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SERIES: Heavy-Duty Vehicle Policies for Mexico

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Revising Mexico's NOM 044 standards: Considerations for decision-making

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1. Introduction

Mexico is working to revise existing emissions standards for heavy-duty vehicles, NOM 044. The changes to the regulation would require manufacturers to meet either U.S. Environmental Protection Agency (EPA) 2010 standards or Euro VI standards, beginning in 2018; the implementation timing is tied to nationwide availability of ultralow sulfur diesel, anticipated for 2017. Comprehensive on-board diagnostic (OBD) systems, which will be fully phased in for the U.S. and Europe in 2017, are required in both compliance options.

The ICCT conducted a cost-benefit analysis of NOM 044 emission standards for heavy-duty diesel vehicles through the year 2037, taking into account effects on public health and climate and incremental vehicle and operational costs. Based on that analysis, we estimate that over the period 2018 to 2037 the NOM 044 standards will result in a net benefit to Mexico of 123 billion U.S. dollars (USD) or 1.6 trillion Mexican pesos (MXN). These benefits include the value to society of avoided early deaths and the reduced climate impact from vehicle emissions.

The cost-benefit analysis indicates that NOM 044 would produce substantial net benefits in health effects alone, but the regulation could enable significant fuel savings as well. This is because the EPA 2004–compliant engines that capture 90 percent or more of the market share in Mexico are some of the least-efficient new engines available in the world today. Engine designs have changed significantly to meet EPA 2010 and Euro VI emissions standards, and the new engines are much more efficient. Engines meeting NOM 044 standards in Mexico would necessarily incorporate many of these improvements, and new standards could enable the market to take advantage of further engine research and development.

Heavy-duty truck manufacturers are not concerned about the ability to supply new engines to the Mexican market. One example serves to illustrate why. Approximately 85 percent of the vehicles produced by the Daimler/Mercedes assembly plant in Santiago, Mexico, are destined for the U.S. and Canadian markets. The Santiago plant is fully capable of supplying the exact same vehicles to the Mexican market; in fact, in response to a question after a presentation at the assembly plant on October 1, 2013, the plant director said that, if ultralow sulfur fuel were available, Daimler could start selling these vehicles in Mexico "tomorrow."[1]

1 The visit to the Daimler/Mercedes plant was organized as part of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Workshop on Exchange of Mexican and Colombian Experts Involved in Nationally Appropriate Mitigation Actions (NAMAs) for Freight. Participants included GIZ, ICCT, the Secretary of Environment and Natural Resources (SEMARNAT), the National Commission for the Efficient Use of Energy (CONUEE), and the Secretary of Communications and Transport (SCT), among others.

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ABOUT THIS SERIES ICCT's Heavy-Duty Vehicle Policies for Mexico series is intended to provide technical inputs in support of Mexico's development of transportation and environmental policies to reduce pollutant emissions, fuel consumption, and health and environmental impacts of heavy-duty vehicles. Publications in the series include global comparative reviews, technical studies, and cost-benefit analyses.

The two compliance options to be included in the NOM 044 proposal, EPA 2010 and Euro VI, are functionally equivalent standards: the same technologies, the same very low levels of emissions, very similar OBD requirements, similar incremental cost, and similar expected improvements in efficiency over the EPA 2004–compliant engines. Because of the equivalence of the vehicle technologies, diesel fuel with a nominal maximum sulfur content of 15 parts per million (ppm) is suitable for either compliance option.

2. Current standards in Mexico

Mexico's current heavy-duty vehicle emissions regulation requires compliance with either EPA 2004 or Euro IV standards. These two compliance options differ in many ways, including emissions levels, compliance costs, fuel-quality requirements, technologies, and in-use performance.

The emissions profile of the two options is very different. Euro IV certification levels have slightly higher nitrogen oxides (NO_x) emissions and significantly lower particulate matter (PM) emissions than EPA 2004 standards. Euro IV emission levels require the use of selective catalytic reduction (SCR) technologies, while EPA 2004 emission levels require only the use of exhaust gas recirculation (EGR) technology. EGR is technologically less complex and less expensive than SCR. As a result, EPA 2004 has been the more popular compliance option, capturing approximately 90 percent of the new-vehicle market in Mexico. Also, the emission control technologies required for Euro IV vehicles require diesel fuel with nominal maximum sulfur content of 50 ppm, much lower than the up to 500-ppm sulfur fuel currently available throughout Mexico. Only urban buses, which are more likely to have access to lower-sulfur fuel, are more likely to be Euro-certified vehicles. Neither Euro IV nor EPA 2004 requires the use of filters for particulate-matter control. Filters effectively capture even the ultrafine particles most harmful to human health (MECA 2013).

In real-world operations, however, the differences between Euro IV and EPA 2004 standards are more complex. The SCR technologies used to control NO_x emissions from Euro IV-certified vehicles have not been effective in controlling real-world emissions, especially in urban areas. As a result, Euro IV vehicles tend to have significantly higher NO_x emissions than expected (Lowell and Kamakate 2012). The same SCR technology also allows PM emissions reductions to be achieved through engine tuning only, i.e., without the use of a particulate filter. As a result, despite the more stringent and costly technology requirements under Euro IV, that standard is not a clear winner in terms of health benefits.

3. EPA 2010 and Euro VI Comparison

From a regulatory perspective, the EPA 2010 and Euro VI standards that are the goal of NOM 044 revision are very strong, functionally equivalent options, which require the same emissions control technologies and achieve essentially the same emissions benefits. Compared to the EPA 2004 standard (at present the most common compliance pathway for new HDVs in the Mexican market), vehicles certified to either EPA 2010 or Euro VI will reduce NO_x by 90 percent or more and PM by 97 to 98 percent (EPA 2010). The most important differences between them are that the EPA 2010 standard has a slightly more substantial durability requirement and Euro VI includes a particle number limit ($8x10^{11}$/kwh on the World Harmonized Stationary Cycle [WHSC] and $6x10^{11}$/kWh on the World Harmonized Transient Cycle [WHTC]), which necessitates certification testing of the actual number of particles emitted in addition to the total mass.

Table 1 summarizes the basic equivalence of the EPA 2010 and Euro VI standards, which stands in contrast to current standards as well as any of the possible interim regulatory steps that have been considered (see Appendix A).

Table 1. Comparison on EPA 2010 and Euro VI standards

	EPA 2010	Euro VI	Comments
PM (grams per kilowatt-hour or g/kWh)	0.013	0.01	Equivalent, near-zero particulate matter (PM) emissions because both standards require diesel particle filters (DPFs).
NO_x (g/kWh)	0.27	0.4	Problem of high NO_x emissions in urban areas observed in Euro IV and Euro V vehicles has been resolved in Euro VI.
Predominant Technology	DPF + SCR	DPF + SCR	Equivalent technology options.
OBD requirements	Full application in 2016	Full application in 2016 for new vehicles and 2017 for all vehicles	Requirements include threshold monitoring (emission control systems), non-threshold monitoring (functional, rational and electrical signals), and OBD testing-validation.
Test Cycle	Federal Test Procedure (FTP) + Supplemental Emissions Test (SET)	WHTC + WHSC	Distinct test cycles matched to standards. FTP and WHTC are transient cycles; SET and WHSC are steady-state cycles.
In-Use Testing	Not-to-exceed (NTE) testing	In-service conformity (ISC)	In the U.S., NTE requirements have been enforced since 2010. In Europe, ISC requirements start with Euro VI implementation.
Useful Life	700,000 km/ 10 years	700,000 km/ 7 years	The requirement refers to whichever comes first. Discrepancy between the standards is reduced, as vehicles more typically reach the mileage limits prior to age limits, but is not eliminated.
Fuel Economy	Manufacturers estimate a 3%–5% improvement compared to EPA 2004 baseline		By the time standards are implemented in Mexico, U.S. fuel-efficiency standards will require an additional 5%–9% improvement in engine efficiency over an EPA 2010 baseline engine.
Per Vehicle Costs	+$3,700 to $8,500, compared to EPA 2004 baseline		Costs are proportional to engine size. The incremental cost compared to a Euro IV baseline would be lower.
Medium-duty vehicles	Full-vehicle (chassis) certification testing is optional for Gross Vehicle Weight Rating (GVWR) ≤ 6350 kg	Engine certification testing required for Reference Mass (RM) >2,610 kg. Full vehicle certification for RM≤ 2,610 kg.	A mismatch between weight metrics (GVWR is loaded weight and RM is empty weight) means that a few vehicles subject to light-duty standards in Europe would be subject to heavy-duty standards in Mexico. This is explained in greater detail in a separate working paper (see Blumberg 2014).
Market Considerations	Required and sold in the U.S. since 2010	Required in the EU starting in 2013 for new vehicles and in 2014 for all vehicles	Market and cost considerations are roughly equivalent. There is now more real-world experience with U.S. regulations, but by the NOM 044 implementation date, 2018, this difference will be insignificant. Manufacturers would be more likely to have a mixed compliance strategy than under the current standards.

