minimum levels of infrastructure for refuelling and recharging stations by 2020/2025
US	Renewable Fuel Standard (RFS)	36 billion gallons/year of biofuels by 2022
California	Low Carbon Fuel Standard (LCFS)	10% reduction in fuel GHG intensity by 2020
China	National Plan	4 billion gallons/year by 2020, E10 in 10 provinces.
India	National Policy on Biofuels	Increasing to 20% by 2017.
Canada	Renewable Fuel Standard	5% ethanol in 2010 gasoline, 2% biodiesel in 2012 diesel
Mexico	Law for the promotion and development of bioenergy	2% biofuel usage in selected areas (Guadalajara, Monterrey, Mexico City) by 2011-2012
Japan	Biomass Nippon Strategy	1 billion gallons/year by 2030
Australia	Energy Grants Scheme; Ethanol Production Grants	0.1 billion gallons/year biofuels by 2010
Brazil	Mandatory Biodiesel Requirement; Ethanol fuel program	5% biodiesel by 2010; 25% ethanol by 2007

Source: Malins et al. (2014). "E10" = 10% ethanol, 90% gasoline

As indicated above, many countries have now established targets for increased biofuel deployment for future years. From a GHG mitigation perspective, the most significant of these global alternative fuel policy efforts are those in the US and EU. In the US, there are two major alternative fuel policies that require accounting of, and reduction in, transport fuels' lifecycle carbon intensity. The national US RFS provides specific minimum lifecycle GHG-reduction requirements for biofuels within several different biofuel categories. California's LCFS goes further, placing specific fuel carbon ratings on all distinct biofuels, and using an increasingly stringent performance standard to reduce the average lifecycle carbon intensity of all on-road transport fuels sold in California through 2020. The EU's Fuel Quality Directive (FQD) similarly utilizes a performance standard to require a reduction in the average on-road fuel supply's GHG intensity. Policies in the EU, US, and California have moved toward greater rigor, analysis of more fuel pathways, and comprehensive lifecycle accounting of land use effects to better differentiate the sustainable fuels that are reliably low-carbon. Although not listed in the table, a number of EU member states (e.g., Germany, United Kingdom) are developing programs within the EU directive framework. In addition, several Canadian provinces (e.g., British Columbia) and other US states (e.g., Oregon) are also developing and implementing biofuel and low-carbon fuel policies.

Outlook and projections

As indicated above in Chapter 2, the EU, US and California are still actively developing their policies, addressing key challenges related to how they promote various fuels (biofuel, fossil fuel, and electric-drive fuel sources). Critical attributes of these EU and California policies include their ability to account for, monitor, and improve the lifecycle emissions of fossil fuels. For example, one key determinant is if and how the regulations account for, and discourage deployment and investment in, fuels with *higher* upstream carbon emissions, like Canadian tar sands and Venezuelan heavy oils, which can have

15-20% or greater lifecycle GHG emissions than conventional crude oil. Fuel policies that clearly disincentivize the use of high-carbon fossil fuels for transport are lacking, with the possible exception of California's LCFS.

Another important factor in these fuel carbon policies is whether and how the regulations can increasingly promote only fuels with reliably low lifecycle carbon, low indirect land use, and minimal food system interaction. For example, most current biofuel policies are driving conventional biofuels (i.e., from corn, soy, wheat, and rapeseed) with relatively high GHG emissions. On the other hand, recent EU-based findings indicate that up to 16% of road transport fuel could be derived from low-carbon waste-based sources by 2030 (Harrison et al., 2014). Such findings provide an indication of how fuels policies might shift from conventional food-based feedstocks toward less land-intensive and lower-carbon feedstocks.

As indicated above, California and the EU each continue to evaluate and revise their detailed provisions to strengthen their capacity to reduce fuel carbon intensity by 10% and 6%, respectively, in the 2020 timeframe. As a result of the relatively early and somewhat "in flux" nature of global low-carbon policies, we assess only rather limited scenarios for the potential GHG reductions that could result from such policies. The technical potential scenario considers the global implementation of low-carbon fuel policies that result in a 10% reduction in the lifecycle GHG intensity of on-road fuels and are phased in from 2020-2030. This potential represents a simplistic extrapolation of the California and EU-style objectives and would require technology breakthroughs in the use of advanced low-carbon fuels and electric-drive vehicles. Over the long-term, developing low-carbon fuel policies to especially promote electric-drive, powered by decarbonized electricity (and hydrogen) could be a key climate stabilization strategy for the transport sector.

3.4. ENERGY CONSUMPTION OF INTERNATIONAL MARINE VESSELS

Rapid growth in the demand for global goods movement has resulted in a doubling of CO_2 from international shipping from 1990 to 2007, and currently marine accounts for 1 $GtCO_2$ each year, the equivalent of 11% of CO_2 emissions from transport (Wang & Lutsey, 2013). In the absence of actions to limit international marine GHG emissions, emissions could increase two-thirds by 2030. Since 1997, the Marine Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO) has held the responsibility to regulate emissions from international marine vessels.

Context

In 2011, the MEPC adopted the Energy Efficiency Design Index (EEDI), the first transport regulation to establish CO_2 standards across a global sector. The initial regulation applied to all new cargo ships weighing more than 400 gross tons, which account for 72% of CO_2 emissions from newly built ships (Hon & Wang, 2011), with additional ship types being added over time. The EEDI will improve the efficiency of new ships by 10% in 2015, 20% in 2020, and 30% in 2025, compared to a baseline representing the average efficiency of ships built between 2000 and 2010, and is expected to prevent the release of more than 340 $MtCO_2$ each year by 2030 (Wang & Lutsey, 2013).

In addition, the Ship Energy Efficiency Management Plan (SEEMP), implemented concurrently with the EEDI, establishes mechanisms for companies and operators to improve the efficiency of ship operations. The IMO establishes guidelines for planning, implementing, and monitoring best-practice efficiency strategies for in-use ships. These guidelines lay the foundation for future measures to improve operational efficiency, including a potential efficiency standard for in-use ships. The importance of in-use efficiency is augmented by the long lifetimes of marine vessels and wide variation of in-use performance across similar vessels. Figure 11 shows the variation in technical design CO_2 intensity (how ships are designed to perform) and in-use CO_2 intensity (how ships actually operate) within the international container shipping fleet in 2011. The EEDI will improve the technical design emissions of newly built ships, whereas in-use measures such as SEEMP and market-based measures (MBM) will improve the operations of existing ships.

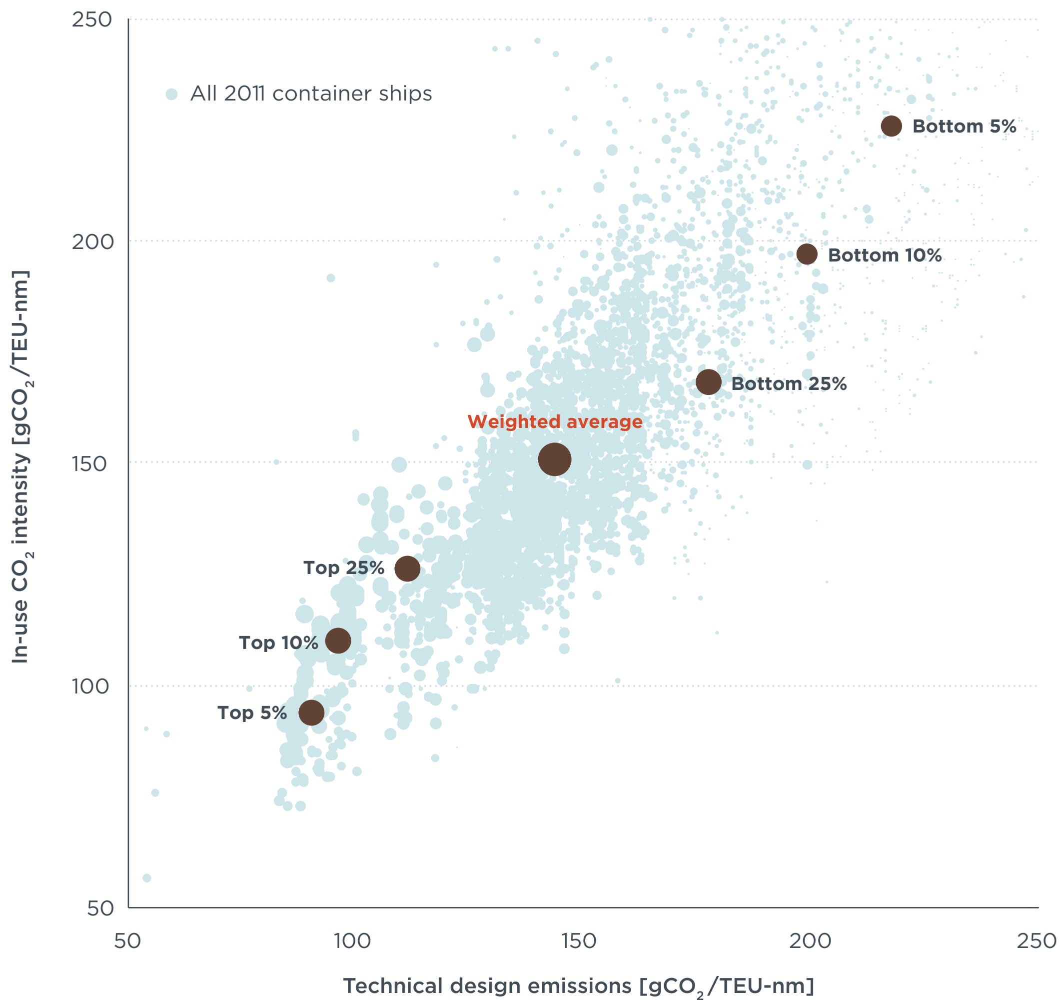


Figure 11. Technical and in-use CO_2 intensity of 2011 containerships (Wang & Lutsey, 2013)

TEU-nm refers to a 20-foot equivalent unit, a measure based on the cargo capacity of a 20-foot-long intermodal shipping container.

Recognizing the importance of measures to boost in-use ship efficiency, the IMO began discussing monitoring, reporting, and verification (MRV) provisions leading to mandatory in-use efficiency requirements at the 2011 MEPC meeting, with support building from key nations and industry at each subsequent meeting. Most recently, at the April 2014 MEPC meeting, a formal working group was formed to deliberate on the issue. The working group, which held constructive discussions at that meeting with minimal resistance from industry, has continued to work as an inter-sessional correspondence group in 2014.

Outlook and projections

Table 10 provides background on major regulatory developments within the IMO toward improving marine efficiency. These developments cover formal invitations to regulate harmful pollutants, major technical studies, adoption, and implementation of policies. Established implementation dates are also included beyond 2014. As shown, the critical benchmarks for increased new ship efficiency are 2015 (10% increased efficiency), 2020 (20%), and 2025 (30%).

Table 10. Timeline of regulatory developments for marine efficiency within the IMO

Year	Regulatory Development
1997	International Convention for the Prevention of Pollution from Ships (MARPOL) invites MEPC to consider feasible CO_2 reductions for ships
2000	First IMO study on GHG emissions from ships
2003	IMO urges MEPC to develop mechanisms to limit GHG emissions
2009	MEPC finalizes a suite of technical and operational GHG reduction measures
2010	MEPC considers mandating technical and operational measures irrespective of flag and ownership
2011	First ever mandatory GHG reduction regime for an entire industry, including technical (EEDI) and operational (SEEMP) measures
2013	EEDI and SEEMP enter into force for all ships over 400 gross tonnage
2015	New ships must be **10%** more energy-efficient (EEDI)
2020	New ships must be **20%** more energy-efficient (EEDI)
2025	New ships must be **30%** more energy-efficient (EEDI)

In addition to existing policies, there is potential for much greater climate mitigation from new IMO policies that promote efficient shipping technologies and practices. Figure 12 shows projected CO_2 emissions from international shipping under three scenarios (based on Wang & Lutsey, 2013). The first two scenarios compare shipping emissions with and without the EEDI standards that are now being implemented. The third scenario investigates the effect of technology-focused measures beyond EEDI that improve the efficiency of new ships 1.5% per year from 2025 on, combined with operational measures that improve in-use efficiency 1% per year starting in 2015. The results indicate that by 2030, the successful implementation of the EEDI will cut lifecycle CO_2 emissions by an estimated 0.34 $GtCO_2$ per year, equivalent to roughly 1.8 mbd. Additional policy progress to improve shipping technology beyond the current EEDI requirements and extend leading operational practices to the full fleet could stabilize shipping emissions at 2010 levels despite a significant increase in the demand for global goods transport. Such policies could reduce 0.4 $GtCO_2$, or 2.1 mbd, in 2030, equivalent to a 30% reduction in global shipping emissions.

