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MEMORANDUM

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TO: Docket ID No. EPA-HQ-OAR-2008-0318

SUBJECT: Documentation of Updated Light-duty Vehicle GHG Scenarios

This memorandum presents our updated analysis of the "4% per year scenario" for control of carbon dioxide and other green house gasses (GHG) in support of the Agency's Advance Notice of Proposed Rulemaking (ANPR). The analysis presented here updates the analysis documented in the Light-duty Vehicle Technical Support Document to the ANPR, and provides the supporting documentation for the analysis presented in Section VI.B.1.b of the GHG ANPR.

Since conducting the original analysis, we have made several updates that address several limitations from our Light-duty Vehicle Technical Support Document (LDV TSD) analysis. Section I of this memorandum presents the results from our modified use of the Volpe Model in which we apply these updates and also use the model in new ways. This section also presents our updated estimate of the costs per vehicle associated with the 4% per year scenario along with other Volpe Model-related inputs and outputs. Section II presents our updated analysis of GHG inventory impacts and fuel consumption impacts of the 4% per year scenario. Section III presents our updated analysis of the costs, benefits, and net benefits of the 4% per year scenario. As noted throughout this updated analysis, much of the supporting technical work is presented in the LDV TSD to the ANPR.

In Table 1 we present the combined car and truck standards we analyzed by updating our work in 2007. As described in this memorandum, we analyzed separate car and truck standards, but present the weighted results in Table 1.

Table 1
Analyzed Vehicle CO_2 (gram/mile units) and MPG Standards (mpg units in square brackets), including Air Conditioning CO_2 limits

Year	Updated Analysis 4 % Per Year
2011	335 [26.5]
2012	321 [27.7]
2013	307 [28.9]
2014	293 [30.3]
2015	283 [31.4]
2016	272 [32.7]
2017	261 [34.0]
2018	251 [35.4]
2019	241 [36.9]
2020	232 [38.3]

In Table 2 we summarize the most important societal and consumer impacts of the standards we have analyzed which are documented in this memorandum.

Table 2
Summary of Societal and Consumer Impacts from Potential Light-Duty Vehicle GHG Standards (2006 $s, AEO2007 Oil Price Estimates)

Societal Impacts		
GHG Reductions (MMTCO2 equivalent in 2040)		635
Fuel Savings (million bpd in 2040)		4.2
Net Societal Benefits in 2040 (Billion $'s)*		$130 + B
Net Present Value of Net Benefits through 2040 (Billion $'s)*	3% DR	$830 + B
	7% DR	$340 + B
Consumer Impacts		
Per-Vehicle Costs	2015	$565
	2018	$1,380
	2020	$1,924
Payback Period**	3% DR	6.0 yrs.
	7% DR	8.7 yrs.
Lifetime Monetary Impact**	3% DR	$1,630
	7% DR	$437

* The identified "B" = unquantified benefits, for example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics), and we have not quantified the benefits of reductions in GHG emissions. Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, for the updated analysis, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.
** The payback period and lifetime monetary impact values are for the average 202 vehicle.

I. Compliance Costs of the 4 Percent per Year Standards

In this updated analysis, EPA used the DOT Volpe Model to estimate the cost of feasible CO2 emission controls from light vehicles which reflect a 4% annual improvement in fuel economy. In general, the Volpe Model runs were very similar to those performed by EPA during its work during 2007 under Executive Order 13432. With only a few exceptions noted below, the inputs to the model, such as vehicle descriptions, technology effectiveness and cost, fuel prices, upstream emissions, vehicle emissions of criteria pollutants, social benefits, etc. are also the same as those used in EPA's 2007 work. EPA's 2007 analysis is documented in the Light-duty Vehicle Technical Support Document (LDV TSD) of EPA's GHG ANPR.

EPA did make several updates to the model inputs and the way in which we utilized the model. First, we applied technology on a five year basis to reflect manufacturers' typical vehicle design cycles, instead of applying technology one year at a time. At the same time, we changed the reference case for trucks to reflect the 2010 CAFE standard for trucks (established by NHTSA in 2006), instead of the 2011 standard. Second, we extended the CO2 emission standards out to 2020, instead of to 2018 for cars and 2017 for trucks. We also developed logistic curve-based standards which produced fleet wide CO2 emission reductions of 4% per year. Third, we used the primary fuel price scenario from the LDV TSD analyses (AEO 2007). Fourth, we estimated the cost savings potentially available to manufacturers from credit trading between a manufacturer's car and truck fleet. These revisions are described in more detail below.

In addition, we ensured that the costs and effectiveness estimates for individual CO2 emission control technologies were consistent with the March 2008 technical report to the National Academy of Sciences (NAS)

A. CO2 Reduction Effectiveness of Dieselization

The effectiveness estimates included in the Volpe Model runs used to support the LDV TSD analyses reflected the effect of technology on fuel consumption. When the fuel used by the engine doesn't change, these effectiveness estimates also reflect the effect of the technology on CO2 emissions. However, when the fuel changes, this is not necessarily the case. In particular, diesel fuel contains about 15% more carbon per gallon, so a conversion to diesel technology reduces fuel consumption far more than it reduces CO2 emissions. Since we are examining CO2 emission controls in this ANPRM, we converted the effectiveness estimates for diesel technology from a fuel consumption basis to a CO2 emissions basis.

The Volpe Model addresses two types of diesel engines which differ according to the type of aftertreatment used: lean NOx trap and SCR. The model also considers dieselization at three points in the engine technology path. The first opportunity to dieselize follows stoichiometric gasoline direct injection technology, with an incremental fuel consumption reduction of 18%. The second opportunity to dieselize follows turbocharging and downsizing, with an incremental fuel consumption reduction of 15.5%. The third opportunity to dieselize follows HCCI technology, with an incremental fuel consumption reduction of 10.5%. These fuel consumption reductions apply to all vehicle classes except subcompact and compact cars, where the effectiveness values are 4% lower.

In order to convert these reductions in fuel consumption to reductions in CO2 emissions, we first multiplied the remaining fuel consumption in percentage terms after dieselization (100% minus the fuel consumption reduction of dieselization) by 1.15. We then subtracted this percentage from 100% in order to determine the effectiveness of dieselization in reducing CO2 emissions. The result was that dieselization following stoichiometric gasoline direct injection reduces CO2 emissions by 5.7% (1.1% for subcompacts and compacts). Dieselization following turbocharging and downsizing reduces CO2 emissions by 2.8% (an increase in CO2 emissions for subcompacts and compacts). There is an increase in CO2 emissions for dieselization following HCCI technology. Where the effectiveness decreased below zero, we set the effectiveness to zero. In general, the effectiveness of dieselization in reducing CO2 emissions becomes too small given its cost for the model to add this technology in order to meet any of the standards evaluated in this ANPRM.

B. Summary of Technology Costs and Effectiveness

Table I-1 presents the CO2 reductions and costs of each technology for midsize sedans and midsize SUVs.

Table I-1. Cost and Effectiveness of Technology Applied to Midsize SUVs and Compact Cars

	Incremental CO2 Reduction		Incremental Cost	
Technology	Midsize SUV	Compact Car	Midsize SUV	Compact Car
Low Friction Lubricants	0.5%	0.5%	$ 3	$ 3
Engine Friction Reduction	2.0%	2.0%	$42	$84
Variable Valve Timing (ICP)	2.0%	2.0%	$59	$119
Variable Valve Timing (CCP)	1.0%	2.0%	$-	$-
Variable Valve Timing (DCP)	1.0%	2.0%	$30	$90
Cylinder Deactivation	---	4.5%	---	$229
Variable Valve Lift & Timing (CVVL)	4.0%	2.5%	$254	$280
Variable Valve Lift & Timing (DVVL)	3.0%	1.5%	$169	$93
Cylinder Deactivation on OHV	---	6.0%	---	$229
Variable Valve Timing (CCP) on OHV	3.0%	2.5%	$59	$59
Multivalve Overhead Cam with CVVL	2.5%	2.5%	$599	$1,380
Variable Valve Lift & Timing (DVVL) on OHV	0.0%	0.0%	$3,389	$3,389
Stoichiometric GDI	1.5%	1.5%	$271	$377
Diesel following GDI-S (SIDI)	1.1%	5.7%	$2,276	$3,071
Turbocharging and Downsizing	2.5%	2.5%	$540	$(98)
HCCI following Turbo D/S	5.1%	5.1%	$(308)	$771
HCCI	7.5%	7.5%	$233	$606
Diesel following HCCI	0.0%	0.0%	$2,044	$2,465
5 Speed Automatic Transmission	2.5%	2.5%	$122	$122
Aggressive Shift Logic	1.5%	1.5%	$38	$38

