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BRIEFING PAPER

POLICIES TO REDUCE FUEL CONSUMPTION, AIR POLLUTION, AND CARBON EMISSIONS FROM VEHICLES IN G20 NATIONS

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MAY 2015

icct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

ACKNOWLEDGEMENTS

The author would like to thank the team of Nic Lutsey, Josh Miller, and Joe Schultz for providing initial drafts of this paper and to give special thanks to Kuangyuan Zhang for his tireless contributions throughout the drafting and editing process. Any document that seeks to touch on the status and potential for further policy action in 20 major economies must rely on input from experts in each jurisdiction, which in this case includes the ICCT team of country and regional leads as well as our partners at the United Nations Environment Program. Special thanks for comprehensive reviews are extended to John German, Kate Blumberg, and Ray Minjares at the ICCT, as well as Vance Wagner, U.S. State Department, who participated in a personal capacity; the views and opinions expressed in this paper do not necessarily state or reflect those of the United States Government or any agency thereof.

This paper has been drafted by the International Council on Clean Transportation at the request of the Transport Task Group of the G20 Energy Efficiency Action Plan. It is solely for informative purposes of the participating countries in that Task Group.

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EXECUTIVE SUMMARY

The transport sector offers an immense challenge and opportunity. In moving people and goods throughout the world, transport plays a vital part in world economic growth, but it also has a significant and growing environmental footprint. The transport sector consumes more than half of global oil production, and releases nearly a quarter of all anthropogenic carbon dioxide emissions. Motor vehicles and engines, especially those fueled with diesel, contribute to ambient air pollution responsible for millions of premature deaths worldwide each year.

Heavy-duty vehicles, including commercial freight trucks and buses, will be especially important in balancing the world's future transport needs with the health and environmental impacts. Heavy-duty vehicles contribute disproportionately to oil consumption, greenhouse gas emissions, and air pollution compared with their fraction of the fleet. Worldwide, heavy-duty vehicles represent just 11% of motor vehicles, but they are responsible for almost half of vehicle CO_2 emissions and over two-thirds of vehicle particulate emissions. Because these impacts are significant, and solutions to address them are known, heavy-duty vehicles are an attractive policy target and a key focus in the G20's 2014 Energy Efficiency Action Plan.

In this briefing paper, we review and summarize the status of motor vehicle energy efficiency and emissions control programs in G20 nations. These programs have four components: (1) clean, low-sulfur fuel standards; (2) tailpipe emissions standards for new vehicles; (3) fuel economy and CO_2 standards for new vehicles; and (4) voluntary Green Freight programs. We assess the current status of G20 countries in terms of their adoption of clean vehicle and fuel policies. In addition, we synthesize the foundational data on technology availability, adoption cost, emission reduction, and benefit-cost analysis that underlie these polices.

Our assessment shows that substantial societal benefits have accrued to those G20 nations that have adopted clean fuel and vehicle policies identified in this policy brief. For a complementary package of tailpipe emission and fuel quality standards, public health benefits consistently and substantially exceed societal costs, indicating that such policies are cost-effective. Similarly, a significant body of evidence demonstrates that vehicle fuel economy and CO_2 standards achieve major reductions in carbon emissions and oil use while simultaneously providing fuel savings and financial benefits to consumers.

OUR ASSESSMENT SHOWS THAT SUBSTANTIAL SOCIETAL BENEFITS HAVE ACCRUED TO THOSE G20 NATIONS THAT HAVE ADOPTED CLEAN FUEL AND VEHICLE POLICIES IDENTIFIED IN THIS POLICY BRIEF.

This points to a number of policy opportunities for G20 countries. To facilitate future collaboration, we propose three groupings of G20 countries according to current policy status and recommended future actions. There are no hard and fast rules to these categories, and G20 nations may choose different groupings as needs and interests dictate.

Table ES-1: Proposed clean fuel and vehicle groups, countries, and next policy actions

Group	Group definition	Countries	Next policy actions
Group 1	Currently has: • Nationwide implementation of clean, low-sulfur fuels • World-class emission standards • Passenger vehicle fuel economy standards • Green Freight program	Canada, EU (Germany, UK, France, Italy), Japan, South Korea, United States	• Establish and upgrade light- and heavy-duty fuel economy standards to world-class • Improve Green Freight programs • Address gap between real-world and laboratory test emissions
Group 2	• Clean, low-sulfur fuel either available or planned • World-class emission standards not yet adopted	Argentina, Australia, Brazil, China, India, Mexico, Russia, Turkey	• Adopt world-class emission standards for passenger and heavy-duty vehicles • Establish passenger vehicle labeling and/or fuel economy standards • Establish heavy-duty Green Freight and/or fuel economy standards
Group 3	• No availability of clean, low-sulfur fuel • No emissions or fuel economy programs implemented	Indonesia, Saudi Arabia, South Africa	• Adoption of clean, low-sulfur gasoline and diesel • In tandem with fuel standards, advance toward world-class tailpipe emission standards as rapidly as possible

While the full set of policy actions for passenger and heavy-duty vehicles are described in Table ES-1, the most immediate policy actions for heavy-duty vehicles are identified as:

» For Group 1 countries, ensure that real-world emissions match the reductions required by regulations; establish and upgrade fuel economy and CO_2 emission standards; and improve and expand existing Green Freight programs.

» For Group 2 countries, effectively adopt and implement clean, low-sulfur fuel standards for gasoline and diesel; adopt world-class emission standards; establish initial fuel economy or CO_2 emission standards and Green Freight programs.

» For Group 3 countries, adopt and implement clean, low-sulfur fuel standards for gasoline and diesel and, in tandem, advance toward world-class tailpipe emissions standards as rapidly as possible.

Overall, the opportunity for G20 countries to help bring forth a fleet of higher-efficiency, lower-emission vehicles is immense. In 2014, G20 countries accounted for over 90% of global vehicle sales. The policies adopted by G20 members thus largely dictate the air pollution, fuel consumption, and CO_2 emissions of the global transport sector. A collective G20 commitment would amplify the impact of these policies and promote sharing of best practices and technology developments among regions. Technical assistance among G20 countries for policy and program design, development, and implementation would accelerate cost-effective policy actions. In sum, this briefing paper highlights how policies and programs in these areas have been successfully and cost-effectively implemented, and identifies opportunities for further actions within the G20.

THE POLICIES ADOPTED BY G20 MEMBERS THUS LARGELY DICTATE THE AIR POLLUTION, FUEL CONSUMPTION, AND CO_2 EMISSIONS OF THE GLOBAL TRANSPORT SECTOR.

I. INTRODUCTION

An important outcome of the G20 summit held in Brisbane, Australia in November 2014 was the publication of the G20 Energy Efficiency Action Plan.[1] As G20 members consume 80% of the world's energy output, increased collaboration on energy efficiency can help spur economic growth, enhance energy security, and improve the environment all over the world. Furthermore, international business efficiencies can be improved through the harmonization/alignment of energy efficiency approaches and standards.

The Energy Efficiency Action Plan identified six focus areas for collaborative activity, including motor vehicles, which was characterized as a new area where the G20 could add value by addressing an emerging challenge or a gap in existing international collaboration. With regard to motor vehicles, the stated objective is to improve energy efficiency and emissions performance. Specifically, the Action Plan described the commitment in this way:

> Participating countries will work together to improve vehicle energy efficiency and emissions performance, particularly for heavy-duty vehicles. In 2015, this work will include developing recommendations, for G20 consideration, including for strengthening domestic standards in G20 countries in as many areas as possible related to clean fuels, vehicle emissions, and vehicle fuel efficiency, and for Green Freight programs. Participating countries will work together with IPEEC and relevant international expert organizations to establish a new IPEEC Transportation Task Group to support this work.[2]

The G20 Energy Efficiency Action Plan is a voluntary initiative. To date, there are 12 participating economies in the transport work stream of the Plan: Australia, Brazil, Canada, the European Union (EU), France, Germany, Italy, Japan, Mexico, Russia, the United Kingdom, and the United States. The transport work stream is coordinated by the United States, while the International Partnership for Energy Efficiency Cooperation (IPEEC) is in charge of supporting collaboration in cooperation with international expert organizations.

THE ACTION PLAN SINGLES OUT HEAVY-DUTY VEHICLES FOR FOCUSED ACTIVITIES IN 2015 BECAUSE OF THEIR DISPROPORTIONATELY HIGH ENVIRONMENTAL IMPACTS COMPARED TO THEIR FRACTION OF THE OVERALL FLEET.

This briefing paper summarizes the status within G20 economies of vehicle and fuel policies and programs in four broad categories: (1) clean, low-sulfur fuel standards; (2) tailpipe emissions standards; (3) fuel economy or CO_2 standards; and (4) Green Freight programs. Within these four broad categories are subcategories for light-duty and heavy-duty vehicles, and for gasoline and diesel fuels. Together, these four areas represent a comprehensive approach to reducing the energy and environmental impacts of motor vehicles.