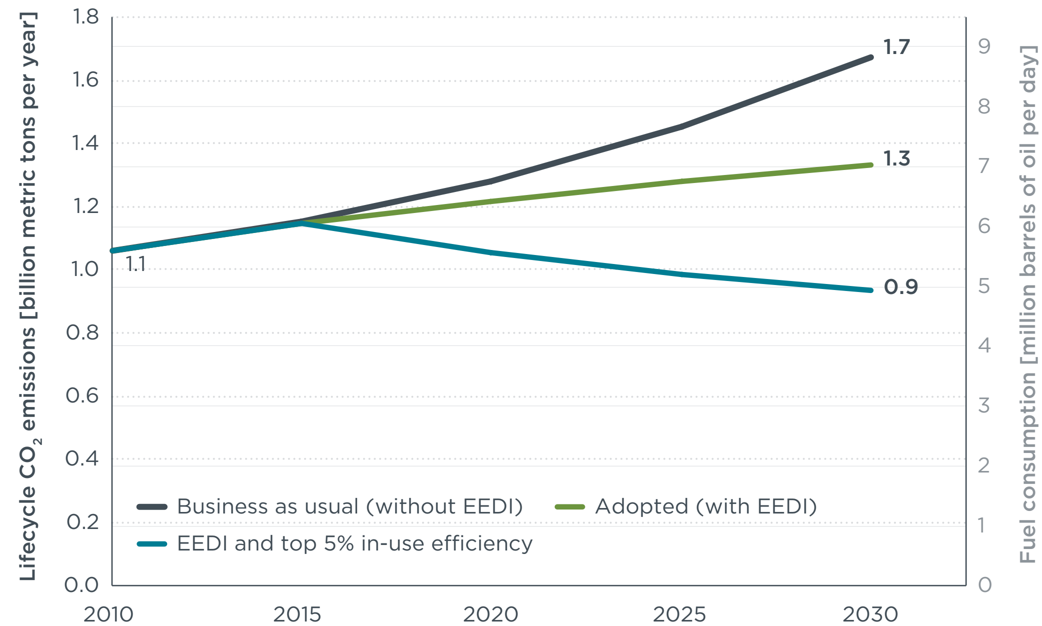


Figure 12. Shipping fleet CO_2 emissions with EEDI and improved technology and practices for in-use ship efficiency (based on Wang & Lutsey, 2013)

3.5. ENERGY CONSUMPTION OF INTERNATIONAL AVIATION

After rapid gains in fuel efficiency from 1960 to 1990, the average fuel efficiency of new aircraft since 1990 has only improved by roughly 10% (Figure 13); over this same period, aviation activity for both passenger travel (measured in seat-km) and freight transport (measured in ton-km) grew by roughly a factor of 2.5. Since 2000, aviation activity has continued to grow, but the efficiency of new aircraft has stagnated, resulting in a 3% to 4% annual increase of aviation GHG emissions. Aviation accounts for about 11% of CO_2 emissions from transport (Façanha et al., 2012). If current trends continue, aviation CO_2 emissions could double by 2030.

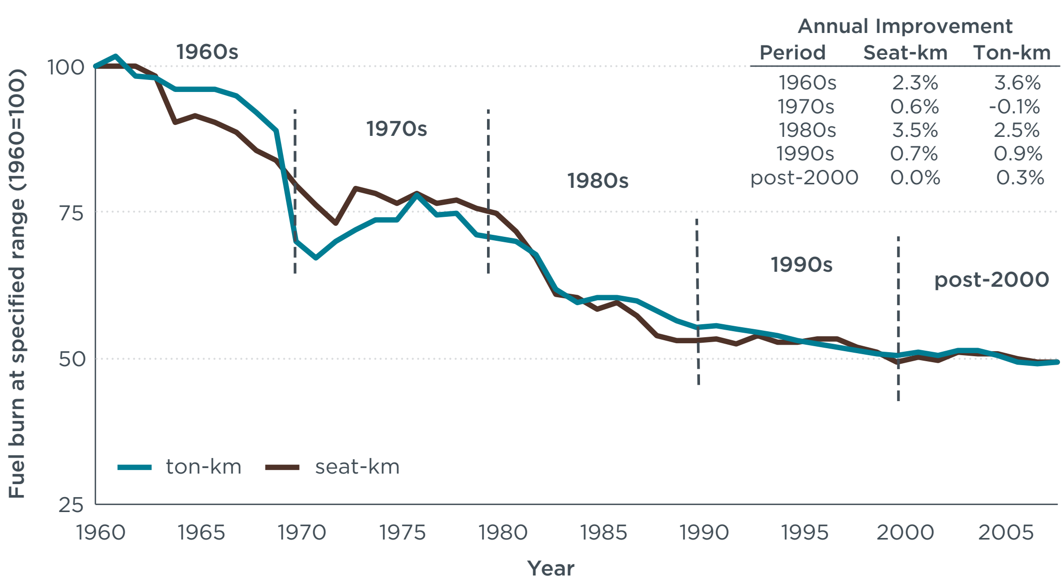


Figure 13. Average fuel burn for new aircraft, 1960-2008 (Rutherford & Zeinali, 2009)

Context

In October 2010, the International Civil Aviation Organization (ICAO) established a 2% annual fuel efficiency goal (aspirational from 2020 to 2050) along with the target of carbon neutral growth from 2020 (Hupe, 2011). Other regions, notably the EU, support even more aggressive goals (5% below 2005 levels by 2020) and have adopted regional measures consistent with these goals. Between 1991 and 2009, international aviation fleetwide fuel intensity fell by 2.5% annually on a tonne-kilometer basis, while aviation demand grew by 4.2% annually (World Bank, 2014). Coordinated, near-term international policy action will be needed if ICAO's goals are to be met by 2020.

Outlook

In 1997, ICAO was given responsibility for regulating international aviation emissions under the Kyoto Protocol. ICAO began the scoping process for a global CO_2 standard for new aircraft in 2009 and committed to developing the standard in 2010; however, progress has been slow, and ICAO is now expected to deliver a standard by 2016. As of April 2014, ICAO has not yet determined whether the standard will cover newly delivered aircraft that have already received type certificates—called "new in-production aircraft"—in addition to new "clean sheet" designs. ICAO is still determining the stringency of such a standard, which will be a key contributor to meeting ICAO's goal of 2% annual improvements in aircraft fleet efficiency through 2050.

In addition to a CO_2 standard, which would only affect newly delivered aircraft, ICAO member states have been working toward developing a framework since 2010 for a market-based measure (MBM) for international aviation. In the absence of global action toward MBMs, the EU decided to include international aviation in its Emissions Trading Scheme (ETS) as of 2012, sparking opposition from other ICAO member states to the EU's unilateral action. In 2013, ICAO agreed to develop a global MBM. In response, the EU agreed to limit the ETS to intra-EU flights. In agreeing to develop a global MBM, ICAO is to come up with a proposal by 2016 for implementation by 2020 (ICAO, 2013). Simultaneously, the US EPA is required to soon determine whether GHG emissions from aircraft endanger human health and welfare, and whether these should therefore be subject to regulations under the Clean Air Act (CAA).

A global framework for MBMs would allow regions to set up their own programs in the absence of a global MBM. Such regional approaches could account for a limited share of emissions (i.e., those occurring within sovereign airspace), estimated to be up to 22% of sector total (Lee et al., 2009). In contrast, a global MBM for international aviation would replace regional approaches like the EU ETS and capture a greater share of global aviation emissions; however, if ICAO cannot come to an agreement on global measures to limit aviation emissions, regional actions may proceed within the EU and the US.

In addition to efforts toward a global CO_2 standard and MBMs for aircraft, progress on a policy for alternative fuels is still in the early stages, since ICAO is determining a methodology for measuring GHG reductions from alternative fuels. While alternative fuels could contribute a share of the potential reduction in global aviation GHGs, there remains significant uncertainty about the production potential and lifecycle emissions of alternative fuels up to 2050.

Table 11 summarizes and compares the timelines of regulatory developments for aviation GHGs within ICAO, the EU, and the US. These developments include the establishment of regulatory authority, invitations to develop regulations, milestones toward adoption, and changes in implementation.

Table 11. Timeline of regulatory developments for aviation GHGs in ICAO, EU, and US

Year	ICAO	EU	US
1997	Kyoto Protocol assigns ICAO responsibility to reduce aviation emissions		
2001	ICAO endorses an open emissions trading system for international aviation, rules out possibility of aircraft GHG standards		
2002		European Parliament and Council direct the European Commission to propose aviation emission reductions if ICAO does not proceed	
2004	ICAO rules out an aviation-specific global emissions trading system, favoring inclusion of international aviation into national emissions trading schemes		
2005		EU ETS launched as the world's first international company-level "cap-and-trade" system for reducing CO_2 emissions European Council concludes that international aviation is to be included in the EU ETS	
2007			US environmental groups represented by Earthjustice petition the EPA to regulate US aviation emissions
2008		EU includes international aviation in its ETS, to take effect in 2012	EPA issues advanced notice of proposed rulemaking (ANPR) for regulating GHGs under CAA
2009	ICAO begins scoping out a CO_2 standard for aircraft		
2010	ICAO adopts goals for global 2% annual average fuel efficiency improvement until 2020, and from 2021 to 2050, capping international aviation CO_2 at 2020 levels ICAO requests development of a CO_2 standard for new aircraft and the development of a framework for market-based measures (MBMs), and decides to explore a global MBM scheme for international aviation		US environmental groups file a lawsuit against the US EPA for delaying regulation of non-road GHGs
2011		Some ICAO states adopt a (Delhi) Joint Declaration opposing the EU's plan to include international flights by all carriers registered in non-EU Member States in its EU ETS	Court rules EPA must make a final decision on endangerment for aircraft GHG emissions under CAA; EPA promises an endangerment finding
2012	ICAO agrees on a CO_2 metric system	Aviation activity included in the EU ETS starting 1 January 2012 23 countries meet and adopt Moscow Joint Declaration opposing EU ETS inclusion of international aviation, and urge EU Member States to work within ICAO on a multilateral approach to address international aviation emissions EU limits the scope of the ETS to intra-EU flights until 2016, when this decision will be reviewed in light of the global MBM	
2013	ICAO finalizes a CO_2 certification procedure for new aircraft ICAO agrees to develop a global MBM for international aviation		
2014		EU limits the scope of the EU ETS to intra-EU flights, which includes foreign aircraft flying in the EU.	

3.6. PUBLIC HEALTH IMPACTS OF LIGHT- AND HEAVY-DUTY VEHICLES

The regulatory approaches for vehicle emissions and fuel quality developed in the US and EU provide a pathway that other countries can follow to improve the environmental performance of their vehicle fleets. Regulations for LDVs in the EU progress from Euro 1 to Euro 6 using Arabic numerals, and in the US include Tier 1, Tier 2, and Tier 3—the most recent of which sets the most stringent emission limits of any national level LDV regulation in the world. HDV regulations in the EU progress from Euro I to Euro VI using Roman numerals, and in the US include EPA 2004, 2007, and 2010 standards. Regulations for LDVs require new vehicles to meet emission limits based on distance traveled, while those for HDVs tend to limit new vehicle emissions based on engine work done. Both such standards tend to apply first to all new type approvals, followed by application to all new sales and registrations up to a year or so later. The timelines in this report refer to standards by the date of application to all new sales and registrations. The impact of these standards on fleetwide emissions depends on the rate of fleet turnover, which averages significantly longer for HDVs than for LDVs. In addition to setting stringent emission limits, the latest generation of emission standards also include requirements for on-board diagnostic systems, extended engine durability periods, and in-use emissions testing to promote compliance over the lifetime of the vehicle. The latest standards for gasoline vehicles also include limits on evaporative emissions of hydrocarbons.

