Motor Vehicle Greenhouse Gas Emissions

An Analysis of Emission Reductions Due to Greenhouse Gas and Corporate Average Fuel Economy (CAFE) Standards

Final Report

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1.0 Introduction

Meszler Engineering Services (MES) has estimated the greenhouse gas (GHG) emission reductions that will accrue between 2000 and 2050 in Maryland due to the implementation of four specific GHG and/or Corporate Average Fuel Economy (CAFE) programs. The four programs evaluated consist of:

1. CAFE standards for light duty vehicles that have been adopted for model years 2005 through 2011. These standards actually include three sets of nationally adopted standards, one set applicable to model year (MY) 2005 through 2007 light duty trucks,[1] a second set applicable to model year 2008 through 2010 light duty trucks,[2] and a third set applicable to model year 2011 passenger cars and light duty trucks.[3] In this report, these standards are collectively referred to as the model year 2011 (or the MY05-11) standards.

2. GHG/CAFE standards for light duty vehicles that have been adopted for model years 2012 through 2016.[4]

3. GHG/CAFE standards for light duty vehicles that have been proposed for adoption for model years 2017 through 2025.[5] In the preliminary proposal for such standards, the U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) discussed four possible proposals expressed as three, four, five, and six percent annual reductions in GHG emissions (relative to model year 2016). Only the six percent option has been evaluated in this analysis.

4. GHG/CAFE standards for medium and heavy duty vehicles that have been proposed for adoption for model years 2014 through 2018.[6]

It should be noted that Maryland has also adopted the California Low Emission Vehicle (LEV) Program (referred to, in Maryland, as the Clean Cars Program), with implementation beginning

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[1] National Highway Traffic Safety Administration, "*Light Truck Average Fuel Economy Standards Model Years 2005-2007*," Final Rule, Federal Register, 68FR16868, April 7, 2003.

[2] National Highway Traffic Safety Administration, "*Average Fuel Economy Standards for Light Trucks Model Years 2008–2011*," Final Rule, Federal Register, 71FR17566, April 6, 2006. The model year 2011 standards established under this rule were superseded prior to implementation by a subsequent model year 2011 rulemaking, so that only the standards for model years 2008-2010 were ultimately implemented.

[3] National Highway Traffic Safety Administration, "*Average Fuel Economy Standards Passenger Cars and Light Trucks Model Year 2011*," Final Rule, Federal Register, 74FR14196, March 30, 2009.

[4] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "*Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule*," Final Rule, Federal Register, 75FR25324, May 7, 2010.

[5] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "*2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards; Notice of Intent*," Notice of Intent to Conduct a Joint Rulemaking, Federal Register, 75FR62739, October 13, 2010.

[6] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "*Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles*," Proposed Rules, Federal Register, 75FR74152, November 30, 2010.

in model year 2011. The LEV program also includes specific GHG standards. However, the California and Federal governments have agreed that vehicle manufacturers that comply with national GHG standards through model year 2016 will be deemed to comply with California GHG standards for the same model year. Negotiations are currently underway to extend this allowance through model year 2025. As a result, it is expected that the *GHG standards* of the LEV program will be subsumed within the national GHG/CAFE programs throughout the period covered by this analysis, so that distinct modeling of the GHG impacts of the LEV program is not appropriate. If the California and Federal governments do not reach a consensus regarding model year 2017-2025 GHG standards, then it may be necessary to augment this analysis with independent modeling of the LEV program GHG standards. It is also important to recognize that the LEV program also imposes non-GHG standards that are independent of corresponding national standards and would require independent modeling to evaluate. However, since this analysis is concerned only with GHG emissions, failure to account for non-GHG LEV program impacts is of no consequence.

In estimating GHG emission reductions, four specific greenhouse gas species are considered: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and air conditioning refrigerant. These constitute the four GHG species that are regulated under the above referenced emission standard programs and the four GHG species that are generally considered when evaluating motor vehicle GHG emissions. Impacts are evaluated both individually by emission species and in the aggregate. Aggregate impacts are expressed in terms of CO_2-equivalent emissions, with mass emissions of CH_4, N_2O, and air conditioning refrigerant converted to equivalent CO_2 mass using associated 100 year global warming potential (GWP) values. The specific GWP values utilized in this analysis are:

CO_2 GWP:	1	(by definition)
CH_4 GWP:	25	
N_2O GWP:	298	
HFC-134a GWP:	1430	(air conditioning refrigerant HFC-134a)
HFC-152 GWP:	124	(air conditioning refrigerant HFC-152)
HFO-1234yf GWP:	4	(air conditioning refrigerant HFO-1234yf)

For example, one gram of CH_4 emissions is assumed to have the same GHG impact as 25 grams of CO_2 emissions. GWP values are developed by the Intergovernmental Panel on Climate Change (IPCC) and are reasonably standardized, although they are subject to update as GHG science evolves. The values used in this analysis reflect the latest estimates developed by the IPCC.[7]

Estimated GHG impact estimates exclude potential "upstream" emission reductions associated with reduced petroleum processing, etc. Such an approach is appropriate for two reasons. First, emissions from upstream facilities are generally accounted for in stationary and area source emission inventories. As a result, including impact estimates from upstream facilities alongside

[7] Intergovernmental Panel on Climate Change, "*Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*," edited by Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and Miller, H.L., Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States, 2007. See specifically, "Technical Summary," Table TS.2.

mobile source emissions could result in the potential for double counting upstream emission reductions. Second, the geographic location of upstream emissions (e.g., fuel refinery emissions), may lie outside the area of interest – i.e., outside Maryland in this case. It is therefore, critical that geographic considerations be addressed in any upstream emissions accounting. Failure to do so could lead to different regions taking redundant credit for the same emission reductions. Since these issues are beyond the scope of this analysis, upstream emission impacts are not included in the presented impact estimates. For interested readers, a rough estimate of incremental upstream benefits can be derived by multiplying analysis impacts by a factor of 1.28.[8]

Finally, criteria pollutant (i.e., non-GHG) impacts associated with GHG/CAFE standard changes are not estimated. While vehicle criteria pollutant emission standards are unchanged under GHG/CAFE standard programs, changes in vehicle miles of travel (VMT) can lead to proportional changes in vehicle criteria pollutant emissions and changes in fuel demand will lead to proportional changes in upstream criteria pollutant emissions. The magnitude of the VMT-related impact is indicated by the change in vehicle VMT, which results from assumed VMT elasticity with the cost of driving. The change in upstream emissions is indicated by the change in GHG CO_2 emissions, such that emissions from gasoline production and distribution would be expected to change proportionally. These two effects act in offsetting directions (with elasticity generally leading to emissions increases and CO_2 reductions leading to emissions decreases), and could be precisely quantified given additional effort. In the interim, reasonable estimates can be derived from estimated changes in VMT and CO_2.

2.0 Methods and Data Sources

The basic approach employed to assess GHG/CAFE standard impacts on GHG emissions in Maryland relies on projected fuel sales as the primary basis for developing GHG emissions estimates under both baseline and alternative GHG/CAFE standard futures. For the baseline future, total fuel sales are allocated to specific vehicle classes and model years using baseline fuel consumption estimates from the EPA's MOBILE6.2 emission factor model in conjunction with fleet characterization data expressed as vehicle age distributions, vehicle sales fractions, vehicle mileage accumulation rates, and vehicle class-specific VMT fractions, each developed locally for Maryland or derived from the MOBILE6.2 emission factor model (in the absence of local data). All locality-specific data were provided by the Maryland Department of the Environment (MDE), as discussed in more detail below.

These same fleet characterization data in conjunction with the fuel consumption impacts estimated for the alternative GHG/CAFE standard futures are used to estimate the overall change in CO_2, CH_4, N_2O, air conditioning refrigerant, and total GHG emissions. Emission impacts consider the change in VMT due to changes in the cost of driving (i.e., VMT elasticity). Total

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[8] This factor was developed from material presented in: Argonne National Laboratory, "*GREET 1.5 - Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use, and Results,*" Appendix B, August 1999, and "*GREET 1.5 - Transportation Fuel-Cycle Model, Volume 2: Appendices of Data and Results*," Appendix B, August 1999. Newer versions of this model and associated documentation are available, but the impact of included updates on the effective upstream factor is negligible.

and class-specific vehicle sales are assumed to be unaffected by any of the evaluated GHG/CAFE programs.

It is important to recognize that this approach fundamentally differs from an approach that relies more directly on a bottom-up model such as MOBILE6.2 or MOVES. Such bottom-up approaches rely on baseline fuel consumption and fleet characteristics to estimate GHG emissions per unit VMT (e.g., grams per mile, g/mi) and then apply estimated VMT data to derive absolute GHG emissions. The weakness in this approach is that it substitutes relatively more uncertain *estimated* fuel consumption data for less uncertain *reported* fuel consumption data (upon which the MES evaluation is based). For example, the bottom-up approach basically estimates GHG emissions as follows:

$$\text{GHG emissions} = \text{estimated fuel volume per VMT} \times \text{estimated VMT} \times \text{fuel carbon per unit fuel volume}$$

The potential problem is that estimated fuel volume per VMT (i.e., vehicle efficiency) times estimated VMT also produces an estimate for overall fuel consumption. Since data on overall fuel consumption is generally collected and reported, it is, for the most part, a *known* parameter (with some uncertainty of course). Adjustments are required when the bottom-up estimates are not consistent with the reported estimates, as is quite likely since estimating fuel consumption per VMT for all of the various vehicles that comprise the subject fleet is fraught with uncertainty. The only effective options available to “force” calculated fuel consumption to match reported fuel consumption are to either alter estimated VMT or alter estimated fuel volume consumed per VMT (vehicle efficiency). There are no other degrees of freedom. Given that analysts will be reluctant to alter estimated VMT since such estimates are used to derive non-GHG emission estimates for other emissions inventory purposes, the only practical approach is to alter estimated fuel volume per VMT -- which then changes the relationship between baseline fuel consumption and “alternative future” (i.e., scenario) fuel consumption unless corresponding adjustments are applied to both. This can, of course, be accomplished, but the whole exercise can also be easily avoided by simply using total *reported* fuel consumption as the basis for the GHG impact analysis.

Under a reported fuel consumption approach, as employed for the analysis documented in this report, GHG estimates are generally produced as follows:

$$\text{GHG} = \text{reported total fuel volume} \times \text{fuel carbon per unit fuel volume}$$

Of course this vastly oversimplifies the estimation process since the reported fuel volume must be disaggregated into its component vehicle types and ages to accurately estimate the near term impacts of programs that alter fuel consumption.[9] Moreover, the fuel disaggregation process relies on the same fuel volume per VMT (vehicle efficiency) estimates used in the bottom-up approach. However, there is a key difference. Whereas the bottom-up approach requires the *explicit* adjustment of the fuel volume per VMT estimates to derive total GHG emission

[9] This is due to the fact that the impacts of these programs must be phased-into the overall fleet through the sale of new, lower fuel consumption vehicles and the retirement of older, higher fuel consumption vehicles. Thus, the age distribution and rate of fleet turnover are critical elements for accurately determining impacts until such time as the entire fleet is replaced. Long term impacts can be assessed directly from total fuel sales (but they implicitly assume a complete fleet turnover).

estimates that are consistent with total estimated VMT, the reported fuel consumption approach *inherently* assumes that any error in the fuel volume per VMT estimates is unbiased and spread consistently across the various estimates for each vehicle type and age. In effect, the *relative* fuel consumption estimates for the various vehicle types and ages are unaffected by the error and the uncertain estimates can be used directly to disaggregate total fuel consumption into its component parts without error (or, more accurately, any additional error due to the fuel volume per VMT estimates). In effect, there is a degree of freedom not available in the bottom-up approach.[10]

Since it is expected that reported fuel sales are more accurate than fuel volume per VMT (vehicle efficiency) estimates and the other myriad fleet characterization estimates used to derive overall vehicle class and age-specific fuel consumption (as alluded to above), this analysis relies on reported fuel sales as its fundamental analysis parameter. It is expected that this approach will produce more accurate GHG emission estimates, but readers should use caution in comparing estimates from this analysis to estimates derived using alternative methods, such as a bottom-up MOBILE6.2 or MOVES analysis.

Gasoline and diesel fuel consumption data, as obtained from the U.S. Federal Highway Administration (FHWA), were used as the basis for the analysis documented in this report.[11] Diesel data, as published by FHWA, do not include consumption by public agencies. To account for such use, reported FHWA diesel fuel consumption is adjusted upward using VMT fractions provided by MDE (as discussed further below) in conjunction with baseline fuel economy data by vehicle class from MOBILE6.2. Future fuel consumption is estimated on the basis of forecasted VMT growth and changes in vehicle fuel economy, as described below – and is the principal metric used to contrast GHG emissions under the alternative GHG/CAFE standard programs.