Early Torque Converter Lockup	0.5%	0.5%	$30	$30
6 Speed Automatic Transmission	1.5%	1.5%	$-	$-
Automatic Manual Transmission	6.0%	6.0%	$141	$141
Continuously Variable Transmission	3.5%	---	$100	---
6 Speed Manual	0.5%	0.5%	$107	$107
Improved Accessories	1.5%	1.5%	$104	$104
Electronic Power Steering	1.5%	2.0%	$158	$158
42-Volt Electrical System	1.5%	1.5%	$163	$163
Low Rolling Resistance Tires	1.5%	---	$6	---
Low Drag Brakes	---	1.0%	---	$87
Secondary Axle Disconnect - Unibody	1.0%	0.0%	$676	$676
Secondary Axle Disconnect - Ladder Frame	---	1.5%	---	$114
Aero Drag Reduction	3.0%	2.0%	$38	$38
Material Substitution (1%)	---	0.7%	---	$2 *
Material Substitution (2%)	---	0.7%	---	$2 *
Material Substitution (5%)	---	1.9%	---	$3 *
ISG with Idle-Off	7.5%	7.5%	$497	$534
IMA/ISAD/BSG Hybrid	8.5%	---	$1,489	---
2-Mode Hybrid	---	3.5%	---	$4,979
Power Split Hybrid	7.1%	---	$1,276	---
Plug-in Hybrid	30.0%	30.0%	$746	$4,194
Low Friction Lubricants	0.5%	0.5%	$3	$3

* Cost per pound of weight reduction

All of the above technologies were assumed to be available throughout the entire analysis period, with two exceptions. One exception was HCCI, which was assumed to be available starting in 2016. Thus, HCCI was not available at all for the analysis of compliance in 2015. However, it was available for up to 65% of sales in 2020. The other exception was plug-in hybrids. Plug-in hybrids were assumed to be available some time during the 2011-2015 time period. However, we limited their use to roughly a total of 2% of vehicles in the 2015 model year. For 2020, we limited their use to roughly 10%. We estimate that these maximum technology application percentages are reasonable in the 2011-2015 and 2016-2020 time frames.

With respect to limits on the application of other technologies, we generally multiplied the annual limits used in the ANPR LDV TSD analyses by a factor of five to represent the allowed total application over a five year period. For example, in the LDV TSD analyses, ISG was allowed to be applied at a rate of 17% per year. This rate was based on an assumption that ISG could be applied across a manufacturer's entire product line over a six year period. For this analysis, this was increased to 85% over a five year period. Table I-2 lists the application limits for those technologies which we project to be less than 100% applicable in either 2015 or 2020.

Table I-2. Five-Year Technology Application Limits

Technologies	2015 Limit	2020 Limit
HCCI	0%	65%
Plug in hybrid	2%	10%
2-mode, IMA, and power-split hybrid	55%	100%

Dieselization	65%	100%
Integrated Starter Generator (ISG)	85%	100%
6-speed, automated manual and continuously variable transmissions Secondary axle disconnect, aerodynamic drag reduction Material substitution	85%	100%

Finally, we assumed that lean-burn gasoline direct injection technology would not be available prior to 2020. This was due to the assumed absence of ultra-low sulfur gasoline which appears necessary to enable vehicles with this technology to comply with Tier 2 NOx emission standards. It is of course possible that ultra-low sulfur gasoline could be available prior to 2020 due to either market or regulatory forces, but this was considered beyond the scope of this analysis.

C. Multi-Year Planning

As discussed in the GHG ANPR, EPA believes that the Clean Air Act provides EPA with a number of flexibilities which were not captured in our 2007 modeling results presented in the LDV TSD.. One of these aspects is the way the Volpe Model adds technology to meet a standard in one model year with no reference to future model years (i.e., a strict one year planning horizon versus a multi-year planning horizon). This issue can become severe when either a relatively small or large percentage of a manufacturer's vehicles are being redesigned in a given model year. This is due to the fact that the Model restricts the technologies which produce the largest reductions in fuel consumption or CO2 emissions to the year in which a vehicle is being redesigned.

For example, if only 10% of a manufacturer's vehicle sales are being redesigned in a given model year and the stringency of the standard increases by 3-4%, ignoring technologies which can be applied at any time, the fuel economy or CO2 emissions of the 10% of sales being redesigned must improve by 30-40%. This requires the application of major fuel saving or CO2 reducing technology. In contrast, if 50% of a manufacturer's vehicle sales are being redesigned in that model year, the fuel economy or CO2 emissions of the 50% of sales being redesigned only needs to improve by 6-8%. The Volpe Model will apply only modest levels of technology in order to meet the standard. Situations even more extreme than these occur in the product redesign schedules used in the LDV TSD analyses. Table I-3 shows the percentage of cars and trucks of the seven highest volume manufacturers projected to be redesigned in each year.

Table I-3. Percentage of Sales Being Redesigned by Model Year

	2011	2012	2013	2014	2015
	Cars				
Company A	0%	51%	13%	31%	5%
Company B	10%	18%	4%	9%	62%
Company C	11%	34%	28%	19%	11%
Company D	12%	74%	10%	3%	0%
Company E	20%	36%	57%	4%	0%
Company F	22%	20%	0%	20%	21%

Company G	37%	8%	0%	54%	0%
Industry Total	15%	27%	10%	23%	20%
	Trucks				
Company A	9%	18%	46%	6%	15%
Company B	19%	36%	22%	10%	2%
Company C	26%	25%	22%	0%	13%
Company D	29%	71%	0%	0%	0%
Company E	19%	0%	42%	24%	12%
Company F	14%	29%	39%	7%	12%
Company G	0%	26%	35%	20%	20%
Industry Total	15%	24%	34%	12%	11%
	Cars and Trucks Combined				
Company A	3%	38%	27%	20%	9%
Company B	15%	28%	14%	9%	28%
Company C	17%	30%	26%	11%	12%
Company D	19%	73%	6%	2%	0%
Company E	19%	8%	45%	20%	9%
Company F	18%	25%	21%	13%	16%
Company G	23%	15%	14%	40%	8%
Industry Total	15%	25%	22%	17%	16%

The method of applying technology used by the Volpe Model coupled with these uneven redesign schedules can cause the Model to apply extensive use of hybrid and diesel technology to a manufacturer's cars or trucks in one year and then only variable valve timing and 6 speed transmissions in the next year. In reality, it is very unlikely any manufacturer would do this. Instead a manufacturer would attempt to comply with the standards with a more consistent set of technologies. The simplest solution would be for the manufacturer to generate credits in years when larger percentages of its vehicles are being redesigned for use in years when few vehicles are being redesigned. NHTSA is prohibited by the Energy Independence and Security Act and EPCA from considering the benefits of credit banking and trading in developing its CAFE standards. However, EPA is not prohibited from utilizing credit banking and trading in developing standards under the Clean Air Act, and we have done so in many mobile source standard-setting rulemakings.

Besides credit trading, there are other options available to a manufacturer to even out technology application. First, a manufacturer could shift the redesign of some its vehicles a year or two to even out its redesign schedule. Redesign schedules are fluid due to fluctuating market conditions, product popularity and the regulatory landscape. A manufacturer could consider the impact of its redesign schedule on compliance and reduce the year to year variation when feasible. Second, in years with a relatively large percentage of redesigned vehicles, a manufacturer could decide to delay use of technologies which can be applied at any time in the redesign cycle and apply technologies which are generally restricted to vehicle redesign. This "redesign only" technology would then provide continued benefits in subsequent years when few vehicles are being redesigned. In the extreme, a manufacturer could overcomply with the standard in years when a large percentage of vehicles are redesigned so that the benefits of this technology would be available in subsequent years. Third, a manufacturer could implement some of the "redesign only" technologies outside of a redesign year. While such technologies generally occur during redesign, full line manufacturers often use the same engine in a number of vehicle lines. When this engine is upgraded, the modified engine replaces the original engine in all applications, whether or not every vehicle is being redesigned at that time. This also occurs when a "new" technology is introduced into a manufacturer's vehicle line-up. Examples would include diesels, hybrids, turbocharged engines, automated manual transmissions, integrated starter generator systems, etc. Absent regulatory necessity, manufacturers often offer such technologies as an option on specific vehicle models.