The Action Plan singles out heavy-duty vehicles for focused activities in 2015 because of their disproportionately high environmental impacts compared to their fraction of the overall fleet. Policies for these vehicles are also less mature than in the passenger vehicle sector. New collaborative work on heavy-duty vehicles could focus on "effectively measuring, comparing and controlling"[2] emissions and energy consumption through common approaches and coordinated national standards.

1 *G20 energy efficiency action plan: voluntary collaboration on energy efficiency.* (2014). Retrieved from https://g20.org/wp-content/uploads/2014/12/g20_energy_efficiency_action_plan.pdf

2 *G20 Energy Efficiency Action Plan,* at section 2.4.

BACKGROUND

The world has over 1.5 billion motor vehicles today, and that number is projected to surpass 2 billion by about 2020. The transport sector consumes about 48 million barrels of oil per day (MBD), against current global oil consumption of 93 MBD.[3] More than half of global oil production goes to fuel the transport sector (Figure 1), which is almost entirely powered by oil.

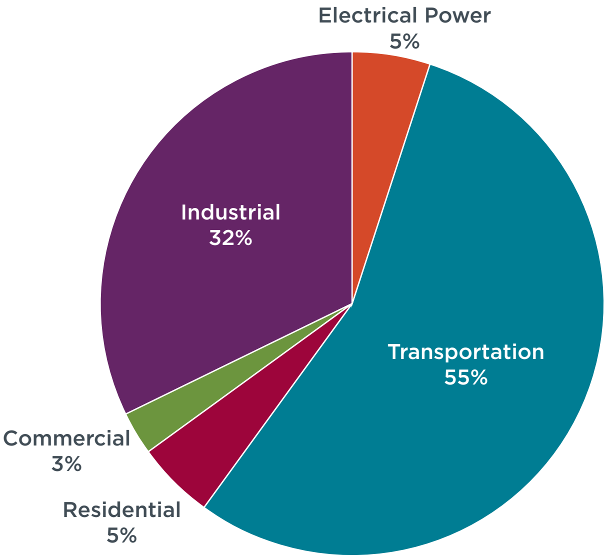

Figure 1. Global oil consumption by sector in 2010[4]

Motorized transport also contributes to air pollution, such as ground-level ozone or particulate matter, that leads to adverse health effects. Exposure to high ambient concentrations of ground-level ozone has been linked to hospital admissions and emergency room visits for respiratory problems. Exposure to vehicle exhaust is associated with a range of acute and chronic health effects, including exacerbation of asthma, cardiovascular mortality, and lung cancer. Long-term exposure to outdoor air pollution is a major risk factor for some of the most common causes of death, including cardiopulmonary disease, stroke, and lung cancer. An estimated 3.2 million annual premature deaths were attributable to ambient $PM_{2.5}$ exposure in 2010, making that the ninth leading risk factor for early death.[5]

MORE THAN 80% OF GROUND TRANSPORT PARTICULATE AND BLACK CARBON EMISSIONS ARE FROM HEAVY-DUTY VEHICLES.

Black carbon, a component of particulate matter, has a powerful near-term atmospheric warming effect: it is between 900 and 3,200 times more potent than carbon dioxide on a mass-equivalent basis. After carbon dioxide, black carbon is the second most important human-emitted climate forcer in terms of its impact in the present-day atmosphere.[6] Black carbon constitutes a significant fraction of particulate emissions from on-road and off-road diesel engines, particularly older engines without particulate filters. More than 80% of ground transport particulate and black carbon emissions are from heavy-duty vehicles.[7]

In 2010, almost a quarter of all anthropogenic CO_2 emissions, 8.8 gigatons (Gt), came from the global transport sector (Figure 2).[8] Within the transport sector, on-road vehicles accounted for about three-quarters of fuel consumption (35 MBD) and CO_2 emissions (6.5 Gt).

3 US Energy Information Administration, *Short-Term Energy Outlook* (2014). Retrieved from http://www.eia.gov/forecasts/steo/report/global_oil.cfm

4 US Energy Information Administration, *International Energy Outlook* (2014). Retrieved from http://www.eia.gov/forecasts/ieo/

5 Chambliss, S.E., Silva, R., West, J.J., Zeinali, M., Minjares, R., (2014). Estimating source-attributable health impacts of ambient fine particulate matter exposure: Global premature mortality from surface transportation emissions in 2005. *Environ. Res. Lett*. 9 104009 doi:10.1088/1748-9326/9/10/104009. Retrieved from http://iopscience.iop.org/1748-9326/9/10/104009

6 Bond, T.C. et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research-Atmospheres.* doi:10.1002/jgrd.50171. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50171/full.

7 Chambliss, S., Miller, J., Façanha, C., Minjares, R., Blumberg, K. (2013). The impact of stringent fuel and vehicle standards on premature mortality and emissions. Retrieved from www.theicct.org/global-health-roadmap

8 Façanha, C., Blumberg, K., Miller, J. (2012). Global transportation energy and climate roadmap. Retrieved from www.theicct.org/global-transportation-energy-and-climate-roadmap. US Energy Information Administration, *International Energy Outlook* (2011). International Energy Agency, *Annual Energy Outlook* (2013) and *World Energy Outlook: Renewable Energy Outlook* (2012).

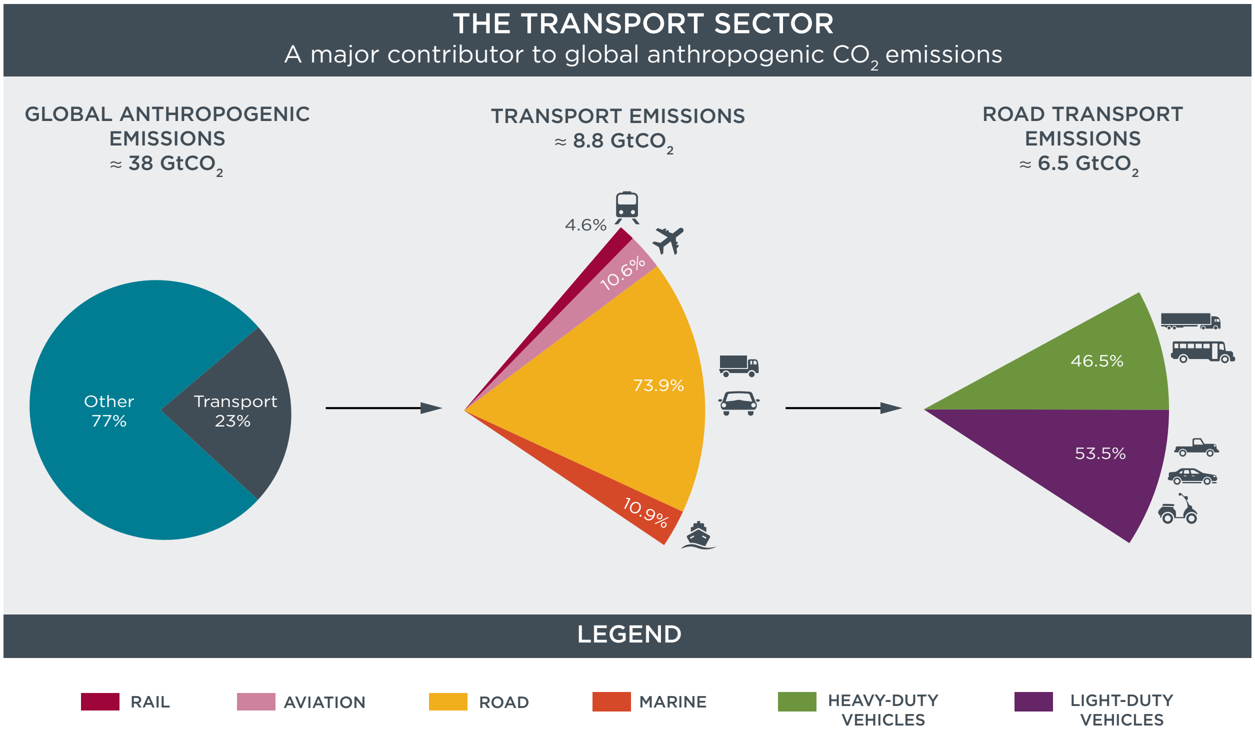

Figure 2. Global anthropogenic CO_2 emissions from the transport sector[9]

Notes: Global anthropogenic CO_2 emissions in 2010 based on IPCC Fifth Assessment.[10] Transport CO_2 emissions in 2010, as estimated by ICCT, reflect the full fuel lifecycle, including direct emissions from combustion and upstream emissions from extraction, refining, and distribution of fuels.[11]

FOCUS ON HEAVY-DUTY VEHICLES

The potential for policy action to address heavy-duty vehicle emissions and targeted climate mitigation is particularly great within the G20—a conclusion that strongly supports the emphasis on heavy-duty vehicles in the G20 Energy Efficiency Action Plan. This is primarily due to heavy-duty vehicles' severe air-quality and climate impacts, and to the fact that regulation in this sector remains at an early stage of development in most nations, relative to passenger vehicles.