Baseline HPMS (Highway Performance Monitoring System) VMT data, disaggregated by county, road type, and average travel speed bin, were provided by MDE for 2005. Data on HMPS and summertime VMT adjustment factors were also provided by county and road class. Finally, MDE provided VMT multipliers by county and road class for 2012, 2015, 2018, and 2025. The baseline 2005 data were aggregated to the county and road class level of detail, and the provided forecast year multipliers were applied to derive corresponding VMT estimates for each forecast year. The data were then aggregated to derive an overall statewide VMT estimate for each year, and an associated aggregate VMT multiplier was calculated. These multipliers were annualized for the intervening periods and subjected to regression analysis to derive a continuous VMT growth function. Figure 1 presents the resulting function. Baseline VMT was forecasted for every year through 2050 using the associated data. For the GHG/CAFE standard scenarios, baseline VMT as adjusted in accordance with changes in vehicle fuel economy and the assumed VMT elasticity estimates.

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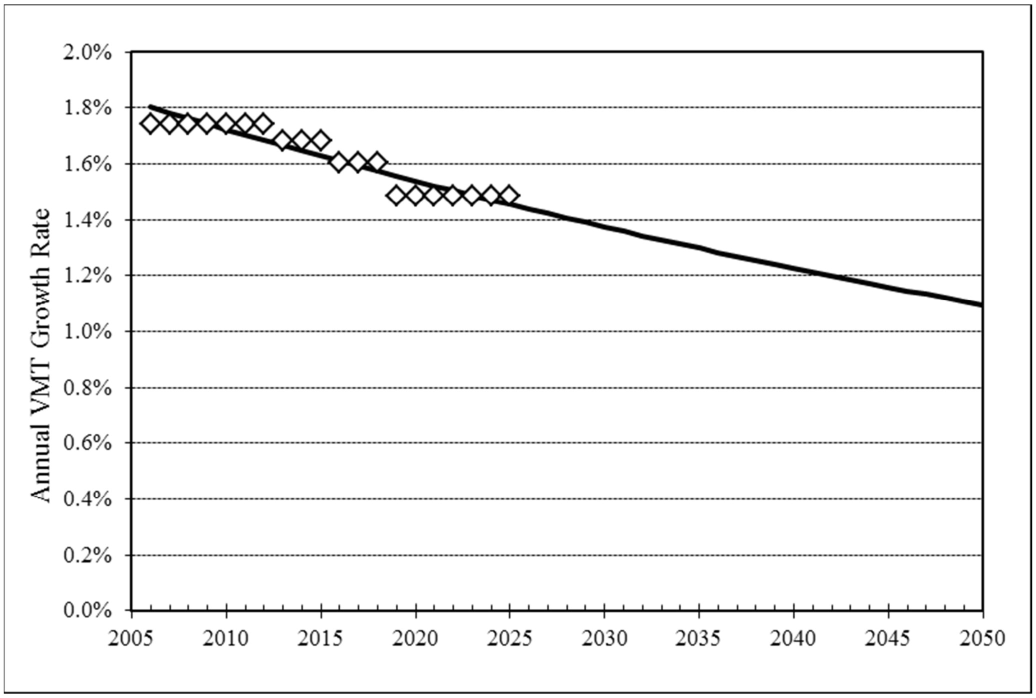
[10] Of course, one would expect overall vehicle fuel use and VMT estimates to be reasonably consistent regardless of the methodology employed in their development, so long as that methodology is technically correct and employed carefully.

[11] Federal Highway Administration, Highway Statistics, Table MF-21 (Highway Use Only), published annually.

Figure 1. Baseline VMT Growth Function



Vehicle class-specific VMT fractions serve as a critical parameter in this analysis through two mechanisms. First, VMT fractions are used to aggregate vehicle class-specific fuel efficiency values into aggregate efficiency estimates (e.g., passenger car fuel consumption and light truck fuel consumption are aggregated in accordance with their relative VMT shares). Such aggregation in conjunction with the estimated VMT growth rate allows for the estimation of overall future year fuel sales. Second, these overall fuel sales are disaggregated into vehicle class-specific shares in accordance with VMT-weighted class-specific fuel consumption. The impacts of the alternative GHG/CAFE standard futures are then estimated by vehicle class and aggregated to derive overall impact estimates.

The vehicle class-specific VMT fractions used for this analysis are derived from data provided by MDE. The MDE data were provided at the county, road class, and vehicle type level of detail, with vehicle type signifying four specific groups of vehicles: (1) motorcycles, (2) light duty vehicles, (3) medium and heavy duty vehicles, and (4) buses. These data were further disaggregated into the 28 vehicle classes included in the analysis using VMT relationships from the MOBILE6.2 model for the vehicles that comprise each of the four MDE vehicle groups.

Since the analysis underlying this report relies on reported fuel sales data as the primary basis for developing baseline GHG emission estimates, the developed VMT mix were validated against reported gasoline and diesel fuel sales to ensure that the developed gasoline and diesel VMT fractions were consistent with those sales. This process involves weighting class-specific VMT mix and fuel economy data to develop an estimate of overall gasoline and diesel sales. The differential between reported and estimated sales is used to adjust the MDE-provided VMT mix data to ensure consistency between the two data parameters (i.e., fuel sales and estimated VMT mixes). Generally, the results of this validation indicated good agreement between reported fuel sales and VMT mix, with adjustments limited to shifting between 0.1 and 2.1 percent of VMT from gasoline to diesel vehicles (with shifts varying by calendar year). The largest shifts occurred in the latest calendar years and, as a result, the shift that is applied prior to the development of the forecast year VMT mix data is equal to 2.1 percent of VMT.

VMT mixes are forecasted to change over time in accordance with forecasted national vehicle class-specific sales data, vehicle class-specific registration age fractions, and vehicle class- and age-specific annual mileage accumulation rates. The base vehicle sales data are extracted from MOBILE6.2, and adjusted using forecast data from the U.S. Department of Energy's Annual Energy Outlook to capture the latest trends in consumer preference with regard to sales of light duty trucks versus passenger cars. Vehicle class-specific registration age fractions were provided separately for eight regions of Maryland by MDE. Using provided VMT data, the eight sets of registration age fractions were weighted to produce a single statewide dataset. Annual mileage accumulation rates by vehicle class and age were taken directly from MOBILE6.2. Together, these data were processed to develop forecast year-specific VMT fractions based on the 2005 fractions provided by MDE.

The overall analysis essentially uses these data, implemented through appropriate algorithms, to apportion annual fuel use to individual model year vehicles within a specific vehicle class, and estimate the rate at which these vehicles enter and exit the fleet. Such algorithms are critical to estimating the *short run* impacts that accrue immediately after the implementation of a GHG/CAFE standard program since the impacts of that program take time to filter through the entire motor vehicle fleet. However, such algorithms have virtually no effect on *long run* impacts since the "pre-control" fleet of vehicles is ultimately replaced in its entirely with a "post-control" fleet. Thus, while it is important to understand how the fleet turnover effects are modeled in this analysis, it is also important to recognize that such effects have no bearing on the full turnover impact estimates under any of the alternative GHG/CAFE standard futures. Finally, it is also important to recognize that while these data (i.e., VMT mixes, registration age fractions, vehicle sales forecasts, mileage accumulation rates, etc.) are critical for evaluating fleet turnover, they are *not* used to estimate absolute fuel consumption or VMT, but rather to disaggregate independently estimated or reported data into various underlying component vehicle classes. MDE-provided VMT estimates and reported fuel sales determine overall analysis results.

Aggregate GHG impact estimates are expressed in terms of CO_2-equivalent (CO_2-eq) emissions. Readers wishing to compare the estimates to other independent impact estimates should also recognize that in this analysis, CO_2-equivalent is "as CO_2," not "as carbon." Carbon-specific impacts can be obtained by multiplying reported CO_2 impacts by a mass correction factor of 0.27 (or 12/44). CO_2-equivalent emissions include tailpipe CO_2, incremental tailpipe CO_2 due to air conditioning use (weighted by the load-adjusted fraction of VMT accumulated with the air conditioning system operating), tailpipe methane (adjusted for global warming potential using a factor of 25), tailpipe N_2O (adjusted for global warming potential using a factor of 298), and released air conditioning refrigerant (adjusted for global warming potential using factors of 1,430 for HFC-134a and 4 for HFO-1234yf refrigerants, as applicable). Baseline refrigerant is assumed to be HFC-134a, while programs that grant credit for air conditioning improvements are assumed to induce the replacement of HFC-134a with HFO-1234yf on a gradual basis between 2012 and 2025.

Air conditioning usage in Maryland is estimated using data developed by the National Renewable Energy Laboratory.[12] Based on these data, air conditioning is assumed to be utilized for 28 percent of VMT in the state, as compared to 34 percent of national VMT. However, the average specific enthalpy of the ambient air during those operations in Maryland is about 6 percent higher than average U.S. air conditioning operating conditions. Thus, since air conditioning emission rates are based on national average usage conditions, a load adjustment is applied to the Maryland data such that the "effective utilization rate" is increased to 32 percent of total VMT.[13]

Since GHG/CAFE standard programs do not impose specific reductions in either methane or nitrous oxide emissions, this analysis assumes no change in the emission rates of these GHG sources under any of the alternative GHG/CAFE program futures.[14] For light duty gasoline vehicles, the specific emission rates for methane, N_2O, air conditioning efficiency impacts on emissions, and air conditioning refrigerant leakage rates assumed in this analysis are taken from the support documents for both the 2012-2016 GHG/CAFE standards and the proposed 2017-2025 standards (as referenced in Section 1 above). Corresponding emission rates for light duty diesel and all medium and heavy duty vehicles are taken from the EPA's draft State Inventory Tool (methane and N_2O) or scaled from the data for light duty gasoline vehicles (air conditioning emissions).[15] For methane and N_2O, the same emission rates are applied under both the baseline and GHG/CAFE alternative program futures. Air conditioning load and leakage emissions are adjusted in accordance with credits granted under each GHG/CAFE program scenario.

The analysis also considers the impact of "VMT rebound" on overall GHG emissions impacts. The degree to which VMT will change in response to GHG/CAFE standards is uncertain. Most analyses, including this analysis, rely on an estimate of the elasticity of VMT with respect to the cost of driving to estimate the overall impacts on VMT. However, change in the cost of driving is only one aspect of the economic impacts of a GHG/CAFE standards program. Such programs also affect vehicle purchase price, so that estimating vehicle usage impacts solely on the basis of changes in the variable cost of driving neglects (entirely) potential offsetting impacts of

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[12] See Johnson, V.H., National Renewable Energy Laboratory, "*Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach*," 2002-01-1957, Society of Automotive Engineers, Inc., 2002 and Rugh, J. and Hovland, V., National Renewable Energy Laboratory, "*National and World Fuel Savings and CO_2 Emission Reductions by Increasing Vehicle Air Conditioning COP*," presented at the SAE Alternate Refrigerants Symposium, Phoenix, Arizona, July 15-17, 2003.

[13] The load adjustment is based on Figure D-4 in "*Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles*," Northeast States Center for a Clean Air Future, September 2004.

[14] The GHG/CAFE standard programs do allow manufacturers to test and take credit for reductions in either emission species, they simply don't require such testing. The programs do impose requirements to demonstrate no net increase in such emissions. Manufacturers that elect to take credit for methane and/or N_2O reductions will receive appropriate CO_2 credits that allow "increases" in direct CO_2 emissions above levels otherwise allowed, so that total allowable GHG emissions (expressed on a CO_2-equivalent basis) will be unchanged.

[15] The EPA State Inventory Tool can be obtained via *http://www.epa.gov/statelocalclimate/resources/tool.html*, last accessed on May 24, 2011.

increased transportation expenditures associated with vehicle purchase. To the extent that these two price influences result in a net change in total transportation expenditures (under a constant VMT scenario) that is near zero, it is reasonable to expect an insignificant change in vehicle usage, and thus, an "effective" VMT elasticity that is also near zero. Of course, elasticity will diverge from zero (in either direction) as *net* savings (or costs) diverge from zero.