By design the Volpe Model was not designed to consider these options as they are not relevant to NHTSA when establishing a CAFE standard. However, we were able to develop a relatively simple approach to running the model which essentially enables multi-year planning, which EPA is allowed consider in a standard-setting context. As discussed in the LDV TSD, the redesign cycle for both cars and trucks is on the order of five years. Thus, roughly every five years, each manufacturer will redesign its entire product line once. Therefore, over a five year period, given sufficient leadtime prior to the first model year being evaluated, a manufacturer is able to add essentially any technology to any individual vehicle (within other limits which may not be related to the vehicle redesign cycle). We then conceptualized a single run of the Volpe Model as evaluating the technology and cost to meet a given CO2 emission standard which is five years in the future. Because we did not modify the program code of the Volpe Model, when the model evaluated the model year 2011, this actually represented the 2015 model year. We changed vehicle sales in 2011 in the Volpe Model to represent those in 2015. We also indicated that every vehicle was being redesigned in 2011. Because the Volpe Model is evaluating the cost and effectiveness of all technologies being applied to all vehicles in the same "year", the application of technology across a manufacturer's product line is much more even than when the model is run in the traditional way. We believe that the model's predictions when used in this manner are much closer to the types of decisions that manufacturers would make in order to comply with potential CO2 emission standards than the highly variable and oscillating predictions of the model when run in the traditional fashion.

We ran the Volpe Model for 2015 and again for 2020. The simulation of the 2020 model year was performed separately from that for 2015. In other words, the starting point for 2020 was a car or truck fleet which met the existing 2010 CAFE standards. We desired to use the predicted 2015 car and truck fleets as the basis for the 2020 analysis. However, this could not be done with the Volpe Model. In particular, we desired to have caps on the penetration of a number of technologies in 2015, but not in 2020 (e.g., AMT, diesel, various hybrid technologies, etc.). The Volpe Model allows for a cap on the increased use of each technology, but it must be for each new model year. The potential problem in starting the 2020 analysis essentially from 2010 and not from 2015 is that the technology applied in 2020 might be inconsistent with the technology applied in 2015. However, very few changes in technology availability are projected to occur between 2015 and 2020. As noted earlier, only one new technology was enabled in the 2016-2020 period: HCCI. Otherwise, the only difference was the increase in the allowed penetration of the technologies listed in Table I-2, such as the three types of full hybrids. Thus, the largest potential discontinuity was a shift towards a new engine technology in 2015 and then a subsequent shift towards HCCI in 2020. Due to the higher carbon content of diesel fuel, the model does not dieselize any vehicles in either the 2015 or 2020 timeframes. In 2015, numerous engines are converted to direct injection gasoline technology and downsized. Many of these engines are then converted to HCCI technology in 2020. Thus, the shift towards gasoline direct injection is the only major technology that appears and then to some degree disappears in the 10-year timeframe of this analysis. This same phenomena would occur if the Volpe Model were run in its traditional year-by-year fashion and is not unique to either using the model to simulate an entire product redesign cycle, or to basing 2020 designs on technology applied in 2015.

While we believe that this approach produces reasonable projections of manufacturers' capabilities over a five year period, it does not predict CO2 emission standards for the first four model years of the five year period. We estimate these standards using simple linear interpolation. For the industry as a whole, this approach is satisfactory and likely conservative. As shown on the very last line of Table I-3 above, there is some variability in the percentage of vehicle sales which are being redesigned in a given model year. However, over any five year period, these percentages should not be particularly front or back loaded. In addition, there are a number of technologies which can be applied at any time or at vehicle refresh. These technologies can be applied earlier in the five year period if a particular manufacturer's redesign schedule is oriented towards the latter part of the five year period. The potential of these technologies to significantly reduce CO2 emissions is evidenced by the fact that the "model optimized" fuel economy standards presented in the LDV TSD require the greatest percentage improvement in fuel economy in the first few years of the proposed program. It is possible that a specific manufacturer's redesign schedule is oriented towards the end of the five year period that these "anytime" and "refresh" technologies would not be sufficient. In this case, the manufacturer may have to move up the redesign of some of its vehicles or at least implement some technologies which are normally associated with vehicle redesign. However, such manufacturers would also likely have difficulty with standards determined on a year by year basis due to their unusually low redesign percentage compared to the rest of the industry in that year.

D. Car and Truck CO2 Emission Standards Modeled

The standards modeled here represent a 4% decrease in fleetwide CO2 emissions from the CAFE standards applicable to the 2010 model year. These 2010 standards are 27.5 mpg for cars and 23.5 mpg for trucks. The equivalent levels in terms of CO2 emissions are 323 and 378 g/mi, respectively. Table I-4 shows the fuel economy and CO2 emission levels which reflect a 4% per year increase in fuel economy from 2010 through 2020. Also shown are the effective levels for cars and trucks combined. The fraction of sales represented by cars decreases from 0.509 in 2010 to 0.475 in 2015 and remains constant thereafter.

Table I-4. Car, Truck and Combined CO2 and MPG Standards: 4% per Year Scenario

Model Year	Car		Truck		Combined	
	MPG	CO2 g/mi	MPG	CO2 g/mi	MPG	CO2 g/mi
2010	27.5	323	23.5	378	25.4	350
2011	28.6	311	24.4	364	26.4	337

2012	29.7	299	25.4	350	27.4	324
2013	30.9	287	26.4	336	28.5	312
2014	32.2	276	27.5	323	29.6	301
2015	33.5	266	28.6	311	30.7	289
2016	34.8	255	29.7	299	31.9	278
2017	36.2	246	30.9	287	33.2	268
2018	37.6	236	32.2	276	34.5	257
2019	39.1	227	33.4	266	35.9	247
2020	40.7	218	34.8	255	37.4	238

These standards differ slightly from those described and analyzed in the ANPR LDV TSD. The difference arises because the base year for the truck standards is assumed to be 2010 here, while it was assumed to be 2011 in the LDV TSD analyses, reflecting NHTSA's 2006 reformed CAFE rules establishing truck standards for MY 2011. The LDV TSD analyses assumed that this previously established 2011 truck standard would not be revised. However, NHTSA reproposed a 2011 CAFE standard for trucks in their May 2, 2008 NPRM. Thus, we decided to be consistent and shift the base of the 4% per year scenario for trucks from 2011 to 2010.

In order to model compliance in 2015 and 2020 using the Volpe Model, we used a constrained logistic footprint versus CO2 curve, as described in the ANPR LDV TSD. This meant that the coefficients of these constrained logistic curves had to be determined. For both cars and trucks, we took the shape of the logistic curve (i.e., coefficients C and D) directly from the ANPR LDV TSD For cars, we chose to use the coefficients from the flattened curve, as opposed to the steep curve, for reasons described in the LDV TSD.

The values for coefficients A and B were set so that the effective fleetwide fuel economy standards for 2015 and 2020 met the values shown in Table I-4. We started with the values for A and B from the LDV TSD analyses and adjusted these values upward or downward by the same amount until the application of the curve across the entire car or truck fleet yielded the fuel economy standards shown in Table I-8. The resultant coefficients which accomplish this goal are shown in Table I-5.

Table I-5. Coefficients of the Constrained Logistic Curves Under the 4% per Year Scenario

Coefficient	Cars		Trucks	
	2015	2020	2015	2020
A	40.42	48.0	35.15	40.49
B	28.32	35.7	25.15	30.09
C	45.98	45.2	50.64	53.53
D	4.48	4.40	4.80	4.94

E. Fuel Prices and Other Economic Inputs to the Volpe Model

We performed our Volpe Model runs using fuel prices from the Energy Information Administration's (EIA) 2007 Annual Energy Outlook. These are the same fuel prices used in the primary analyses presented in the ANPR LDV TSD. Between 2011 and 2045, the prices of gasoline and diesel fuel are estimated by EIA to average $2.15 and $2.25 per gallon, respectively.

NHTSA, in its analyses performed for its May 2, 2008 NPRM, used more recent fuel price projections based on EIA's Early Release of its 2008 Annual Energy Outlook. We chose not to use these more recent projections here because the manufacturer product plans dated from last 2006 through the first half of 2007 and these plans were likely based on future fuel prices reflected in the 2007 Annual Energy Outlook. Thus, we tried to maintain consistency between future fuel prices and manufacturers' plans to improve fuel economy due to market forces. As indicated by the higher price projections in the Early Release 2008 Outlook and today's fuel prices at the pump, it is likely that future updates of the analyses presented here will involve higher fuel prices, higher baseline fuel economy levels due to market forces, and greater benefits due to fuel savings.

Regarding other inputs to the Volpe Model, we generally used those described in the LDV TSD. This included a zero value for the social cost of carbon. The social value of GHG emission reductions do not affect the technology application rates or vehicle costs estimated by the Volpe Model when it is run to simulate compliance with specified emission standards, as was the case here. The benefits of GHG emission reductions using the various values for the social cost of carbon were developed outside of the Volpe Model itself (as described further below).

F. Technology Application and Compliance Costs without Car-Truck Credit Trading

We ran the Volpe Model in standard compliance mode using the logistic curves developed in the previous section in order to estimate both technology application and compliance costs for the 4% per year standards. The results are shown in Table I-6.