Because the EPA 2010 and Euro VI standards are functionally equivalent, the vehicles and emission-control technologies needed to comply with the standards are equivalent as well. Both standards require near-zero PM emissions and very low NO_x emissions. Both require full adoption of onboard diagnostic (OBD) systems by 2016/2017 (see Appendix B, and Posada 2014 for additional detail). And each requires fail-safes, warnings and inducements to ensure that SCR systems are being operated correctly to achieve low emissions, especially to ensure the proper use of the necessary urea solution, also known as diesel exhaust fluid (on SCR system requirements see Appendix C). As a result, a measurable difference in environmental outcomes is not expected, regardless of how market share varies between the options.

Previous standards in the U.S. and Europe have not been so closely matched. The previous section summarized key differences between EPA 2004 and Euro IV standards. See Appendix C for a comparison of EPA 2007 and Euro V certification levels.

Table 2 provides an overview of the EPA and Euro regulatory standards for heavy-duty vehicles. EPA 2007, EPA 2010, and Euro VI standards are the only options that require a DPF. While both EPA 2004-compliant vehicles and Euro IV-compliant vehicles may currently be sold in Mexico, EPA 2004 engines are the current market standard.

Table 2. Regulatory overview of EPA and Euro heavy-duty standard

Country	Standard	Enforcement schedule in country of origin	Mexico enforcement schedule	NO_x (g/kWh)	PM (g/kWh)	Requires Diesel Particle Filter	Fuel sulfur (ppm)	Durability (for the heaviest vehicle category)
U.S.	EPA 1994	1994		6.7	0.13		500	470,000 km/ 8 years
	EPA 1998	1998	2003	5.4	0.13		500	
	EPA 2004	2002	2008	2.7	0.13		500	700,000 km/ 10 years
	EPA 2007	2007		1.6	0.013	X	15	
	EPA 2010	2010		0.27	0.013	X	15	
EU	Euro I	1992		8.0	0.36		2000	500,000 km/ 7 years
	Euro II	1996		7.0	0.25		500	
	Euro III	2000	2003	5.0	0.16		350	
	Euro IV	2005	2008	3.5	0.03		50	
	Euro V	2008		2.0	0.03		10	
	Euro VI	2013		0.4	0.01	X	10	700,000 km/ 7 years

In terms of vehicle technologies, there is no discernable difference between the Euro VI and EPA 2010 regulatory options. Both standards require high-pressure and variable common-rail fuel-injection systems, variable-geometry turbochargers, and high-efficiency diesel particulate filters and SCR systems (Figures 1 and 2).