A literature review conducted for the U.S. Department of Energy, indicates the *fuel price* elasticity of VMT for light duty vehicles to be in the range of -0.1 to -0.2.[16] This same review indicated that the fuel *efficiency* elasticity of VMT could be much smaller, and may approach zero. Based on these data and the fact that variable operating cost impacts are but one aspect of the overall cost impacts of the GHG/CAFE standards programs, a best estimate for the "effective" VMT elasticity for light duty vehicles is likely to be in the range of 0.0 to -0.1. It is important to note that a "real world" opportunity to quantify the magnitude of VMT elasticity is provided by the dramatic increase in fuel price observed between 2003 and the first half of 2008. During this period, fuel price increased by a factor of nearly three. An examination of U.S. VMT and fuel prices during this period indicates elasticity estimates of between -0.03 and -0.16, with an overall average of -0.10. These estimates are quite consistent with the lower half of the cited literature elasticity range. Given these data and the fact that elasticity with respect to efficiency is almost certainly lower than elasticity with respect to fuel price (due the need to recoup any increased vehicle purchase price), this analysis assumes a light duty vehicle VMT elasticity estimate of -0.05. For medium and heavy duty vehicles, this analysis assumes an elasticity estimate of zero, on the premise that such vehicles are subject to little, if any, discretionary usage and that commercial operators will simply pass any fuel savings or costs onto consumers.

3.0 GHG/CAFE Standard Programs

While modeling the impacts of GHG/CAFE standards is theoretically straightforward, there are several issues associated with such standards that render a definitive forecast difficult. Among these is the fact that independent standards are set by vehicle class, so shifts in sales across classes can affect overall program stringency. Moreover, the latest standards also vary by vehicle size, even within a given vehicle class, so that changes in size can similarly affect overall program stringency. Finally, there are compliance credits available for technologies such as non-petroleum fueling capability that can affect vehicle manufacturer compliance without leading to commensurate GHG reductions. It is, therefore, important to understand how all such issues are treated to fully appreciate the derived emissions impact estimates.

It is not necessary to understand the entire history of GHG/CAFE standards, but a basic understanding of developments over the last few years is important.[17] From 2000-2004, CAFE

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[16] See Greene, David L., "Why CAFE Worked," prepared for the U.S. Department of Energy, November 6, 1997.

[17] At the national level, no GHG standards existed prior to model year 2012. While Maryland has adopted the California light duty vehicle GHG standards effective in model year 2011, California has agreed that vehicle manufacturers in compliance with national CAFE standards through model year 2016 are deemed to be in compliance with applicable California standards. Therefore, for practical purposes, the *GHG provisions* of the California requirements will lead to GHG reductions identical to those of the federal CAFE program. At this time, California and the federal government are negotiating the extension of this agreement through model year 2025, and it is assumed for this analysis that such negotiations will be successful. Finally, while federal standard for both GHG and CAFE exist beginning with model year 2012, these standards are being developed in harmony, so

standards were set at 27.5 miles per gallon (mpg) for passenger cars and 20.7 mpg for light trucks. Passenger car standards remained at 27.5 mpg through model year 2010, while light duty trucks were subject to increasingly stringent standards during this period as follows: 21.0, 21.6, 22.2, 22.5, 23.1, and 23.5 mpg in model years 2005, 2006, 2007, 2008, 2009, and 2010 respectively. Throughout the model year 2000-2010 period, manufacturers were able to take credit for non-gasoline vehicle sales to generate credits of up to 1.2 mpg for both their passenger car and light duty truck fleets. Such credits were "routinely" earned and utilized, generally through the production of flex fuel vehicles capable of running on gasoline, ethanol, or any blend of the two.

Model year 2008 also represented the first year during which light duty truck manufacturers could (optionally at their discretion) take advantage of size-based standards. In addition to the "traditional" numerical standards provided above, manufacturers could alternatively demonstrate compliance through a size based standard algorithm that tailors the specific standard applicable to the manufacturer to the sales-weighted size of its fleet. "Size" in this context is defined by a vehicle's footprint, where footprint is the product of the vehicle's wheelbase and track width.[18] This essentially means that the fleet average standard for any given model year is subject to change should the size of the affected vehicle fleet change (relative to that forecasted when the standard was developed). As a result, with the advent of size-based compliance, it is not possible to define future CAFE standards with certainty. All national standards for light duty vehicles adopted after model year 2010, both GHG and CAFE standards, are size-based.

The optional model year 2008-2010 size-based light truck standards as well as the standards adopted for model year 2011 passenger cars and light trucks are based on the logistic curve algorithm:

$$\text{CAFE Standard} = \frac{1}{\frac{1}{a} + \left(\frac{1}{b} - \frac{1}{a}\right)\left(\frac{e^{((FP - c)/d)}}{1 + e^{((FP - c)/d)}}\right)}$$

where: a, b, c, and d are curve parameters as defined in Table 1, and

FP is vehicle footprint in square feet (to the nearest tenth).

Although size-based standards were also adopted for model year 2012-2016 passenger cars and light trucks, the form of the algorithm was changed. Instead of the logistic algorithm presented above, the model year 2012 and later algorithm is linear (in fuel consumption space), bounded by

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that GHG reductions can be estimated using either set of standards as a starting point, so long as all appropriate adjustments are made accordingly (e.g., air conditioning-related reductions are added to CAFE program benefits). Given the historic longevity of CAFE standards, the discussion supporting this analysis focuses on the construct of the CAFE standards (with appropriate adjustments). However, the reader should recognize that corresponding GHG standards have been adopted and could be similarly used as the basis for an equivalent GHG impact analysis.

[18] Wheelbase and track width are automotive (and in this case regulatory) terms that respectively signify the longitudinal and lateral distance between tire centerlines.

maximum and minimum standards at prescribed vehicle footprints. The specific form of the algorithm is:

$$\text{CAFE Standard} = \frac{1}{\min\left(\max\left(c(FP) + d, \frac{1}{a}\right), \frac{1}{b}\right)}$$

where: a, b, c, and d are algorithm parameters as defined in Table 1, and

FP is vehicle footprint in square feet (to the nearest tenth).

Table 1 presents the specific values for the function parameters. If these functions are evaluated for a range of vehicle footprints, the model year-specific curves presented in Figures 2 and 3 are derived (for comparative convenience, the range of both the x and y axes in the two figures are identical). From these curves, it is obvious that the proposed approach to CAFE is such that the standard for any given vehicle varies in accordance with its footprint only over a limited range. Once a footprint reaches a certain minimum value, the CAFE standard reaches a maximum and once a footprint reaches a certain maximum value, the CAFE standard reaches a minimum. Footprint changes below the effective minima and footprint changes above the effective maxima have no additional impact on the CAFE standard. Under the model year 2008-2011 algorithm, the rate of change of the CAFE standard with footprint (in the affected range of footprints) is not linear, but rather is greatest in the midrange between the effective minima and maxima. The net effect is that the fleet average CAFE standard can be quite different than the standard that would be implied if one evaluated the CAFE standard function for the mathematic fleet average footprint. Thus, this analysis utilizes the term "effective" fleet average footprint to account for the various nonlinearities of the CAFE function, with the effective fleet average footprint signifying that footprint which would evaluate to the projected fleet average CAFE value for any given vehicle class and model year.

Table 1. CAFE Standard Algorithm Parameters

Model Year	Passenger Car Parameter				Light Truck Parameter			
	a	b	c	d	a	b	c	d
Logistic Algorithm Format								
2008	n/a	n/a	n/a	n/a	28.56	19.99	49.30	5.58
2009	n/a	n/a	n/a	n/a	30.07	20.87	48.00	5.81
2010	n/a	n/a	n/a	n/a	29.96	21.20	48.49	5.50
2011	31.20	24.00	51.41	1.91	27.10	21.10	56.41	4.28
Linear Algorithm Format								
2012	35.95	27.95	0.0005308	0.006057	29.82	22.27	0.0004546	0.014900
2013	36.80	28.46	0.0005308	0.005410	30.67	22.74	0.0004546	0.013968
2014	37.75	29.03	0.0005308	0.004725	31.38	23.13	0.0004546	0.013225
2015	39.24	29.90	0.0005308	0.003719	32.72	23.85	0.0004546	0.011920
2016	41.09	30.96	0.0005308	0.002573	34.42	24.74	0.0004546	0.010413

Figure 2. CAFE Standard Curves for Passenger Cars

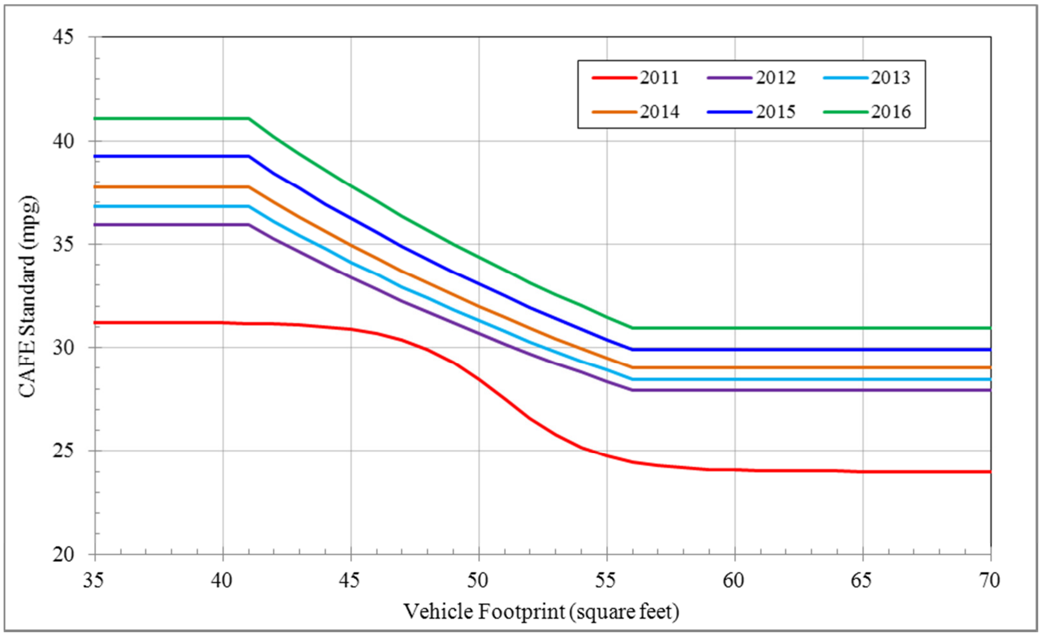

Figure 3. CAFE Standard Curves for Light Duty Trucks

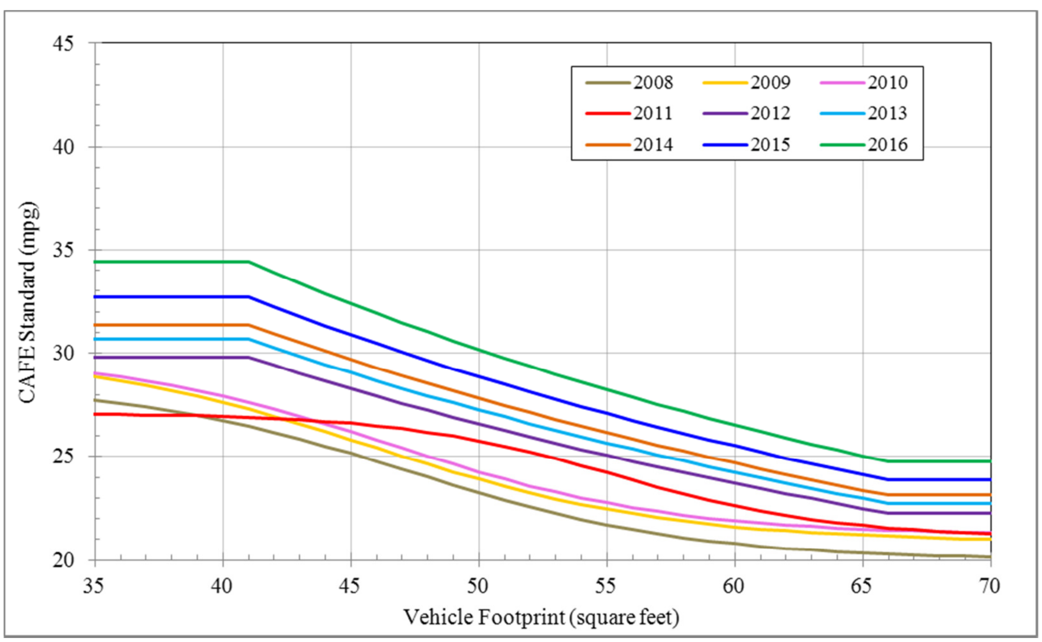

Table 2 illustrates the EPA/NHTSA forecasted fleet average CAFE levels and associated effective fleet average footprints for the model years 2011-2016 for which EPA/NHTSA data are available. Table 2 also shows the optional model year 2008-2010 light truck fleet average standards that would be applicable if the model year 2011 effective fleet average footprint is assumed to be unchanged over the model year 2008-2011 period.[19] Finally, Table 2 shows the estimated fleet average CAFE levels for model years 2017-2025 that would be applicable under a six percent annual decline in GHG emissions and a constant effective fleet average footprint (under the assumption that both passenger car and light truck standards are subject to an equal six percent annual stringency increase). These same assumptions are employed in the analysis documented in this report, so that the effective fleet average footprints for both passenger cars and light trucks are assumed to remain unchanged after model year 2016. If this assumption should prove to be invalid, the emissions estimates presented herein will be equally invalid.