Table I-6. Achieved CO2 and Fuel Economy Levels and Costs Under the 4% per Year Standards

	2015			2020		
	Cars	Trucks	All	Cars	Trucks	All
CO2 Emissions (g/mi)						
Standard	265	311	289	218	255	238
Achieved Level	263	311	288	220	256	239
Fuel Economy (mpg)						
Standard	33.55	28.60	30.76	40.75	34.80	37.40
Achieved Level	33.80	28.60	30.86	40.40	34.75	37.23
Technology Cost	$414	$696	$562	$1,474	$2,568	$2,048
CAFE Fines	$2	$0	$1	$16	$3	$9
Total Cost	$416	$697	$563	$1,490	$2,571	$2,057
Total cost adjusted for	$415	$680	$554	$1,477	$2,508	$2,018

turbocharging/downsizing						

The Volpe Model appears to set any negative technology cost listed in the technology input file to zero. This is not described in the model documentation, but was verified through a number of model runs which set the cost of turbocharging and downsizing to negative, zero and positive values. Based on our March 2008 technical report to the National Academy of Science, and the incremental nature of the technology cost input file for the Volpe Model, the cost of turbocharging and downsizing 6 cylinder engines is negative in the input files for these model runs. Thus, the output from the Volpe Model does not include these savings. We estimated these savings by applying a $210 savings to the vehicles which had 6 cylinder engines and were turbocharged and downsized (or went through this step to more extensive technology) in the various scenarios. The last line of Table I-6 includes the adjustment made to the model estimates to reflect these savings.

As can be seen, both cars and trucks essentially achieve the 4% per year standards in both 2015 and 2020. There is a slight over-compliance by cars in 2015 due to the fact that Honda and Toyota's product plans show greater fuel economy levels in 2015 than required by the standard. There is slight under-compliance in 2020 by cars due to the four manufacturers which we assumed could pay fines in lieu of compliance whenever the cost of technology exceeded that of the current CAFE fine ($55 per mpg). These four manufacturers are Ferrari, Lotus, Maserati and Porsche. Together, these manufacturers only represent 0.4% of total car sales and an even lower percentage of truck sales.

This should not be construed as an indication that EPA would allow non-compliance with potential future CO2 emission standards with the payment of such a fine. However, as discussed in the LDV TSD, it is an indication that we may consider an alternative CO2 emission standard for high performance vehicles and that essentially all of the vehicles produced by these four manufacturers would likely qualify for such a standard. Since we are not able to estimate the level of such a standard at this time, the simplest way to represent this in the modeling runs was to allow these manufacturers to pay a fine in lieu of compliance.

In 2015, trucks comply with the 2015 standard of 28.6 mpg. Mercedes is the only manufacturer who does not comply which was not allowed to pay fines in lieu of compliance. It should be noted that Mercedes did not submit a product plan to NHTSA in 2007, so the representation of their truck sales was derived from NHTSA's 2005 CAFE database.

Cars again fall short of the 2020 standard slightly, for the same reason as in 2015. Trucks basically comply with the 2020 standard due to the additional reductions afforded by HCCI availability and additional use of hybrid technology.

Table I-7 shows the use of technology estimated to enable compliance with the reference standards in 2010 and under the 4% per year standards in 2015 and 2020.

Table I-7. Total Use of Technology by Model Year

	2010	2015	2020

Technology	Car	Truck	Car	Truck	Car	Truck
Low Friction Lubricants	79%	54%	100%	99%	100%	100%
Engine Friction Reduction	12%	57%	51%	100%	85%	100%
For OHC Engines						
Variable Valve Timing (ICP)	68%	60%	76%	74%	43%	23%
Variable Valve Timing (CCP)	7%	4%	13%	34%	31%	13%
Variable Valve Timing (DCP)	32%	27%	33%	32%	18%	7%
Cylinder Deactivation	6%	20%	13%	39%	22%	56%
Variable Valve Lift & Timing (CVVL)	4%	2%	14%	4%	9%	0%
Variable Valve Lift & Timing (DVVL)	14%	14%	29%	34%	32%	12%
For OHV Engines						
Cylinder Deactivation on OHV	1%	10%	1%	17%	3%	17%
Variable Valve Timing (CCP)	4%	8%	4%	17%	5%	10%
Multivalve Overhead Cam with CVVL	7%	16%	7%	16%	2%	6%
Variable Valve Lift & Timing (DVVL)	0%	0%	0%	0%	0%	0%
For All Engines						
Stoichiometric GDI	19%	24%	28%	30%	5%	19%
Turbocharging and Downsizing	8%	11%	15%	30%	6%	23%
HCCI	0%	0%	0%	0%	36%	34%
Diesel	1%	3%	1%	4%	1%	3%
5 Speed Automatic Transmission	22%	32%	21%	23%	6%	0%
Aggressive Shift Logic	3%	11%	31%	38%	0%	0%
Early Torque Converter Lockup	3%	0%	4%	19%	0%	0%
6 Speed Automatic Transmission	29%	40%	28%	24%	1%	0%
Automatic Manual Transmission	15%	12%	15%	47%	47%	94%
Continuously Variable Transmission	10%	3%	12%	3%	23%	1%
6 Speed Manual	8%	2%	9%	2%	10%	3%
Improved Accessories	20%	22%	31%	35%	70%	100%
Electronic Power Steering	21%	6%	31%	32%	66%	100%
42-Volt Electrical System	0%	1%	10%	29%	61%	100%
Low Rolling Resistance Tires	8%	1%	50%	34%	78%	34%
Low Drag Brakes	21%	25%	21%	26%	21%	39%
Secondary Axle Disconnect - Unibody	0%	1%	1%	2%	3%	18%
Secondary Axle Disconnect - Ladder Frame	0%	0%	0%	13%	0%	15%
Aero Drag Reduction	14%	4%	48%	90%	70%	97%
Material Substitution (1%)	0%	0%	0%	13%	0%	24%
Material Substitution (2%)	0%	0%	0%	13%	0%	24%
Material Substitution (5%)	0%	0%	0%	1%	0%	24%

ISG with Idle-Off	3%	23%	46%	84%	67%	72%
IMA/ISAD/BSG Hybrid	1%	0%	3%	0%	5%	0%
2-Mode Hybrid	1%	2%	1%	3%	2%	22%
Power Split Hybrid	3%	1%	3%	1%	12%	1%
Plug-in Hybrid	0%	0%	2%	1%	12%	7%

G. Credit Trading Between Cars and Trucks

The Volpe Model by design does not consider credit trading between a given manufacturer's car and light truck fleets. Under the Clean Air Act, EPA could consider such trading in a standard-setting regulatory context. In order to simulate such trading, we used the Volpe Model to estimate the seven largest manufacturers' compliance costs for a wide range of separate CO2 emission standards for cars and trucks. We did this by running the Volpe Model in optimization mode and generating an OptInd report. The OptInd report summarizes the results of running the Volpe Model in way which maximizes estimated net benefits. In particular, the OptInd report presents compliance costs and benefits the seven largest manufacturers' vehicles as the industry-wide average fuel economy level is varied over a specified range. When running the Model in this way, we held the "C" and "D" coefficients of the constrained logistic curves constant, maintaining the shape of the curves described above.

As mentioned above, the OptInd report from the Volpe Model presents each manufacturer's compliance cost for a range of industry-wide average fuel economy levels. However, because each manufacturer's sales differ, each manufacturer has a distinct distribution of footprints and thus, has a different effective CAFE standard compared to the effective average standard for the entire fleet. For example, when the fleetwide fuel economy for cars is 31 mpg, the corporate average fuel economy level for a manufacturer of larger than average cars, such as General Motors, might be 30 mpg. We calculated the difference between each manufacturer's fuel economy target and the effective fleetwide fuel economy standard and found that this difference, or offset, was essentially constant across the wide range of fleetwide fuel economy levels evaluated in the OptInd report. This is not surprising given the way the Volpe Model adjusts the footprint-based logistic curve in order to increase or decrease the stringency of the CAFE standard. As described in the ANPR LDV TSD, the entire logistic curve is raised or lowered by a set amount in order to increase or decrease the stringency of the CAFE standard. Since the fuel economy standard for every vehicle, regardless of its footprint value, is increased or decreased by the same amount, and the sales of each manufacturer's vehicles do not change in a particular model year, the offset between each manufacturer's effective standard and that for the entire fleet should be constant.

These offsets are shown below in Table I-8. A negative offset indicates that a manufacturer's sales have a larger than average footprint and thus, the manufacturer must meet a lower effective standard than the industry as a whole, and *vice versa*.