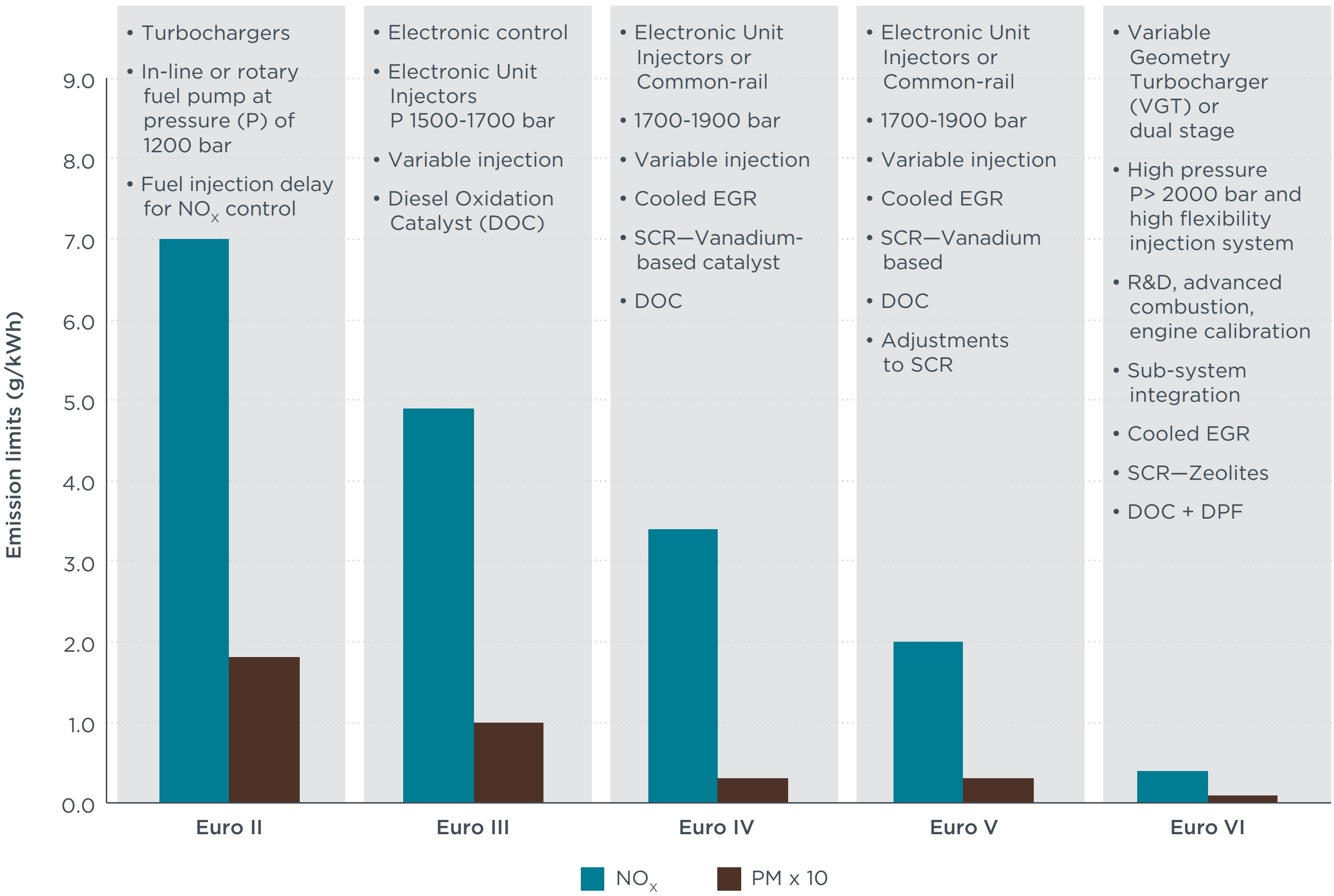

Figure 1. Technologies used to meet Euro standards

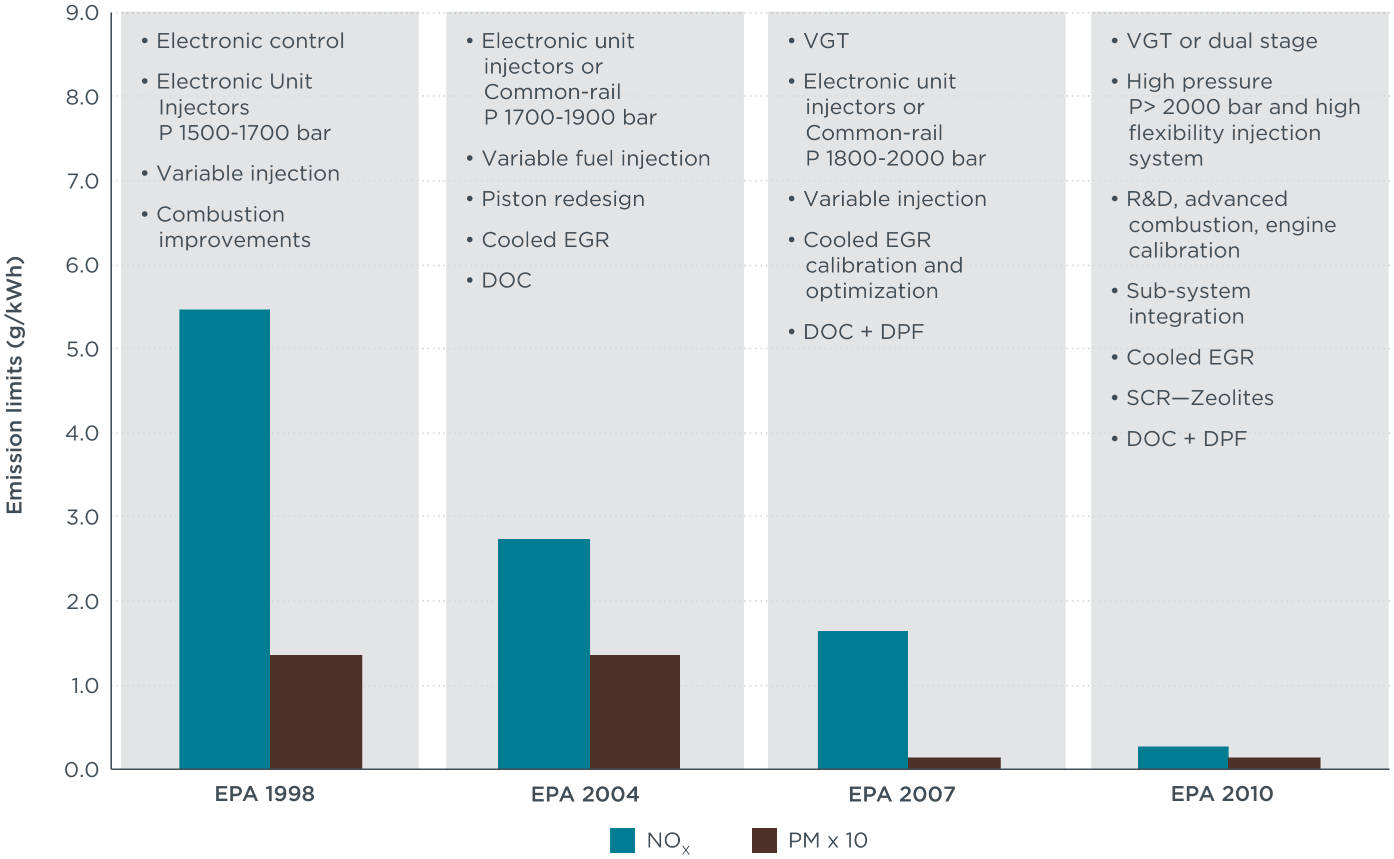

Figure 2. Technologies used to meet EPA standards

4. Fuel Sulfur and Diesel Exhaust Fluid Requirements

The availability of ultralow sulfur diesel fuel and diesel exhaust fluid (DEF) are two of the main requirements, besides engine and aftertreatment technology, for achieving the emission targets under discussion for NOM 044.

The amount of sulfur in diesel fuel has a significant effect on the performance of advanced clean vehicle technologies, and also can enhance or detract from the emission performance of vehicles that are not equipped with those technologies. Current fuel-sulfur requirements in the U.S. (15 ppm) and Europe (10 ppm) are both considered ultralow or "near-zero". Sulfur limits of 10–15 ppm represent a 97 to 98 percent reduction in sulfur levels from the current 500-ppm limit in Mexico. The U.S. and EU fuel quality standards can be considered functionally equivalent because:

1. The vehicle technologies sold in each region under the most advanced standards are the same
2. The emissions impact of the different fuel qualities, even at the fuel sulfur limit values, is marginal.
3. Both 10 ppm and 15 ppm are maximum sulfur levels; the real-world levels at the fuel pump are typically lower, and are equivalent in each region.

In contrast to Europe, which set its fuel-sulfur limits well in advance of the emissions standards, fuel-quality and emissions standards were linked in U.S. regulations. 15 ppm was set as the upper limit for sulfur content under U.S. regulations based on EPA's assessment of technology requirements. In the end, the technology that was most sensitive to sulfur levels, and upon which the 15-ppm limit was based—lean NO_x traps—has not been commercialized for heavy-duty vehicles, only in light-duty ones. As reported in Section 3, in terms of vehicle policies and technologies in use, there is no discernable difference between U.S. and European standards. Both Euro VI and EPA 2010 standards require the same technologies.

For purposes of compliance with standards, fuel efficiency, and durability there is no difference or compromise between 15-ppm and 10-ppm sulfur fuel. With sulfur at the 15-ppm limit, the engine-out emissions would be approximately half of a percent higher than if fueled with 10-ppm fuel, which would not have a measureable impact on actual emissions after the DPF. The technical basis for setting the sulfur limit at 15 ppm in the U.S. is described in greater detail in Appendix D.

In terms of the sulfur content of the fuels sold at retail stations, the U.S. and European fuel-quality standards are basically indistinguishable. Average sulfur levels of diesel fuel sold in both the U.S. and the EU is around 5 to 8 ppm. European regulators enforce their limit values through testing at retail stations, resulting in average sulfur content of 5 ppm for fuels leaving the refinery in Europe. In order to ensure compliance with the 15 ppm limit, some major pipelines and distributors in the U.S. will not accept diesel that has higher than 8 ppm sulfur content (Szalkowska 2013; Oil & Gas Journal 2006). As a result, as can be seen in Figure 3, sulfur content has been reported at less than 10 ppm in over 90 percent of samples (more than 4,500 samples per year) in the United States (EPA 2013).

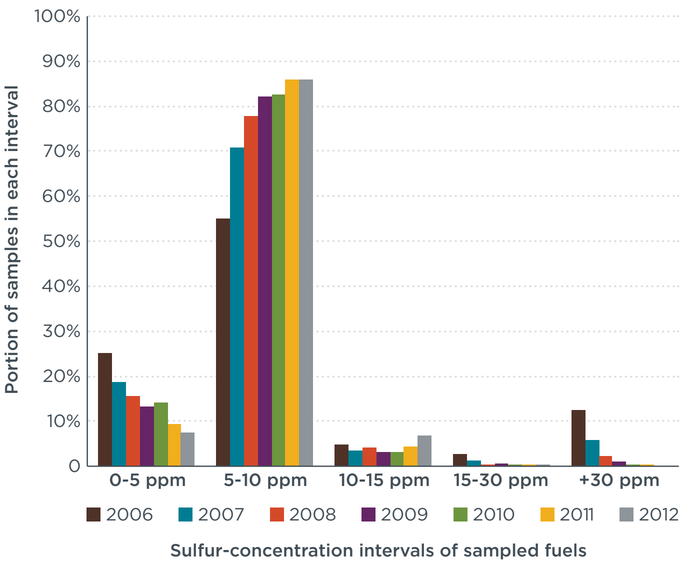

Figure 3. Results of fuel quality testing in the U.S. (EPA 2013)

EPA provided a transition period of four months or less between the beginning of the phase-in of national standards requiring 15-ppm sulfur fuels and enforcement of emissions standards that required those fuels. The standards allowed a four-year phase-in of 15-ppm sulfur fuel, in order to both protect against supply constraints and ensure widespread, national availability of ultralow sulfur diesel (ULSD). By September 1, 2006, 80 percent of the fuel supply was required to meet the 15-ppm limit. Model year 2007 engines[2] were required to be equipped with DPF technology, requiring use of ULSD. Between 2007 and 2010, a small but significant portion of fuel sold in the U.S. was above 15 ppm sulfur, ranging from 5 to 15 percent in the first 18 months of the program to 1 to 2 percent for the next two years. This fuel was required to be clearly labeled as higher-sulfur fuel and not intended for use in EPA 2007 or newer vehicles (EPA 2001).

Brazil had an even more gradual approach to the phase in of ultralow sulfur diesel. Euro IV fuels (50 ppm sulfur) were required in identified cities starting in 2010 and 2011 (ANP 2009). Euro V-equivalent emissions standards were mandatory starting in 2012, and Euro V fuels (10 ppm sulfur) were introduced one year later (ANP 2011a). The emissions standards required the Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP) to complete a supply plan for low sulfur diesel that would ensure nationwide availability and accessibility of the fuel (CONAMA 2008). As part of that plan, ANP defined a set of service stations around the country where sale of low sulfur diesel was mandatory, starting with 50 ppm in 2012 and moving to 10 ppm in 2013 (ANP 2011b). These mandatory stations, plus stations volunteering to sell ULSD, accounted for approximately 35 percent of the service stations in the country as of May 2014 (ANP 2014; Kardec Duailibe 2011).

In addition to ultralow-sulfur fuels, these advanced standards require the use of a solution of automotive-grade urea, known as diesel exhaust fluid (DEF), for the proper functioning of SCR technologies. In order to ensure adequate DEF availability, EPA requires manufacturers to submit plans for DEF availability and accessibility as part of the certification process (EPA 2011a). As DEF tank capacity is required to provide a range of at least 2 or 3 times the fuel tank capacity for most vehicle applications, the phase-in of DEF supply has been more gradual than for ULSD (EPA 2009). DEF availability has not been a significant concern in other countries where SCR systems have become prevalent. In Brazil, for example, when Euro V standards came into effect urea suppliers automatically entered the market and urea availability has not been a constraint.