In the US, EU and Japan, vehicle emissions regulations have accelerated the commercialization of advanced emission control technologies. Because many of these technologies require cleaner fuels to function optimally, vehicle regulations have been paired with fuel quality regulations that allow the proper function of emission controls as well as reduce emissions from the legacy fleet. Such regulations have proven to be a highly cost-effective means of controlling vehicle emissions, with the most recent Tier 3 LDV regulations in the US yielding 4.5 to 13 dollars of benefits for every dollar spent on cleaner vehicles and fuel (US EPA, 2014a). Today, the technologies for clean vehicles and fuels necessary to meet the latest regulations in the US, Europe, and Japan are commercially available and can be transferred to other countries that adopt such regulations.

Context

To date, most countries follow the progression of European Union standards, which have been adopted by the World Forum for Harmonization of Vehicle Regulations for the United Nations Economic Commission for Europe (UNECE, 2012). Notable exceptions include the US, Canada, Mexico and Japan. There remains considerable variation in progress toward clean vehicles and fuels even among the top vehicle markets, and especially in rapidly growing smaller markets in the Asia-Pacific, Africa, Latin America, and the Middle East, with countries implementing standards anywhere from a few years to several decades after such regulations in the US and EU.

Figure 14 compares historical and future implementation dates for adopted nationwide emission standards in selected markets. Since the lag between adoption and application to all sales and registrations can run four or more years, some regulations provide incentives for early compliance or phase-in over several years. For example, the US Tier 3 standards—which have emission limits up to 80% lower than current Tier 2 standards—will phase-in from 2017 to 2025 to allow manufacturers lead time to develop new emission control technologies.

As shown in Figure 14, best-practice emission standards have yet to be adopted uniformly across regions. Six markets have adopted world-class emission standards for LDVs (US, Canada, EU, Japan, South Korea, and Australia), accounting for 43% of global new passenger car sales in 2013. Five markets have implemented or adopted world-class emission standards for HDVs (US, EU, Japan, Canada, and South Korea) and have ultralow-sulfur diesel fuel available. Another four major markets—China, India, Brazil and Russia—could adopt world-class standards within the next several years.

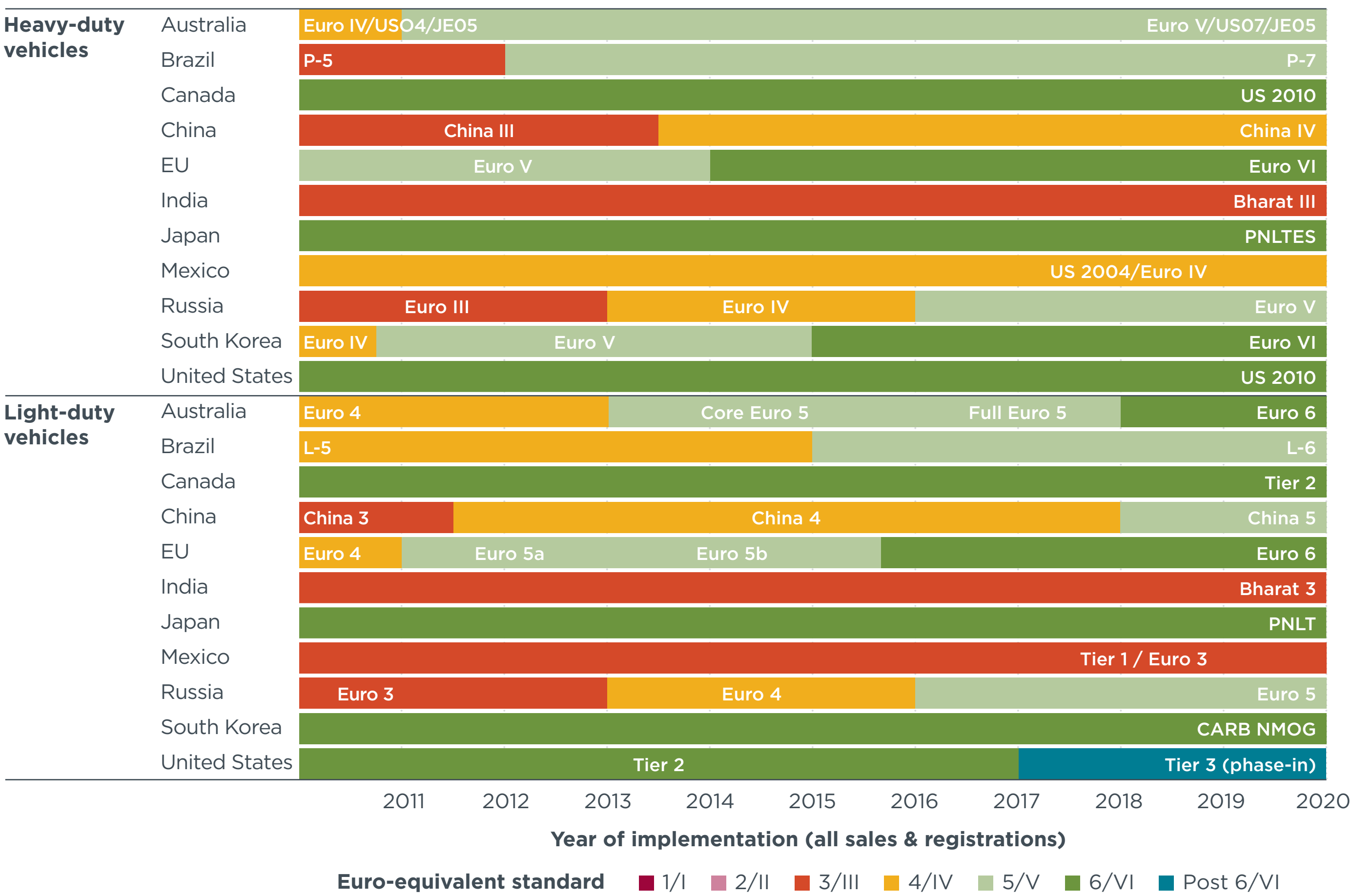


Figure 14. Adopted light- and heavy-duty vehicle emission standards in selected markets

Australia's 'Core' Euro 5 adopts the technical requirements of ECE R83/06, except that it does not require the new, PMP-based testing methods for PM mass and has no particle number (PN) limit. Some other requirements are also relaxed, including the OBD threshold.

Japan's PNLTES stands for 'Post New Long Term Emission Standards'.

Outlook and projections

To date, adopted emission standards for LDVs and HDVs have yielded tremendous benefits. Figure 15 compares the estimated number of premature deaths in the selected vehicle markets from exposure to exhaust PM under currently adopted policies and with accelerated adoption of international best practices. Similarly, Figure 16 compares projected changes in NO_x relative to 2010. Looking forward, adopted standards are projected to significantly reduce the health impacts of PM emissions; however, these gains could be counteracted by growth in vehicle activity without the implementation of standards equivalent to Euro 6/VI or better. Advancing to such standards in all eleven markets could avoid on the order of 90,000 premature deaths caused by vehicle emissions in 2030, and cut emissions of NO_x by 80% from 2010 levels. The impacts of standards on PM and NO_x emissions are broken down by region in Table 12. More in-depth analysis of the impact of vehicle emissions and fuel quality standards on on-road emissions and health impacts can be found in the ICCT's global health roadmap report (Chambliss et al. 2013).

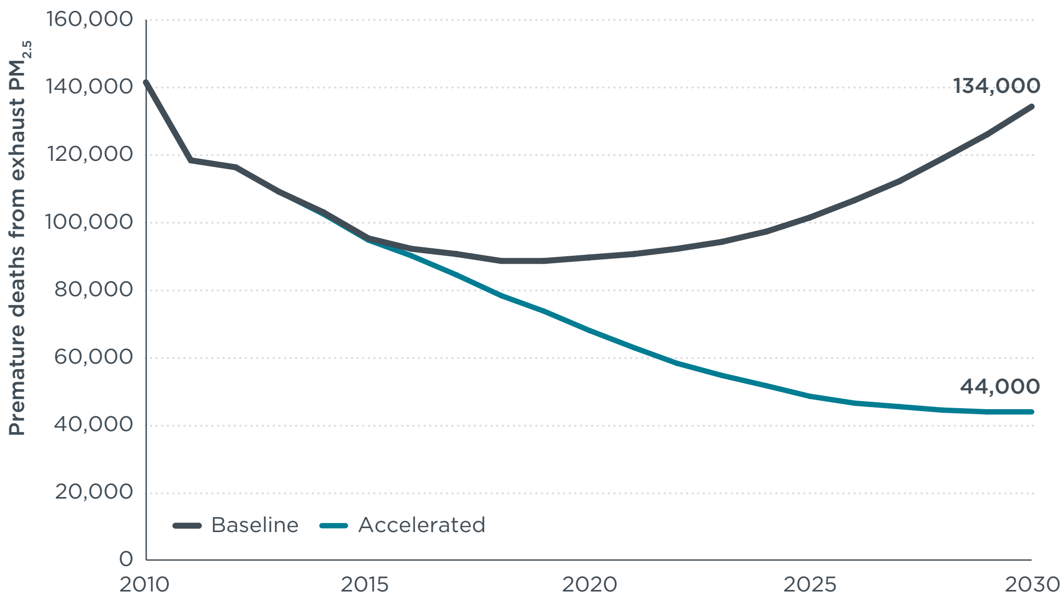


Figure 15. Premature mortalities from light- and heavy-duty vehicle exhaust $PM_{2.5}$ in selected markets*

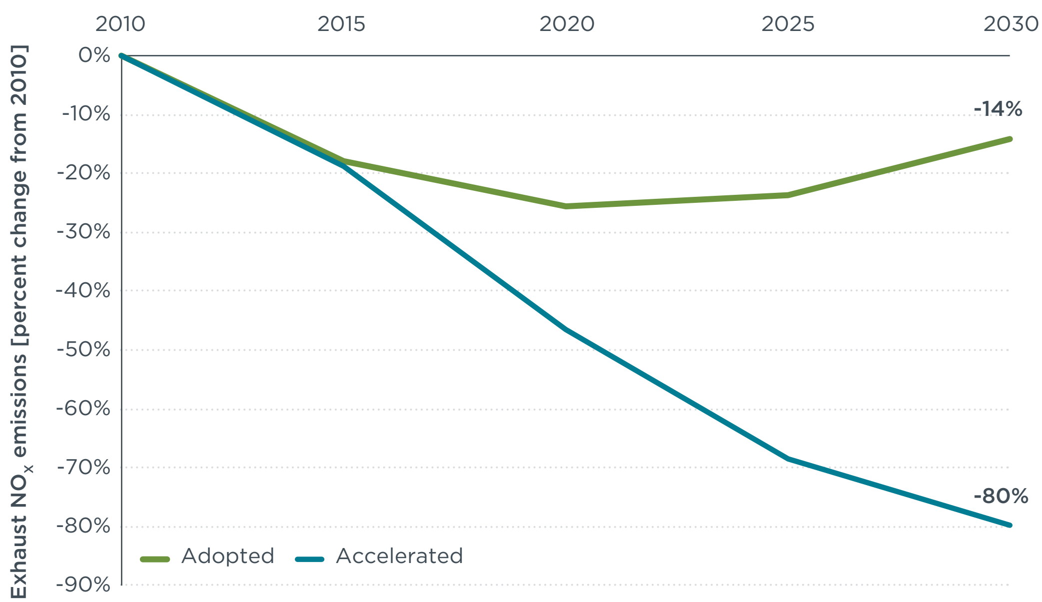


Figure 16. Trends in light- and heavy-duty vehicle exhaust NO_x in selected markets*

* *Estimated using ICCT's Global Transportation Roadmap model (ICCT, 2014).* ***Adopted*** *= currently adopted policies.* ***Accelerated*** *= all markets implement Euro 6/VI; some markets move to next-generation standards (Chambliss et al., 2013). Includes eleven of the top vehicle markets (China, the US, EU, Japan, Brazil, India, Russia, Canada, South Korea, Australia, Mexico)*

BOX 5. HEALTH IMPACTS FROM ON-ROAD VEHICLES

This report includes estimates of premature mortality from exposure to exhaust emissions of $PM_{2.5}$ in urban areas, and is not intended to capture the full burden of health impacts from the transport sector. Intake fractions are used to convert exhaust $PM_{2.5}$ emissions to urban concentrations. Intake fractions, which vary by geography, meteorology, and population size, represent the share of total emissions that are inhaled. This health assessment method offers unique advantages: (1) it utilizes previously developed global health, demographic, and intake fraction datasets that permit consistent application and comparison across regions; (2) it provides rapid estimates of health impacts that do not require resource-intensive global chemical dispersion modeling; and (3) it does not rely on detailed modeling of emissions from other sectors, enabling the analysis to focus on the transport sector. A more comprehensive description of this methodology is described in Chambliss et al. (2013).