Table 1 shows the disproportionate contribution of heavy-duty vehicles to vehicle CO_2 and particulate emissions. The heavy-duty sector globally represents just 11% of motor vehicles, but is responsible for almost half (46%) of vehicle CO_2 emissions, and over two-thirds (71%) of vehicle particulate emissions. The table also shows that heavy-duty vehicles' contribution to emissions is disproportionately high across major economies. In round numbers, only 5%–20% of vehicles in this group are heavy-duty vehicles, but they generally represent 30%–80% of vehicle CO_2 and particulate emissions.

9 Miller, J. and Facanha, C. The state of clean transport policy: A 2014 synthesis of vehicle and fuel policy developments (2014). Retrieved from http://www.theicct.org/state-of-clean-transport-policy-2014

10 IPCC, 2014: Summary for Policymakers. In: 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. Retrieved from http://mitigation2014.org/report/summary-for-policy-makers

11 ICCT Global Transportation Roadmap Model. See http://www.theicct.org/global-transportation-roadmap-model

Table 1. Heavy-duty vehicles' contribution to on-road climate pollutants[12]

	Percent of vehicles that are heavy-duty vehicles	Percent of vehicle carbon dioxide emissions that are from heavy-duty vehicles	Percent of vehicle particulate emissions that are from heavy-duty vehicles
China	10%	65%	83%
United States	5%	30%	36%
European Union	11%	37%	47%
Japan	19%*	43%	59%
Brazil	4%	61%	85%
India	5%	71%	74%
Russia	14%	54%	81%
Canada	15%	42%	52%
Global	11%	46%	71%

*Includes mini commercial vehicles

Heavy-duty vehicles are also a high-priority target for climate mitigation. In absolute terms they represent a relatively small number of emission sources, but a high proportion of both carbon and particulate emissions in many countries. The technologies required to comply with the most stringent emissions limits are mature, widely available, and cost-effective. Implementation of world-class policies for clean, low-sulfur fuels and vehicle emissions throughout the G20 could virtually eliminate fine particle and black carbon emissions from new heavy-duty vehicles by 2020–2025. And the G20 is uniquely positioned to pursue long-term technology-forcing efficiency standards for heavy-duty vehicles, given the market share of the member countries.

12 Façanha, C., Blumberg, K., Miller, J. (2012). Global transportation energy and climate roadmap.

II. STATUS OF CLEAN VEHICLE AND FUEL POLICIES

Globally, most major economies regulate their vehicle markets with some type of vehicle tailpipe emissions and/or fuel economy standards. The fact that so many vehicle standards are already in place is very promising. However, many of the various national and regional standards lag best practice in terms of stringency and compliance and enforcement. Accordingly, there is great potential in many countries and regions to adopt world-class standards that would drive investment in clean vehicles and fuels and more fully deploy proven, cost-effective technologies and solutions. In this section, we describe the status of the four major policies and programs to reduce the energy and environmental impacts of vehicles.

Throughout this briefing paper, we use the term "world-class emission standards" to refer to the suite of government policies to control air pollution, fuel consumption and greenhouse gas emissions from vehicles and fuels that we consider at present the world's best designed and most stringent policies. Table 2 summarizes today's world-class emission standards.

CLEAN, LOW-SULFUR FUELS

Motor vehicle emissions are strongly influenced by fuel quality. Starting in the 1970s, governments required petroleum companies to supply unleaded gasoline in order to reduce emissions of lead, a neurotoxin, and to enable auto manufacturers to install catalytic converters, which are rendered inoperable by tetraethyl lead in gasoline. More recently, government agencies have required petroleum companies to supply gasoline and diesel fuel with increasingly low levels of sulfur. While tetraethyl lead was added to gasoline to raise octane levels, sulfur is a naturally occurring element in crude oil, and thus is more difficult, and more expensive, to remove. High-sulfur fuels result in elevated emissions of sulfate particles that have been linked to premature mortality and other adverse health consequences. Sulfur is present in all motor fuels (e.g., gasoline and diesel), unlike tetraethyl lead, which is a gasoline additive. Sulfur inhibits the effectiveness of noble metal catalysts in catalytic converters, diesel particulate filters, and selective catalytic reduction systems. This is particularly problematic for diesel particle filters, as high-sulfur fuels will cause the filters to clog with soot particles and could render the vehicle inoperable.

Table 2. World-class emissions standards

Policy Type	World-Class Emission Standard
Clean, low-sulfur fuel	• 10 to 15 parts per million (ppm) sulfur for gasoline and diesel fuel plus Euro 6/VI, US Tier 2/HD2010, or equivalent fuel specifications
Tailpipe emissions standards	• Passenger vehicles: Euro 6 or US Tier 2* • Heavy-duty vehicles: Euro VI or US HD2010* • In-use compliance programs (inspection and maintenance, OBD, warranty and recall, etc.)
Fuel economy and CO_2 standards	• Passenger vehicles: 95 g CO_2/km, or measures to cut new vehicle fuel consumption in half by 2030 from a 2005 baseline • Heavy-duty vehicles: Measures to cut new vehicle fuel consumption by 35% by 2030 from a 2010 baseline.
Green Freight	• Heavy-duty vehicles: Measures that promote real-world, market-based performance improvements tracked through standardized and verifiable reporting mechanisms (e.g., SmartWay in the U.S. and Canada).

* Other equivalent standards include Japan PNLTES. Note that we expect US Tier 3 standards, and California LEV III standards, to establish a new level of world-class standards for passenger vehicles once they go into effect in 2017.

Low-sulfur fuels provide air pollution benefits in two distinct ways for all vehicles. First, there is an immediate, direct benefit of sulfate particle emissions reductions from the entire in-use fleet once low-sulfur fuel is available in refueling stations. Second, low-sulfur fuel provides an indirect benefit as it enables automakers to incorporate advanced emission-control technologies on vehicles that are sensitive to higher levels of sulfur. In general, the indirect reduction of emissions enabled by low-sulfur fuel contributes the vast majority of overall emissions reduction. For this reason it is important to see fuel desulfurization as a complement to tailpipe emission standards, the primary policy lever for vehicle emission controls.

Among the G20 countries, gasoline and diesel fuel sulfur levels range from a high of 3,500 parts per million (ppm) of sulfur to a low of 10 ppm. World-class gasoline and diesel standards that enable stringent emission controls limit fuel sulfur levels to 10 to 15 ppm. Most G20 countries have already taken measures to reduce fuel sulfur content through more stringent fuel quality standards. And a number of G20 countries are expected to require low fuel sulfur in the next three to five years, including Argentina, China, India, Mexico, and Russia.

A number of studies have summarized or estimated the costs of low-sulfur fuel production in order to meet more stringent fuel quality standards, mostly in the United States and the EU, but also for some developing countries. The increase in fuel costs due to investments in low-sulfur fuels typically ranges from 0.5 cents per liter to 2.8 cents per liter.[13] Key factors that influence the cost of sulfur reductions include the age and type of oil refinery, the type and size of new equipment required, the magnitude of sulfur reduction required, and cost of financing. It stands to reason that the cost of low-sulfur fuels is directly related to the magnitude of the required reduction. According to a recent study that examined the potential cost of low-sulfur fuel across four major G20 countries, Brazil started with a relatively high baseline sulfur level of 1,350 ppm that resulted in a cost of 2 cents per liter, while India started with a lower baseline of 230 ppm that incurred an expected cost of 0.8 cents per liter.[14]

> ...IT IS IMPORTANT TO SEE FUEL DESULFURIZATION AS A COMPLEMENT TO TAILPIPE EMISSION STANDARDS, THE PRIMARY POLICY LEVER FOR VEHICLE EMISSION CONTROLS.

While the increase in fuel prices is modest, the initial investment cost can be quite large. The required investment to upgrade a petroleum refinery includes the cost of new equipment, the cost of financing and operating costs. In the United States, low-sulfur gasoline required under the Tier 2 rule was estimated to cost refineries $4.5 billion during the phase-in period and resulted in an additional 1.26 cents per gallon to the consumer when fully phased in. Other countries with fewer oil refineries are likely to have lower capital investment costs than the United States. For example, one recent study estimated investment costs to range from just under $2 billion to just over $4 billion in four major G20 economies: Brazil, China, India, and Mexico.[15]

TAILPIPE EMISSIONS STANDARDS

Elevated levels of air pollution in major urban areas such as London and Los Angeles in the first half of the last century led atmospheric scientists to identify motor vehicle emissions as an important contributor. The first motor vehicle emission standards were established in California and the United States in the late 1960s to address elevated levels of smog. Over the course of the last half century, three major regulatory programs have been developed in the United States, Europe, and Japan. More stringent emission standards were adopted as our understanding of the science of

13 Hart Energy and MathPro Inc. (2012). Technical and economic analysis of the transition to ultra-low sulfur fuels in Brazil, China, India, and Mexico. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_ULSF_refining_Oct2012.pdf

14 Hart Energy and MathPro Inc. (2012). Technical and economic analysis of the transition to ultra-low sulfur fuels in Brazil, China, India, and Mexico.

15 Hart Energy and MathPro Inc. (2012). Technical and economic analysis of the transition to ultra-low sulfur fuels in Brazil, China, India, and Mexico.