Mexico already has a small market for DEF to fill the tanks of new advanced vehicles produced in Mexico and for growing portion of urban buses in major cities that meet Euro IV or Euro V standards. TerraCair, a major DEF supplier in the U.S., has developed a partnership and distribution network for supply of DEF in Mexico with Alveg Distribucion Quimica to supply DEF to manufacturers and aftermarkets, and already offers fairly comprehensive coverage of Mexico (TET 2012). In addition, Petroleos Mexicanos (PEMEX) has purchased a urea plant in Veracruz and has committed funds to make it operational by 2015, potentially providing a local supply option (Naso 2014).

2 An engine model year must include January 1 of the indicated year but could start before that time.

5. Fuel Economy Impacts

One of the most beneficial side effects of the revision of NOM 044 standards is that new standards will allow for significant improvements in engine fuel efficiency.[3] As can be seen in Figure 4, while the fuel efficiency of heavy truck engines had been steadily improving since the 1970s, the EPA 2004 standards resulted in a sharp decrease in efficiency. The need to reduce NO_x but not PM resulted in engine tuning that was less efficient,[4] and high levels of EGR offered a much cheaper compliance pathway than installing SCR systems. The end result was a loss of 15 years' worth of efficiency improvements in heavy-duty engines. The 2010 standards then resulted in a marked improvement in fuel efficiency, getting engines back on the trajectory for reducing fuel consumption.

The reason for the improvement in efficiency was that engines meeting the 2010 standards are equipped with SCR systems. The very high level of NO_x reduction capability of these systems allows the engine to be tuned for higher efficiency, resulting in high NO_x and low PM engine-out emissions. The SCR systems then reduce NO_x by up to 80 percent and the DPF reduces the (already lower) PM emissions by more than 95 percent. Partly because the PM emissions are lower going into the filter, the manufacturers have been able to compensate for any efficiency penalty associated with the filter. Figure 4 shows the steep decline in brake-specific fuel consumption (BSFC) between 2004 and 2010, with the continued reductions needed to meet efficiency standards in 2014 and 2017. According to Figure 4, efficiency has improved by approximately 6 percent for EPA 2010 engines compared to engines meeting EPA 2004 standards.

Manufacturers estimated in advance that the efficiency improvement realized in the transition from EPA 2004 (the current market standard in Mexico) to EPA 2010 (as proposed for NOM 044) would be two to four percent. Volvo's backward-looking estimate of the actual historical improvement is closer to six percent (National Research Council 2010; Greszler 2011). Cummins researchers describe a reduction in operating costs between 2007 and 2010 of four to five percent, taking into account both reduced fuel consumption and the increased cost of DEF (Charlton

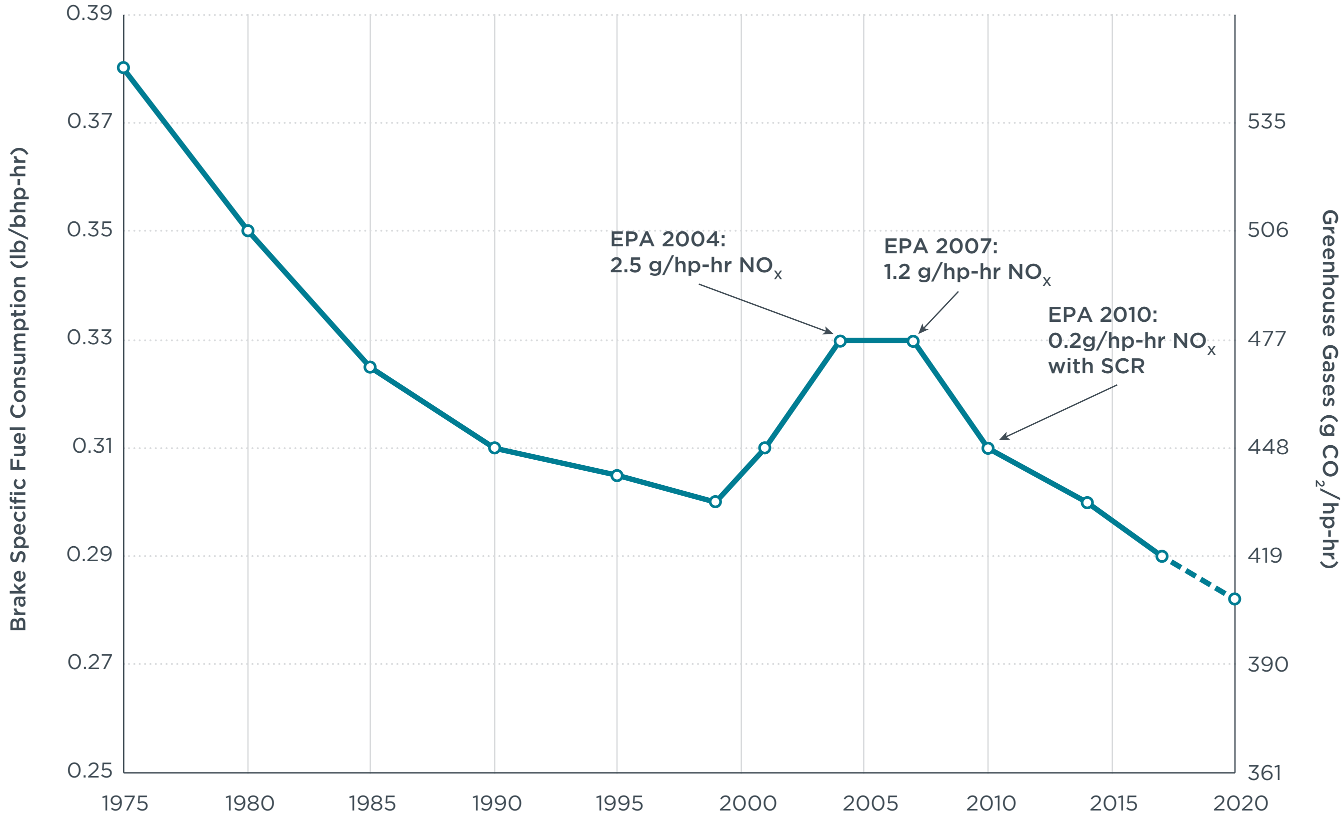

Figure 4. Historical and projected heavy-duty (HD) engine efficiency (Greszler 2011)

3 Emissions standards will allow for significant improvements to *engine* efficiency but do nothing to promote vehicle technologies that can provide important additional improvements in overall *vehicle* efficiency. A forthcoming white paper from ICCT provides some insight into how potential for improved engine efficiency contributes to overall potential to reduce fuel consumption from heavy-duty vehicles (Oscar Delgado and Nic Lutsey, The U.S. Supertruck Program: Expediting the development of advanced heavy-duty vehicle efficiency technologies).

4 An engine tuned to mainly optimize efficiency will have high engine-out NO_x emissions and low engine-out PM emissions.

et al. 2010). U.S. fuel-economy standards for heavy-duty vehicles require an additional 5 to 9 percent improvement in engine efficiency (depending on vehicle type) from a 2010 baseline by 2017 (EPA and DOT 2011). This adds up to a potential 7 to 15 percent gain in efficiency over the EPA 2004 engines that continue to be sold in Mexico today.[5] Mexico will realize some, perhaps a great deal, of these additional fuel-efficiency benefits through the implementation of fully harmonized standards that include both emissions and OBD requirements. This is mainly because heavy-duty manufacturers develop fewer different engine models and, through harmonization, Mexico can expect to reap the benefits of research and development efforts to reduce both fuel consumption and emissions.

Because the Euro VI and EPA 2010 standards are equivalent, the distribution of vehicle sales may shift under NOM 044. Even so, because the technology pathways are very similar, with both entailing a shift to SCR technologies that permit more efficient engine tuning, improvements in fuel consumption are expected on both compliance pathways.

6. Technology Costs

Figures 5 and 6 show the results of an engineering analysis intended to derive the direct costs to manufacturers of new emissions standards (ICCT 2013). The analysis includes variable costs that depend on engine displacement, such as catalyst volume, substrate, washcoat and urea injection system, as well as fixed costs, such as sensors, other components, and accessories. Some notable results of this analysis:

- Compliance with EPA 2004 is estimated to cost $1,000 to $2,000 less per vehicle than Euro IV, a significant difference that may explain the dominance of EPA 2004 as the compliance pathway under Mexico's current regulation.
- Because the same technologies are used, the compliance costs of Euro IV and Euro V standards are essentially the same.
- Because EPA 2010 and Euro VI require the same set of technologies and are functionally equivalent standards, the final costs for either compliance pathway are the same.
- Because most manufacturers are currently using EPA 2004 vehicles to comply with NOM 044, the real incremental cost of moving to EPA 2010 or Euro VI would be expected to range from $3,700 to $8,500, depending on engine size. The lower costs are associated with emission control technology for a delivery truck; higher costs are for a long-haul truck.