Table 12. Percent change in light- and heavy-duty vehicle exhaust emissions of NO_x and $PM_{2.5}$ from 2010 to 2030

Status	Region	Percent of world vehicle sales 2013	Percent change in NO_x, 2010-2030		Percent change in $PM_{2.5}$, 2010-2030	
			With adopted policies	With Euro 6/VI or better	With adopted policies	With Euro 6/VI or better
Already adopted Euro 6/VI or better	EU	19%	-45%	*	-75%	*
	US	17%	-15%	*	-15%	*
	Japan	6%	-66%	*	-75%	*
	Canada	2%	-21%	*	-14%	*
	South Korea	2%	-57%	*	-59%	*
	Total	**46%**				
Considering adoption of Euro 6/VI or better	China	25%	41%	-48%	-55%	-68%
	Brazil	4%	-28%	-69%	-50%	-84%
	India	4%	180%	-4%	150%	-12%
	Russia	3%	-22%	-48%	-31%	-37%
	Australia	1%	-35%	-68%	-26%	-37%
	Mexico	1%	57%	-46%	46%	-76%
	Total	**38%**				

Estimated using ICCT's Global Transportation Roadmap model (ICCT, 2014). Policy pathways based on Chambliss et al. (2013).
* Already adopted Euro 6/VI or better; same as with adopted policies

3.7. SULFUR CONTENT OF GASOLINE AND DIESEL ON-ROAD FUELS

Reducing the sulfur content of diesel and gasoline is key to enabling the introduction of advanced vehicle emission controls to meet post-Euro 2/II regulations. Sulfur content of fuel is also directly tied to the production of sulfates, which contribute to PM emissions. Regulations for diesel vehicles require reductions in fuel sulfur content for optimal function and durability: these include 500 ppm for exhaust gas recirculation (EGR), 50 ppm for selective catalytic reduction (SCR) and diesel oxidation catalysts (DOC), and 15 ppm for NO_x adsorbers and diesel particulate filters (DPF) (Blumberg et al., 2003); while technical capabilities are slightly different than regulatory requirements, lower sulfur levels generally result in lower tailpipe emissions. Similarly, gasoline vehicles are recommended to operate using fuel with fewer than 50 ppm sulfur for three-way catalysts (TWC), 30 ppm for advanced TWCs, and 15 ppm for NO_x traps for full function of emissions controls (Blumberg et al., 2003).

Context

Limiting the sulfur content of on-road gasoline and diesel to a maximum of 10 to 15 ppm (ultralow-sulfur) is an essential component of best-practice vehicle emissions control programs in both fuel-importing and fuel-producing countries. Such improvements yield immediate emission benefits from the existing vehicle fleet and enable the progression of emission standards. In countries without domestic vehicle production, improving fuel quality can enable the proper function of emission controls on imported vehicles that would otherwise malfunction with lower-quality fuel. In addition to regulatory requirements, national and local governments in fuel-importing countries can incentivize cleaner fuels with differential taxation; markets with local refining capacity can either invest directly in refinery upgrades or offer refiners subsidies or tax breaks to produce cleaner fuels. To date, six of the selected markets have established pathways to ultralow-sulfur gasoline, while eight have done so for ultralow-sulfur diesel.

The following timelines for adoption of gasoline and diesel sulfur limits highlight the wide variation among countries regarding current nationwide sulfur limits for on-road gasoline and diesel. As of August 2014, only five of the eleven markets (US, Canada, EU, Japan, South Korea), representing 50-60% of the global consumption of on-road gasoline and diesel, have such fuels ubiquitously available (Australia also has ultralow-sulfur diesel available). In many countries such as Brazil, China, and India, lower sulfur fuels are available in major metropolitan areas or select provinces, while higher sulfur fuels are sold in other areas of the country.

Table 13. Timeline for adopted nationwide gasoline sulfur limits (parts per million)

Region	Share of world road gasoline consumption (2010 data)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
US	39%	30							10			
EU	10%	10										
China	8%	150				50 (10)				10		
Japan	5%	10										
Mexico	4%	150 (30)										
Russia	4%	500			150		10					
Canada	4%	30										
Brazil	2%	1000				50						
India	2%	150 (50)										
Australia	1%	50										
South Korea	1%	10										
Other countries	22%											

Euro-equivalent: Pre-Euro 2/II | 2/II | 3/III | 4/IV | 5/V+ **US-equivalent**: Tier 2*

* US Tier 2 requires 30 ppm average; EU requires caps

Values are rounded to the nearest percent. Due to rounding, the total may not sum to one hundred percent.

Table 14. Timeline for adopted nationwide diesel sulfur limits (parts per million)

Region	Percent of world road diesel consumption (2011 data)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
EU	24%	10										
US	16%	15										
China	13%	2000	350		350 (50, 10)		50 (10)			10		
India	4%	350 (50)										
Brazil	4%	1800 (500/50)			(500/10)	500 (10)						
Japan	3%	10										
Canada	2%	15										
Russia	2%	2000			350		50	10				
South Korea	2%	10										
Mexico	2%	500	500 (15)									
Australia	1%	10										
Other countries	26%											

Euro-equivalent	Pre-Euro 2/II	2/II	3/III	4/IV	5/V+

Values are rounded to the nearest percent. Due to rounding, the total may not sum to one hundred percent.

Apart from regulations for lower sulfur fuels, fuel pricing and taxation policies can have a significant impact on consumer choices and resulting motor vehicle pollution. In an effort to encourage freight transportation, some governments have subsidized diesel fuel relative to gasoline and unintentionally caused a shift from gasoline to diesel passenger cars. Two ways to counteract such a shift are to ban the sale of diesel cars or to phase out fuel subsidies. The Government of India has employed the latter strategy, committing to transition to market pricing by removing the diesel subsidy in monthly increments. From January 2014 to August 2014, the price differential between diesel and gasoline decreased from 33% to 14%, which resulted in a significant drop in the sales share of diesel cars (MyPetrolPrice.com, 2014; Gopalan, 2014).

3.8. AIR POLLUTANT EMISSIONS OF INTERNATIONAL MARINE VESSELS

Conventional pollutants from international marine vessels are regulated by the IMO's MEPC under Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL). While GHG discussions within the IMO have focused primarily on CO_2, BC is a potent short-lived climate pollutant in addition to its adverse health effects. SO_x and NO_x are targets for emission reduction primarily because of their adverse air quality impacts. While a portion of shipping emissions occur far out at sea, 70-80% of SO_x, NO_x, and BC are emitted from ships traveling within 400 km of a coastline, close enough to have significant impacts on human health (Wang, 2013a). For all three pollutants, proven technologies and fuels exist that are capable of reducing emissions by over 90% from uncontrolled levels (ICCT, 2013).

Context

Reducing the sulfur content of fuel has a direct impact on SO_x emissions, and the MEPC has made low-sulfur marine fuel a core component of its strategy to limit air pollution from shipping. Figure 17 shows the timeline for fuel sulfur requirements adopted by the IMO. Since 2000, the IMO has capped marine fuel sulfur at 4.5% (45,000 ppm) globally, and in 2012, it tightened this limit to 3.5%. Ships are required to switch to lower sulfur fuel (1%) when operating within designated ECAs; as of 2014, these include the North Sea, Baltic Sea, North American, and Caribbean. Starting in 2015, the fuel sulfur limit within existing ECAs will tighten to 0.1% (still a factor of 100 higher than ultralow-sulfur on-road fuel), and in 2020 the global limit for marine fuel sulfur is scheduled to decrease to 0.5%. A fuel availability review, which began in March 2014, will determine if the 2020 implementation date will stand. Currently, a correspondence group of nations headed by the US has been convened to discuss the issue and provide recommendations by 2016.

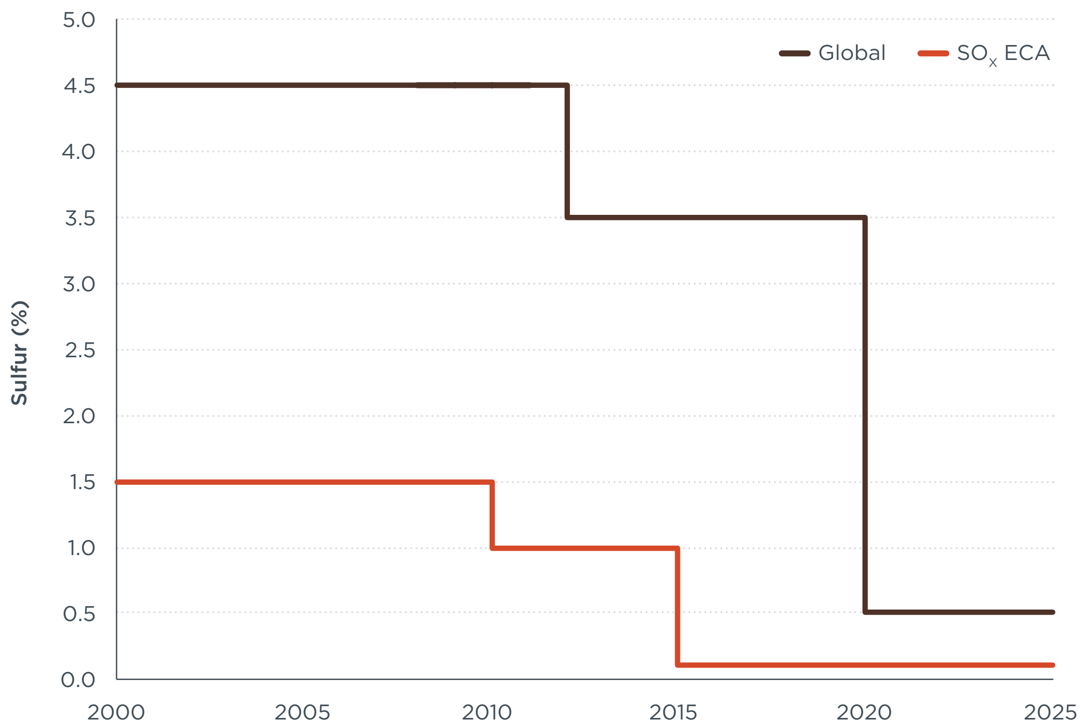


Figure 17. IMO low-sulfur fuel requirements, 2000-2025 (ICCT & DieselNet, 2014)

In coastal areas not protected by an ECA, local governments have taken fiscal and regulatory actions to encourage ships to switch to lower sulfur fuel when entering a port area (Wang, 2013b). Such local actions have significant potential to improve regional air quality and augment the benefits of international action (Wang, 2013a).