Table I-8. Offsets Between Manufacturer Standards and Fleet-wide Standards

Company	Car (mpg)	Truck (mpg)
Chrysler	-1.9	0.4
Ford	-0.1	0.1
General Motors	-0.8	-1.2
Honda	0.7	1.0
Hyundai	1.5	2.3
Nissan	0.3	-0.5
Toyota	-0.8	-0.6

We then determined the combinations of car and truck standards for each manufacturer which produced the same combined CO2 emissions as the car and truck standards developed under the 4% per year scenario. These car and truck standards differed by manufacturer, since the ratio of cars and trucks sold by each manufacturer varies. We then determined the compliance cost of each of the complying combinations of car and truck standards and selected the combination which produced the minimum compliance cost. We then compared these compliance costs to those projected from the Volpe Model runs of cars and trucks separately in order to estimate the amount of savings associated with car-truck credit trading.

The shifts in car and truck fuel economy levels predicted to occur in order to minimize compliance costs are summarized in Table I-9 below.

Table I-9. Shifts in Projected Fuel Economy Levels for Analyzed Program Due to Car-Truck Trading (mpg)

Company	No Trading		With Trading	
	Car	Truck		
	2015			
Chrysler	31.6	29.0	30.5	29.3
Ford	33.4	28.7	30.3	30.7
General Motors	32.7	27.4	35.0	26.3
Honda	34.2	29.6	34.7	29.2
Hyundai	35.0	30.9	34.5	31.6
Nissan	33.8	28.1	34.5	27.5
Toyota	32.7	28.0	34.2	27.0
	2020			
Chrysler	39.4	35.2	41.1	34.8
Ford	40.6	34.9	37.6	36.7
General Motors	40.1	33.8	42.3	32.7
Honda	41.1	35.7	44.7	33.2
Hyundai	41.6	36.7	41.3	37.2
Nissan	40.8	34.4	39.8	35.5
Toyota	40.1	34.3	44.5	31.7

As can be seen from Table I-9, some manufacturers are projected to shift controls from trucks to cars, while others shift control from cars to trucks. In 2015, General Motors, Honda, Nissan and Toyota increase the fuel economy level of their car sales and reduce their truck fuel economy levels. Chrysler, Ford, and Hyundai decrease the fuel economy level achieved by their car sales and increase that of trucks.

The direction of trading in 2020 changes for some manufacturers compared to 2015. Chrysler, General Motors, Honda, and Toyota are projected to shift control towards cars, while the other three manufacturers shift control towards trucks.

Industry-wide, the potential savings due to car-truck savings are significant. In 2015, the savings are estimated to average \$97 per vehicle, while in 2020, this increases to \$177 per vehicle. These savings apply to both cars and trucks, on average. In reality, the cost of one vehicle type increases, while the cost of the other vehicle type decreases. The decrease in cost times the sales of that vehicle type exceeds the increase in cost times the sales of that vehicle type. We only estimated the net savings for cars and trucks combined, and did not estimate the specific increases and decreases in costs for each vehicle type by manufacturer or for the industry as a whole. Thus, the estimated compliance costs for cars and trucks individually including the savings associated with credit trading should be considered approximate. These trading adjusted costs are most accurate when combined into a single cost applicable to both cars and trucks.

H. Payback Period and Lifetime Monetary Impact

In this section, we calculate the number of years required for the value of fuel savings to equal the cost of the technology added to reduce CO2 emissions. We also calculated the net monetary impact over the life of the vehicle. This is simply the discounted value of fuel savings minus the cost of emission reducing technology.

Both metrics were estimated using the AEO2007 reference case oil prices and two discount rates (3 and 7 percent). The vehicle survival rates and annual mileage accumulations used are the same as those described in the ANPR LDV TSD.

In this calculation, the cost of technology is that associated with meeting the analyzed tailpipe CO2 emission scenario (shown in Table I-6) plus the cost of a higher efficiency and lower leakage air conditioning system (described in the Appendix III.B to this technical memorandum) less the savings associated with car-truck credit trading (described in Section I.G above) and lower A/C system maintenance (\$51 in 2015, \$68 in 2020, as described in the Appendix III.E to this technical memorandum). These costs, along with the payback periods and lifetime monetary impacts are summarized in Table I-10.

Table I-10. Vehicle Costs, Payback Period and Lifetime Monetary Impact of the 4% per Year CO2 Emission Standards: Cars and Trucks Combined

	2015	**2020**
CO2 Tailpipe Emission Control	\$554	\$2,018
A/C Efficiency Improvement	\$70	\$54
A/C Leakage Reduction	\$38	\$29

Car-Truck Credit Trading	-$97		-$177	
Net Cost per Vehicle	$565		$1,924	
Discount Rate	3%	7%	3%	7%
Payback Period (years)	3.2	3.8	6.0	8.7
Lifetime Monetary Impact	$1,116	$561	$1,630	$437

II. Estimation of GHG Emission and Fuel Savings from EPA Scenario

A. Overview

For the baseline and updated 4% per year scenario, the EPA's Motor Vehicle Emission Simulator (MOVES) was used to generate estimates of light-duty vehicle greenhouse gas (GHG) emissions and fuel use. The 4% scenario included potential increases in car and truck CO_2 standards, potential air conditioning (A/C) CO_2 limits, and potential A/C refrigerant leakage limits. To model these scenarios, we created new MOVES inputs to simulate the potential vehicle CO_2 limits; the contributions of A/C to GHG emissions and fuel use were added to the MOVES outputs via post processing. Projections were made to 2040 to show the full effect of new standards on the light-duty fleet.

Creating new MOVES inputs involved multiple steps. First, new Alternative Vehicle Fuels and Technologies (AVFT) files were created to model the CO_2 limits. These files are used to specify the fraction of the vehicle fleet in a given calendar year that is comprised of vehicles of a certain vehicle technology (e.g., conventional gasoline, conventional diesel, electric vehicle, etc.). For simplicity, CO_2 limits were simulated by shifting a fraction of the gasoline and diesel vehicle fleets into the electric vehicle (EV) fleet; since EVs do not contribute to onroad GHG emissions, shifting vehicles to the EV fleet has the same effect as improving the efficiency of the gasoline and diesel fleets in terms of total GHG emissions. It should be noted this approach is not attempting to predict that EVs will be used to meet tighter CO_2 limits, it is simply the method used to achieve the desired overall fleet CO_2 levels. A vehicle miles traveled (VMT) rebound effect of 15% was also applied during the creation of the AVFT files. Changes to MOVES's default diesel market penetration rates were also incorporated into the AVFT files.

The second major MOVES input change made for these simulations was to create a user input database containing new diesel energy rates, to account for the higher energy content of diesel fuel on a per-gallon basis. In MOVES, energy consumption values per unit distance, or energy rates, are fundamental for modeling fuel use, and ultimately GHG emissions. For these scenarios, we assumed that diesels would meet the same potential CO_2 limits as gasoline vehicles. Diesel fuel has a higher energy content per unit volume than gasoline, so a diesel vehicle with the same fuel consumption (gallons per mile) as a gasoline vehicle will consume energy at a higher rate (BTUs per mile). To account for this, new diesel energy rates were created by simply multiplying the default gasoline energy rates by the ratio the lower heating values of diesel and gasoline, which is approximately 1.13.

After running MOVES for the baseline and 4% scenarios, the contribution of A/C to total GHG emissions and fuel use was added via post processing. A/C contributes to GHG emissions in two ways. First, by adding an additional load to the powertrain, A/C indirectly causes an increase in tailpipe CO_2 emissions. Second, A/C contributes directly to GHG emissions via refrigerant leakage: A/C refrigerants are hydrofluorocarbons (HFCs), which are potent greenhouse gases. These two components (direct and indirect) were treated differently in the post processing. The indirect (tailpipe CO_2) component was added in proportion to the rebound-adjusted VMT, while the magnitude of the direct (HFC) component was simply an additive function of calendar year. For the 4% scenario, we project that both the indirect and direct contributions of A/C to GHG emissions would decrease due to advancements in technology, as described in detail below.

B. MOVES version

The version of MOVES used for this analysis was an internal draft (March 31, 2008 version), and has been placed in the docket for public access. This version has been updated from the most recent public version ("MOVES Demo")[a] in two ways pertaining to CO_2 emissions: first, energy rates for high speed / high load operation have been revised upward; second, the impacts of intermediate soak periods have been factored into start emissions estimates. Taken together these changes serve to increase total light-duty CO_2 emissions about 3 percent nationally relative to MOVES Demo. The inputs used to simulate the updated 4% per year scenario (AVFT files) are also included in the docket, and their development is discussed below.