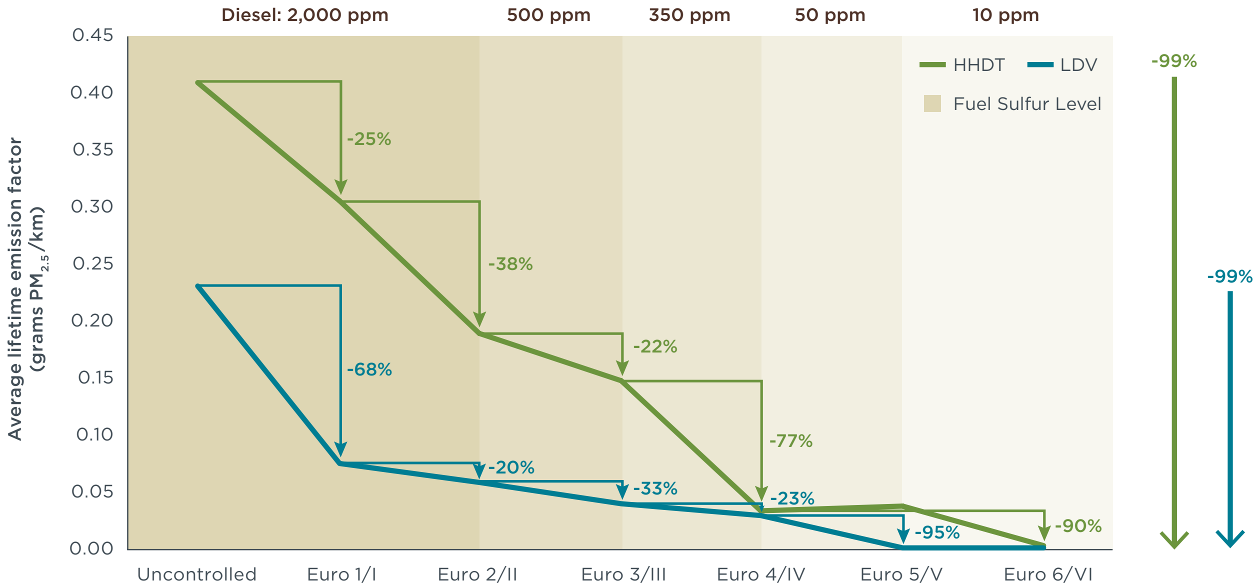

Figure 3. European tailpipe emission standards and matching fuel sulfur content[16]

air pollution, and of the effects of pollution on public health and the environment, improved over time.

Most countries around the world have chosen to adopt European tailpipe emissions standards and the associated clean, low-sulfur fuels. For this reason, we have chosen to illustrate the progressive reductions in particulate matter emissions by the Euro standards for light-duty vehicles (LDV) and heavy-duty vehicles (designated as HHDT, for heavy heavy-duty trucks, in Figure 3). The European standards are designated by Arabic numerals for light-duty vehicles and Roman numerals for heavy-duty vehicles, and have progressed from Euro 1/I (1992) through Euro 6/VI (2015). Many countries throughout Asia and Latin America are currently implementing Euro 2/II, 3/III, and 4/IV standards. Today, the most advanced European emission control standards are called Euro 6 for light-duty vehicles, and Euro VI for heavy-duty vehicles. Each emission standard is matched by a fuel quality standard that progressively reduces the sulfur content of the fuel in both diesel and gasoline. The diesel fuel sulfur limit of each standard is indicated at the top of the chart.

Diesel vehicles, especially heavy-duty trucks and buses, are the prime targets for policies intended to reduce the ambient concentrations of $PM_{2.5}$ and NO_X. Fine particulates cause the vast majority of premature deaths from outdoor air pollution, while nitrogen oxides contribute to the ozone exposures that are associated with asthma and other respiratory diseases.[17] Heavy-duty diesels accounted for more than 80% of $PM_{2.5}$ and NO_X emissions from on-road vehicles in 2010.

Figure 3 shows the dramatic effect that each successive Euro vehicle emissions standard has had on particulate matter. As the arrows on the right indicate, the current standard, Euro 6/VI, lowers actual emissions of $PM_{2.5}$ (measured in grams per kilometer) from both light- and heavy-duty vehicles by 99% from the historical uncontrolled levels. The standards virtually eliminate $PM_{2.5}$ and black carbon emissions from vehicles, and this also means that with proper in-use compliance programs future growth in the activity of these vehicles will no longer lead to growth in emissions.

The figure also illustrates the close interaction between particulate emission limits and fuel sulfur content limits. The gradient background shows the decline in permitted levels of sulfur in diesel fuel from 2,000 ppm to 10 ppm, the current standard in Europe,

16 Chambliss, S., Miller, J., Façanha, C., Minjares, R., Blumberg, K. (2013). The impact of stringent fuel and vehicle standards on premature mortality and emissions.

17 US Environmental Protection Agency website, Six common pollutants, http://www.epa.gov/oaqps001/nitrogenoxides/health.html

matching the progression from first Euro standards to the present. As discussed previously, lowering sulfur content is a key step in enacting advanced emission control technologies and reducing emissions.

The cost associated with adopting better emission control technologies in new vehicles varies, depending on the baseline emission standard of the current fleet, as well as the type of vehicle. Economies of scale and continuous improvement by the auto manufacturers have steadily reduced costs of emissions control technologies over the last several decades. For those G20 countries with Euro 2/II emission standards, we estimate that leapfrogging all the way to Euro 6/VI standards would incur a cost of USD$160 for a gasoline passenger car (4-cyl, 1.6L engine), USD$1,300 for a diesel passenger car (4-cyl, 1.6L engine) and between USD$3,900 and USD$7,000 for a heavy-duty truck, depending on engine size. These costs are significantly reduced in countries starting from a more advanced baseline of Euro 3/III or better.[18]

Table 3 summarizes the current status of light- and heavy-duty vehicle emissions standards and fuel sulfur standards in the G20 members. World-class standards are color-coded dark green. The EU member states that are also individual G20 members—Germany, the United Kingdom, France, and Italy—are individually listed in the table, but it's important to note that the European Commission sets European-wide vehicle and fuel standards that these countries and other European Union member states are obligated to follow.

Overall, this table shows that a large fraction of the G20 countries are already achieving world-class standards for vehicles and fuels. Specifically, Canada, the European Union and its member states, Japan, South Korea, and the United States have all adopted world-class standards. The next steps for this group of countries include increasing the stringency and length of passenger vehicle and heavy-duty vehicle fuel economy standards, building up or enhancing national or regional Green Freight programs, and establishing or enhancing compliance and enforcement programs to ensure that vehicle emission standards are maintained throughout the vehicle's full useful life.

WORLD-CLASS STANDARDS VIRTUALLY ELIMINATE $PM_{2.5}$ AND BLACK CARBON EMISSIONS FROM VEHICLES, AND THIS ALSO MEANS THAT WITH PROPER IN-USE COMPLIANCE PROGRAMS FUTURE GROWTH IN THE ACTIVITY OF THESE VEHICLES WILL NO LONGER LEAD TO GROWTH IN EMISSIONS.

The next group of nations to consider are those that have adopted world-class fuel quality standards but not the matching world-class vehicle emission standards: Argentina, Australia, Brazil, China, Mexico, India, Turkey, and Russia. This group of countries could move to world-class emission standards as soon as convenient, once the fuels are available. The next steps for this group of countries include adoption of world-class emission standards for passenger and heavy-duty vehicles, establishing passenger vehicle labeling programs, and establishing and enhancing Green Freight programs targeted at heavy-duty vehicles.

Those countries that have not adopted or implemented world-class fuel quality standards nationwide should adopt low-sulfur fuel for gasoline and diesel, and improve tailpipe emission standards.

18 Posada, F., Bandivadekar, A., German, J., (2012). Estimated cost of emission reduction technologies for light-duty vehicles. Retrieved from http://theicct.org/estimated-cost-emission-reduction-technologies-ldvs

Table 3. Light- and heavy-duty tailpipe emissions and fuel sulfur standards, G20

Region	Total Vehicle Sales in 2014	Emission standards		Fuel sulfur standards	
		Light-duty	Heavy-duty	Gasoline	Diesel
China	23,491,893	China 4[a]	China IV	10 [2017]	10 [2017]
EU	16,841,973	Euro 6	Euro VI	10	10
US	14,935,563	Tier 3 [2017]	US 2010	10 [2017]	15
Japan[b]	5,562,887	PNLTES	PNLTES [2016]	10	10
Brazil[c]	3,498,012	L-6	P-7	50	500 (10)[d]
Germany	3,356,718	Euro 6	Euro VI	10	10
India	3,176,763	Bharat III[e]	Bharat III[e]	150 (50)	350 (50)
UK	2,843,025	Euro 6	Euro VI	10	10
Russia	2,545,666	Euro 5 [2016]	Euro V [2016]	10 [2016]	10 [2016]
France	2,210,927	Euro 6	Euro VI	10	10
Canada	1,889,437	Tier 2[f]	US 2010	30[g]	15
South Korea	1,730,322	Euro 6	Euro VI	10	10
Italy	1,492,642	Euro 6	Euro VI	10	10
Indonesia[h]	1,208,019	Euro 2	Euro II	500	3500 (avg.), (500)
Mexico	1,176,305	Tier 1 / Euro 4	US 2004/Euro IV	80 (30)	500 (15)
Australia[j]	1,113,224	Euro 6 [2018]	Euro V/US07/JE05	50	10
Saudi Arabia	828,200	Euro 2	Euro II		500[k]
Turkey	807,331	Euro 5	Euro VI	10	10
South Africa[l]	644,504	Euro 2	Euro II	500 (50)	500 (50)
Argentina[m]	613,848	Euro 5	Euro V	150	30 (10) [2016]
Total G-20	**80,063,947**				
Total World	**88,164,642**				
G-20 Share	**90.8%**				