Similar to emission standards for HDVs, MEPC has limited NO_x emissions from new ships globally at Tier I levels since 2000, and Tier II since 2011. As shown in Figure 18, the NO_x limits of adopted Tier I and Tier II programs will be significantly tightened with the newest Tier III standards, which will apply to ships traveling within ECAs. Prior to the MEPC meeting in 2013 (MEPC-65), amendments to Annex VI were slated to require new build ships to meet Tier III standards when operating within ECAs starting in 2016. This 2016 application date would apply to any future NO_x control areas, creating consistency in technology application requirements. At MEPC-65 following the report of the correspondence group tasked with determining the feasibility of the NO_x Tier III implementation date, the Russian Federation raised objections to 2016 citing an inability of current technologies to reach the required NO_x reductions in safe, economical ways. Several countries and industry groups submitted papers supporting current technologies, specifically selective catalytic reduction (SCR), to meet the NO_x Tier III requirements and urging members to uphold the 2016 implementation date for existing ECAs (Azzara et al., 2014). After deliberation, the 2016 implementation date was upheld for NO_x Tier III standards in existing ECAs, including the North American and Caribbean ECAs (Rutherford, 2014). For new ECAs, the emission control requirement for new vessels will come into effect only after the ECA application has been approved by the MEPC.

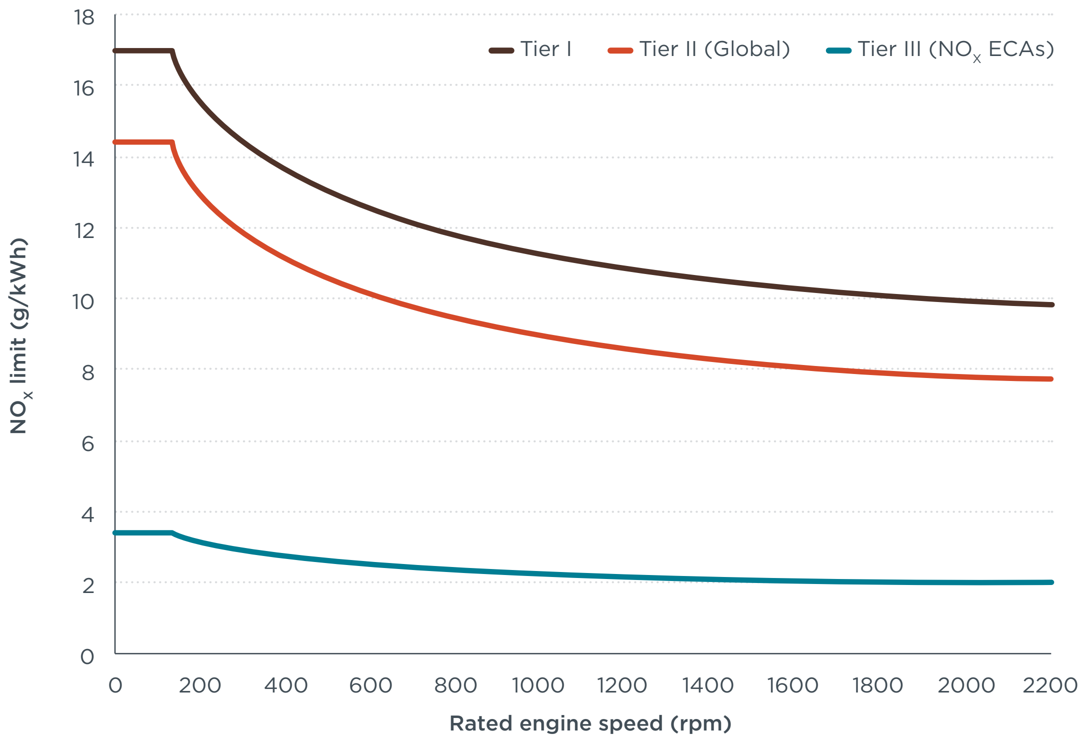


Figure 18. IMO Tier I, Tier II, and Tier III NO_x requirements (ICCT & DieselNet, 2014)

In addition to their impact on human health, black carbon (BC) emissions from international shipping are accelerating the pace of climate change, especially in the Arctic region due to the melting impacts of BC on ice and snow (Azzara, 2014). In 2010, the IMO committed to take action to reduce marine BC specifically in the Arctic: "The Committee agreed that ship's emissions of BC and other particulate matter affecting the Arctic region needed to be addressed specifically as an integral part of the Organization's work on prevention of air pollution from ships and its contribution to combat climate change and global warming" (MEPC 60/22). In 2011, the MEPC created a correspondence group with the mission to 1) define BC, 2) recommend methods to measure BC emissions from vessels, and 3) identify technologies to reduce emissions. The first two components have suffered considerable delay due to a lack of consensus on the specific definition of BC and an appropriate mechanism to measure emissions. Until the issues of definition and measurement are resolved, the conversation cannot progress to mitigation technology—nor can the issue of BC emissions be taken up by other subcommittees, for example, Ship Design and Construction, which is tasked with developing the Polar Code for safety and environmental protection in the Arctic (Azzara, 2014). Two possible definitions of BC, each associated with one or more means of measurement, were considered by IMO at the MEPC-67 meeting in October 2014; however, the issue is still awaiting resolution.

Outlook and projections

The effects of adopted IMO regulations are expected to vary substantially by pollutant over the next fifteen years. Based on ICCT modeling, as shown in Figure 19, emissions of NO_x, SO_x, and PM_{10} from shipping would have increased by factors ranging from 1.7 to 3.4 from 2007 to 2030 without policy action. Under adopted IMO regulations, NO_x emissions are still forecast to increase, albeit less quickly as a result of Tier III regulations. Lower sulfur fuel regulations are forecast to reduce emissions of SO_x and PM to 60% and 40% below 2007 levels by 2030, respectively, despite rapid growth in shipping activity.

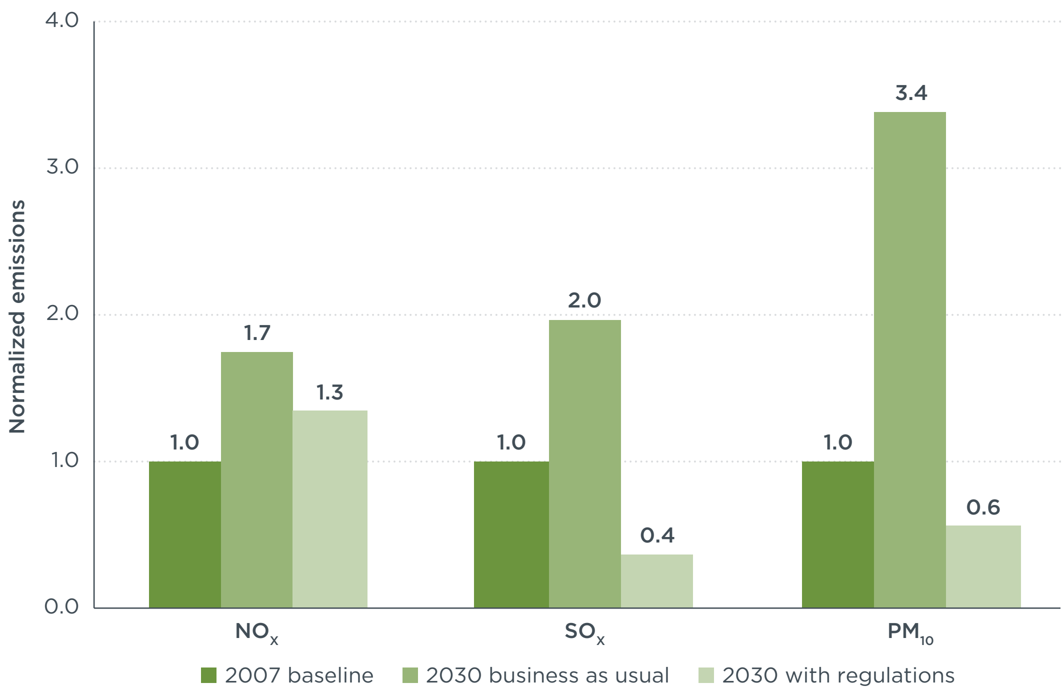


Figure 19. Trends in global marine emissions, 2007-2030

Table 15 provides additional background regarding regulatory developments within the IMO for lower sulfur fuel, NO_x emission standards, and BC emission reductions. These developments cover establishment of regulatory authority, formal calls to regulate harmful pollutants, major technical studies, adoption, and implementation of policies. Established implementation dates are also included beyond 2014.

Table 15. Timeline of regulatory developments for marine pollutants within the IMO

Year	Lower sulfur fuel	NO_x emission standards	Black carbon (BC)
1997		1997 protocol to MARPOL, including Annex IV, agreed upon at IMO	
2000	1.5% sulfur limit in SO_x ECA; 4.5% global sulfur limit	Tier I (retroactive to new engines installed on vessels after Jan 1, 2000)	
2004		Annex VI was ratified	
2005	Baltic Sea SO_x ECA entered into force	Annex VI entered into force	
2006	North Sea SO_x ECA entered into force		
2008	IMO adopted amendments for fuel standards beginning in 2010	IMO adopted amendments for Tier II & III NO_x standards along with Tier I NO_x requirements for pre-2000 engines (known as the 2008 Amendments)	
2009			Arctic Council identifies BC as of particular concern due to effects on snow and sea ice
2010	North American SO_x ECA adopted	2008 Amendments enter into force	
2011	Caribbean SO_x ECA adopted	Tier II implementation	MEPC BLG subcommittee begins work to define, measure, identify control options for BC
2012	ECA 1% sulfur; 3.5% global sulfur limit	IMO NO_x technology correspondence group undertook technology feasibility study	Report submitted to IMO on BC mitigation technologies
2013		Russian Proposal to push implementation date to 2021	US acknowledges potential for unintended consequences of arctic BC on climate trends
2014	US Caribbean ECA comes into force	Compromise on implementation: US ECA 2016; future ECAs to be determined by date of application approval	PPR-1 IMO subcommittee meeting held. During the meeting a BC working group was established.
2015	ECA 0.1% sulfur		
2016	IMO expected to complete fuel availability study	North American and Caribbean ECA Tier III	
2020	Global 0.5% sulfur		
2025	Alternate 0.5% pending study results		

3.9. INTERNATIONAL AVIATION EMISSIONS

ICAO has developed, or is currently developing, several policy instruments to control aviation emissions, including aircraft NO_x emission standards, and most recently a new certification requirement for PM emissions from aircraft engines that will serve as the basis for a future standard. ICAO has also developed standards for noise control at airports, but those are beyond the scope of this report.

NO_x emission standards

In response to concerns about local air quality in the vicinity of airports, in 1981 ICAO adopted engine certification standards for NO_x, CO, unburned HC, smoke, and liquid fuel venting based on the Landing and Take-Off (LTO) cycle below 3,000 feet altitude (Dickson, 2014). Known as the CAEP/1NO_x standard (in reference to the first meeting of the Committee on Aviation Environmental Protection), this applied to newly manufactured engines beginning in 1986. In the following decade, ICAO adopted increasingly stringent NO_x standards in an effort to constrain emissions growth (NACAA, 2003) (parenthesis denote year of adoption):

» CAEP/2 NO_x (1993): Reduced emission limits by 20% for newly certified engines starting in 1996 and for already-certified, newly manufactured engines starting in 2000;

» CAEP/4 NO_x (1999): Required additional 16% reductions relative to CAEP/2 standard beginning in 2004;

» CAEP/6 NO_x (2005): Required additional 12% reduction from CAEP/4 levels;

» CAEP/8 NO_x (2011): Mandated additional reductions of 5% to 15% for small engines and 15% for large engines certified starting in 2014 compared to the CAEP/6 standard. Also confirmed that all individual engines produced on or after 1 January 2013 must comply with CAEP/6 NO_x standard or face a production cutoff.

In addition to these standards, which are typically established as technology-following standards to prohibit backsliding from new engines, in 2010 ICAO established more aggressive but non-binding medium- and long-term NO_x technology goals equivalent to a 45% reduction from CAEP/6 levels in 2016 and 60% reduction from CAEP/6 in 2026 (Dickson, 2014).

Since ICAO has no formal enforcement authority, these standards are translated into national requirements under domestic legislature and implemented by national transportation or environmental authorities. For example, the US EPA adopted the CAEP/2 NO_x standard to align its aircraft emissions standards with ICAO in 1997, updated the NO_x standard in 2005 to be equivalent with the CAEP/4 standard, and revised those standards again in 2012 to take into account the CAEP/6 and CAEP/8 standards for engines depending on their original type certification dates.