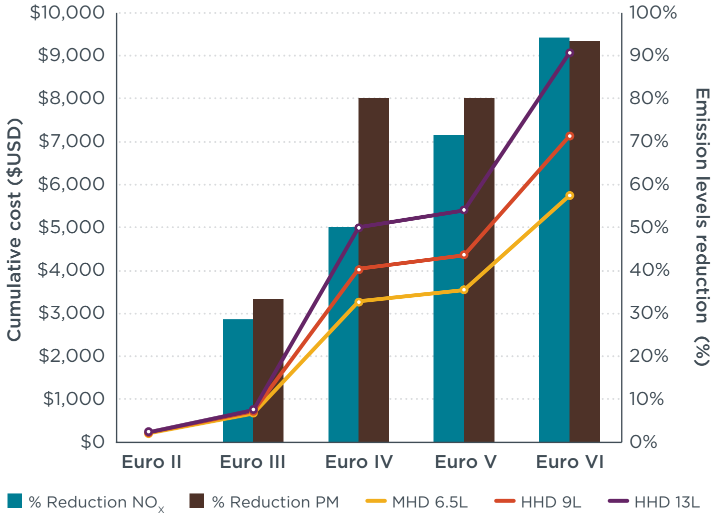

Figure 5. Estimated cost to comply with Euro standards for vehicles with different engine sizes

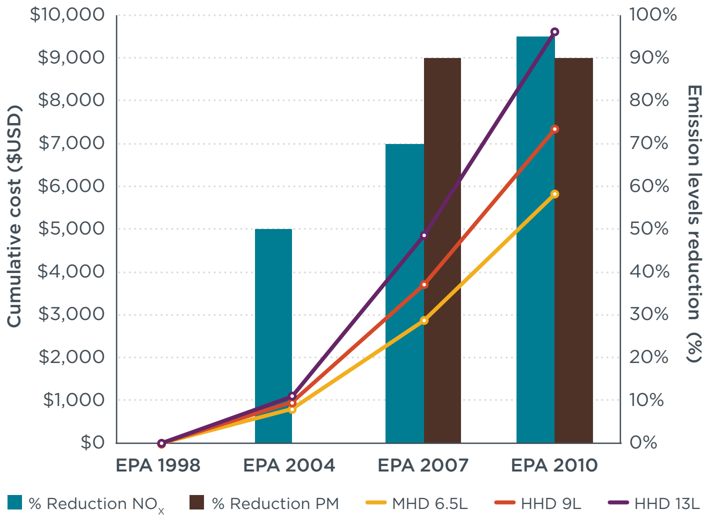

Figure 6. Estimated cost to comply with U.S. standards for vehicles with different engine sizes

5 No estimate has been provided by U.S. EPA for the efficiency benefits of moving from EPA 2004 to EPA 2010 standards.

7. Benefit and Cost Analysis

ICCT completed an analysis of the costs and benefits to Mexico of moving to EPA 2010 or Euro VI emission standards for heavy-duty diesel vehicles, taking into account benefits to public health and climate and the costs of implementing the standards.[6] These costs and benefits were monetized and converted into present-value terms, allowing an assessment of the net benefits of the regulation through the year 2037. Details are presented in the forthcoming ICCT working paper *Cost-Benefit Analysis of NOM 044 Regulation* (Miller 2014).

The costs and benefits of the NOM 044 regulation were estimated by comparing emissions, incremental fuel, DEF and vehicle technology costs, and health impacts of vehicle emissions under two scenarios: the baseline scenario, in which new diesel trucks and buses continue to meet EPA 2004 standards; and the NOM 044 scenario, in which new vehicles meet EPA 2010 and Euro VI standards starting in 2018.

Table 3 summarizes the contribution in 2018 of each vehicle type to heavy-duty emissions, fuel consumption, activity, and sales in the baseline scenario.

Table 3. Share of sales, activity, fuel consumption, and emissions by vehicle type in baseline scenario

Share by vehicle type (MY 2018)	Sales	VKT	Fuel / CO_2	PM	NO_x
HD Pickup Truck/ Van	26%	11%	7%	4%	5%
Tractor	15%	40%	35%	33%	33%
Vocational Vehicle	59%	49%	58%	64%	62%
Total	100%	100%	100%	100%	100%

Some basic assumptions made for projecting vehicle fleet size and the costs of the regulation along the years where it applies: (a) sales grow at a rate of 3 percent per year for the heavy-duty vehicle fleet in Mexico; (b) the fleet average incremental cost of moving from EPA 2004 to EPA 2010/Euro VI is around $5,300, with lower costs for smaller trucks and higher costs for long-haul trucks; (c) use of diesel exhaust fluid is two percent of total diesel consumption,[7] and the cost is 80 percent of the cost of diesel fuel;[8] (d) the incremental cost of ultralow sulfur diesel is 2.5 U.S. cents per liter.[9]

Implementing NOM 044 is expected to reduce heavy-duty vehicle emissions of $PM_{2.5}$ by 225 thousand metric tons, black carbon (BC) by 160 thousand metric tons, and NO_x by 4.0 million metric tons cumulatively over the period 2018–2037.

The emissions reductions would result in health benefits that can be quantified and monetized. The ICCT has developed a methodology for assessing the number of avoided premature mortalities from a reduction in tailpipe $PM_{2.5}$ emissions in urban areas (Chambliss et al., 2013). For this analysis we introduce a 20-year distributed lag structure for mortality impacts, applying the methodology used by EPA in assessing the costs and benefits of reducing air pollution (EPA 2011b). This analysis considers all costs and benefits that occur within twenty years of the start of implementation, i.e., out to 2037. Benefits that accrue from avoided cases of premature mortality occurring after this timeframe, even if a result of emissions reductions within the timeframe, are not included in this assessment.

Over the time period of 2018 to 2037, the NOM 044 regulation is expected to avoid over 55,000 premature mortalities from cardiopulmonary disease, lung cancer, and acute respiratory disease caused by diesel vehicle emissions. The regulation will reduce cumulative black carbon, organic carbon (OC), and sulfate emissions equivalent to 500 million metric tons of CO_2 using 20-year global warming potential (GWP-20) as a measure, or 140 million metric tons CO_2 using GWP-100. The climate impacts are dominated by black carbon, which is only slightly offset by cooling from OC and sulfate emissions.

Discounted annual costs and benefits can be summed over the period 2018 to 2037 to assess the total net benefits of implementing the regulation over this period. The total present value of the benefits (135 billion USD) exceeds exceeds the total present value of costs (12 billion USD) by a factor of 11. While fuels and vehicles have

6 This analysis includes only the incremental technology costs associated with new vehicles and the incremental operating costs associated with DEF and cleaner fuels. It does not take into account maintenance costs.

7 Actual use varies depending on duty cycle, vehicle operation, etc, but the industry standard is approximately 2 percent (ARB 2014).

8 The average DEF truck stop price in the U.S. is approximately 70 percent of the current diesel prices and has held steady for several years. The cost in Canada is similar, but due to the unknowns associated with DEF pricing in Mexico, this analysis uses a conservative value of 80 percent, approximately ten percent higher than prices in the rest of region. The DEF price is linked to the increase in diesel prices forecast by the Energy Information Administration (EIA), consistent with guidance from the National Institute of Ecology and Climate Change (Integer 2014; EIA 2014; EIA 2013).

9 This analysis uses the country-specific investment parameters for the per-liter refining costs to achieve 10-ppm sulfur diesel at existing refineries in Mexico. As approximately 30 percent of the diesel in Mexico is imported and is already available at 10-ppm sulfur levels, the actual incremental costs are expected to be lower (Hart Energy and MathPro Inc. 2012; PEMEX 2013).

been regulated separately in Mexico, the ICCT considers fuels and vehicles as a system. The incremental costs of ultralow sulfur diesel account for half of the total costs included in this analysis. The net benefits (benefits minus costs) are 123 billion USD with most of the value coming from the premature mortalities avoided as a result of reduced $PM_{2.5}$ emissions. Figure 7 demonstrates how the discounted annual net benefits of the regulation will continue to grow over time.