To accurately estimate GHG emission reductions using adopted and expected CAFE standards, the CAFE standards must be adjusted and additional estimates for air conditioning and other GHG reduction credits estimated. CAFE standards must be adjusted because beginning in model year 2011, two-wheel drive sport utility vehicles (2WDSUV) were "reclassified" from the light duty truck class to the passenger car class under CAFE requirements. Therefore, model year 2011 and later standards are not directly comparable for model year 2010 and earlier standards. To produce the required consistency, this analysis is based on CAFE standards that "remove" the 2WDSUVs from the passenger car fleet and put them back into the light truck fleet. It is possible to formulate these adjustments using data provided in EPA/NHTSA support documents for the model year 2011 and model year 2012-2016 GHG/CAFE standard rulemakings, as previously referenced in Section 1 above. Generally, when 2WDSUVs are reclassified from the passenger car to the light truck fleet, the CAFE standards for each class increase. Passenger car standards increase as relatively larger, lower fuel economy 2WDSUVs are removed and light truck standards increase as generally smaller, higher fuel economy 2WDSUVs are added. The post-adjustment CAFE forecasts are presented in Table 3.

Air conditioning-related credits are similarly estimated using data that appear in the EPA/NHTSA support documents for the GHG/CAFE standard rulemakings, as previously referenced in Section 1 above. Generally, air conditioning credits are available beginning in model year 2012, and can be earned both for reducing refrigerant leakage (or replacing current refrigerant with a lower GWP counterpart) and increasing air conditioning system efficiency. Technologies available for both approaches are more cost effective than alternative vehicle efficiency improvements, so it is expected that manufacturers will take full advantage of these credit provisions (given appropriate leadtime). Thus, both EPA/NHTSA and this analysis assume that GHG reductions due to air conditioning improvements will be generated. Table 3 includes the magnitude of the estimated credits.

[19] The effective light truck footprint for model years 2008-2010 appears to differ from that of model year 2011 because 2WDSUVs are included in the light truck class for the 2008-2010 model years, but excluded from the class for model year 2011. Since 2WDSUVs have a somewhat smaller footprint than other light trucks, their inclusion in the model year 2008-2010 standards reduces the overall class effective footprint even though both 2WDSUV and non-2WDSUV light truck effective footprints are held constant across model years 2008-2011.

Table 2. Projected CAFE Levels and Effective Fleet Average Footprint

Vehicle Model Year	PC/2WDSUV (a)		LDT/MDPV (b)	
	CAFE (mpg)	Footprint (sq ft)	CAFE (mpg)	Footprint (sq ft)
2008	27.5	n/a	22.0	53.9
2009	27.5	n/a	22.7	53.9
2010	27.5	n/a	23.0	53.9
2011 (c)	30.2	47.4	24.1	55.4
2011 (d)	30.4	47.0	24.4	54.5
2012	33.3	45.1	25.4	53.8
2013	34.2	44.9	26.0	53.9
2014	34.9	45.1	26.6	53.6
2015	36.2	45.0	27.5	53.8
2016	37.8	45.0	28.8	53.5
2017 (e)	40.0	45.0	30.5	53.5
2018 (e)	42.3	45.0	32.3	53.5
2019 (e)	44.7	45.0	34.2	53.5
2020 (e)	47.3	45.0	36.2	53.5
2021 (e)	49.9	45.0	38.3	53.5
2022 (e)	52.7	45.0	40.5	53.5
2023 (e)	55.6	45.0	42.7	53.5
2024 (e)	58.6	45.0	45.1	53.5
2025 (e)	61.7	45.0	47.6	53.5

Notes: (a) PC = passenger cars, 2WDSUV = two-wheel drive sport utility vehicles. Prior to model year 2011, data are applicable to passenger cars only and 2WDSUV are included with LDT.
(b) LDT = light duty trucks, excluding 2WDSUV, MDPV = medium duty passenger vehicle. Prior to model year 2011, data include 2WDSUV and exclude MDPV.
(c) As estimated in the CAFE rulemaking for model year 2011.
(d) As estimated in the CAFE rulemaking for model years 2012-2016.
(e) The model year 2017 through 2025 CAFE levels assume a constant six percent decrease in PC and LDT GHG emissions.

Finally, this analysis also assumes that manufacturers will continue to take advantage of the non-gasoline credit provisions of CAFE. These provisions phase out between model years 2014 and 2019, but they continue to provide a convenient compliance mechanism for manufacturers through the phase out period. Table 3 presents the magnitude of the credits assumed in this analysis.

There is no existing or historic GHG or CAFE standards program for medium and heavy duty vehicles. However, EPA/NHTSA has proposed an initial program for such vehicles beginning with model year 2014, as previously referenced in Section 1 above. This initial program would establish standards through model year 2018. Since this program is still in the proposal stage, it is unclear what, if any, actions will be taken for subsequent model years. For this reason, this

Table 3. Analysis Parameters for Light Duty Vehicles

Vehicle Model Year	PC CAFE (mpg)	LDT CAFE (mpg)	Dual Fuel Credits (mpg)	PC A/C Load Credits	LDT A/C Load Credits	PC A/C Leak Credits	LDT A/C Leak Credits
2000	27.5	20.7	1.2	0.0	0.0	0.0	0.0
2001	27.5	20.7	1.2	0.0	0.0	0.0	0.0
2002	27.5	20.7	1.2	0.0	0.0	0.0	0.0
2003	27.5	20.7	1.2	0.0	0.0	0.0	0.0
2004	27.5	20.7	1.2	0.0	0.0	0.0	0.0
2005	27.5	21.0	1.2	0.0	0.0	0.0	0.0
2006	27.5	21.6	1.2	0.0	0.0	0.0	0.0
2007	27.5	22.2	1.2	0.0	0.0	0.0	0.0
2008	27.5	22.0	1.2	0.0	0.0	0.0	0.0
2009	27.5	22.7	1.2	0.0	0.0	0.0	0.0
2010	27.5	23.0	1.2	0.0	0.0	0.0	0.0
2011	30.4	25.2	1.2	0.0	0.0	0.0	0.0
2012	33.5	26.5	1.2	1.2	1.3	1.9	2.2
2013	34.3	27.2	1.2	1.6	1.8	2.6	3.2
2014	35.0	27.8	1.2	2.5	2.8	3.9	5.0
2015	36.4	28.8	1.0	3.6	3.7	5.6	6.6
2016	37.9	30.1	0.8	3.7	3.9	5.7	7.1
2017	40.1	32.0	0.6	3.9	4.1	6.1	7.5
2018	42.4	33.8	0.4	4.1	4.3	6.5	7.8
2019	44.9	35.8	0.2	4.3	4.5	6.8	8.2
2020	47.4	37.9	0.0	4.6	4.7	7.1	8.6
2021	49.9	40.1	0.0	4.8	4.9	7.5	8.9
2022	52.5	42.4	0.0	5.0	5.1	7.9	9.3
2023	55.1	44.8	0.0	5.2	5.3	8.2	9.7
2024	57.8	47.3	0.0	5.5	5.5	8.5	10.0
2025	60.6	49.9	0.0	5.7	5.7	8.9	10.4

PC data excludes 2WDSUV, LDT data includes 2WDSUV.
All air conditioning credits are expressed in terms of grams CO_2-equivalent per mile.

analysis assumes no additional changes after model year 2018, with impacts between model years 2014 and 2018 based on data presented in the EPA/NHTSA rulemaking documents. Table 4 presents the associated GHG impact parameters.

Table 4. Analysis Parameters for Medium and Heavy Duty Vehicles

Vehicle Model Year	Gasoline Pickups and Vans	Diesel Pickups and Vans	Gasoline Vocational Trucks	Diesel Vocational Trucks	Diesel Tractors
Change in Fuel Economy					
2013	0.0%	0.0%	0.0%	0.0%	0.0%
2014	1.5%	1.5%	0.0%	5.2%	9.2%
2015	1.5%	3.0%	0.0%	5.2%	9.2%
2016	3.1%	6.2%	5.6%	5.2%	9.2%
2017	6.5%	9.5%	5.6%	9.7%	12.8%
2018	10.0%	16.9%	5.6%	9.7%	12.8%
Change in Air Conditioning Leakage					
2013	0.0%	0.0%	0.0%	0.0%	0.0%
2014	-13.0%	-13.0%	-13.0%	-13.0%	-13.0%
2015	-13.0%	-13.0%	-13.0%	-13.0%	-13.0%
2016	-13.0%	-13.0%	-13.0%	-13.0%	-13.0%
2017	-13.0%	-13.0%	-13.0%	-13.0%	-13.0%
2018	-13.0%	-13.0%	-13.0%	-13.0%	-13.0%
Change in Air Conditioning Load					
2013	0.0%	0.0%	0.0%	0.0%	0.0%
2014	0.0%	0.0%	0.0%	0.0%	0.0%
2015	0.0%	0.0%	0.0%	0.0%	0.0%
2016	0.0%	0.0%	0.0%	0.0%	0.0%
2017	0.0%	0.0%	0.0%	0.0%	0.0%
2018	0.0%	0.0%	0.0%	0.0%	0.0%

4.0 Analysis Results

Tables 5 through 9 present the GHG emission estimates for 2005-2050 for the five specific scenarios evaluated in this analysis. The tables are distinguished as follows:

- Table 5 presents estimates for the baseline scenario. Since MDE specified 2006 as the base year for their GHG reduction analysis, the baseline scenario includes the impacts of all GHG/CAFE standard programs through vehicle model year 2006.
- Table 6 adds the impacts of all light duty vehicle GHG/CAFE standard programs through vehicle model year 2011. This includes the impacts of the model year 2005-2007 light truck standards, the model year 2008-2010 light truck standards, and the model year 2011 passenger car and light truck standards.

Table 5. Baseline Emissions (million tons CO_2-eq)