ICAO's NO_x standards are based upon an LTO test cycle and targeted improvements in air quality around airports. ICAO has chosen not to regulate cruise NO_x emissions, which contribute to global climate change, on the basis that LTO NO_x has a positive relationship to cruise NO_x emissions, and so the existing LTO NO_x standards should correspondingly reduce cruise NO_x (Transport & Environment, 2010).

Particulate matter standard development

In 2010, ICAO began the development of a non-volatile particulate matter (nvPM) standard aimed at reducing the impacts of ultrafine particulate matter on air quality, human health, and global climate (ICAO, 2013). At CAEP/9 in 2013, CAEP agreed to develop, in conjunction with the SAE E-31 committee, a new emission certification requirement for turbofan/turbojet engines greater than 26.7 kN to measure and quantify nvPM emissions based upon both mass and number (ICAO, 2013). ICAO expects to adopt the first nvPM standard at the CAEP/10 meeting in February 2016. In addition, ICAO is considering a potential nvPM emissions standard for turbofans/turbojets less than 26.7 kN, including turboprops, helicopter turboshaft, and auxiliary power unit engines.

Aircraft noise standards

Although noise is beyond the scope of this report, aviation noise pollution has been a serious environmental concern such that it was the first environmental issue addressed by ICAO with the implementation of the Stage 2 noise standard in 1972. Since then, ICAO's noise standard has been periodically updated, most recently at the CAEP/9 meeting in 2013 with the adoption of a new "Chapter 14" noise standard. To date, CAEP has followed the approach of establishing technology-following standards meant to ensure that new technologies, once developed, are deployed in a timely manner across the in-production fleet. This means that new aircraft types easily meet the standards, suggesting further room for improvement and near-term updates given sufficient environmental pressures.

CHAPTER 4. CONCLUSIONS

This chapter describes the current state of clean transport policies by summarizing the major regulatory developments from January 2013 through August 2014 and distilling nine high-level conclusions.

Conclusion 1: In 2013/2014, major regulatory developments occurred that are associated with emission reductions of 1.2 $GtCO_2$ and oil savings of 5 mbd by 2030, as well as thousands of lives saved each year.

From January 2013 through August 2014, 17 major new policies were implemented, nine new such policies were adopted, and there were two new regulatory proposals in the eleven selected vehicle markets and for international marine and aviation (Table 6). Brazil, India, and Mexico adopted or implemented their first regulations to improve the efficiency of new light-duty vehicles (LDVs), while the EU approved and China proposed more stringent standards. The EU's standards make its CO_2 requirements the most stringent in the world by 2021. With respect to heavy-duty vehicles (HDVs), the US, Canada, and China are just implementing their first HDV efficiency standards. Canada announced its intention to harmonize with the latest US light-duty efficiency and emissions standards. In addition, the EU, US, and California have proposed several revisions to strengthen their low-carbon fuel policies. At the international level, two policies entered into force in 2013 that will improve the efficiency of marine vessels: the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). Together these policies will reduce GHG emissions by an estimated 1.2 $GtCO_2$ (and 5 mbd) in 2030, equivalent to a 7% reduction compared to a 2030 baseline without those policies in place. This reduction includes 0.42 $GtCO_2$ from light-duty efficiency, 0.21 $GtCO_2$ from heavy-duty efficiency, 0.22 $GtCO_2$ from low-carbon fuels, and 0.34 $GtCO_2$ from marine efficiency.

Table 16. Number of developments by policy type (Jan. 2013—Aug. 2014)*

Policy Type	Implemented	Adopted	Proposed	Delayed	Total
Light-duty efficiency	2	4	1		**7**
Heavy-duty efficiency	3	1			**4**
Light-duty emissions	2	1			**3**
Heavy-duty emissions	4				**4**
Gasoline fuel sulfur	1	2			**3**
Diesel fuel sulfur	1	1			**2**
Low-carbon fuel	2		1		**3**
International marine	2			1	**3**
International aviation					**0**
Total	**17**	**9**	**2**	**1**	**29**

* Includes eleven of the top vehicle markets (China, the US, EU, Japan, Brazil, India, Russia, Canada, South Korea, Australia, Mexico), and international marine and aviation

Many countries implemented more stringent vehicle standards for local air pollutants, including the EU (Euro VI for HDVs), South Korea (Euro VI for HDVs), China (Euro IV-equivalent for HDVs), Brazil (Euro 5-equivalent for LDVs), and Russia (Euro 5 for LDVs and Euro V for HDVs). The US also adopted Tier 3 emission standards for LDVs, currently the most stringent national standards worldwide. There has also been progress toward higher quality fuels in China (nationwide 50 ppm diesel by the end of 2014, and 10 ppm gasoline and diesel by 2018), Brazil (nationwide 50 ppm gasoline and 500 ppm diesel by 2014; and 10 ppm diesel in major metropolitan regions and select stations nationwide to fuel Euro V-equivalent trucks), and the US (10 ppm gasoline by 2017) that lay the foundation for dramatically tighter vehicle emission standards. Together, these policies will save thousands of lives each year from lower emissions of local air pollutants.

With the addition of policies that have been adopted from January 2013 through August 2014 as described in this report, Table 17 summarizes the current state of adoption of clean fuel and vehicle policies. The markets that are assessed here encompass 85% of the 2013 world vehicle market by sales. Nationwide ultralow-sulfur fuel standards and LDV efficiency standards (nine of eleven) have been adopted in the majority of the selected vehicle markets, even if not yet implemented in all of them. The most stringent vehicle emission standards, those equivalent to Euro 6/VI standards or better (across the board in five of eleven markets), and regulations that would increase HDV efficiency (four of eleven) have had more limited adoption to date. Only two of eleven markets have fuel standards that require reduced fuel GHG intensity over time.

Table 17. Status of clean vehicle and fuel policies in selected vehicle markets

	Percent of world vehicle sales 2013	Light-duty efficiency standards (reduction in average CO_2 rate with most recent)	Heavy-duty efficiency standards (reduction in average CO_2 rate with most recent)	Low-carbon fuel policies	Light-duty emission standards equivalent to Euro 6 or better	Heavy-duty emission standards equivalent to Euro VI or better	Ultralow-sulfur diesel standards (nationwide)
China	25%	9%	11%				■ *
EU	19%	27%	0%	■	■	■	■
US	17%	35%	14%	■	■	■	■
Japan	6%	16%	12%		■	■	■
Brazil **	4%	12%	0%				■ ***
India	4%	17%	0%				
Russia	3%	0%	0%				■ *
Canada	2%	20%	14%		■	■	■
South Korea	2%	9%	0%		■	■	■
Australia	1%	0%	0%		■		■
Mexico	1%	13%	0%				■ ***
Other countries	15%						

Green fill denotes adopted; "Efficiency standards" refer to fuel economy, fuel consumption, or CO_2 standards.

* Some adopted standards have not yet been fully implemented. These include LDV efficiency standards for India (2021) and Mexico (2016); HDV efficiency standards for China (2015) and Japan (2015); ultralow-sulfur diesel (ULSD) for China (2018) and Russia (2016)

** Brazil's Inovar-Auto program offers fiscal incentives that are considered equivalent to a standard; therefore, Brazil is counted in the number of regions that have adopted the equivalent of light-duty efficiency standards

*** Mexico has adopted a nationwide ULSD standard but has not yet achieved full nationwide compliance. Brazil requires ULSD availability in select stations and metropolitan areas to supply Euro V-equivalent heavy-duty trucks operating nationwide.

4.1. CLIMATE IMPACTS AND ENERGY USE

Conclusion 2: Efficiency standards now cover over four out of five passenger cars sold.

In a span of just ten years through 2014, the share of global passenger car sales regulated for fuel consumption or CO_2 emissions increased from roughly 30% to over 80%. However, efficiency standards for such vehicles have not been adopted in many emerging economies where vehicle sales will grow the fastest (e.g., in Asia-Pacific, Latin America, Middle East, and Africa). As a result, standards adopted thus far will be insufficient to offset the projected increase in vehicle activity and associated emissions.

Current technology assessments indicate that commercially available, fuel-saving technologies could be more effectively driven into the marketplace through extended and strengthened vehicle standards at payback periods of one to five years (Façanha et al., 2012). As of August 2014, only the US (with Canada now following with aligned standards) has long-term standards with enough regulatory lead-time—through 2025—to drive investments in the most advanced fuel-saving technologies. Other existing and proposed standards, including those in the EU and China, set targets only through 2020 or 2021 (or earlier), with updates generally made at 5-year intervals. Extending LDV efficiency standards in current markets and expanding standards to new markets could essentially stabilize GHG emissions from the light-duty fleet after 2025 and cut emissions by 1.1 $GtCO_2$, or 5.8 mbd, in 2030, as well as provide strong incentives for technology innovation.

Conclusion 3: HDV efficiency standards have been adopted in a few of the largest vehicle markets, but important markets remain unregulated.

Although HDVs represent more than 40% of on-road fuel consumption in most vehicle markets and more than 50% in Brazil, China, and India (ICCT, 2014), standards for HDVs have only just begun implementation in China, the US, Japan, and Canada. In many cases, data limitations, challenges to tackle a diverse set of vehicle types (e.g., long-distance heavy-duty trucks, interurban buses, garbage trucks), and insufficient industry engagement prevent more immediate progress in HDV efficiency standards. Because of increased demand for freight truck and transit bus activity, HDV emissions are projected to continue to grow substantially; current estimates indicate that CO_2 emissions from the sector will grow nearly 60% by 2030 from 2010 levels (ICCT, 2014).

Expanded adoption of HDV efficiency standards could stabilize HDV emissions after 2025 and save 0.65 $GtCO_2$ and 3.4 mbd in 2030 compared to a scenario without these policies in place. While the EU has not yet adopted standards, it has conducted extensive data collection and laboratory investigation, which could provide a strong foundation for mandatory HDV standards to reduce HDV CO_2 emissions. Such a standard in the EU could save on the order of 70 $MtCO_2$ and 0.4 mbd in 2030 and serve as a step toward similar policies in markets around the world that are following EU emission standards. Leveraging technical developments (e.g., technology costs, simulation software) in the US and EU could also reduce some barriers for adoption in developing countries. Voluntary "green freight" programs could also offer an important opportunity for early action and data collection for entire fleets while regulations for fuel efficiency of HDVs are being considered.

Conclusion 4: Adopted standards to improve the efficiency of new marine vessels will substantially reduce GHG emissions from international freight transport, and even greater mitigation potential exists in both the marine and aviation sectors.

In the marine sector, new vessel efficiency standards have entered into force with the EEDI, which will save an estimated 0.34 GtCO_2 and 1.8 mbd in 2030 compared to a business-as-usual scenario, equivalent to a 20% reduction in emissions from global shipping by 2030. However, a comprehensive policy requiring mandatory reductions in in-use fuel consumption remains under development, a critical undertaking since older and less efficient vessels can take decades to retire. Strengthening the EEDI requirements for new ships and implementing a mandatory program to improve operational efficiency could save an additional 0.4 GtCO_2 and 2.1 mbd in 2030, equivalent to a 30% reduction in global shipping emissions.

As of August 2014, no final proposals or adopted policies have emerged for either a global CO_2 standard for new aircraft or a global market-based measure to constrain and offset emissions from the in-service fleet. Such international policies could be among the most significant actions to reduce long-run transport CO_2 emissions and fuel use, with the potential to reduce GHG emissions by 0.48 GtCO_2 annually and oil use by 2.6 mbd in 2030—representing a 23% reduction from business-as-usual trends in the aviation sector.

Conclusion 5: Policies to promote electric-drive vehicles and renewable fuel use—while also minimizing indirect land use change from biofuels and upstream fossil fuel emissions—could contribute substantially to long-term GHG reductions.

The achievement of global climate targets will rely on reducing the carbon intensity of the energy sources used to power vehicles, including electricity, hydrogen, natural gas, and liquid fuels. Electric-drive vehicles, including plug-in hybrid electric vehicles, battery electric vehicles, and fuel cell electric vehicles, have clear advantages over conventional engines due to their higher efficiency and ability to draw from low-carbon, renewable energy sources. Regulatory vehicle efficiency and GHG standards will encourage greater investment in and deployment of in advanced efficiency and electric-drive vehicle technologies, especially as their costs decrease with higher production volumes and continued research and development. In addition to efficiency standards, numerous regions have already adopted tax exemptions, direct subsidies, and a range of non-fiscal incentives to encourage the sale of electric-drive vehicles. However, such vehicles still account for a small share of overall passenger car sales, representing about 5-6% in Norway and the Netherlands, and generally less than 1% outside leading markets (Mock & Yang, 2014).