In addition to the health benefits, NOM 044 would promote the adoption of more-efficient engines, resulting in lower fuel consumption and reduced emissions of CO_2 and other greenhouse gases. If Mexico were able to take advantage of the full opportunities to improve efficiency of vehicle engines, including alignment with the U.S. heavy-duty fuel-economy program that is enabled by the move to EPA 2010 standards with full OBD, the full costs of NOM 044 standards could be more than recovered through reduced fuel consumption. Achievement of the full fuel-efficiency and greenhouse-gas-reduction potential from heavy-duty vehicle engines, and the even greater benefits available when considering the entire vehicle, requires an additional regulatory step to align with U.S. heavy-duty fuel-economy and greenhouse-gas standards.

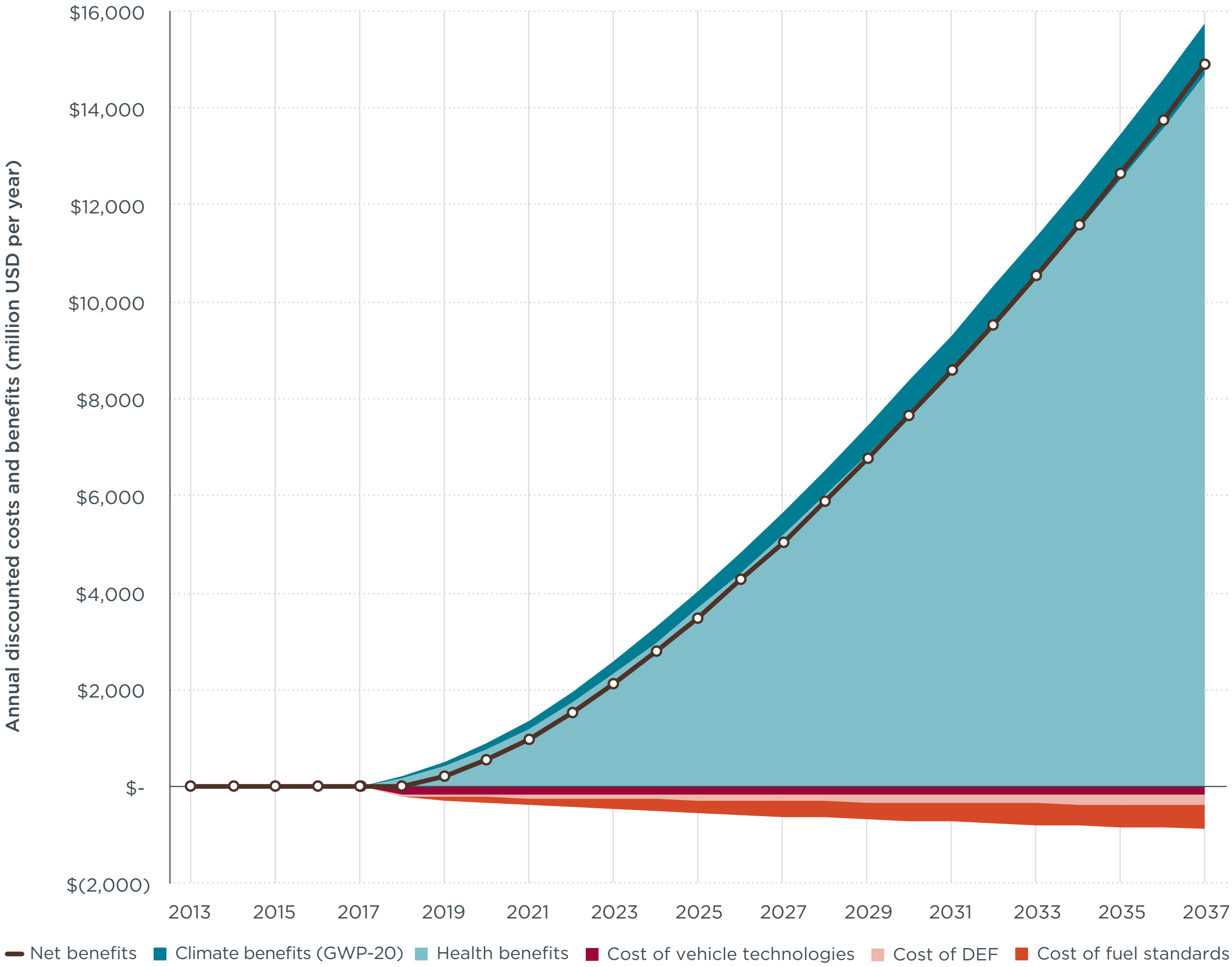

Figure 7. Present Value of Annual Costs and Benefits of NOM 044 Implementation

8. Conclusions for Mexico

It is critical to move directly to EPA 2010 / Euro VI standards. These standards are functionally equivalent and will result in the same compliance costs and technologies. The estimated net benefits of the regulation over twenty years from the time of implementation amount to 123 billion USD, a benefit-to-cost ratio of 11.

Full implementation of OBD systems and safeguards to ensure full SCR functioning are integral to both EPA 2010 and Euro VI standards. These requirements are critical to ensure that the standards are delivering the expected emissions reductions and will also help to promote the sale in Mexico of the most advanced and efficient engines available on the market.

Manufacturers will have no problem meeting new standards, and heavy-duty truck buyers should benefit from reduced fuel consumption. These standards will enable significant fuel-efficiency benefits compared to market-standard EPA 2004 engines.

Ultralow-sulfur diesel fuel is needed to comply with standards, but there is no need for a significant lag between widespread availability of ULSD and promulgation of new standards. Vehicle manufacturers are producing vehicles in Mexico that already meet these standards and PEMEX will continue to increase production and supply of clean fuels over the coming years. EPA regulations provided only 4 months between requiring that at least 80 percent of the fuel sold in the U.S. met ultralow sulfur standards and implementation of the world's first national standards requiring advanced aftertreatment technologies for control of PM.

There is no functional difference between 10-ppm and 15-ppm sulfur limits. Fuel-sulfur limits up to 15 ppm are sufficient to ensure that sulfur levels do not impact vehicle performance, emissions, or fuel efficiency.

Scaling up commercial availability of diesel exhaust fluid, required for SCR systems, is not expected to be a problem. Mexico already has a nationwide distribution network for this product, and market growth has not been an issue in any country that has phased in SCR systems to date.

Federal and local authorities should seek opportunities and incentives for early adoption or phase-in of new standards. More than 30 percent of the diesel fuel sold in Mexico already meets ultralow sulfur limits, including fuel supplied to Mexico City, Monterrey, and Guadalajara, and the share of ULSD will continue to grow. Cleaner vehicles could be used in city fleets, on major freight corridors, and in the border region.

Appendix A. Comparison between Euro V and EPA 2007

Table A1. Comparison of EPA 2007 and Euro V standards

	EPA 2007	Euro V	Comments
PM (g/kWh)	0.013	0.03	Euro standards have significantly higher PM emissions and even higher fine particle emissions.
NO_x (g/kWh)	1.6	2.0	Euro standards have high off-cycle emissions, especially in cities.
Predominant Technology	DPF + EGR	SCR	Completely different technology pathways.
Test Cycle	FTP + SET + NTE	ESC + ETS	The Euro test cycle is not representative of urban driving conditions, resulting in much higher off-cycle emissions of NO_x. The new test cycles used in Euro VI standards resolve these issues.
Useful Life	700,000 km/ 10 years	500,000 km/ 7 years	Durability requirements under Euro standards are significantly shorter than expected usage.
Fuel Economy	-0-2% (penalty)	+5% (improvement)	EU: SCR allows engines to be tuned to high NO_x and higher efficiency. EPA: DPF may have a small fuel penalty.
Costs	+$2,100-3,700	$0 from Euro IV baseline, $2,600-4,300 from EPA 2004 baseline	Both standards require a significant investment compared to the EPA 2004 market standards. Euro V standards, however, are roughly equivalent in cost to Euro IV, which has equivalent emissions control technology.
Market Considerations	Not currently sold in any market	Still sold in many other markets	The option of either EPA 2007 or Euro V is likely to move the market entirely to Euro certification because of lower costs and higher fuel economy, at the expense of emissions and health benefits.

Euro IV and V standards have not been successful in ensuring low NO_x from vehicles in use, as explained in greater detail in *Urban off-cycle emissions from Euro IV/V trucks and* buses (Lowell and Kamakate 2012). These vehicles are certified using test cycles that do not include typical low-speed urban driving conditions, which exhibit low exhaust temperature conditions. As a result, the SCR systems installed on these vehicles have very poor low-temperature performance and high NO_x emissions in urban areas, precisely where emissions need to be reduced the most.

The limitations of the current Euro IV and V type approval[10] process, including a non-representative test cycle without cold-start requirements, have resulted in use of a lower-cost SCR technology with poor low-load performance. The end result has been significantly higher urban NO_x emissions associated with Euro IV vehicles and no improvement with Euro V vehicles. Furthermore, neither Euro IV nor Euro V requires diesel particulate filters (DPFs), the best available control technology for PM.