C. Development of MOVES input files

1. Fuel economy inputs

Incorporating potential CO_2 limits into the MOVES AVFT files was achieved by shifting a fraction of the gasoline and diesel fleets into the electric vehicle fleet to simulate increased fleetwide energy efficiency relative to the MOVES default assumptions.   The basis of the MOVES CO_2 estimates is energy consumed, and we modeled the potential CO_2 limits by reducing energy consumption rates in MOVES using fuel consumption as a surrogate for these reductions; hence our discussion focuses on mpg in the following section. The default MOVES database does not include the increase in truck CAFE standards from 20.7 to 23.5 mpg through the 2010 model year, so the baseline scenario includes a fraction of trucks in the EV fleet to account for this increase. In contrast, passenger cars were assumed to meet or exceed the current CAFE standards, so the baseline scenario does not include any vehicles in the passenger car EV fleet.

Table II-1 shows the fuel economy assumptions for the MOVES default, baseline, and updated 4% scenarios. These fuel economy values are unadjusted values (i.e. in CAFE space), so they are higher than the actual onroad fuel economy; we used the CAFE values to generate the percent reductions in fuel consumption that were applied to the on-road MOVES emissions. Note that the baseline passenger car fleets exceed the CAFE standard of 27.5, which represent the achieved 2011-2015 CAFE levels from the reference case from the May 1, 2008 NHTSA NPRM.   Truck fleets are assumed to meet, but not exceed, CAFE standards and represent the achieved 2010 CAFE levels from the reference case from the May 1, 2008 NHTSA NPRM applied to 2011-2015; we assumed that model years 2010 and forward continued to achieve the 23.5 mpg level reported for MY 2010 trucks in the May 1, 2008 NHTSA NPRM, as trucks have historically not overcomplied with CAFE standards.

[a] MOVES model and documentation can be downloaded from http://www.epa.gov/otaq/ngm.htm

Table II-1
MPG values for Baseline and 4% Scenarios

Model Year	Cars		Trucks	
	baseline	*4%*	*baseline*	*4%*
2001	29.8	29.8	20.7	20.7
2002	29.8	29.8	20.7	20.7
2003	29.8	29.8	20.7	20.7
2004	29.8	29.8	20.7	20.7
2005	29.8	29.8	21.0	21.0
2006	29.8	29.8	21.6	21.6
2007	29.8	29.8	22.0	22.0
2008	29.6	29.6	22.5	22.5
2009	29.7	29.7	23.1	23.1
2010	29.7	29.7	23.5	23.5
2011	30.1	30.1	23.5	24.4
2012	30.4	30.4	23.5	25.4
2013	30.7	30.9	23.5	26.4
2014	30.7	32.2	23.5	27.5
2015	30.7	33.5	23.5	28.6
2016	30.7	34.8	23.5	29.7
2017	30.7	36.2	23.5	30.9
2018	30.7	37.6	23.5	32.2
2019	30.7	39.1	23.5	33.4
2020 - 2040	30.7	40.7	23.5	34.8

The diesel market share was assumed to be the same for the baseline and the 4 % per year scenario, as shown in Table II-2.

Table II-2
Diesel market share (%)

Model year	Cars	Trucks
2001 - 2010	1.0	1.3
2011	1.2	3.4
2012	1.3	4.0
2013	1.3	3.3
2014	1.3	3.3
2015 - 2040	1.3	3.1

For a given model year, the percentage of electric vehicles was calculated based on the scenario fuel economy, and the diesel market share, as follows:

$$\text{baseline }\%EV = \left[1 - \left(\frac{\frac{1}{BaselineFuelEconomy}}{\frac{1}{DefaultFuelEconomy}}\right)\right],$$

$$\text{nominal scenario }\%EV = \left[1 - \left(\frac{\frac{1}{ScenarioFuelEconomy}}{\frac{1}{DefaultFuelEconomy}}\right)\right],$$

$$\text{final scenario }\%EV = \text{baseline }\%EV + (\text{nominal }\%EV\ -\ \text{baseline }\%EV) \times (1 - \%\text{rebound})$$

For example, the percentage of EVs for trucks in MY 2020, for the 4% scenario, was:

$$\text{baseline }\%EV = \left[1 - \left(\frac{\frac{1}{23.5}}{\frac{1}{20.7}}\right)\right] = 11.9\%,$$

$$\text{nominal scenario }\%EV = \left[1 - \left(\frac{\frac{1}{34.8}}{\frac{1}{20.7}}\right)\right] = 40.5\%,$$

$$\text{final scenario }\%EV = 11.9\% + (40.5\%\ -\ 11.9\%) \times (1 - 0.15)\ =\ 36.2\%$$

The percentages of gasoline and diesel vehicles in the car and truck fleets were then calculated such that the percentages of diesels in the car and truck fleets, excluding the EVs, equaled the market share percentages specified in Table II-2, as follows:

$$\%diesel = (1 - \%EV) \times DieselMarketShare$$
$$\%gasoline = (1 - \%EV) \times (1 - DieselMarketShare)$$

For example, returning to the MY 2020, 4% scenario, the gasoline and diesel percentages were:

$$\%diesel = (1 - 0.362) \times 0.031 = 2.0\%$$
$$\%gasoline = (1 - 0.362) \times (1 - 0.031) = 61.8\%$$

2. Diesel energy inputs

For these scenarios, we assumed that diesels would meet the same fuel economy standards as gasoline vehicles. As discussed above, diesel fuel has a higher energy content per unit volume than gasoline, so a diesel vehicle with the same fuel consumption (gallons per mile) as a gasoline vehicle will consume energy at a higher rate (BTUs per mile). To account for this, new diesel energy rates were created by simply multiplying the gasoline energy rates by the ratio of diesel to gasoline lower heating values, which is (131,238 BTU/gal)/(116,485 BTU/gal), or approximately 1.13.

D. Estimation of Emissions and Fuel Savings Reductions from A/C

1. Indirect A/C emissions - CO_2

The indirect contribution of A/C to tailpipe CO_2 emissions was modeled as an additional energy demand, in BTU/mile. The magnitude of the additional energy demand was calculated in terms of a percentage of the baseline energy use in model year 2010. In other words, the additional energy required for A/C in all model years was determined by referring back to the baseline energy use in 2010 and calculating a specified percentage of that 2010 baseline energy use. The baseline energy use rate in 2010 was determined by running the baseline MOVES scenario in 2010, which produced average values of 4855 BTU/mi, 6066 BTU/mi, and 6608 BTU/mi for passenger cars, passenger trucks, and light commercial trucks, respectively. The percentages of these 2010 baseline values added to account for A/C use, by model year, is shown in Table II-3. See Appendix I of this memo for more detail on indirect A/C emissions.

Table II-3
Indirect impact of A/C use on tailpipe CO_2 emissions
(% of MY 2010 energy use, in BTU/mi)

Model year	baseline	4%
pre-2011	3.47	3.47
2011	3.47	3.47
2012	3.47	3.12
2013	3.47	2.77
2014	3.47	2.43
2015	3.47	2.08
2016	3.47	2.08
2017	3.47	2.08
2018	3.47	2.08
2019	3.47	2.08
2020-2040	3.47	2.08

To calculate the total contribution of A/C to the tailpipe CO_2 emissions for a specific calendar year, we first had to calculate the VMT by model year for the gasoline and diesel fleets, including the rebound effect. Using this rebound-adjusted VMT, the baseline energy use rate in 2010, and the A/C impact percentages shown in Table II-3, the additional energy use due to A/C was calculated for each model year. The total for a given calendar year was calculated by summing the contributions of all model years in the fleet. This increase in energy use was then converted to CO_2 emissions using the appropriate lower heating values (116,485 BTU/gal for gasoline and 131,238 BTU/gal for diesel) and carbon contents (8,744 g/gal for gasoline and 10,052 g/gal for diesel) to determine the additional GHG emissions due to A/C use.

2. Direct A/C emissions - HFCs

The direct contribution of A/C to GHG emissions due to refrigerant (HFC) leakage was modeled as a simple addition, with the magnitude varying by calendar year. The GHG contributions, by calendar year, for the two scenarios are shown in Table II-4. See Appendix I of this memo for more detail on HFC leakage estimates.

Table II-4
A/C GHG emissions from HFC leakage
(million metric tons, CO_2 equivalent)

Year	baseline	4%
2011	52.3	52.3
2012	52.1	51.4
2013	52.0	49.8
2014	51.8	47.5
2015	51.7	44.5
2016	51.5	41.4
2017	51.4	38.4
2018	52.2	36.4
2019	53.1	34.5
2020	53.9	32.5
2021	54.8	30.6
2022	55.6	28.6
2023	57.6	27.8
2024	59.7	26.9
2025	61.7	26.1
2026	63.8	25.3
2027	65.8	24.4
2028	67.8	23.6
2029	69.9	22.7
2030	71.9	21.9
2031	74.0	22.0
2032	76.1	22.1
2033	78.2	22.2
2034	80.3	22.3
2035	82.4	22.4
2036	84.5	22.5
2037	86.6	22.6
2038	88.7	22.7
2039	90.8	22.8

2040	93.0	23.0

E. Calculation of GHG emissions and fuel savings

The output of the MOVES runs, after being post processed to incorporate the effects of A/C use, were used to estimate total GHG emissions and fuel use for both the baseline and the 4% scenario. Using these totals, the GHG emissions reductions and fuel savings for the 4% scenario relative to the baseline were calculated.