Biofuels can reduce GHG emissions by partially offsetting the CO_2 released from combustion with the CO_2 sequestered while growing feedstocks. However, accurate measurement of the carbon intensity of these fuels has been challenging, and the lifecycle analysis of biofuels has been especially controversial. Many regions have now established targets for increased biofuel deployment in future years. Policies in the EU, US, and California have gone further, moving toward greater rigor, analysis of more fuel pathways, and comprehensive lifecycle accounting of land use effects to better differentiate the sustainable fuels that are reliably low-carbon. These three leading governments are still actively developing their policies and resolving key questions about how they promote various biofuel, fossil fuel, and electric-drive fuel sources. The policies in the EU and California would reduce average fuel carbon intensity by approximately 6% and 10%, respectively, in the 2020 timeframe. Combined, the regulations in the EU, US, and California are projected to reduce 0.22 GtCO_2 in 2020.

In contrast to generic biofuel targets, leading low-carbon fuel policies promote fuels with reliably low lifecycle carbon, low indirect land use change, and minimal food system interaction. Recent EU-based findings indicate that up to 16% of road transport fuel could be derived from waste-based sources by 2030 (Malins et al, 2014). In addition, fuel policies that disincentivize the use of high-carbon fossil fuels (e.g., oil sands, high-upstream leakage natural gas) are lacking, with the possible exception of California. The unclear future effects of high-carbon fuels, uncertainty in the growth rate of the electric-drive vehicle market, and challenges associated with ramp up in supply of low-carbon biofuels each contribute to the significant uncertainty concerning the reduction potential for low-carbon fuels in 2030. In estimating the future potential in this area, and as shown in Figure 20, the potential of low-carbon fuels is based on a 10% reduction in the carbon intensity of on-road fuels in 2030. Expanded adoption of such policies—including those that accelerate the deployment of low-carbon fuels and electric drive and also curb high-carbon fossil fuels—could mitigate another 1.1 $GtCO_2$ annually in 2030.

Conclusion 6: Adopted policies in the transport sector will avoid an estimated 2.2 $GtCO_2$ annually in 2030, with an additional reduction of 4.4 $GtCO_2$ achievable with expanded policies for low-carbon vehicles and fuels.

Through their efforts to improve vehicle efficiency, governments and industry leaders have set a clear example that sector-specific, national-level policy actions can make substantive progress toward meeting global climate goals. Actions to improve the efficiency of international marine vessels have also demonstrated the potential effectiveness of international fora when they have a sectoral focus and a strong business case. There remains significant opportunity to reduce transport sector CO_2 emissions in a cost-effective manner, in which fuel savings fully make up for the costs of fuel-efficient technology within a few years of the initial investment. Such opportunities include extending existing vehicle efficiency policies to 2025 and beyond, adopting similar policies in emerging vehicle markets, and expanding progress to other transport modes (including HDVs, marine, and aviation).

Figure 20 summarizes the estimated impact of adopted and potential vehicle and fuel regulations on global CO_2 emissions from the transport sector. By 2030, transport emissions are expected to increase by roughly two-thirds from 2010 levels to 15 $GtCO_2$ and 78 mbd of oil. Regulations adopted to date will reduce lifecycle CO_2 emissions by an estimated 2.2 $GtCO_2$ and fuel use by approximately 11 mbd from business-as-usual levels in 2030, equivalent to about a 13% reduction. Further expanding best-practice policies could deliver an additional 4.4 $GtCO_2$ and 21 mbd reduction in 2030, equivalent to a 30% and 27% reduction, respectively. Such policies, which include actions to promote ultralow-carbon transport alternatives such as electric-drive vehicles powered by renewable electricity, could begin to substantially reduce total transport CO_2 emissions in the 2020-2025 timeframe, even as the demand for passenger and freight transport increases.

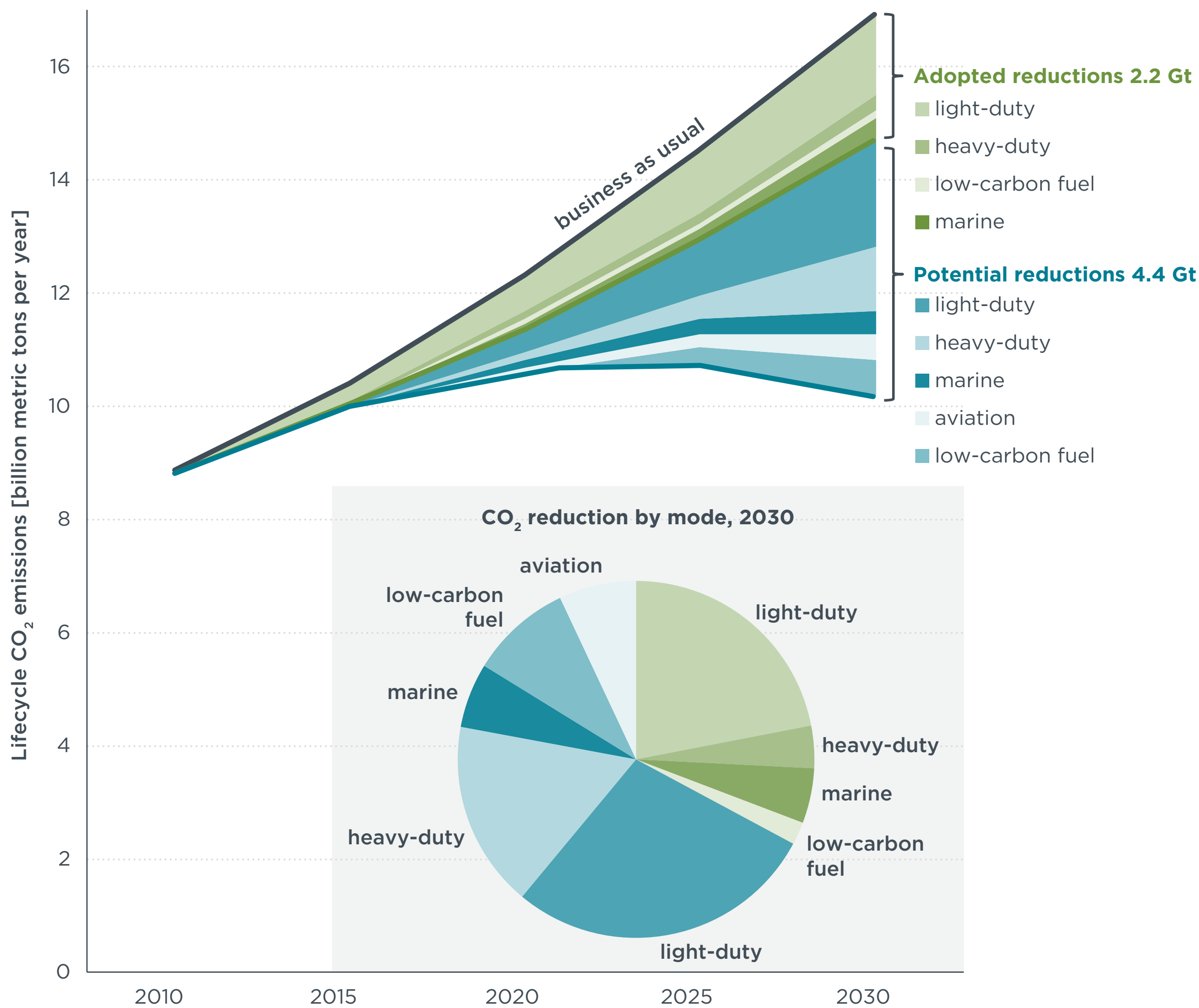


Figure 20. Global CO_2 emissions from transport, 2010-2030

Based on the ICCT's review of 11 major vehicle markets and international fora for marine and aviation, adopted GHG reduction policies alone will not be enough to avoid sustained increases in transport-sector emissions through 2030. However, timely action to expand and extend proven best-practice policies could put the transport sector on a pathway more consistent with a two-degree Celsius temperature change by 2050 (IPCC, 2014). While new policies for low-carbon vehicles and fuels have the potential to stabilize emissions from the transport sector, achieving steep, sustained reductions in total transport sector GHG emissions would likely require the implementation of policies and strategies to lower total transport demand and shift the movement of people and goods to low-carbon transport modes such as non-motorized transport, public transit, and rail. Future research could include a comparison of the impacts of adopted and potential climate mitigation actions across the economic sectors (e.g., transport, electric power, industrial, forestry) toward achieving global climate targets.

4.2. AIR POLLUTANT EMISSIONS AND PUBLIC HEALTH

Air quality continues to be a problem in most major metropolitan areas, especially in emerging economies that are still working toward world-class environmental regulations. Exposure to outdoor air pollution resulted in 3.2 million early deaths in 2010 and ranks among the top ten health risks worldwide (Lim et al., 2012), and transportation is one of the main contributors to poor air quality and associated public health impacts. Most developed economies have already implemented world-class standards for vehicles and fuels, which have demonstrated clear net benefits to society through dramatically reduced health impacts from vehicle emissions (Zapata & Kleeman, 2014). Recent cost-benefit analyses indicate that the likely benefits to society of world-class standards would far outweigh the costs of vehicle technology and cleaner fuels in countries such as Mexico and China (Miller et al., 2014; Shao et al., 2014).

Conclusion 7: Nearly half of new vehicle sales include world-class emission controls.

World-class vehicle standards for local air pollutants require state-of-the-art emission control technologies for pollutants with strong adverse health impacts such as PM and NO_x. A prominent benchmark is to achieve Euro 6/VI emission levels, at which exhaust emissions of PM and NO_x are reduced by over 97% from unregulated levels. Such standards apply to all sales and registrations in the US, Japan, and Canada, and to all type approvals in the EU and South Korea. These regions accounted for 45% of worldwide vehicle sales in 2013 (OICA, 2014).

The need for strong controls on vehicle emissions in emerging and developing economies is increasing as vehicle sales continue to grow. Figure 21 shows trends in total vehicle sales by region from 2005 to 2013, as well as the annualized change in sales over this period (OICA, 2014). The four fastest growing major vehicle markets—China, India, Brazil, and Russia—have yet to adopt emission standards equivalent to Euro 6/VI or better, even as leading regions develop next-generation standards (e.g., US Tier 3). Moreover, while other countries in the Asia-Pacific, Latin America, the Middle East, Africa, and post-Soviet states had greater combined sales in 2013 than the total of China and India, many of these countries have requirements that are several levels behind world-class standards.