Vehicles meeting U.S. standards have relied on a different SCR catalyst and, due to a more representative test cycle and stronger regulatory program, are performing better in actual use. Euro VI standards are also expected to solve these concerns by:

1. Moving to the World Harmonized Test Cycle, which captures more urban driving and operating conditions;
2. Requiring a cold start for the certification test; and
3. Requiring manufacturer testing with Portable Emissions Measurement Systems (PEMS) to ensure that low emissions are actually achieved during standard vehicle use and outside of the test cycle.

The in-service conformity requirements introduced as a part of the Euro VI program are more similar to Not-to-Exceed provisions of the U.S. standards, intended to verify compliance during normal in-use operation.

10 In the U.S., vehicle manufacturers must "certify" that they meet emissions standards for each model year. In the European system, manufacturers must go through a "type approval" process for each new engine model, but are not required to renew this certification until there is a change in emissions standards or a new engine model.

Appendix B. Onboard Diagnostics

On-board diagnostic (OBD) systems monitor the performance of engine and aftertreatment components including those responsible for controlling emissions. OBD systems were first deployed in light-duty vehicles in the U.S. in 1991, and 10 years later in Europe. Those first OBD systems were very basic and had very little standardization, meaning that each manufacturer adopted a different system to read and provide data to drivers and mechanics. By 1996 the OBD system was standardized and the monitoring and emission limits for malfunction were unified across U.S. manufacturers. OBD was introduced to heavy-duty vehicles (HDVs) in 2005 in Europe, and a few years later also in the U.S., but only for vehicles and engines applications with gross vehicle weight rating (GVWR) below 6,350 kg. The extension of OBD requirement to heavier HDVs began in the U.S. in 2010. There is also a process underway to develop a worldwide harmonized heavy-duty OBD global technical regulation. If that regulation adequately meets the OBD needs of the advanced vehicle technologies, the U.S. and European regulatory agencies may allow this global technical regulation to take the place of current OBD requirements.

Table B1 shows the implementation schedules in the U.S. and EU for HD vehicles with GVWR over 6,350 kg.

By the time the new standards are implemented in Mexico, beginning in January 2018, the U.S. and EU would have full next-generation OBD systems (OBD II) in place in all vehicle categories, including both current models and new ones. Even before full implementation, however, HD vehicles and engines in the U.S. and all HD vehicles and engines in Europe would have some level of OBD sensing, suggesting that Mexico could start to take advantage of these systems through voluntary or mandatory measures prior to 2018.

A more complete discussion of OBD standards and requirements in the U.S. and Europe is available in a separate ICCT working paper, *On-board diagnostics for heavy-duty vehicles: Considerations for Mexico* (Posada 2014).

Table B1. HDV Implementation Schedule in the U.S. and EU

Year	EU	U.S.
Pre-2013	**Euro V** OBD & NO_x control monitoring	**EPA 2010**
2013	**Euro VI** (01.01.2013, new vehicle types) • Phase-in Euro VI OBD	**EPA 2010** • OBD Phase in for Diesel HDV, GVWR >14,000 lbs • Full OBD for 1 to 3 engine families per year, extrapolated OBD for the rest • OBD is standardized across manufacturers
2014	**Euro VI** (01.01.2014, all vehicle types)	Full OBD for 1 to 3 engine families per year, extrapolated OBD for the rest **GHG/FE Phase 1**
2015	Alternative DPF monitoring (pressure drop, instead of PM sensor) PM sensor (01.09.2015)	Full OBD for 1 to 3 engine families per year, extrapolated OBD for the rest • PM sensor phase-in • Urea quality sensor
2016	Final OBD Euro VI (01.01.2016, new vehicle types)	Full OBD for HDVs, all engines, all vehicles • Full PM sensor
2017	Final OBD Euro VI (01.01.2017, all vehicle types)	
2018		**GHG/FE Phase 2**

Appendix C. Diesel Exhaust Fluid for Selective Catalytic Reduction Systems

Proper operation of the SCR system requires keeping the Diesel Exhaust Fluid tank sufficiently filled with DEF for the next trip, and using the right quality of DEF. Without use of DEF, the SCR system will not function and NO_x emissions would be significantly higher than certification levels. NO_x emissions levels of SCR-equipped vehicles operating without DEF can be as high as 1990-era vehicle models, more than 20 times higher than emissions limits.

In order to ensure that SCR systems function as intended, it is also critical to adopt provisions for safeguards to ensure proper use of the SCR reagent, urea, during vehicle use. Both U.S. EPA and Euro standards include provisions outside of the primary regulatory text that requires the use of driver warnings and driver inducements and other fail-safes to ensure use of the right quality of urea, minimum levels in the urea tank, and monitoring of urea consumption. More detail on inducements included in U.S. and EU regulations is provided in Table C1 below (adapted from "Mobile SCR Applications to meet Euro Standards: Implementation Challenges and Recommendations for Policymakers in Developing Countries," Rutherford et al., 2011).

Table C1. Provisions to ensure proper DEF use in SCR systems

Requirement		**Europe**[1]	**U.S.**[2]
Urea Monitoring	**Level**	Dashboard indicator required	Dashboard indicator
	Quality	Required	Required (direct or indirect[3])
	Dosing	Required	Required
	Freeze prevention	No specific requirements below -7 C	"Freeze start" test[4]
Driver warnings		Warning for low DEF (10% volume or fuel reserve distance)[4]	Warning for low DEF (10% volume)
Vehicle performance degradation		Torque limiter [5, 6] (60~75% max) at: 1. No DEF 2. Poor reagent quality 3. Improper dosing 4. NO_x >7 g/kWh	25% engine derate, mileage countdown or 55 mph speed limit at: 1. below 5% volume 2. poor DEF quality 5 mph speed limit at any/both: 1. No DEF + 15% fuel refill, restart, or continuously idling engine with vehicle parked for 1 hour or more 2. Poor DEF quality for 250 miles/5 hrs operation + 15% fuel refill, restart, or continuously idling engine with vehicle parked for 1 hour or more
Vehicle function restored at		At idle when conditions for torque limiting activation has ceased.	≥ 2.5% DEF level in DEF tank, or when conditions for torque limiting activation has ceased
NH_3 slip		Mean <25 ppm (Euro IV/V) <10 ppm (Euro VI)	Useful life ≤10 ppm (California Air Resources Board) 50 ppm (EPA)
Other		Record of fault: 400 days or 9600 operating hours	1. Tamper resistant designs for warnings, performance degradation, urea dosing 2. Mandated driver info

Notes:
1. Sources: European Parliament and Council of the European Union 2005 and European Commission 2011.
2. Proposed by SCR-equipped engine manufacturers to EPA and ARB. All final designs subject to review and certification by EPA and ARB. Sources: ARB 2010 and EPA 2012.
3. NO_x sensor, etc.
4. Demonstrate proper dosing after -18 degrees C for 72 hrs or until DEF freeze; 70 min operation (20 minute idle, 50 minutes at rated speed and <40% load) at -18 C .
5. OBD sensing is temporary interrupted if less than 20% fuel in the tank.
6. Within 50 hours of detection of default, upon first time the vehicle becomes stationary (Bodek 2008)

Appendix D. Technical basis for 15-ppm sulfur limit in the U.S.

EPA set diesel fuel quality standards at 15 ppm in order to enable the necessary technologies for the implementation of 2007 interim emission standards and to limit the regulation's impact on fuel economy. A diesel fuel sulfur cap of 15 ppm was implemented primarily in order to enable proper operation of two aftertreatment systems: diesel particulate filters and NO_x adsorber (EPA 2000). The fuel economy penalty of these systems was also taken into account. As demonstrated in Table C1, the 15 ppm sulfur cap, which would imply an average sulfur content of ~7 ppm, was intended to reduce the fuel economy impact from NO_x adsorbers to less than one percent absent other changes in engine design. The NO_x adsorber technology, however, has not been deployed and the particulate filter technologies in use have little impact on fuel economy.

Table D1. Estimated Fuel Economy Impact from Desulfation of a 90 Percent Efficient NO_x Adsorber (EPA 2000)

Fuel Sulfur Cap (ppm)	Average Fuel Sulfur (ppm)	Fuel Economy Penalty (%)
500	350	27
50	30	2
25	15	1
15	7	< 1
5	2	<<< 1

According to the Diesel Emission Control Sulfur Effects (DECSE) Project Report, the effect of increasing sulfur at ultra-low levels results in minimal engine-out PM changes. The DECSE report states that engine-out PM increases linearly with sulfur. The report shows that engine-out emissions of PM increase by three percent when increasing S concentration from 3 ppm to 30 ppm (DECSE 2001). Applying the linearity found by the study, the relative effect on a change from 10 ppm to 15 ppm would be only of 0.52 percent. It would be expected that DPF design would cope with a less than one percent increase in engine-out PM.