Euro-equivalent[n]

No standard	Euro 2/II	Euro 3/III	Euro 4/IV	Euro 5/V	Euro 6/VI	Post Euro 6/VI

a Current standards are China 4/IV nationwide, while some regions, such as Beijing, Shanghai, and Guangdong province, have adopted China 5/V and 10 ppm sulfur fuel. Standards that have been adopted but not yet implemented are indicated with the first implementation year in brackets, such as China gasoline 10 ppm sulfur (expected implementation in 2018).

b PNLTES standing for Japan's Post-New Long-Term Emission Standard (2009) is the current emission standard for the country's heavy-duty and light-duty vehicles. Japan will implement a new 0.4 g/kWh NO_x standard for HDVs in 2016.

c PROCONVE L-6 (2013) is the current light-duty emission standard; PROCONVE P-7 (2012) is the current heavy-duty emission standard; PROCONVE stands for "Programa de Controle da Poluição do Ar por Veículos Automotores" (The motor vehicle emission control program in Brazil)

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

e As of April 2014, Bharat IV standards were in effect in 33 cities including the national capital region; a nationwide implementation date has yet to be formally adopted.

f Canada issued a proposal to harmonize with the US Tier 3 regulation; however formal adoption is pending.

g Canada has proposed 10 ppm for gasoline sulfur standard.

h Indonesia's average sulfur content of diesel fuel in market is 3,500 ppm, though Euro II is implemented and 500 ppm diesel fuel is available in a few major cities; a move towards Euro 4 adoption is in progress, which will hopefully come true in 2016; Indonesia's national petroleum company is also moving to revitalize their refineries to be able to produce at least Euro 4 fuel.

j On Australia's regulation see TransportPolicy.net, http://transportpolicy.net/index.php?title=Australia:_Fuels:_Diesel_and_Gasoline

k As of January 2015, Saudi Arabia's diesel fuel standards are being updated to require Euro 5 sulfur levels in all the kingdom's refineries (http://www.unep.org/transport/new/pcfv).

l Information for South Africa from 1) http://www.unep.org/Transport/new/PCFV/pdf/10gpm/10GPM_AfricaRegionalUpdates.pdf and 2) Delphi Automotive, *Worldwide Emissions Standards: Passenger Cars and Light Duty Vehicles*.

m Emission and sulfur standards for Argentina, Turkey, Saudi Arabia, Mexico, South Africa and Indonesia are from http://www.unep.org/transport/new/pcfv); Argentina has Euro 5/V in 2014 for new models, and will adopt Euro 5/V for all models

n Euro-equivalent emission standards based on limit values

Adoption of a world-class standards for vehicles is not the final goal; the final goal is to obtain the benefits under real-world driving conditions. The technologies to achieve type-approval limits under real-world operation are available, but policies are not yet in place to ensure that manufacturers use these technologies and calibrate them to effectively control emissions over the majority of real-world operating conditions, not just those covered by the test cycle. The European Commission (EC) is in the process of resolving this real world vs. laboratory discrepancy in diesel passenger cars by introducing the Euro 6c amendments.

FUEL ECONOMY AND CO_2 EMISSION STANDARDS

The world's first fuel economy standards were established in the United States and Japan in the 1970s and 1980s. Automakers were required to produce new passenger vehicles with increased energy efficiency and lower fuel consumption. In the 1990s, Europe established voluntary CO_2 standards for passenger vehicles that also required vehicle manufacturers to improve the fuel efficiency of new motor vehicles. Since the only way to reduce CO_2 emissions is to improve the fuel efficiency of the vehicle, we consider fuel economy and CO_2 standards interchangeable (see Figure 4). Fuel economy standards for heavy-duty trucks are relatively new, with the first standards coming into effect for new trucks and buses in Canada, China, Japan, the United States in 2014 and 2015.

Today, Japan and Europe are home to the world's most efficient fleets of new passenger vehicles, and Europe's 95 g CO_2 /km is designated the world-class emission standard. Similarly, the United States has adopted the world's most transformational fuel economy standards, which will double new passenger vehicle fuel economy by 2025. The US is the only nation to date that has achieved the Global Fuel Economy Initiative's target of doubling new passenger vehicle fuel economy by 2030.[19] There is no aftertreatment device available to convert CO_2 emissions to a benign substance (as NO_X is converted to nitrogen by catalytic converters). The only means available to lower vehicle CO_2 emissions is to improve the energy efficiency of the vehicle, which also results in lower fuel use and savings to the consumer.

As regulations become more stringent, there is greater need for programs to ensure compliance with new vehicle emission standards for the full useful life of the vehicle. Recent studies have demonstrated that year-over-year fuel efficiency improvements reported via the type-approval tests in European vehicles have not been matched in everyday driving—and that the gap between the vehicle emissions testing laboratory and the real world of the road is getting wider, reaching 38% in 2013.[20,] This gap represents lower real CO_2 emission benefits than expected with the regulation and higher fuel costs for buyers of new vehicles under the EU program.

Establishment of a labeling program is a typical forerunner of fuel economy standards. Labeling programs are in place in many major markets. Benefits of labeling include: (1) disclosing more information on vehicle fuel economy and helping consumers to recognize clean vehicles; (2) encouraging auto manufacturers to expand production and marketing of clean vehicles; (3) reducing petroleum consumption and CO_2 emissions, thereby enhancing national energy security.

About three-quarters of global light-duty vehicle sales occur in markets regulated by efficiency standards that drive down CO_2 emissions through 2015.[21] These standards only apply to new motor vehicles, and do not require any changes to the existing motor vehicle fleet.

Figure 4 compares all new passenger vehicle fuel economy standards that have been adopted or proposed worldwide, showing their historical progression (and, in the case of the most recently adopted regulations, their inception point) and future performance targets. Vehicle efficiency requirements are shown in terms of both CO_2 emissions (left axis) and fuel consumption (right axis).

19 *Global Fuel Economy Initiative Plan of Action 2012 to 2015*. Retrieved from https://www.iea.org/media/files/GlobalFuelEconomyInitiativePlanofAction20122015.pdf

20 Emissions Analytics, Are you paying the correct tax for your vehicle? http://emissionsanalytics.com/are-you-paying-the-correct-tax-for-your-vehicle/. Mock et al. (2014) From Laboratory To Road: A 2014 update of official and "real-world" fuel consumption and CO_2 values for passenger cars in Europe. Retrieved from http://www.theicct.org/laboratory-road-2014-update