Year	LD GHG	MD/HD GHG	Total GHG	LD CO_2	MD/HD CO_2	Total CO_2	LD CH_4	MD/HD CH_4	Total CH_4	LD N_2O	MD/HD N_2O	Total N_2O	LD Refrig	MD/HD Refrig	Total Refrig
2005	25.53	7.80	33.32	24.70	7.71	32.40	0.0069	0.0014	0.0084	0.0990	0.0171	0.1161	0.7207	0.0736	0.7943
2006	25.66	7.75	33.40	24.83	7.66	32.48	0.0069	0.0014	0.0084	0.0993	0.0170	0.1163	0.7225	0.0733	0.7958
2007	25.85	7.93	33.78	25.01	7.84	32.85	0.0070	0.0015	0.0085	0.1004	0.0173	0.1177	0.7302	0.0750	0.8052
2008	26.21	8.11	34.32	25.36	8.01	33.37	0.0071	0.0015	0.0086	0.1021	0.0177	0.1197	0.7424	0.0768	0.8192
2009	26.58	8.30	34.87	25.71	8.20	33.91	0.0073	0.0015	0.0088	0.1038	0.0180	0.1218	0.7548	0.0786	0.8334
2010	26.96	8.46	35.42	26.08	8.36	34.44	0.0074	0.0015	0.0089	0.1055	0.0183	0.1238	0.7677	0.0801	0.8478
2011	27.37	8.62	35.99	26.47	8.52	34.99	0.0075	0.0016	0.0091	0.1073	0.0187	0.1260	0.7807	0.0817	0.8624
2012	27.78	8.79	36.57	26.87	8.69	35.56	0.0076	0.0016	0.0092	0.1091	0.0190	0.1282	0.7939	0.0834	0.8773
2013	28.20	8.97	37.17	27.27	8.86	36.14	0.0078	0.0016	0.0094	0.1109	0.0194	0.1303	0.8069	0.0851	0.8920
2014	28.63	9.16	37.79	27.69	9.05	36.74	0.0079	0.0017	0.0095	0.1127	0.0198	0.1325	0.8200	0.0869	0.9069
2015	29.07	9.32	38.40	28.12	9.21	37.33	0.0080	0.0017	0.0097	0.1146	0.0201	0.1347	0.8336	0.0885	0.9221
2016	29.51	9.49	39.00	28.54	9.38	37.92	0.0081	0.0017	0.0099	0.1164	0.0205	0.1369	0.8467	0.0901	0.9368
2017	29.95	9.67	39.62	28.97	9.56	38.52	0.0083	0.0018	0.0100	0.1182	0.0209	0.1391	0.8599	0.0918	0.9518
2018	30.41	9.86	40.27	29.41	9.74	39.15	0.0084	0.0018	0.0102	0.1201	0.0213	0.1414	0.8734	0.0936	0.9670
2019	30.84	10.04	40.88	29.83	9.92	39.75	0.0085	0.0018	0.0103	0.1218	0.0217	0.1435	0.8860	0.0953	0.9813
2020	31.28	10.23	41.51	30.25	10.11	40.36	0.0086	0.0019	0.0105	0.1235	0.0221	0.1456	0.8987	0.0972	0.9959
2021	31.73	10.39	42.13	30.69	10.27	40.96	0.0088	0.0019	0.0106	0.1254	0.0224	0.1478	0.9119	0.0987	1.0106
2022	32.19	10.58	42.77	31.13	10.45	41.58	0.0089	0.0019	0.0108	0.1272	0.0228	0.1500	0.9252	0.1004	1.0257
2023	32.66	10.76	43.42	31.58	10.63	42.21	0.0090	0.0019	0.0110	0.1290	0.0232	0.1523	0.9387	0.1022	1.0409
2024	33.13	10.95	44.08	32.04	10.82	42.86	0.0092	0.0020	0.0111	0.1309	0.0236	0.1545	0.9524	0.1040	1.0563
2025	33.61	11.14	44.75	32.50	11.01	43.51	0.0093	0.0020	0.0113	0.1328	0.0240	0.1569	0.9662	0.1058	1.0720
2026	34.08	11.33	45.41	32.96	11.19	44.15	0.0094	0.0021	0.0115	0.1347	0.0244	0.1591	0.9799	0.1076	1.0875
2027	34.56	11.52	46.08	33.42	11.38	44.80	0.0096	0.0021	0.0116	0.1366	0.0249	0.1614	0.9936	0.1094	1.1029
2028	35.04	11.71	46.74	33.88	11.57	45.45	0.0097	0.0021	0.0118	0.1385	0.0253	0.1637	1.0073	0.1112	1.1185
2029	35.51	11.90	47.41	34.34	11.76	46.10	0.0098	0.0022	0.0120	0.1403	0.0257	0.1660	1.0210	0.1130	1.1340
2030	35.99	12.09	48.08	34.80	11.95	46.75	0.0099	0.0022	0.0121	0.1422	0.0261	0.1683	1.0348	0.1148	1.1496
2031	36.47	12.29	48.76	35.27	12.14	47.41	0.0101	0.0022	0.0123	0.1441	0.0265	0.1706	1.0486	0.1167	1.1652
2032	36.95	12.48	49.43	35.73	12.33	48.07	0.0102	0.0023	0.0125	0.1460	0.0269	0.1730	1.0624	0.1185	1.1809
2033	37.44	12.67	50.11	36.20	12.52	48.73	0.0103	0.0023	0.0126	0.1479	0.0274	0.1753	1.0762	0.1204	1.1966
2034	37.92	12.87	50.79	36.67	12.72	49.39	0.0105	0.0023	0.0128	0.1498	0.0278	0.1776	1.0901	0.1222	1.2124
2035	38.40	13.07	51.47	37.14	12.91	50.05	0.0106	0.0024	0.0130	0.1518	0.0282	0.1800	1.1040	0.1241	1.2281
2036	38.89	13.27	52.15	37.61	13.11	50.71	0.0107	0.0024	0.0131	0.1537	0.0286	0.1823	1.1179	0.1260	1.2439
2037	39.37	13.46	52.84	38.07	13.30	51.38	0.0109	0.0024	0.0133	0.1556	0.0291	0.1846	1.1318	0.1279	1.2597
2038	39.86	13.66	53.52	38.54	13.50	52.04	0.0110	0.0025	0.0135	0.1575	0.0295	0.1870	1.1458	0.1298	1.2756
2039	40.34	13.86	54.21	39.01	13.70	52.71	0.0111	0.0025	0.0137	0.1594	0.0299	0.1893	1.1597	0.1317	1.2914
2040	40.83	14.06	54.89	39.48	13.90	53.38	0.0113	0.0025	0.0138	0.1613	0.0304	0.1917	1.1737	0.1336	1.3073
2041	41.32	14.26	55.58	39.95	14.10	54.05	0.0114	0.0026	0.0140	0.1633	0.0308	0.1940	1.1877	0.1355	1.3231
2042	41.80	14.47	56.27	40.43	14.29	54.72	0.0116	0.0026	0.0142	0.1652	0.0312	0.1964	1.2016	0.1374	1.3390
2043	42.29	14.67	56.96	40.90	14.49	55.39	0.0117	0.0027	0.0143	0.1671	0.0317	0.1988	1.2156	0.1393	1.3549
2044	42.78	14.87	57.65	41.37	14.70	56.06	0.0118	0.0027	0.0145	0.1690	0.0321	0.2011	1.2296	0.1412	1.3709
2045	43.27	15.07	58.34	41.84	14.90	56.73	0.0120	0.0027	0.0147	0.1709	0.0325	0.2035	1.2436	0.1432	1.3868
2046	43.75	15.28	59.03	42.31	15.10	57.41	0.0121	0.0028	0.0149	0.1729	0.0330	0.2058	1.2576	0.1451	1.4027
2047	44.24	15.48	59.72	42.78	15.30	58.08	0.0122	0.0028	0.0150	0.1748	0.0334	0.2082	1.2716	0.1471	1.4186
2048	44.73	15.69	60.41	43.25	15.50	58.75	0.0124	0.0028	0.0152	0.1767	0.0339	0.2106	1.2855	0.1490	1.4345
2049	45.21	15.89	61.11	43.72	15.71	59.43	0.0125	0.0029	0.0154	0.1786	0.0343	0.2129	1.2995	0.1510	1.4504
2050	45.70	16.10	61.80	44.19	15.91	60.10	0.0126	0.0029	0.0155	0.1805	0.0347	0.2153	1.3135	0.1529	1.4664

GHG = CO_2 + CH_4 + N_2O + Refrig, where "CO_2" includes both fuel economy and air conditioning efficiency improvements (if any), and "Refrig" indicates reductions in air conditioning refrigerant emissions.

Since MDE has established 2006 as the baseline from which it measures GHG emission reductions, the baseline estimates include MY05-06 light duty vehicle CAFE standards.

Table 6. Emissions with MY05-11 Light Duty Standards (million tons CO_2-eq)

Year	LD GHG	MD/HD GHG	Total GHG	LD CO_2	MD/HD CO_2	Total CO_2	LD CH_4	MD/HD CH_4	Total CH_4	LD N_2O	MD/HD N_2O	Total N_2O	LD Refrig	MD/HD Refrig	Total Refrig
2005	25.53	7.80	33.32	24.70	7.71	32.40	0.0069	0.0014	0.0084	0.0990	0.0171	0.1161	0.7207	0.0736	0.7943
2006	25.66	7.75	33.40	24.83	7.66	32.48	0.0069	0.0014	0.0084	0.0993	0.0170	0.1163	0.7225	0.0733	0.7958
2007	25.81	7.93	33.75	24.98	7.84	32.81	0.0070	0.0015	0.0085	0.1004	0.0173	0.1177	0.7302	0.0750	0.8053
2008	26.13	8.11	34.24	25.28	8.01	33.29	0.0071	0.0015	0.0086	0.1021	0.0177	0.1197	0.7425	0.0768	0.8193
2009	26.42	8.30	34.71	25.55	8.20	33.75	0.0073	0.0015	0.0088	0.1038	0.0180	0.1218	0.7551	0.0786	0.8336
2010	26.69	8.46	35.14	25.81	8.36	34.16	0.0074	0.0015	0.0089	0.1056	0.0183	0.1239	0.7681	0.0801	0.8482
2011	26.78	8.62	35.40	25.89	8.52	34.41	0.0075	0.0016	0.0091	0.1074	0.0187	0.1261	0.7816	0.0817	0.8633
2012	26.82	8.79	35.61	25.90	8.69	34.59	0.0076	0.0016	0.0092	0.1093	0.0190	0.1284	0.7954	0.0834	0.8788
2013	26.88	8.97	35.85	25.95	8.86	34.82	0.0078	0.0016	0.0094	0.1112	0.0194	0.1306	0.8090	0.0851	0.8941
2014	26.97	9.16	36.13	26.03	9.05	35.07	0.0079	0.0017	0.0096	0.1131	0.0198	0.1328	0.8227	0.0869	0.9096
2015	27.11	9.32	36.43	26.15	9.21	35.36	0.0080	0.0017	0.0097	0.1150	0.0201	0.1351	0.8368	0.0885	0.9253
2016	27.25	9.49	36.75	26.28	9.38	35.66	0.0082	0.0017	0.0099	0.1169	0.0205	0.1374	0.8504	0.0901	0.9405
2017	27.44	9.67	37.11	26.45	9.56	36.01	0.0083	0.0018	0.0101	0.1188	0.0209	0.1396	0.8640	0.0918	0.9559
2018	27.68	9.86	37.54	26.68	9.74	36.42	0.0084	0.0018	0.0102	0.1207	0.0213	0.1420	0.8778	0.0936	0.9715
2019	27.92	10.04	37.95	26.89	9.92	36.81	0.0086	0.0018	0.0104	0.1224	0.0217	0.1441	0.8908	0.0953	0.9861
2020	28.18	10.23	38.42	27.15	10.11	37.26	0.0087	0.0019	0.0105	0.1242	0.0221	0.1463	0.9038	0.0972	1.0010
2021	28.48	10.39	38.87	27.43	10.27	37.70	0.0088	0.0019	0.0107	0.1261	0.0224	0.1485	0.9173	0.0987	1.0160
2022	28.80	10.58	39.37	27.73	10.45	38.18	0.0089	0.0019	0.0109	0.1280	0.0228	0.1508	0.9308	0.1004	1.0313
2023	29.15	10.76	39.91	28.06	10.63	38.70	0.0091	0.0019	0.0110	0.1298	0.0232	0.1531	0.9445	0.1022	1.0467
2024	29.52	10.95	40.47	28.42	10.82	39.24	0.0092	0.0020	0.0112	0.1317	0.0236	0.1554	0.9583	0.1040	1.0623
2025	29.91	11.14	41.05	28.79	11.01	39.80	0.0093	0.0020	0.0114	0.1337	0.0240	0.1577	0.9724	0.1058	1.0782
2026	30.29	11.33	41.62	29.16	11.19	40.35	0.0095	0.0021	0.0115	0.1356	0.0244	0.1600	0.9862	0.1076	1.0938
2027	30.68	11.52	42.20	29.54	11.38	40.92	0.0096	0.0021	0.0117	0.1375	0.0249	0.1623	1.0000	0.1094	1.1094
2028	31.08	11.71	42.79	29.92	11.57	41.49	0.0097	0.0021	0.0119	0.1394	0.0253	0.1646	1.0138	0.1112	1.1250
2029	31.49	11.90	43.39	30.31	11.76	42.07	0.0099	0.0022	0.0120	0.1413	0.0257	0.1669	1.0277	0.1130	1.1407
2030	31.90	12.09	43.99	30.71	11.95	42.66	0.0100	0.0022	0.0122	0.1432	0.0261	0.1693	1.0416	0.1148	1.1564
2031	32.32	12.29	44.61	31.11	12.14	43.25	0.0101	0.0022	0.0124	0.1451	0.0265	0.1716	1.0555	0.1167	1.1721
2032	32.74	12.48	45.22	31.51	12.33	43.85	0.0103	0.0023	0.0125	0.1470	0.0269	0.1739	1.0694	0.1185	1.1879
2033	33.16	12.67	45.84	31.92	12.52	44.45	0.0104	0.0023	0.0127	0.1489	0.0274	0.1763	1.0833	0.1204	1.2037
2034	33.59	12.87	46.46	32.33	12.72	45.05	0.0105	0.0023	0.0129	0.1508	0.0278	0.1786	1.0973	0.1222	1.2195
2035	33.99	13.07	47.06	32.72	12.91	45.63	0.0107	0.0024	0.0130	0.1528	0.0282	0.1810	1.1113	0.1241	1.2354
2036	34.42	13.27	47.69	33.13	13.11	46.24	0.0108	0.0024	0.0132	0.1547	0.0286	0.1833	1.1253	0.1260	1.2513
2037	34.85	13.46	48.32	33.54	13.30	46.85	0.0110	0.0024	0.0134	0.1566	0.0291	0.1857	1.1394	0.1279	1.2672
2038	35.28	13.66	48.94	33.96	13.50	47.46	0.0111	0.0025	0.0136	0.1585	0.0295	0.1880	1.1534	0.1298	1.2831
2039	35.71	13.86	49.57	34.37	13.70	48.07	0.0112	0.0025	0.0137	0.1605	0.0299	0.1904	1.1674	0.1317	1.2991
2040	36.14	14.06	50.21	34.79	13.90	48.68	0.0114	0.0025	0.0139	0.1624	0.0304	0.1928	1.1815	0.1336	1.3151
2041	36.57	14.26	50.84	35.20	14.10	49.30	0.0115	0.0026	0.0141	0.1643	0.0308	0.1951	1.1955	0.1355	1.3310
2042	37.00	14.47	51.47	35.62	14.29	49.91	0.0116	0.0026	0.0142	0.1663	0.0312	0.1975	1.2096	0.1374	1.3470
2043	37.43	14.67	52.10	36.03	14.49	50.53	0.0118	0.0027	0.0144	0.1682	0.0317	0.1999	1.2237	0.1393	1.3630
2044	37.87	14.87	52.74	36.45	14.70	51.14	0.0119	0.0027	0.0146	0.1701	0.0321	0.2022	1.2378	0.1412	1.3790
2045	38.30	15.07	53.37	36.86	14.90	51.76	0.0120	0.0027	0.0148	0.1721	0.0325	0.2046	1.2518	0.1432	1.3950
2046	38.73	15.28	54.01	37.28	15.10	52.37	0.0122	0.0028	0.0149	0.1740	0.0330	0.2070	1.2659	0.1451	1.4110
2047	39.16	15.48	54.64	37.69	15.30	52.99	0.0123	0.0028	0.0151	0.1759	0.0334	0.2094	1.2800	0.1471	1.4270
2048	39.59	15.69	55.28	38.11	15.50	53.61	0.0124	0.0028	0.0153	0.1779	0.0339	0.2117	1.2940	0.1490	1.4431
2049	40.02	15.89	55.91	38.52	15.71	54.23	0.0126	0.0029	0.0155	0.1798	0.0343	0.2141	1.3081	0.1510	1.4591
2050	40.45	16.10	56.55	38.93	15.91	54.84	0.0127	0.0029	0.0156	0.1817	0.0347	0.2165	1.3222	0.1529	1.4751