EPA states in the Regulatory Impact Assessment for the EPA 2010 standards "We, therefore, believe that in order to ensure reliable and economical operation over a wider range of expected operating conditions a diesel fuel sulfur level of 15 ppm will be needed. With these very low sulfur levels we believe, as demonstrated by experience in Europe, that [catalyzed diesel particulate filters] CDPFs will prove to be both durable and effective at controlling diesel PM emissions to the very low levels required by this standard" (EPA 2000).

References

ANP. 2009. RESOLUÇÃO ANP Nº 42, DE 16.12.2009 - DOU 17.12.2009—RETIFICADA DOU 14.1.2010. National Agency of Petroleum, Natural Gas and Biofuels.

ANP. 2011a. RESOLUÇÃO ANP Nº 65, DE 9.12.2011 - DOU 12.12.2011. National Agency of Petroleum, Natural Gas and Biofuels.

ANP. 2011b. RESOLUÇÃO ANP Nº 62, DE 1º.12.2011 - DOU 2.12.2011. National Agency of Petroleum, Natural Gas and Biofuels.

ANP. 2014. Obrigados a Comercializar. Excel document listing fueling stations providing ULSD nationwide. Version dated 05/02/2014 downloaded from www.anp.gov.br/?dw=58835 on May 14, 2014. National Agency of Petroleum, Natural Gas and Biofuels.

ARB. 2010. California Code of Regulations. On-Board Diagnostic System Requirements--2010 and Subsequent Model-Year Heavy-Duty Engine. Title 13, Section 1971.1.

ARB. 2013. Field Evaluation of Heavy-duty NO_x Control Strategies. January 2013. Air Resources Board.

Blumberg, K. 2014. Tratamiento para los vehículos medianos bajo la NOM 044. International Council on Clean Transportation.

Bodek, K. 2008. Heavy-Duty Diesel Vehicle NO_x Aftertreatment in 2010: The Infrastructure and Compliance Challenges of Urea-SCR. Thesis, Massachusetts Institute of Technology. February.

Charlton, S., Dollmeyer, T., & Grana, T. 2010. Meeting the US Heavy-Duty EPA 2010 Standards and Providing Increased Value for the Customer. SAE International. Vol. 3. Issue 1.

Chambliss, S., Miller, J., Façanha, C., Minjares, R., & Blumberg, K. 2013. The Impact of Stringent Fuel and Vehicle Standards on Premature Mortality and Emissions. The International Council on Clean Transportation.

CONAMA. 2008. Dispõe sobre a nova fase de exigência do Programa de Controle da Poluição do Ar por Veículos Automotores-PROCONVE para veículos pesados novos (Fase P-7) e dá outras providências. Data da legislação: 11/11/2008 - Publicação DOU nº 220, de 12/11/2008, págs. 92-93. National Commission on Environment, Ministry of Environment.

Diesel Emission Control Sulfur Effects (DECSE) Program. 2000. Phase I Interim Data Report No. 4: Diesel Particulate Filters—Final Report. Sponsored by: The U.S. Department of Energy (DOE), Engine Manufacturers Association, and Manufacturers of Emissions Controls Association.

EIA. 2013. Annual Energy Outlook 2013 (AEO2013). DOE/EIA-0383(2013).

EIA. 2014. Petroleum & Other Liquids. Diesel Fuel Release Date: May 5, 2014. Independent Statistics and Analysis, U.S. Energy and Information Administration, U.S. Department of Energy. http://www.eia.gov/petroleum/gasdiesel/

EPA. 2000. Regulatory Impact Analysis: Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Environmental Protection Agency, Office of Air and Radiation. EPA420-R-00-026.

EPA. 2001. Rules and Regulations: Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Federal Register: Vol. 66. No. 12. 5002-5193.

EPA. 2009. Notice: Control of Emissions From New Highway Vehicles and Engines: Approval of New Scheduled Maintenance for Selective Catalyst Reduction Technologies. Federal Register: Vol. 74. No. 215. 57671-57674

EPA. 2010. User Guide for MOVES2010a. Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency.

EPA. 2011a. Request for Comments: Control of Emissions From New Highway Vehicles and Engines; Guidance on EPA's Certification Requirements for Heavy-Duty Diesel Engines Using Selective Catalytic Reduction Technology. Federal Register: Vol. 76. No. 109. 32886-32896.

EPA. 2011b. The Benefits and Costs of the Clean Air Act from 1990 to 2020. Office of Air and Radiation, U.S. Environmental Protection Agency.

EPA and DOT. 2011. Rules and Regulations: Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles. Federal Register: Vol. 76. No. 179. 57106-57513.

EPA. 2012. Notices: Control of Emissions From New Highway Vehicles and Engines; Approval of New Scheduled Maintenance for Selective Catalytic Reduction Technologies. Federal Register: Vol. 77. No. 3. 488-497.

EPA. 2013. Spreadsheet of ULSD Data provided to ICCT of results of the consortium ULSD surveys, September 2006 through the second quarter of 2013. Email dated October 22, 2013.

European Parliament and Council of the European Union. 2005. Directive 2005/55/EC of the European Parliament and of the Council of 28 September 2005 on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles. Official Journal of the European Union. L 275. Vol. 48. 20 October 2005.

European Commission. 2011. Commission Regulation (EU) No 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI) and amending Annexes I and III to Directive 2007/46/EC of the European Parliament and of the Council. Official Journal of the European Union. L 167. Vol. 54. 25 June 2011.

Greszler, T. 2011. Volvo's Achievements and Plans for Fuel Efficiency and GHG Reduction. The Role of the Internal Combustion Engine in our Energy Future. Diesel Emissions Conference 2011.

Hart Energy and MathPro Inc. 2012. Technical and Economic Analysis of the Transition to Ultra-Low Sulfur Fuels in Brazil, China, India and Mexico. Prepared for the International Council on Clean Transportation. October 2012.

ICCT. 2013. Draft: Estimated Cost of Emission Reduction Technologies for Heavy-Duty engines.

Integer. 2014. DEF Tracker. Issue from April 2014. http://www.integer-research.com/environment-emissions/products/def-tracker/diesel-exhaust-fluid-def-price-tracker/

Kardec Duailibe, A. 2011. Plano de Abastecimento do Novo Diesel S50 e S10. Presentation by ANP to the association of motor vehicle producers (ANFAVEA) on May 30, 2011. Downloaded from http://www.altanova.com.br/anp.pdf on May 14, 2014.

Lowell, D. and Kamakate, F. 2012. Urban Off-Cycle NO_x Emissions from Euro IV/V Trucks & Buses: Problems and Solutions for Europe and Developing Countries. International Council on Clean Transportation.

MECA. 2013. Ultrafine Particulate Matter and the Benefits of Reducing Particle Numbers in the United States. Manufacturers of Emissions Controls Association. Prepared by Gladstein, Neandross, and Associates.

Miller, J. 2014. Cost-Benefit Analysis of NOM044 Regulation. International Council on Clean Transportation.

Naso, C. 2014. Mexico's Pemex Drops $475M To Buy, Revamp Fertilizer Plant. Law360. http://www.law360.com/articles/502152/mexico-s-pemex-drops-475m-to-buy-revamp-fertilizer-plant

National Research Council. 2010. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: The National Academies Press.

Oil & Gas Journal. 2006. Pipeline engagement Eases Move to ULSD. Vol 104, Issue 40.

PEMEX. 2013. Anuario Estadistico 2013. http://www.pemex.com/acerca/informes_publicaciones/Documents/anuario_estadistico_2013/anuario-estadistico-2013_131014.pdf

Posada, F. 2014. On-board diagnostics for heavy-duty vehicles: Considerations for Mexico. International Council on Clean Transportation.

Rutherford, D., Kamakate, F., Fung, F., and Sharpe, B. 2011. Mobile SCR Applications to meet Euro Standards: Implementation Challenges and Recommendations for Policymakers in Developing Countries. International Council on Clean Transportation.

Szalkowska, U. 2011. Personal communication with Urszula Szalkowska, Director Europe & Africa, International Fuel Quality Center, Hart Energy. Email dates Dec 2, 2011.

TET. 2012. TerraCair – Diesel Exhaust Fluid Market Update August 2012. Presentation posted at http://www.epa.gov/international/air/9-dieselfluid-presentation.pdf.