Total GHG emissions for each scenario were obtained by summing the tailpipe CO_2 emissions (obtained directly from the MOVES output), the additional tailpipe CO_2 emissions due to A/C use (calculated via post processing, as described above), and the CO_2-equivalent A/C refrigerant leakage. In 2040, the total CO_2-equivalent GHG emissions were 2288 MMT for the baseline case and 1652 MMT for the 4% scenario, for a reduction of 635 MMT (**Table II-5**).

Total fuel use was obtained by adding the indirect energy use due to A/C (calculated via post processing, as described above) to the energy use reported in the MOVES output and then converting to gallons of fuel using the lower heating values of gasoline and diesel (116,485 BTU/gal for gasoline and 131,238 BTU/gal for diesel). Therefore, the gallons of fuel use (total and savings) include both gasoline and diesel fuels. The total fuel use in 2040 for the baseline and 4% scenario was 16.3 and 12.1 million barrels per day, respectively, for a reduction of 4.2 million bpd (**Table II-6**). Additional VMT due to the rebound effect was also calculated (**Table II-7**).

Table II-5
GHG emissions
(million metric tons, CO_2 equivalent)

	Baseline			4% Scenario			Total Reductions	
	tailpipe w/o A/C	tailpipe	tailpipe + HFC leakage	tailpipe w/o A/C	tailpipe	tailpipe + HFC leakage	By Year	Cumulative
2011	1284	1326	1379	1282	1325	1377	2	2
2012	1306	1350	1402	1301	1344	1395	7	8
2013	1328	1372	1424	1316	1360	1409	14	23
2014	1350	1396	1447	1330	1373	1421	27	50
2015	1374	1420	1472	1341	1383	1428	44	94
2016	1397	1444	1495	1347	1390	1431	64	157
2017	1422	1470	1521	1353	1395	1434	87	245
2018	1448	1496	1549	1356	1398	1435	114	359
2019	1474	1523	1576	1357	1398	1433	144	502
2020	1498	1549	1603	1353	1395	1427	176	678
2021	1524	1576	1630	1351	1392	1422	208	886
2022	1551	1603	1659	1350	1390	1419	240	1,126
2023	1578	1632	1689	1350	1390	1418	271	1,398
2024	1607	1661	1721	1351	1391	1418	302	1,700

2025	1636	1691	1753	1355	1394	1420	332	2,033
2026	1666	1722	1786	1359	1399	1424	362	2,394
2027	1697	1754	1820	1366	1406	1430	390	2,784
2028	1727	1786	1854	1374	1414	1437	417	3,201
2029	1759	1819	1889	1384	1424	1447	442	3,643
2030	1791	1851	1923	1395	1435	1457	466	4,109
2031	1821	1883	1957	1407	1447	1469	487	4,596
2032	1852	1914	1990	1421	1461	1484	507	5,103
2033	1883	1947	2025	1436	1477	1500	525	5,628
2034	1915	1980	2060	1454	1495	1517	543	6,171
2035	1948	2014	2096	1472	1514	1537	560	6,731
2036	1981	2048	2133	1492	1535	1557	576	7,306
2037	2015	2084	2170	1514	1557	1579	591	7,897
2038	2050	2120	2208	1536	1580	1603	606	8,503
2039	2086	2157	2247	1560	1604	1627	620	9,123
2040	2122	2194	2287	1584	1629	1652	635	9,758

Table II-6
Fuel use
(million barrels per day, gasoline and diesel)

Calendar Year	Baseline		4% Scenario		Reduction	
	tailpipe w/o A/C	tailpipe	tailpipe w/o A/C	tailpipe	tailpipe w/o A/C	tailpipe
2011	9.6	9.9	9.5	9.9	0.0	0.0
2012	9.7	10.0	9.7	10.0	0.0	0.0
2013	9.9	10.2	9.8	10.1	0.1	0.1
2014	10.0	10.4	9.9	10.2	0.2	0.2
2015	10.2	10.6	10.0	10.3	0.2	0.3
2016	10.4	10.7	10.0	10.3	0.4	0.4
2017	10.6	10.9	10.1	10.4	0.5	0.6
2018	10.8	11.1	10.1	10.4	0.7	0.7
2019	11.0	11.3	10.1	10.4	0.9	0.9
2020	11.1	11.5	10.1	10.4	1.1	1.1
2021	11.3	11.7	10.0	10.3	1.3	1.4
2022	11.5	11.9	10.0	10.3	1.5	1.6
2023	11.7	12.1	10.0	10.3	1.7	1.8
2024	11.9	12.3	10.0	10.3	1.9	2.0
2025	12.2	12.6	10.1	10.4	2.1	2.2
2026	12.4	12.8	10.1	10.4	2.3	2.4
2027	12.6	13.0	10.1	10.4	2.5	2.6
2028	12.8	13.3	10.2	10.5	2.6	2.8
2029	13.1	13.5	10.3	10.6	2.8	2.9
2030	13.3	13.8	10.4	10.7	2.9	3.1

2031	13.5	14.0	10.5	10.8	3.1	3.2
2032	13.8	14.2	10.6	10.9	3.2	3.4
2033	14.0	14.5	10.7	11.0	3.3	3.5
2034	14.2	14.7	10.8	11.1	3.4	3.6
2035	14.5	15.0	10.9	11.2	3.5	3.7
2036	14.7	15.2	11.1	11.4	3.6	3.8
2037	15.0	15.5	11.2	11.6	3.7	3.9
2038	15.2	15.7	11.4	11.7	3.8	4.0
2039	15.5	16.0	11.6	11.9	3.9	4.1
2040	15.8	16.3	11.8	12.1	4.0	4.2

Table II-7
VMT due to rebound
(billion miles)

Year	4%	
	Cars	Trucks
2011	0.0	6.1
2012	0.0	18.1
2013	1.4	35.8
2014	10.6	59.4
2015	27.2	88.6
2016	51.1	123.3
2017	82.3	163.8
2018	120.5	209.6
2019	165.3	260.4
2020	216.4	315.5
2021	267.1	370.1
2022	317.3	423.5
2023	366.6	475.9
2024	414.4	527.3
2025	460.7	577.3
2026	505.4	625.3
2027	547.8	671.7
2028	587.4	715.7
2029	623.7	758.0
2030	656.5	798.0
2031	685.8	836.3
2032	711.5	873.1
2033	733.8	908.6
2034	753.1	942.9
2035	769.8	976.2
2036	784.5	1,008.7

2037	797.6	1,040.5
2038	809.4	1,071.9
2039	820.4	1,103.0
2040	830.7	1,134.0

III. What are the Estimated Cost, Economic, and Other Impacts?

In this section, we present the potential vehicle program cost impacts of the 4% per year scenario, impacts on fuel consumption and the associated savings, and our analysis of the expected economy-wide impacts. The projected benefits of reducing GHG emissions are also presented. We also present our estimates of the impact on vehicle miles traveled and the impacts associated with those miles as well as other societal impacts of the 4% per year scenario. These are factors EPA typically considers in evaluating the appropriateness of standards under section 202(a) of the Clean Air Act.

Using projected AEO2007 fuel prices, the total monetized benefits under the 4% per year scenario are projected to be over $100 billion in 2040. The hardware costs and associated fuel savings are estimated to save society $91 billion in 2040. The net present value of the monetized benefits under the 4% per year scenario, through 2040 assuming a 3 percent discount rate, are projected to be $680 billion (or $300 billion through 2040 assuming a 7 percent discount rate). The net present value of the costs under the 4% per year scenario, through 2040 assuming a 3 percent discount rate, are projected to be negative $550 billion (or negative $211 billion through 2040 assuming a 7 percent discount rate). Note that these costs are highly negative due to the offsetting fuel savings which far outweigh the cost of new vehicle hardware. This results in a net present value of the net benefits, through 2040 assuming a 3 percent discount rate, of $1.2 trillion (or $510 billion through 2040 assuming a 7 percent discount rate).

Further information on these and other aspects of the economic impacts are summarized in the following sections.