21 ICCT, Global passenger vehicle standards, www.theicct.org/info-tools/global-passenger-vehicle-standards.

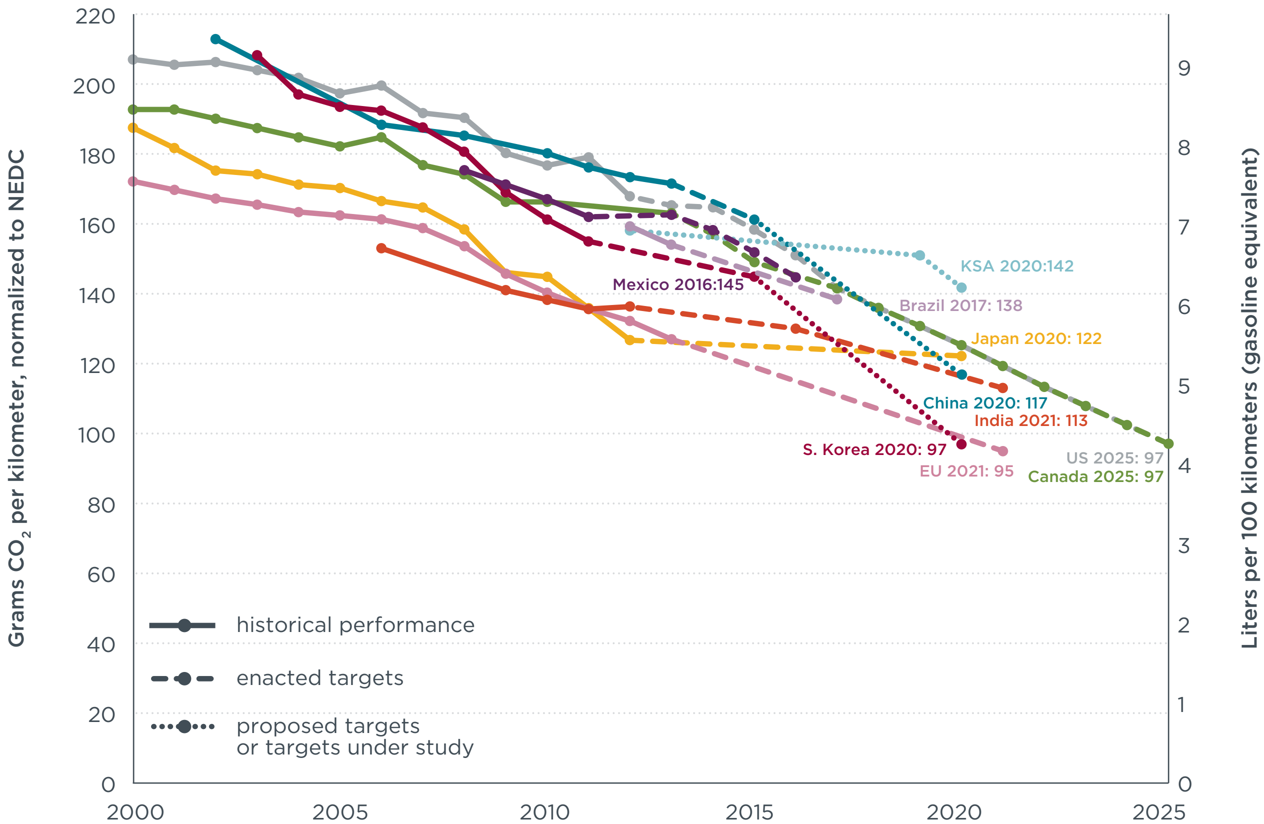

Figure 4. Comparison of light-duty vehicle efficiency standards (passenger cars only, light-duty trucks excluded)

These regulations take varying approaches, using different drive cycles and vehicle certification test procedures. Fairly comparing their fuel-efficiency mandates or emissions limits involves a mathematical conversion to account for the impacts of various differences and normalize the new-vehicle performance requirements to one or another test cycle—in this case, to the New European Driving Cycle (NEDC).

Compared to passenger vehicle regulations, heavy-duty vehicle fuel economy standards are at a much earlier stage of development. Only four governments—the US, Canada, China, and Japan—have adopted HDV fuel economy standards,[22] and those markets account for only about one-quarter of world truck sales. As shown in Table 4, these early examples of heavy-duty vehicle fuel economy standards established relatively modest efficiency improvements (11%–14%). The current Japanese and Chinese standards will be fully phased in by 2015, and the US and Canadian standards will be fully phased in by 2018. As is the case with light-duty vehicle regulations, heavy-duty vehicle regulations typically result in fuel savings that greatly exceed the costs of efficiency-improving technologies.

Now that four nations have created the regulatory design for heavy-duty vehicle fuel economy standards, interest is rising in other major heavy-duty vehicle markets. The EU is developing a certification protocol and reporting program, while others, such as Mexico, Brazil, India, and South Korea, are gathering data and other information to inform future regulatory proposals. Finally, Canada, China, Japan and the United States are each working on the next phase of heavy-duty vehicle standards. Together, these nations account for 82% of global heavy-duty vehicle sales.[23]

22 Transportpolicy.net, Heavy-duty Vehicles, http://transportpolicy.net/index.php?title=Category:Heavy-duty_Vehicles

23 International Organization of Motor Vehicle Manufacturers, Registrations or sales of new vehicles (2014), http://www.oica.net/wp-content/uploads//total-sales-2014.pdf

Table 4. Comparison of light-duty and heavy-duty vehicle fuel efficiency regulations of G20 countries*

		Light-duty vehicles			Heavy-duty vehicles		
Region	Total Vehicle Sales in 2014 (OICA)[a]	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	23,491,893	2011	2012-2015	9%	2012	2014-2015	11%
EU	16,841,973	2015	2020-2021	27%			
US	14,935,563	2010	2012-2025	50%	2010	2014-2018	14%
Japan	5,562,887	2015	2020	16%	2006	2015	12%
Brazil[c]	3,498,012	2013	2013-2017	12%			
Germany	3,356,718	2015	2020-2021	27%			
India	3,176,763	2012	2017-2021	17%			
UK	2,843,025						
Russia	2,545,666						
France	2,210,927	2015	2020-2021	27%			
Canada[d]	1,889,437	2017	2017-2025	35%	2010	2014-2018	14%
South Korea	1,730,322	2011	2012-2015	9%			
Italy	1,492,642	2015	2020-2021	27%			
Indonesia	1,208,019						
Mexico	1,176,305	2012	2014-2016	13%			
Australia[e]	1,113,224						
Saudi Arabia	828,200	2016	2016-2020	17%			
Turkey	807,331						
South Africa	644,504						
Argentina	613,848						
Total G-20	**80,063,947**						
Total World	**88,164,642**						
G-20 Share	**91%**						**No standard**

* Adapted from Miller, J., and Façanha, C., The state of clean transport policy: A 2014 synthesis of vehicle and fuel policy developments.

a Vehicle sales data from International Organization of Motor Vehicle Manufacturers, World motor vehicle sales by country and type 2005–2014, http://www.oica.net/category/sales-statistics/

b Percent reduction in new fleet fuel consumption estimated from a baseline year (not necessarily the first model year of implementation) to the final model year covered by the regulation. Reductions for HDVs are sales-weighted by vehicle type.

c Brazil's Inovar-Auto program requires a 12.1% improvement for manufacturers to qualify for tax incentives.

d Canada's fuel economy standards are voluntary for 2014 and 2015, and become mandatory in 2016.

e In Australia from 2005 to 2014, the CO_2 standard improved from 231g/km to 177g/km for passenger cars, and 285g/km to 235 g/km for light-commercial vehicles.

REDUCING FREIGHT EMISSIONS THROUGH GREEN FREIGHT PROGRAMS

Green Freight programs are complementary to yet distinct from the emissions, fuel, and efficiency standards discussed above. They are the one area where countries can implement policies to help the efficiency of the existing fleet. The aim of these programs is to promote real-world, market-based performance improvements that can be tracked through standardized and verifiable reporting mechanisms. The precise scope of what is covered under a Green Freight Program may vary, but there are a number of key elements that can be found in most successful Green Freight programs.

- Green Freight programs are **voluntary**, which distinguishes them from regulations. The voluntary nature of Green Freight programs requires a structure that will encourage strong participation by key players in the freight supply chain. The vehicle-based regulations discussed above typically target vehicle manufacturers; in contrast, the key Green Freight stakeholders are usually shippers, carriers, and logistics companies.
- Green Freight programs are **win-win** for both the public and private sectors. Typical Green Freight programs are established through some sort of public-private partnership that can improve efficiency and reduce emissions by a number of different mechanisms that appeal to both the public sector and the private sector. Examples include accelerated renewal or modernization of fleets, guidance on implementation technologies or strategies that reduce fuel consumption and decrease emissions, and enabling the flow of funding through financing programs (such as development banks or government incentive programs).
- Green Freight programs are **results focused**. The goal of these programs is to deliver real-world performance improvements: metrics must be tracked, benchmarked, and reported using a verifiable tool or methodology. In addition, these improvements should be recognized though labeling or branding components.
- Lastly, Green Freight programs are **customizable**. Green Freight programs should be customized to meet the needs of a particular region or country based on sound analyses and assessments of that country or region's freight system.

All Green Freight programs are not created equal. The SmartWay program, which is established in the US and Canada, has the largest membership at more than 3,000 partners. Those partners have saved 120.7 million barrels of fuel, eliminated 51.6 million metric tons of CO_2, 738,000 tons of NO_x, and 37,000 tons of PM since the program was initiated.[24] Other programs, such as Green Freight Europe, which is still in the process of ramping up in terms of membership, scope, and impact, have used the SmartWay experience as a guide.

Table 5 lists existing Green Freight programs around the world, including several in G20 countries. In addition, there are a large number of initiatives (not listed here) that are focusing their efforts on one or more key areas of importance to Green Freight programs (such as the development of tools and methodologies or the verification of relevant technologies). The large number of disconnected programs and other initiatives, combined with the global and boundary-less nature of freight transport, show there is a distinct need for greater harmonization or alignment among existing and emerging programs in order to extract the most benefit. The Climate and Clean Air Coalition's (CCAC) Global Green Freight Action Plan aims to do just that.[25] The purpose of the Action Plan is to facilitate collaboration among governments, the private sector, and civil society to enhance the environmental and energy efficiency of goods movement in ways that significantly reduce the climate, health, energy, and cost impacts of freight shipping around the world.

G20 countries with existing national Green Freight programs and partners in the Global Green Freight Action Plan are noted in Table 6. Properly implemented, Green Freight programs can be successful and have impact in any country, no matter the status of its fuel and vehicle standards. These programs can be established at a relatively low cost and, in the process, will create a coalition of collaborative stakeholders that can be a valuable resource in itself.