GHG = CO_2 + CH_4 + N_2O + Refrig, where "CO_2" includes both fuel economy and air conditioning efficiency improvements (if any), and "Refrig" indicates reductions in air conditioning refrigerant emissions.

Table 7. Emissions with MY05-16 Light Duty Standards (million tons CO_2-eq)

Year	LD GHG	MD/HD GHG	Total GHG	LD CO_2	MD/HD CO_2	Total CO_2	LD CH_4	MD/HD CH_4	Total CH_4	LD N_2O	MD/HD N_2O	Total N_2O	LD Refrig	MD/HD Refrig	Total Refrig
2005	25.53	7.80	33.32	24.70	7.71	32.40	0.0069	0.0014	0.0084	0.0990	0.0171	0.1161	0.7207	0.0736	0.7943
2006	25.66	7.75	33.40	24.83	7.66	32.48	0.0069	0.0014	0.0084	0.0993	0.0170	0.1163	0.7225	0.0733	0.7958
2007	25.81	7.93	33.75	24.98	7.84	32.81	0.0070	0.0015	0.0085	0.1004	0.0173	0.1177	0.7302	0.0750	0.8053
2008	26.13	8.11	34.24	25.28	8.01	33.29	0.0071	0.0015	0.0086	0.1021	0.0177	0.1197	0.7425	0.0768	0.8193
2009	26.42	8.30	34.71	25.55	8.20	33.75	0.0073	0.0015	0.0088	0.1038	0.0180	0.1218	0.7551	0.0786	0.8336
2010	26.69	8.46	35.14	25.81	8.36	34.16	0.0074	0.0015	0.0089	0.1056	0.0183	0.1239	0.7681	0.0801	0.8482
2011	26.78	8.62	35.40	25.89	8.52	34.41	0.0075	0.0016	0.0091	0.1074	0.0187	0.1261	0.7816	0.0817	0.8633
2012	26.42	8.79	35.21	25.68	8.69	34.36	0.0076	0.0016	0.0092	0.1094	0.0190	0.1284	0.6242	0.0834	0.7076
2013	26.16	8.97	35.12	25.47	8.86	34.33	0.0078	0.0016	0.0094	0.1113	0.0194	0.1307	0.5698	0.0851	0.6549
2014	25.75	9.16	34.91	25.18	9.05	34.23	0.0079	0.0017	0.0096	0.1132	0.0198	0.1330	0.4473	0.0869	0.5342
2015	25.28	9.32	34.61	24.85	9.21	34.07	0.0081	0.0017	0.0097	0.1153	0.0201	0.1354	0.3077	0.0885	0.3962
2016	24.91	9.49	34.40	24.50	9.38	33.88	0.0082	0.0017	0.0099	0.1172	0.0205	0.1377	0.2905	0.0901	0.3806
2017	24.59	9.67	34.26	24.16	9.56	33.72	0.0083	0.0018	0.0101	0.1192	0.0209	0.1401	0.2954	0.0918	0.3872
2018	24.34	9.86	34.19	23.91	9.74	33.65	0.0085	0.0018	0.0103	0.1212	0.0213	0.1425	0.3004	0.0936	0.3940
2019	24.10	10.04	34.14	23.67	9.92	33.59	0.0086	0.0018	0.0104	0.1231	0.0217	0.1448	0.3050	0.0953	0.4004
2020	23.93	10.23	34.16	23.49	10.11	33.60	0.0087	0.0019	0.0106	0.1250	0.0221	0.1471	0.3097	0.0972	0.4069
2021	23.81	10.39	34.21	23.36	10.27	33.63	0.0089	0.0019	0.0108	0.1270	0.0224	0.1494	0.3145	0.0987	0.4133
2022	23.76	10.58	34.34	23.30	10.45	33.75	0.0090	0.0019	0.0109	0.1289	0.0228	0.1517	0.3193	0.1004	0.4198
2023	23.78	10.76	34.54	23.31	10.63	33.95	0.0092	0.0019	0.0111	0.1308	0.0232	0.1541	0.3242	0.1022	0.4264
2024	23.86	10.95	34.80	23.38	10.82	34.20	0.0093	0.0020	0.0113	0.1328	0.0236	0.1564	0.3291	0.1040	0.4330
2025	23.98	11.14	35.12	23.50	11.01	34.51	0.0094	0.0020	0.0114	0.1348	0.0240	0.1588	0.3340	0.1058	0.4398
2026	24.14	11.33	35.46	23.65	11.19	34.84	0.0096	0.0021	0.0116	0.1367	0.0244	0.1612	0.3388	0.1076	0.4464
2027	24.32	11.52	35.84	23.83	11.38	35.21	0.0097	0.0021	0.0118	0.1387	0.0249	0.1635	0.3436	0.1094	0.4530
2028	24.54	11.71	36.25	24.04	11.57	35.61	0.0098	0.0021	0.0120	0.1406	0.0253	0.1659	0.3484	0.1112	0.4596
2029	24.79	11.90	36.69	24.28	11.76	36.04	0.0100	0.0022	0.0121	0.1426	0.0257	0.1682	0.3532	0.1130	0.4662
2030	25.05	12.09	37.14	24.54	11.95	36.48	0.0101	0.0022	0.0123	0.1445	0.0261	0.1706	0.3580	0.1148	0.4729
2031	25.33	12.29	37.61	24.81	12.14	36.95	0.0102	0.0022	0.0125	0.1464	0.0265	0.1730	0.3628	0.1167	0.4795
2032	25.62	12.48	38.10	25.09	12.33	37.42	0.0104	0.0023	0.0126	0.1484	0.0269	0.1753	0.3676	0.1185	0.4862
2033	25.92	12.67	38.59	25.39	12.52	37.91	0.0105	0.0023	0.0128	0.1503	0.0274	0.1777	0.3725	0.1204	0.4928
2034	26.23	12.87	39.10	25.69	12.72	38.41	0.0106	0.0023	0.0130	0.1523	0.0278	0.1800	0.3773	0.1222	0.4995
2035	26.53	13.07	39.59	25.98	12.91	38.89	0.0108	0.0024	0.0132	0.1542	0.0282	0.1824	0.3821	0.1241	0.5062
2036	26.83	13.27	40.09	26.28	13.11	39.38	0.0109	0.0024	0.0133	0.1562	0.0286	0.1848	0.3869	0.1260	0.5129
2037	27.15	13.46	40.62	26.59	13.30	39.90	0.0111	0.0024	0.0135	0.1581	0.0291	0.1872	0.3918	0.1279	0.5196
2038	27.48	13.66	41.14	26.91	13.50	40.41	0.0112	0.0025	0.0137	0.1601	0.0295	0.1896	0.3966	0.1298	0.5264
2039	27.80	13.86	41.66	27.23	13.70	40.93	0.0113	0.0025	0.0138	0.1620	0.0299	0.1919	0.4014	0.1317	0.5331
2040	28.13	14.06	42.19	27.54	13.90	41.44	0.0115	0.0025	0.0140	0.1640	0.0304	0.1943	0.4063	0.1336	0.5398
2041	28.46	14.26	42.72	27.87	14.10	41.97	0.0116	0.0026	0.0142	0.1659	0.0308	0.1967	0.4111	0.1355	0.5466
2042	28.79	14.47	43.26	28.20	14.29	42.49	0.0117	0.0026	0.0144	0.1679	0.0312	0.1991	0.4159	0.1374	0.5533
2043	29.13	14.67	43.80	28.53	14.49	43.02	0.0119	0.0027	0.0145	0.1698	0.0317	0.2015	0.4208	0.1393	0.5601
2044	29.46	14.87	44.33	28.85	14.70	43.55	0.0120	0.0027	0.0147	0.1718	0.0321	0.2039	0.4256	0.1412	0.5669
2045	29.80	15.07	44.87	29.18	14.90	44.08	0.0121	0.0027	0.0149	0.1737	0.0325	0.2063	0.4305	0.1432	0.5736
2046	30.13	15.28	45.41	29.51	15.10	44.61	0.0123	0.0028	0.0151	0.1757	0.0330	0.2087	0.4353	0.1451	0.5804
2047	30.47	15.48	45.95	29.84	15.30	45.14	0.0124	0.0028	0.0152	0.1776	0.0334	0.2111	0.4401	0.1471	0.5872
2048	30.80	15.69	46.49	30.17	15.50	45.67	0.0126	0.0028	0.0154	0.1796	0.0339	0.2135	0.4450	0.1490	0.5940
2049	31.14	15.89	47.03	30.50	15.71	46.20	0.0127	0.0029	0.0156	0.1815	0.0343	0.2158	0.4498	0.1510	0.6008
2050	31.47	16.10	47.57	30.82	15.91	46.73	0.0128	0.0029	0.0157	0.1835	0.0347	0.2182	0.4546	0.1529	0.6075

GHG = CO_2 + CH_4 + N_2O + Refrig, where "CO_2" includes both fuel economy and air conditioning efficiency improvements (if any), and "Refrig" indicates reductions in air conditioning refrigerant emissions.