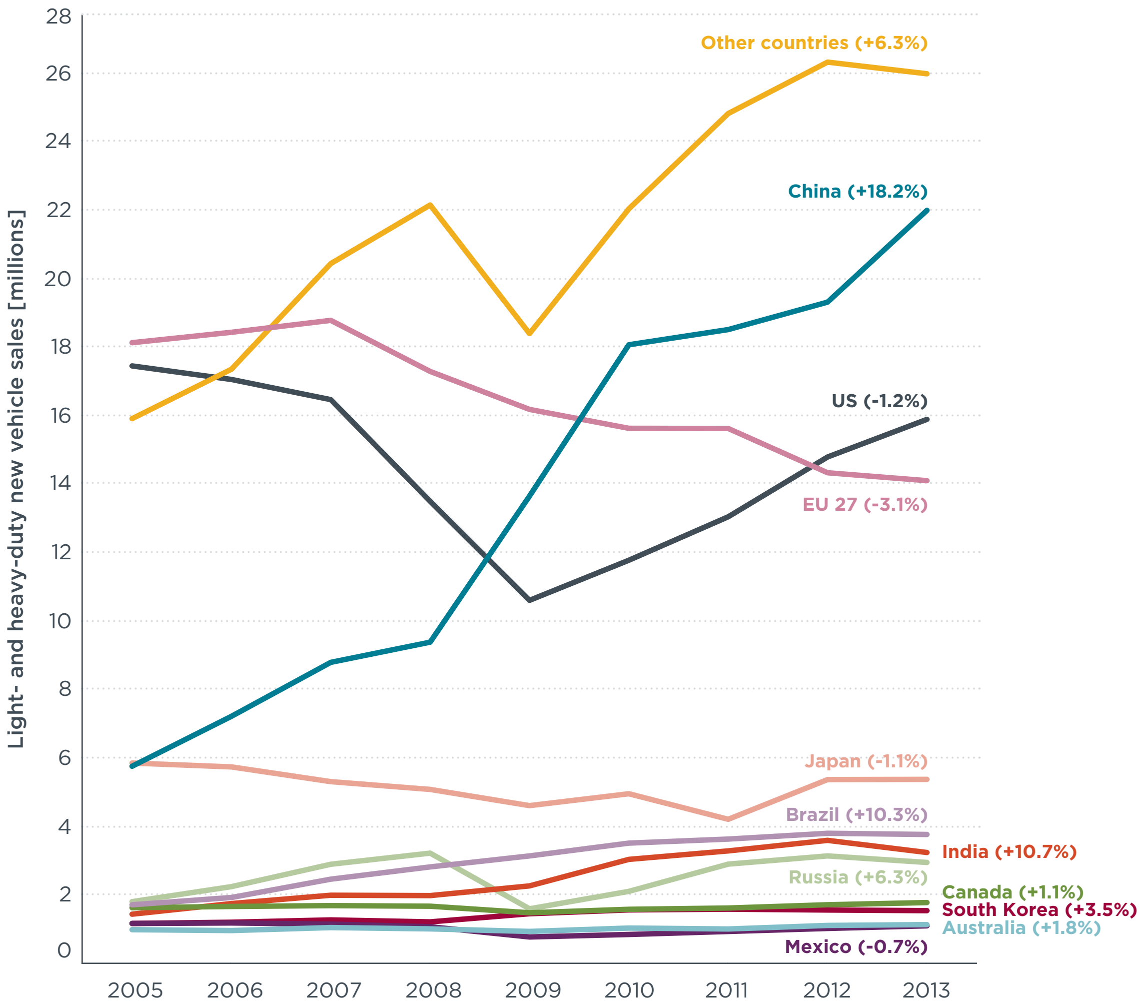


Figure 21. Sales of new light- and heavy-duty vehicles, 2005-2013 (OICA, 2014)
Data labels indicate annualized sales growth from 2005-2013.

Conclusion 8: Expanded adoption of standards requiring proven world-class vehicle emission controls and ultralow-sulfur fuel could avoid three out of four premature deaths projected to occur from exposure to vehicle emissions in 2030.

Figure 22 illustrates the effects of two policy pathways on the number of global premature deaths caused by exposure to vehicle emissions in the year 2030. These estimates are based on exhaust emissions of $PM_{2.5}$ from light- and heavy-duty on-road vehicles in urban areas and reflect the greatest impact of vehicle emissions on public health. Additional impacts that were not quantified include premature deaths from exposure to off-road and marine diesel emissions, and secondary PM and ozone. Also absent from these health impact estimates are non-fatal health outcomes and lost productivity as a result of exposure to direct and indirect vehicle emissions. Without additional action beyond formally adopted regulations, the number of premature deaths from exposure to vehicle emissions could increase by two-thirds in just 16 years. The vast majority of these impacts would occur in regions such as India, China, Brazil, Mexico, and countries in Asia-Pacific, Latin America, the Middle East, and Africa. Importantly, governments in China, India, Brazil and Mexico are actively considering adoption of standards equivalent to Euro 6/VI or better, which would dramatically increase the share of new vehicle sales subject to world-class standards worldwide; however, as of August 2014, such standards have yet to be adopted in any of these regions. Implementing world-class vehicle emission standards would reduce transport air pollution-related mortality in 2030 from approximately 270,000 deaths to 71,000 deaths in 2030 globally, with benefits that are greatly concentrated in major cities.

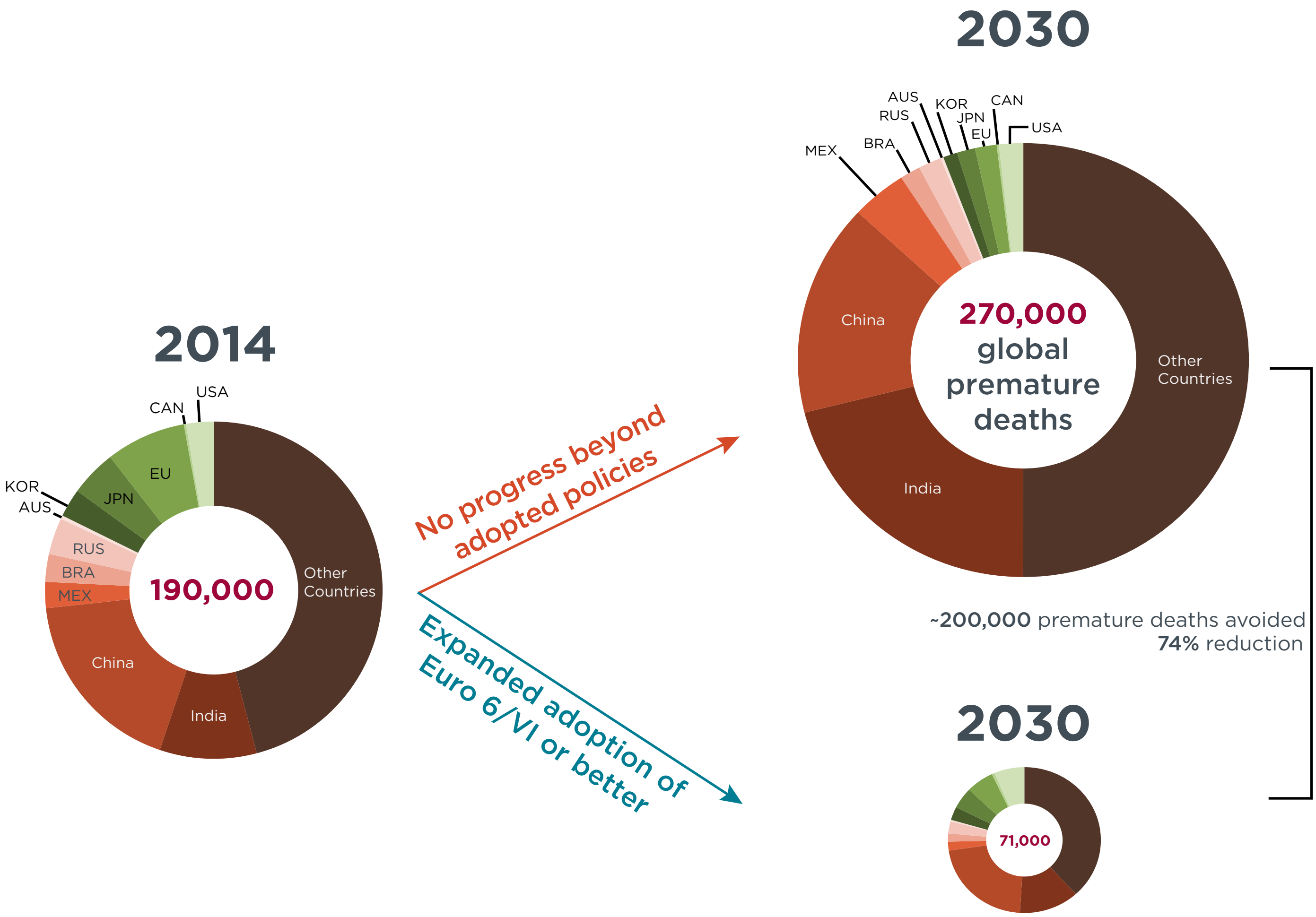


Figure 22. Global premature deaths from light- and heavy-duty vehicle exhaust $PM_{2.5}$

Conclusion 9: Adopted standards for international marine and aviation will significantly reduce emissions of air pollutants, with additional reductions possible from the application of proven technologies and fuels.

The IMO is responsible for setting emission standards for international vessels, and has to date regulated emissions of NO_X and sulfur content of bunker fuels. Tier I levels for NO_X were introduced in 2000 and were replaced by Tier II levels in 2011, which reduced emission rates further by about 15%. Tier III levels, which will eventually apply to ECAs, will reduce emission rates further of NO_X by roughly 80% from Tier II levels. Sulfur content is currently regulated at 3.5% (35,000 ppm) and is scheduled to be reduced to 0.5% in 2020. The regulation of BC to address both climate change and human health is pending technical discussion regarding the definition and measurement methods for BC. For ECAs, sulfur levels are currently set at 1% and are scheduled to be reduced to 0.1% in 2015. ECAs are especially important because 70-80% of SO_x, NO_x, and BC are emitted from ships traveling within 400 km of a coastline, close enough to have significant impacts on human health (Wang, 2013a).

Proven technologies and fuels can reduce marine emissions of PM, sulfur oxides (SO_x), and NO_x by over 90% from uncontrolled levels (ICCT, 2013); however, these technologies and fuels have been largely under-utilized due to limited ECA adoption around the world. More-stringent standards to drive the adoption of these technologies and fuels could reduce international marine emissions of NO_x by 23%, and PM and SO_x by more than 80% in 2030 compared to business-as-usual levels.

For international aviation, the ICAO has developed multiple tiers of global aircraft NO_x emission standards, which are based on the landing and take-off cycle and target air quality improvements around airports. In 2010 ICAO established more aggressive but non-binding NO_x reduction targets equivalent to a 45% reduction from the latest standard by 2016 and a 60% reduction by 2026. Making these non-binding targets mandatory would ensure that the intended benefits are realized. Following up on its previous announcements, adoption of an ICAO non-volatile particulate matter standard would reduce the aviation sector’s impacts of ultrafine PM on air quality, human health, and global climate.

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LIST OF ACRONYMS

ANPR	advanced notice of proposed rulemaking
BC	black carbon
BEV	battery electric vehicle
CAA	Clean Air Act (United States)
CAEP	Committee on Aviation Environmental Protection
CO_2	carbon dioxide
DOC	diesel oxidation catalyst
DPF	diesel particulate filter
ECA	emission control area
EEDI	Energy Efficiency Design Index
EGR	exhaust gas recirculation
EPA	Environmental Protection Agency (United States)
ETS	Emissions trading scheme
EU	European Union
FCEV	fuel cell electric vehicle
FQD	Fuel Quality Directive
GFEI	Global Fuel Economy Initiative
GHG	greenhouse gas
$GtCO_2$	billion metric tons of carbon dioxide
HDV	heavy-duty vehicle
ICAO	International Civil Aviation Organization
ICCT	International Council on Clean Transportation
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LCFS	Low Carbon Fuel Standard
LCV	light commercial vehicle
LDV	light-duty vehicle
LTO	landing and take-off
mbd	million barrels of oil per day
MARPOL	International Convention for the Prevention of Pollution from Ships
MBM	market-based measure
MEPC	Marine Environment Protection Committee
MRV	monitoring, reporting, and verification
$MtCO_2$	million metric tons of carbon dioxide
MY	model year
NO_x	nitrogen oxides
OICA	International Organization of Motor Vehicle Manufacturers
PHEV	plug-in hybrid electric vehicle
PM	particulate matter

$PM_{2.5}$	particulate matter with an aerodynamic diameter less than 2.5 micrometers
PM_{10}	particulate matter with an aerodynamic diameter less than 10 micrometers
ppm	parts per million
RED	Renewable Energy Directive
RFS	Renewable Fuel Standard
SCR	selective catalytic reduction
SEEMP	Ship Energy Efficiency Management Plan
SO_X	sulfur oxides
SUV	sport utility vehicle
TTW	tank-to-wheel
TWC	three-way catalyst
ULSD	ultralow-sulfur diesel, with fewer than 15 ppm sulfur content
UNECE	United Nations Economic Commission for Europe
US	United States
WHO	World Health Organization
WTT	well-to-tank
WTW	well-to-wheel