24 US EPA, SmartWay Transport Overview, http://epa.gov/smartway/about/documents/basics/420f14006.pdf

25 CCAC, Action Statement, Global Green Freight Action Plan, September 2014, http://www.unep.org/ccac/Portals/50162/docs/ccac/initiatives/diesel/Green%20Freight.pdf

Table 5. Existing Green Freight programs or initiatives, and others in development[26]

Scope	Program
Global: Maritime	• Business for Social Responsibility: Clean Cargo Working Group • Clean Shipping Index • Green Marine • EcoPorts
Global: Air	• IATA: Air Cargo Carbon Footprint working group • Air Freight Carbon Initiative
Regional: Road	• Green Freight Europe • Green Freight Asia
National	• Canada and US: SmartWay Transport Partnership • Australia: Ecostation* • Belgium: Lean and Green • China: China Green Freight Initiative; Guangdong Green Freight Pilot Program • Germany: Lean and Green • France: Objectif CO_2 • Italy: Lean and Green • Japan: Tokyo Freight Carrier Assessment System; Green Logistics Partnership • Korea: Green and Smart Transport Partnership • Mexico: Transporte Limpio • Netherlands: Lean and Green • United Kingdom: EcoStars Fleet Recognition

** No longer active*

Table 6. National Green Freight programs or partners in the Global Green Freight Action Plan

Region	National Green Freight Program	Partner in Global Green Freight Action Plan
China	Yes	No
EU	Yes	No
US	Yes	Yes
Japan	Yes	Yes
Brazil	No	No
Germany	Yes	No
India	No	No
UK	Yes	No
Russia	No	Yes
France	Yes	Yes
Canada	Yes	Yes
South Korea	Yes	Yes
Italy	Yes	No
Indonesia	No	No
Mexico	Yes	Yes
Australia	Yes*	No
Saudi Arabia	No	No
Turkey	No	No
South Africa	No	No
Argentina	No	No

* Program currently inactive due to lack of funding

26 Climate and Clean Air Coalition, Global green freight action plan, draft, March 2015, table 5.

III. RATIONALE FOR CLEAN VEHICLE AND FUEL POLICIES

This section summarizes the information developed by regulatory agencies to justify clean, low-sulfur fuel policies, tailpipe emissions standards, and fuel economy standards for passenger cars and heavy-duty vehicles. We examined the current literature on world-class fuel quality and vehicle emission standards that links the emissions benefits from clean, low-sulfur fuel and tailpipe emissions standards to reductions in ambient air pollution, which in turn improves public health. We then summarize results from economic methodologies to monetize the benefits from improved public health, and compare those social benefits against the private compliance costs incurred by the auto and petroleum industries. We also examined the payback periods for fuel economy standards for passenger cars and heavy-duty vehicles

COST-BENEFIT ASSESSMENTS

Health benefits. Long-term exposure to air pollutants closely linked to vehicle emissions, especially fine particulates, increases the risk of cardiopulmonary disease, stroke, and lung cancer, some of the most common causes of premature death.[27] Traffic-related air pollution is also associated with asthma onset in children and impaired lung function, as well as increased infant mortality.[28] The improvements in ambient air quality brought about by the combination of ultralow-sulfur fuel and advanced vehicle emission control technologies can lower rates of fatal heart disease, lung cancer, and other respiratory diseases; reduce hospitalizations for heart attacks and emergency room visits for asthma attacks; increase productivity by avoiding days of school or work lost due to illness; and improve children's overall health.

THE IMPROVEMENTS IN AMBIENT AIR QUALITY BROUGHT ABOUT BY THE COMBINATION OF ULTRALOW-SULFUR FUEL AND ADVANCED VEHICLE EMISSION CONTROL TECHNOLOGIES CAN LOWER RATES OF FATAL HEART DISEASE, LUNG CANCER, AND OTHER RESPIRATORY DISEASES; REDUCE HOSPITALIZATIONS FOR HEART ATTACKS AND EMERGENCY ROOM VISITS FOR ASTHMA ATTACKS; INCREASE PRODUCTIVITY BY AVOIDING DAYS OF SCHOOL OR WORK LOST DUE TO ILLNESS; AND IMPROVE CHILDREN'S OVERALL HEALTH.

The monetary value of lessening the health burdens created by air pollution from vehicles is estimated using either of two well-established methodologies. One technique calculates the total cost of illness (COI), including both the cost of medical treatment and the cost of missed work days. Another uses surveys and wage comparisons to determine the average person's willingness to pay for reducing the risk of injury or death.

27 Lim, S., et al., A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. *Lancet*, vol. 380, no. 9859, p. 2224–2260, 15 December 2012. DOI: http://dx.doi.org/10.1016/S0140-6736(12)61766-8, http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(12)61766-8/fulltext

28 Health Effects Institute, *Traffic-Related Air Pollution: A critical review of the literature on emissions, exposure, and health effects* (2010) (Special Report 17). Retrieved from http://pubs.healtheffects.org/view.php?id=334

Climate benefits. As previously noted, black carbon, a component of particulate emissions from vehicles, is the second most important heat-trapping pollutant, after carbon dioxide. But it is a "short-lived" climate pollutant, persisting in the atmosphere for weeks rather than decades or centuries. Its warming effects are rapid and powerful: one gram of black carbon emitted into the atmosphere can cause warming equal to as much as 3,200 grams of carbon dioxide, measured on a twenty-year time scale (GWP20).[29] Controlling black carbon emissions has equally rapid and significant benefits. Road transport accounts for 9% of global black carbon (in 2000) and diesel engines are responsible for nearly 99% of those emissions.[30] Effective implementation of world-class low-sulfur fuel and vehicle standards can virtually eliminate black carbon emissions from road vehicles.

Compliance costs. The costs to comply with these regulations are primarily borne by the vehicle manufacturers and the petroleum producing companies. Vehicle manufacturers' costs are related to research and development, retooling of manufacturing plants, and certification of new vehicles. Petroleum producer costs are related to upgrading oil refineries to produce low sulfur fuels. There is also a small increase in cost due to the increase in the use of additives to maintain fuel lubricity. Improved fuel quality reduces vehicle maintenance costs to the consumer.

Our review of cost-benefit analyses of light- and heavy-duty vehicle emissions regulations presently in place worldwide, and of cost-effectiveness analyses of vehicle efficiency regulations, shows that such analyses consistently find that benefits outweigh costs by significant margins across multiple jurisdictions.

Tailpipe emission standards typically weight improvements in public health against the costs incurred to vehicle manufacturers and petroleum producers. As summarized in Table 7, while compliance costs are estimated with a range of $1.5 to $14 billion, the benefits vary widely from $2 billion to more than $100 billion in annual savings once the new vehicles have replaced the older vehicles in the fleet. Benefits are generally higher for heavy-duty vehicle tailpipe emission standards because—as we have already noted—the health effects from reduction of diesel particles are substantial. For example, the US Tier 2 rule affects mostly gasoline-powered passenger vehicles, and thus has a lower cost-benefit ratio (5:1) compared to the heavy-duty vehicle regulation (16:1).

OUR REVIEW OF COST-BENEFIT ANALYSES OF LIGHT- AND HEAVY-DUTY VEHICLE EMISSIONS REGULATIONS PRESENTLY IN PLACE WORLDWIDE, AND OF COST-EFFECTIVENESS ANALYSES OF VEHICLE EFFICIENCY REGULATIONS, SHOWS THAT SUCH ANALYSES CONSISTENTLY FIND THAT BENEFITS OUTWEIGH COSTS BY SIGNIFICANT MARGINS ACROSS MULTIPLE JURISDICTIONS.

29 Bond, T.C. et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research-Atmospheres.*

30 World Bank, *Reducing black carbon emissions from diesel vehicles: Impacts, control strategies, and cost-benefit analysis* (2014). Retrieved from http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/04/04/000442464_20140404122541/Rendered/PDF/864850WP00PUBL0l0report002April2014.pdf

Table 7. Benefit-cost analyses for light- and heavy-duty vehicle emissions regulations

Rule	Benefits	Costs	Benefit-Cost Ratio
US LDV Tier 3[1]	\$6.7b–\$19b annually (2030)	\$1.5b annually (2030)	5:1 to 13:1
US LDV Tier 2[2]	\$25.2b	\$5.3b	5:1
US 2010 HDV emissions[3]	\$70b annually (2030)	\$4.2b annually (2030)	16:1
California Advanced Clean Cars Program (LEV-III)[4]	\$10.6b cumulative vehicle operating cost savings	\$3.4b cumulative annualized incremental cost	3:1
Mexico HDV NOM-044[5]	\$135b (cumulative, 2018–2037)	\$12b (cumulative, 2018–2037)	11:1
Euro 5/V and 6/VI[6]	\$2,13b (2009 price)	\$1,55b (2009 price)	1.4:1
China 6/VI[7]	4.4t RMB	1.8t RMB	2.5:1
India Bharat VI[8]	\$43.8b in 2025; \$107b in 2035	\$14.5b in 2025; \$14.2b in 2035	8:1 in 2035