Table 8. Emissions with MY05-25 Light Duty Standards (million tons CO_2-eq)

Year	LD GHG	MD/HD GHG	Total GHG	LD CO_2	MD/HD CO_2	Total CO_2	LD CH_4	MD/HD CH_4	Total CH_4	LD N_2O	MD/HD N_2O	Total N_2O	LD Refrig	MD/HD Refrig	Total Refrig
2005	25.53	7.80	33.32	24.70	7.71	32.40	0.0069	0.0014	0.0084	0.0990	0.0171	0.1161	0.7207	0.0736	0.7943
2006	25.66	7.75	33.40	24.83	7.66	32.48	0.0069	0.0014	0.0084	0.0993	0.0170	0.1163	0.7225	0.0733	0.7958
2007	25.81	7.93	33.75	24.98	7.84	32.81	0.0070	0.0015	0.0085	0.1004	0.0173	0.1177	0.7302	0.0750	0.8053
2008	26.13	8.11	34.24	25.28	8.01	33.29	0.0071	0.0015	0.0086	0.1021	0.0177	0.1197	0.7425	0.0768	0.8193
2009	26.42	8.30	34.71	25.55	8.20	33.75	0.0073	0.0015	0.0088	0.1038	0.0180	0.1218	0.7551	0.0786	0.8336
2010	26.69	8.46	35.14	25.81	8.36	34.16	0.0074	0.0015	0.0089	0.1056	0.0183	0.1239	0.7681	0.0801	0.8482
2011	26.78	8.62	35.40	25.89	8.52	34.41	0.0075	0.0016	0.0091	0.1074	0.0187	0.1261	0.7816	0.0817	0.8633
2012	26.42	8.79	35.21	25.68	8.69	34.36	0.0076	0.0016	0.0092	0.1094	0.0190	0.1284	0.6242	0.0834	0.7076
2013	26.16	8.97	35.12	25.47	8.86	34.33	0.0078	0.0016	0.0094	0.1113	0.0194	0.1307	0.5698	0.0851	0.6549
2014	25.75	9.16	34.91	25.18	9.05	34.23	0.0079	0.0017	0.0096	0.1132	0.0198	0.1330	0.4473	0.0869	0.5342
2015	25.28	9.32	34.61	24.85	9.21	34.07	0.0081	0.0017	0.0097	0.1153	0.0201	0.1354	0.3077	0.0885	0.3962
2016	24.91	9.49	34.40	24.50	9.38	33.88	0.0082	0.0017	0.0099	0.1172	0.0205	0.1377	0.2905	0.0901	0.3806
2017	24.43	9.67	34.10	24.04	9.56	33.60	0.0083	0.0018	0.0101	0.1192	0.0209	0.1401	0.2590	0.0918	0.3508
2018	23.90	9.86	33.76	23.54	9.74	33.28	0.0085	0.0018	0.0103	0.1213	0.0213	0.1426	0.2302	0.0936	0.3238
2019	23.28	10.04	33.32	22.95	9.92	32.87	0.0086	0.0018	0.0104	0.1233	0.0217	0.1449	0.2017	0.0953	0.2971
2020	22.61	10.23	32.84	22.31	10.11	32.42	0.0088	0.0019	0.0106	0.1252	0.0221	0.1473	0.1723	0.0972	0.2695
2021	21.92	10.39	32.31	21.64	10.27	31.91	0.0089	0.0019	0.0108	0.1273	0.0224	0.1497	0.1403	0.0987	0.2390
2022	21.19	10.58	31.77	20.95	10.45	31.40	0.0090	0.0019	0.0110	0.1294	0.0228	0.1522	0.1030	0.1004	0.2034
2023	20.49	10.76	31.25	20.27	10.63	30.91	0.0092	0.0019	0.0111	0.1315	0.0232	0.1547	0.0704	0.1022	0.1726
2024	19.80	10.95	30.75	19.61	10.82	30.43	0.0093	0.0020	0.0113	0.1336	0.0236	0.1572	0.0409	0.1040	0.1448
2025	19.10	11.14	30.24	18.96	11.01	29.97	0.0095	0.0020	0.0115	0.1358	0.0240	0.1598	0.0000	0.1058	0.1058
2026	18.54	11.33	29.87	18.39	11.19	29.59	0.0096	0.0021	0.0117	0.1379	0.0244	0.1623	0.0000	0.1076	0.1076
2027	18.07	11.52	29.58	17.92	11.38	29.30	0.0098	0.0021	0.0119	0.1400	0.0249	0.1648	0.0000	0.1094	0.1094
2028	17.69	11.71	29.40	17.54	11.57	29.11	0.0099	0.0021	0.0121	0.1420	0.0253	0.1673	0.0000	0.1112	0.1112
2029	17.40	11.90	29.30	17.25	11.76	29.00	0.0101	0.0022	0.0122	0.1441	0.0257	0.1698	0.0000	0.1130	0.1130
2030	17.19	12.09	29.28	17.03	11.95	28.98	0.0102	0.0022	0.0124	0.1461	0.0261	0.1722	0.0000	0.1148	0.1148
2031	17.06	12.29	29.34	16.90	12.14	29.04	0.0104	0.0022	0.0126	0.1482	0.0265	0.1747	0.0000	0.1167	0.1167
2032	16.99	12.48	29.47	16.83	12.33	29.16	0.0105	0.0023	0.0128	0.1502	0.0269	0.1771	0.0000	0.1185	0.1185
2033	16.97	12.67	29.64	16.80	12.52	29.33	0.0106	0.0023	0.0129	0.1522	0.0274	0.1795	0.0000	0.1204	0.1204
2034	16.99	12.87	29.86	16.83	12.72	29.55	0.0108	0.0023	0.0131	0.1542	0.0278	0.1820	0.0000	0.1222	0.1222
2035	17.03	13.07	30.10	16.86	12.91	29.78	0.0109	0.0024	0.0133	0.1562	0.0282	0.1844	0.0000	0.1241	0.1241
2036	17.11	13.27	30.37	16.94	13.11	30.05	0.0111	0.0024	0.0135	0.1582	0.0286	0.1868	0.0000	0.1260	0.1260
2037	17.23	13.46	30.69	17.06	13.30	30.36	0.0112	0.0024	0.0136	0.1602	0.0291	0.1892	0.0000	0.1279	0.1279
2038	17.37	13.66	31.03	17.19	13.50	30.69	0.0113	0.0025	0.0138	0.1622	0.0295	0.1917	0.0000	0.1298	0.1298
2039	17.52	13.86	31.38	17.34	13.70	31.04	0.0115	0.0025	0.0140	0.1642	0.0299	0.1941	0.0000	0.1317	0.1317
2040	17.68	14.06	31.74	17.50	13.90	31.40	0.0116	0.0025	0.0142	0.1662	0.0304	0.1965	0.0000	0.1336	0.1336
2041	17.85	14.26	32.11	17.67	14.10	31.76	0.0118	0.0026	0.0143	0.1681	0.0308	0.1989	0.0000	0.1355	0.1355
2042	18.02	14.47	32.49	17.84	14.29	32.14	0.0119	0.0026	0.0145	0.1701	0.0312	0.2014	0.0000	0.1374	0.1374
2043	18.21	14.67	32.88	18.03	14.49	32.52	0.0120	0.0027	0.0147	0.1721	0.0317	0.2038	0.0000	0.1393	0.1393
2044	18.40	14.87	33.27	18.21	14.70	32.91	0.0122	0.0027	0.0149	0.1741	0.0321	0.2062	0.0000	0.1412	0.1412
2045	18.60	15.07	33.67	18.41	14.90	33.30	0.0123	0.0027	0.0150	0.1761	0.0325	0.2086	0.0000	0.1432	0.1432
2046	18.79	15.28	34.07	18.60	15.10	33.70	0.0125	0.0028	0.0152	0.1781	0.0330	0.2110	0.0000	0.1451	0.1451
2047	18.99	15.48	34.48	18.80	15.30	34.10	0.0126	0.0028	0.0154	0.1800	0.0334	0.2135	0.0000	0.1471	0.1471
2048	19.20	15.69	34.88	19.00	15.50	34.50	0.0127	0.0028	0.0156	0.1820	0.0339	0.2159	0.0000	0.1490	0.1490
2049	19.40	15.89	35.29	19.20	15.71	34.91	0.0129	0.0029	0.0157	0.1840	0.0343	0.2183	0.0000	0.1510	0.1510
2050	19.61	16.10	35.71	19.41	15.91	35.32	0.0130	0.0029	0.0159	0.1860	0.0347	0.2207	0.0000	0.1529	0.1529

GHG = CO_2 + CH_4 + N_2O + Refrig, where "CO_2" includes both fuel economy and air conditioning efficiency improvements (if any), and "Refrig" indicates reductions in air conditioning refrigerant emissions.

Table 9. Emissions with MY05-25 Light Duty and MY14-18 Medium and Heavy Duty Standards (million tons CO_2-eq)

Year	LD GHG	MD/HD GHG	Total GHG	LD CO_2	MD/HD CO_2	Total CO_2	LD CH_4	MD/HD CH_4	Total CH_4	LD N_2O	MD/HD N_2O	Total N_2O	LD Refrig	MD/HD Refrig	Total Refrig
2005	25.53	7.80	33.32	24.70	7.71	32.40	0.0069	0.0014	0.0084	0.0990	0.0171	0.1161	0.7207	0.0736	0.7943
2006	25.66	7.75	33.40	24.83	7.66	32.48	0.0069	0.0014	0.0084	0.0993	0.0170	0.1163	0.7225	0.0733	0.7958
2007	25.81	7.93	33.75	24.98	7.84	32.81	0.0070	0.0015	0.0085	0.1004	0.0173	0.1177	0.7302	0.0750	0.8053
2008	26.13	8.11	34.24	25.28	8.01	33.29	0.0071	0.0015	0.0086	0.1021	0.0177	0.1197	0.7425	0.0768	0.8193
2009	26.42	8.30	34.71	25.55	8.20	33.75	0.0073	0.0015	0.0088	0.1038	0.0180	0.1218	0.7551	0.0786	0.8336
2010	26.69	8.46	35.14	25.81	8.36	34.16	0.0074	0.0015	0.0089	0.1056	0.0183	0.1239	0.7681	0.0801	0.8482
2011	26.78	8.62	35.40	25.89	8.52	34.41	0.0075	0.0016	0.0091	0.1074	0.0187	0.1261	0.7816	0.0817	0.8633
2012	26.42	8.79	35.21	25.68	8.69	34.36	0.0076	0.0016	0.0092	0.1094	0.0190	0.1284	0.6242	0.0834	0.7076
2013	26.16	8.97	35.12	25.47	8.86	34.33	0.0078	0.0016	0.0094	0.1113	0.0194	0.1307	0.5698	0.0851	0.6549
2014	25.75	9.07	34.83	25.18	8.98	34.16	0.0079	0.0017	0.0096	0.1132	0.0198	0.1330	0.4473	0.0756	0.5229
2015	25.28	9.16	34.45	24.85	9.06	33.92	0.0081	0.0017	0.0097	0.1153	0.0201	0.1354	0.3077	0.0770	0.3847
2016	24.91	9.26	34.18	24.50	9.16	33.66	0.0082	0.0017	0.0099	0.1172	0.0205	0.1377	0.2905	0.0784	0.3689
2017	24.43	9.35	33.78	24.04	9.25	33.29	0.0083	0.0018	0.0101	0.1192	0.0209	0.1401	0.2590	0.0799	0.3389
2018	23.90	9.42	33.33	23.54	9.32	32.86	0.0085	0.0018	0.0103	0.1213	0.0213	0.1426	0.2302	0.0814	0.3116
2019	23.28	9.50	32.78	22.95	9.39	32.34	0.0086	0.0018	0.0104	0.1233	0.0217	0.1449	0.2017	0.0830	0.2847
2020	22.61	9.60	32.22	22.31	9.49	31.80	0.0088	0.0019	0.0106	0.1252	0.0221	0.1473	0.1723	0.0845	0.2569
2021	21.92	9.70	31.61	21.64	9.59	31.22	0.0089	0.0019	0.0108	0.1273	0.0224	0.1497	0.1403	0.0859	0.2261
2022	21.19	9.80	30.99	20.95	9.69	30.63	0.0090	0.0019	0.0110	0.1294	0.0228	0.1522	0.1030	0.0874	0.1904
2023	20.49	9.92	30.40	20.27	9.80	30.08	0.0092	0.0019	0.0111	0.1315	0.0232	0.1547	0.0704	0.0889	0.1593
2024	19.80	10.04	29.84	19.61	9.93	29.54	0.0093	0.0020	0.0113	0.1336	0.0236	0.1572	0.0409	0.0905	0.1313
2025	19.10	10.19	29.29	18.96	10.07	29.03	0.0095	0.0020	0.0115	0.1358	0.0240	0.1598	0.0000	0.0920	0.0920
2026	18.54	10.33	28.87	18.39	10.21	28.60	0.0096	0.0021	0.0117	0.1379	0.0244	0.1623	0.0000	0.0936	0.0936
2027	18.07	10.48	28.55	17.92	10.36	28.28	0.0098	0.0021	0.0119	0.1400	0.0249	0.1648	0.0000	0.0952	0.0952
2028	17.69	10.64	28.33	17.54	10.51	28.05	0.0099	0.0021	0.0121	0.1420	0.0253	0.1673	0.0000	0.0967	0.0967
2029	17.40	10.80	28.20	17.25	10.67	27.92	0.0101	0.0022	0.0122	0.1441	0.0257	0.1698	0.0000	0.0983	0.0983
2030	17.19	10.96	28.15	17.03	10.83	27.86	0.0102	0.0022	0.0124	0.1461	0.0261	0.1722	0.0000	0.0999	0.0999
2031	17.06	11.12	28.18	16.90	10.99	27.89	0.0104	0.0022	0.0126	0.1482	0.0265	0.1747	0.0000	0.1015	0.1015
2032	16.99	11.28	28.27	16.83	11.15	27.98	0.0105	0.0023	0.0128	0.1502	0.0269	0.1771	0.0000	0.1031	0.1031
2033	16.97	11.45	28.42	16.80	11.31	28.12	0.0106	0.0023	0.0129	0.1522	0.0274	0.1795	0.0000	0.1047	0.1047
2034	16.99	11.62	28.61	16.83	11.48	28.31	0.0108	0.0023	0.0131	0.1542	0.0278	0.1820	0.0000	0.1064	0.1064
2035	17.03	11.79	28.82	16.86	11.65	28.51	0.0109	0.0024	0.0133	0.1562	0.0282	0.1844	0.0000	0.1080	0.1080
2036	17.11	11.96	29.07	16.94	11.82	28.76	0.0111	0.0024	0.0135	0.1582	0.0286	0.1868	0.0000	0.1096	0.1096
2037	17.23	12.13	29.36	17.06	11.99	29.05	0.0112	0.0024	0.0136	0.1602	0.0291	0.1892	0.0000	0.1113	0.1113
2038	17.37	12.31	29.67	17.19	12.16	29.35	0.0113	0.0025	0.0138	0.1622	0.0295	0.1917	0.0000	0.1129	0.1129
2039	17.52	12.49	30.00	17.34	12.34	29.68	0.0115	0.0025	0.0140	0.1642	0.0299	0.1941	0.0000	0.1145	0.1145
2040	17.68	12.66	30.34	17.50	12.52	30.02	0.0116	0.0025	0.0142	0.1662	0.0304	0.1965	0.0000	0.1162	0.1162
2041	17.85	12.84	30.69	17.67	12.69	30.36	0.0118	0.0026	0.0143	0.1681	0.0308	0.1989	0.0000	0.1179	0.1179
2042	18.02	13.02	31.05	17.84	12.87	30.71	0.0119	0.0026	0.0145	0.1701	0.0312	0.2014	0.0000	0.1195	0.1195
2043	18.21	13.20	31.41	18.03	13.05	31.07	0.0120	0.0027	0.0147	0.1721	0.0317	0.2038	0.0000	0.1212	0.1212
2044	18.40	13.39	31.79	18.21	13.23	31.44	0.0122	0.0027	0.0149	0.1741	0.0321	0.2062	0.0000	0.1229	0.1229
2045	18.60	13.57	32.17	18.41	13.41	31.82	0.0123	0.0027	0.0150	0.1761	0.0325	0.2086	0.0000	0.1246	0.1246
2046	18.79	13.75	32.55	18.60	13.59	32.20	0.0125	0.0028	0.0152	0.1781	0.0330	0.2110	0.0000	0.1263	0.1263
2047	18.99	13.94	32.93	18.80	13.77	32.58	0.0126	0.0028	0.0154	0.1800	0.0334	0.2135	0.0000	0.1279	0.1279
2048	19.20	14.12	33.32	19.00	13.96	32.96	0.0127	0.0028	0.0156	0.1820	0.0339	0.2159	0.0000	0.1296	0.1296
2049	19.40	14.31	33.71	19.20	14.14	33.34	0.0129	0.0029	0.0157	0.1840	0.0343	0.2183	0.0000	0.1313	0.1313
2050	19.61	14.49	34.10	19.41	14.32	33.73	0.0130	0.0029	0.0159	0.1860	0.0347	0.2207	0.0000	0.1330	0.1330

GHG = CO_2 + CH_4 + N_2O + Refrig, where "CO_2" includes both fuel economy and air conditioning efficiency improvements (if any), and "Refrig" indicates reductions in air conditioning refrigerant emissions.

- Table 7 adds the impacts of the 2012-2016 passenger car and light truck GHG/CAFE standards, so that all light duty vehicle program standards through model year 2016 are incorporated.
- Table 8 adds the impacts of the anticipated 2017-2025 passenger car and light truck GHG/CAFE standards, so that all light duty vehicle program standards through model year 2025 are incorporated.
- Table 9 adds the impacts of the anticipated 2014-2018 medium and heavy duty vehicle GHG/CAFE standards, so that all light duty vehicle program standards through model year 2025 and all medium and heavy duty vehicle program standards through model year 2018 are incorporated.

MDE specifically requested an analysis of GHG emission reductions that would be achieved relative to a 25 percent emission reduction target between 2006 and 2020. As indicated in Table 5, 2006 baseline emissions (from motor vehicles) are estimated to be 33.40 million tons CO_2-equivalent. A 25 percent reduction target would establish a goal of 25.05 million tons CO_2-equivalent by 2020. However, it is critical to recognize that *baseline* emissions will increase between 2006 and 2020 due to expected VMT growth, so that the expected baseline emissions level in 2020 is 41.51 million tons CO_2-equivalent, necessitating an approximate 40 percent reduction in GHG emissions to actually attain the desired (25 percent reduction) target emissions level. A total reduction of 8.35 million tons CO_2-equivalent (33.40-25.05) would be required between 2006 and 2020 in the absence of VMT growth, but due to anticipated growth an *additional* 8.11 million tons CO_2-equivalent (41.51-33.40) must be offset before any net emission reductions can accrue. In effect, VMT growth between 2006 and 2020 nearly doubles the required emission reduction load.

Table 10, along with Figures 4 and 5, summarize the actual GHG emission reductions expected due to GHG/CAFE standard programs implemented between 2006 and 2020. The GHG/CAFE standard programs through model year 2011 generate reductions of 3.09 million tons CO_2-equivalent. The model year 2012-2016 light duty vehicle program generates 4.26 million tons CO_2-equivalent, while the 2017-2025 light duty program generates 1.32 million tons CO_2-equivalent (through 2020). The model year 2014-2018 medium and heavy duty program generates 0.63 million tons CO_2-equivalent, for a total estimated GHG emission reduction of 9.30 million tons CO_2-equivalent by 2020. This more than fully offsets the 8.11 million tons CO_2-equivalent increase due to growth, but falls considerably short (by 7.16 million tons CO_2-equivalent) of the 16.46 million tons CO_2-equivalent reduction required to achieve the "25 percent by 2020" reduction target.

As measured from 2006, the implemented programs achieve, in total, a 3.6 percent reduction (against a 25 percent reduction target). However, this should not be misinterpreted as trivial since these programs achieve a 22.4 percent reduction relative to a 2020 baseline, or about 57 percent of that required to achieve the "25 percent by 2020" reduction target. Moreover, all of the evaluated programs are "handicapped" by the fact that they are dependent on the complete turnover of the subject vehicle fleet, which takes time. Only program implemented *today* will achieve significant turnover by 2020. An illustration of the turnover effect can be derived from an examination of estimated 2050 emissions, which are 61.80 million tons CO_2-equivalent under the baseline scenario and 34.10 million tons CO_2-equivalent under the "all GHG/CAFE

Table 10. Summary of 2020 Emission Impacts

Scenario	Total GHG	Incremental Change in Total GHG	Change from 2020 Base	Change from 2006 Base	Change from 2020 Base	Change from 2006 Base
2006 Baseline	33.40	0.00	n/a	0.00	n/a	0.0%
2020 Baseline	41.51	8.11	0.00	8.11	0.0%	24.3%
MY11LD Stds	38.42	-3.09	-3.09	5.01	-7.5%	15.0%
MY16LD Stds	34.16	-4.26	-7.35	0.76	-17.7%	2.3%
MY25LD Stds	32.84	-1.32	-8.67	-0.56	-20.9%	-1.7%
MY18HD Stds	32.22	-0.63	-9.30	-1.19	-22.4%	-3.6%
2020 Target	25.05	-7.16	-16.46	-8.35	-39.6%	-25.0%

MY = Model Year, LD = Light Duty Vehicle, HD = Medium and Heavy Duty Vehicle, Stds = GHG/CAFE Standards

All scenarios are implemented "on top" of the previous scenario, so that emissions impacts are incremental. All emission estimates are for calendar year 2020 except for the 2006 baseline scenario, which describes emissions in calendar year 2006.

All emissions are expressed in million tons CO_2-equivalent.

programs" scenario (Table 9 versus Table 5). Thus, the "full turnover" (or more accurately near-full turnover) impacts result in an approximate 45 percent GHG reduction, or almost exactly twice that achieved by 2020. Timing is critically important for production-based motor vehicle controls.

In reviewing these data, the reader should recognize the various issues described earlier in this report. Most of the (and all of the most recent) GHG/CAFE standards evaluated are dependent on the vehicle size (i.e., footprint) characteristics of the affected fleet. If the size characteristics change, the effective GHG/CAFE standard, and thus the associated level of GHG control, will also change. Similarly, all of the GHG/CAFE standards vary by vehicle class, so that unanticipated changes in the vehicle class mix will affect estimated GHG impacts. The GHG/CAFE programs grant credits for manufacturer compliance strategies such as the introduction of non-petroleum based vehicle fueling. Generally these credits far exceed the actual GHG reduction potential of the technology, so that differences in the use of such credits relative to the use assumed for this analysis can impact estimated GHG reduction levels. Finally, both the model year 2017-2025 light duty program standards and model year 2014-2018 medium and heavy duty program standards have yet to be finalized. Should such standards change from the values assumed in this analysis, associated GHG reduction estimates will correspondingly change. While the estimates reported herein are "best estimates" given currently available information, they are nevertheless produced with imperfect foresight and should be revisited over time.

Figure 4. 2020 GHG Emissions (except the 2006 Base Scenario is for 2006)

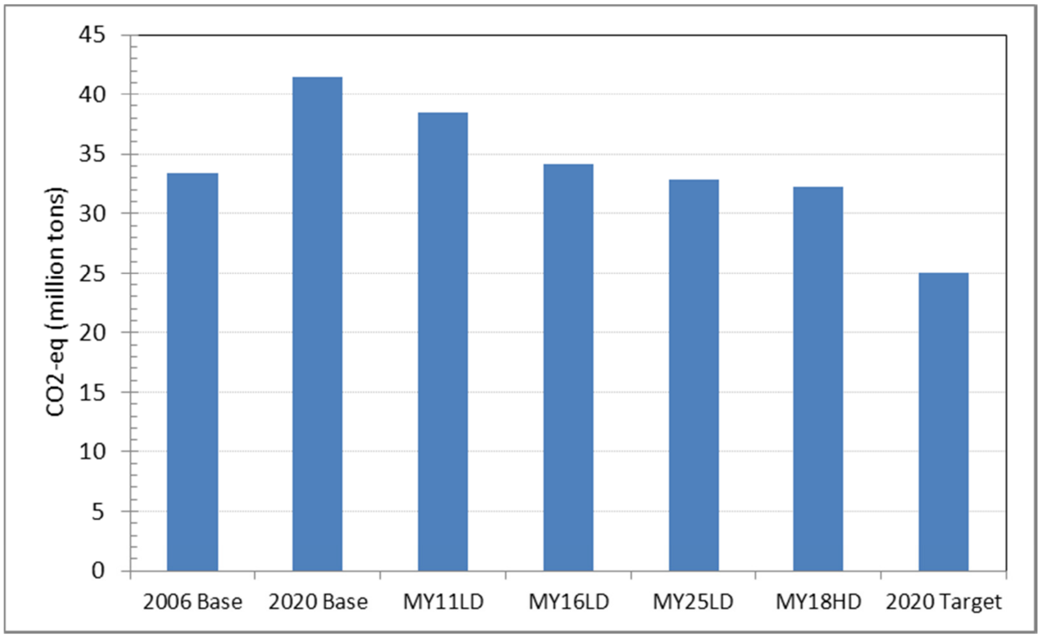

Figure 5. Change in 2020 Emissions from Baseline