1. On Tier 3 benefits and costs, www.gpo.gov/fdsys/pkg/FR-2014-04-28/pdf/2014-06954.pdf. For a summary, see Regulatory Announcement: EPA sets tier 3 motor vehicle emission and fuel standards (March 2014). Retrieved from www.epa.gov/otaq/documents/tier3/420f14009.pdf.
2. On Tier 2 benefits and costs, see Regulatory announcement: EPA's program for cleaner vehicles and cleaner gasoline (1999). Retrieved from www.epa.gov/tier2/documents/f99051.pdf.
3. On the benefit-cost of the US 2010 HDV emissions regulation, see Control of air pollution from new motor vehicles: heavy-duty engine and vehicle standards and highway diesel fuel sulfur control requirements, sec. v "economic impact", www.gpo.gov/fdsys/pkg/FR-2001-01-18/pdf/01-2.pdf.
4. On LEV-III, see the California Air Resources Board staff report, www.arb.ca.gov/regact/2012/leviiighg2012/levisor.pdf. For a press summary, see www.arb.ca.gov/newsrel/newsrelease.php?id=282.
5. On the benefit-cost ratio of the proposed NOM-044 regulation, see Miller, J., Blumberg, K., and Sharpe, B., Revising Mexico's nom 044 standards: Considerations for decision-making (2014) (ICCT Working Paper 2014-5). Retrieved from www.theicct.org/sites/default/files/publications/ICCT_NOM-044_proposal_20140530.pdf
6. Department of Infrastructure and Regional Development, Final regulation impact statement for review of euro 5/6 light vehicle emissions standards. Retrieved from https://www.infrastructure.gov.au/roads/environment/files/Final_RIS_Euro_5_and_6_Light_Vehicle_Emissions_Review.pdf
7. A forthcoming ICCT paper, Costs and benefits of motor vehicle emission control programs in China, projects emissions, health and climate impacts, and costs under varying scenarios featuring China 6/VI emission standards and ultralow sulfur fuel standards.
8. Bansal, G., and Bandivadekar, A., Overview of India's vehicle emissions control program: Past successes and future prospects (2013). Retrieved from www.theicct.org/sites/default/files/publications/ICCT_IndiaRetrospective_2013.pdf. Estimates costs and benefits of progress to more stringent limits under various scenarios, including Bharat VI.

COST EFFECTIVENESS

To determine whether a regulation designed to address oil consumption and climate change is appropriate, government agencies typically compare the oil savings on a per vehicle basis against the fuel price. Such a comparison yields the number of years before the consumer achieves a payback from fuel savings equal to the increased purchase price of the motor vehicle due to installed energy efficiency technologies. There are climate change and oil security benefits associated with the reduction in oil use and CO_2 emissions as well, but these benefits are relatively modest compared to fuel savings.

As Table 8 shows, the increase in the purchase price of a new passenger car ranges from \$400 to \$2,000, and between \$400 and \$6,000 for heavy-duty vehicles. This initial investment pays for itself in fuel savings within a relatively short span of time, one to five years. As vehicles tend to stay on the road for 10 to 12 years in many countries, there are significant additional fuel savings that flow to the consumer, along with continued reductions in CO_2 emissions and oil consumption. Factors that influence the differences across countries include the cost of future technologies, the expected price of motor fuels, and the discount rate applied to the stream of fuel savings in the future.

Table 8. Cost-effectiveness analyses of light- and heavy-duty fuel economy and CO_2 standards

Rule	Per-Vehicle Cost	Payback Period
US LDV 2017–2025[1]	$1,800	3.5 years
US LDV 2012–2016[2]	$950	3 years
US HDV Phase 1 2014 – 2017[3]	$378–$6,215	1–2 years
California Advanced Clean Cars Program 2017 – 2025[4]	$1,340–$1,840	3 years
Canada LDV 2017-2025[5]	$2,095	2 to 5 years
Canada LDV 2011-2016[6]	$1,195	1.5 years
European 95g CO_2/km Standard 2020[7]	€1,300	4-5 years
India LDV 2020[8]	$400 to $600	2–3 years

1. For EPA's and NHTSA's formal discussion of the rule's costs and benefits, see www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf. For a summary, see EPA and NHTSA set standards to reduce greenhouse gases and improve fuel economy for model years 2017-2025 cars and light trucks, www.epa.gov/otaq/climate/documents/420f12051.pdf.
2. The final rule, with cost-effectiveness estimates, is available at www.gpo.gov/fdsys/pkg/FR-2010-05-07/html/2010-8159.htm. For a summary, see EPA and NHTSA Finalize historic national program to reduce greenhouse gases and improve fuel economy for cars and trucks, epa.gov/otaq/climate/regulations/420f10014.pdf
3. For a summary, see Regulatory announcement: EPA and NHTSA adopt first-ever program to reduce greenhouse gas emissions and improve fuel efficiency of medium-and heavy-duty vehicles, http://www.epa.gov/otaq/climate/documents/420f11031.pdf.
4. California Air Resources Board, Amendments to the low-emission vehicle program—LEV III. http://www.arb.ca.gov/msprog/levprog/leviii/leviii.htm
5. For a summary, see http://www.ec.gc.ca/lcpe-cepa/eng/regulations/DetailReg.cfm?intReg=215. For the regulatory impact analysis, see http://www.gazette.gc.ca/rp-pr/p2/2014/2014-10-08/html/sor-dors207-eng.php
6. For summary and regulatory impact analysis, see http://www.gazette.gc.ca/rp-pr/p1/2010/2010-04-17/html/reg1-eng.html
7. OECD and International Transport Forum, Joint Transport Research Center. The cost and effectiveness of policies to reduce vehicle emissions (2008). Retrieved from http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP200809.pdf
8. Bansal and Bandivadekar, Overview of India's vehicle emissions control program: Past successes and future prospects.

IV. CONCLUSION

This assessment points to a number of key potential policy actions for G20 countries. Future actions greatly depend on the current policy status of G20 countries in the progression toward a comprehensive set of world-class vehicle and fuels policies. To generalize the findings, we propose three G20 country groups, as shown in Table 9. Countries at earlier clean vehicle policy stages are in Group 3, whereas those with more mature fuel and vehicle policies already being implemented are in Groups 1 and 2.

The purpose of proposing these categories is to suggest areas of common interest among various nations, which could form the basis of aligned policy actions and identify areas where countries can look to benefit from lessons learned. There are no hard-and-fast rules to these categories. In other words, these groupings are fluid, depending on need and interest.

Clean, low-sulfur fuels are a prerequisite to world-class tailpipe emission standards and are therefore an earlier step in the progression. Group 3 countries are categorized here as those that have little or no low-sulfur gasoline and diesel fuel available. These countries could move to adopt low-sulfur gasoline and diesel fuel, and, in tandem, adopt world-class tailpipe emissions standards. Given the priority importance of diesel vehicles, a next step could be a focus on clean, low-sulfur diesel fuel and matching tailpipe emissions standards.

Group 2 countries are those that already have available low-sulfur fuel, or have this available in limited quantities that need to be expanded, but have not yet adopted world-class emissions standards. The key next steps for Group 2 countries are to ensure nationwide availability of clean, low-sulfur fuels where supplies are currently limited, adopt world-class emission standards, and implement fuel economy labeling programs, which tend to be a useful starting point for fuel economy standards. As a first step, Group 2 countries might consider adoption

Table 9 . Proposed clean fuel and vehicle groups, countries, and next policy steps

Group	Group definition	Countries	Next policy actions
Group 1	Currently has: • Nationwide implementation of clean, low-sulfur fuels • World-class emission standards • Passenger vehicle fuel economy standards • Green Freight program	Canada, EU (Germany, UK, France, Italy), Japan, South Korea, United States	• Establish and upgrade light- and heavy-duty fuel economy standards to world-class • Improve Green Freight programs • Address gap between real-world and laboratory test emissions
Group 2	• Clean, low-sulfur fuel either available or planned • World-class emission standards not yet adopted	Argentina, Australia, Brazil, China, India, Mexico, Russia, Turkey	• Adopt world-class emission standards for passenger and heavy-duty vehicles • Establish passenger vehicle labeling and/or fuel economy standards • Establish heavy-duty Green Freight and/or fuel economy standards
Group 3	• No availability of clean, low-sulfur fuel • No emissions or fuel economy programs implemented	Indonesia, Saudi Arabia, South Africa	• Adoption of clean, low-sulfur gasoline and diesel • In tandem with fuel standards, advance toward world-class tailpipe emission standards as rapidly as possible

of world-class emission standards for heavy-duty vehicles once clean, low sulfur fuels are assured, and establishing heavy-duty vehicle Green Freight and fuel economy or CO_2 emission standards.

Group 1 countries are those that have already adopted world-class fuel and emission standards. For these countries, the key next steps are to ensure that real-world vehicle emissions match the reductions required by the regulations, to upgrade fuel economy and CO_2 standards to world-class, and to improve Green Freight programs. In 2015, Group 1 countries might consider focusing on addressing the gap in real-world emissions from heavy-duty vehicle certification levels through in-use compliance and enforcement programs, establishing or upgrading fuel economy and CO_2 emission standards, and strengthening Green Freight programs.

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