A. Estimated Costs Associated with the 4% per Year Scenario

In this section we present our estimate of the vehicle costs associated with the 4% per year scenario. The presentation here summarizes the costs associated with the new vehicle technology expected to be added to meet potential GHG standards, including hardware costs to comply with the potential A/C requirements. The analysis summarized here provides our estimate of incremental costs at the consumer level on a per vehicle basis and on an annual total basis. There are three parts to the presentation: hardware costs associated with the addition of new technology meant to reduce tailpipe CO2 emissions which includes hardware to improve A/C system efficiency; hardware costs to control the loss of A/C refrigerant and the maintenance savings expected from that hardware; and, a summary section that presents the annual quantified costs.

The presentation here is meant only to summarize the important cost impacts associated with the 4% per year scenario. For details behind the analysis such as the Volpe Model inputs and the estimates of costs associated with individual technologies see Section I of this memorandum. For details behind the estimates of costs associated with the potential A/C program see Appendix IIIB of this memorandum.

1. Vehicle Compliance Costs Associated with CO_2 Efficiency

For the compliance costs associated with adding new CO2-reducing technology to vehicles, we based our estimates on existing literature, meetings with manufacturers and parts suppliers, and meetings with other experts in the field of automotive cost estimation. This work is documented in our recent technical report.[b] We also considered manufacturer product plans, since some vehicles already use or are projected to use many of the fuel saving technologies we have considered. Lastly, we have considered changes needed to meet current CAFE standards.[c] For that reason, the manufacturer product plans combined with changes needed to meet current CAFE standards represent the reference case against which our engineering costs are calculated. Therefore, the estimated costs presented here represent the incremental costs associated with our 4% per year scenario relative to what the future vehicle fleet would be expected to look like under the current 2010 CAFE standards. A more detailed description of the factors considered in our reference case is presented in Section I.

The Volpe Model's estimates of costs cover the years of implementation of the scenario – 2011 through 2020 for both cars and trucks.[d] The cost estimates presented here represent incremental compliance costs during the model years of implementation, where costs are incremental to our reference case. As such, the costs account for the indirect costs incurred in the automobile manufacturing and dealer industries. To account for those indirect costs, we have applied a 1.5 adjustment factor to all of our manufacturer hardware costs to arrive at the incremental compliance costs. Once the analyzed program has been fully implemented, some of the indirect costs would no longer be attributable to potential standards and, as such, the costs would be roughly 25 percent lower in years following full implementation (i.e., the adjustment factor becomes 1.14). We present a detailed discussion of the 1.5 adjustment factor in our recent Staff Technical Report.[e] There, we show the derivation of the factor as based on the information presented in a NHTSA study and shown in Table III-1.[f]

[b] "Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions," EPA420-R-08-008, March 2008.
[c] This does not include the CAFE standards proposed by NHTSA in May 2008 (73 FR 24352).
[d] As explained in Section I of this memorandum, we ran the Volpe Model for years 2015 and 2020. Results for intervening years are interpolated.
[e] "Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions," EPA420-R-08-008, March 2008.
[f] "Advanced Air Bag Systems: Cost, Weight, and Lead Time Analysis Summary Report," Contract No. DTNH22-96-0-12003, Task Orders – 001, 003, and 005, National Highway Traffic Safety Administration, U.S. Department of Transportation, Table III-12.

Table III-1. Domestic Three Auto Manufacturers Weighted Average Marginal Analysis of Operating Results, 1989-1997

Chrysler, Ford, & GM	Average for 1989-1997	Adjustment Factor
Net sales	100%	
Variable Costs – Manufacturing	73.3%	1.00
Contribution Margin	26.7%	0.36
Fixed & Discretionary Costs		
Maintenance & Repairs	3.4%	0.046
Research & Development	4.7%	0.064
Selling, General, & Administrative	6.6%	0.090
Taxes Other than Income	2.6%	0.035
Pension Expense & Other Pension Related Benefits	1.9%	0.026
Depreciation	2.8%	0.038
Amortization, Tooling	2.2%	0.030
Provision for Plant Closing	0.3%	0.004
Amortization, Intangibles	0.1%	0.001
Subtotal	24.6%	0.34
Operating Margin	2.1%	0.028
Net Profit Margin	0.6%	0.008

As explained in our Staff Technical Report, the adjustment factor can be derived as:

Indirect Cost Markup=*Variable Cost* x *Markup on Variable Cost* x *Dealer Margin*

Where the Markup on Variable Cost can be determined as:

Markup on Variable Costs=Contribution Margin/Variable Costs

Or, 26.7%/73.3% = 0.36

We then estimate dealer the dealer markup, as done in the NHTSA study, using an 11% markup factor. In the end, the indirect cost markup factor becomes:

Indirect Cost Markup = Variable Cost x 1.36 x 1.11 = *Variable Cost* x 1.5

As noted, we then adjusted that markup downward once the analyzed program is fully implemented (from 1.5 to 1.14). We derived this lower factor by eliminating some of the indirect costs that we believe do not carry forward in perpetuity in response to new standards (although they may carry on in perpetuity in response to other business pressures). To estimate the long term indirect cost markup factor, we first considered the R&D conducted by the supplier as no longer being applicable to new standards. We estimate that the supplier uses a cost structure similar to the manufacturer and, therefore, spends roughly three to five percent of revenues on R&D (see Table III-1, we have used 5%). Removing that five percent from the supplier price, i.e., the manufacturer cost, results in a long term manufacturer cost of:

Near term manufacturer cost factor – Supplier R&D factor = Long term manufacturer cost factor
or,
1.00 - 0.05 = 0.95.

To estimate the impact on the contribution margins, we estimated that R&D and selling, general, & administrative costs would continue, but would no longer be attributable to new standards. We believe this is valid since we would expect R&D and sales efforts to focus on other regulatory programs (non-GHG) and/or driver comfort, etc., once the potential GHG limits are fully implemented. This is true with the exception of the incremental regulatory burdens associated with new standards. We believe that these regulatory costs fall within the R&D category but also believe that they are on the order of 10 percent of that spending. Instead of a R&D factor of 0.064, we are using a long term R&D factor of 0.006 to reflect that continued regulatory burden. All other costs were considered to continue in perpetuity as attributable to this proposal. This means that our variable cost markup factor becomes:

Variable cost markup = 1.00 + 0.046 + 0.006 + 0.035 + 0.026 + 0.038 + 0.030 + 0.004 + 0.001 = 1.19

We also believe that most of the dealer related costs would not be applicable to new standards, at least not in perpetuity. The only dealer costs we consider as appropriate for the long term would be those associated with financing and property taxes since these expenses are directly correlated to inventory and this rule would result in a more valuable inventory held by the dealer. We have looked at financial information for dealerships complied by the National Automobile Dealers Association and found that floor plan inventory costs per vehicle are roughly one percent of vehicle retail sales.[g] This would suggest a markup of 0.01 to reflect long term dealer inventory costs associated with new standards. In the end, our long term indirect cost markup factor can be expressed as:

Indirect Cost Markup = *Variable Cost* x *Markup on Variable Cost* x *Dealer Margin*
Indirect Cost Markup = *Variable Cost* x 1.19 x 1.01 = *Variable Cost* x 1.2

Where the variable cost for the long term is actually the near term variable cost less the supplier R&D costs or 0.95 x the near term variable cost. So, we can express our long term indirect cost markup as:

Indirect Cost Markup (long term) = ICM_L = *Near term variable cost* x 0.95 x 1.2
ICM_L = *Near term variable cost* x 1.14

[g] Refer to Appendix IIIA of this memorandum for details.

We have used this as our long term indirect cost markup factor and believe that this is reasonable because, as we understand it, automobile manufacturers reinvest approximately three percent of their ongoing revenue into research and development for future products.[h] Hence for a vehicle generating revenues of $20,000 and being redesigned on a five year cycle, a per vehicle investment in research and development would be made on the order of $3,000 ($20,000/car x 5 years x 3%). For a vehicle with annual production volumes of 100,000 units, the total research and development expenditures would be $300 million spread over the five years of the production cycle. As profit seeking entities, manufacturers are assumed to make these investments for one of three reasons: (1) to reduce production costs (e.g., through new designs that are less costly to manufacture or new manufacturing techniques that are more efficient); or, (2) to comply with emissions or safety regulations (requirements to enter or remain in the market); or, (3) to improve vehicle attributes in order to command a higher price for the vehicle.

A look at the overall competitive automobile market over a number of years shows that, like research and development, net profit margin and production costs remain relatively constant.[i] This would seem to confirm the generally held observation that, year in and year out, new vehicles improve while real vehicle prices change very little. In other words, this reinvestment in research and development, while bringing significant improvements to vehicle quality, safety, environmental footprint, and overall performance, does not lead to increases in real vehicle prices.[j] Research and development for this sector is in essence an ongoing cost of doing business in order to remain competitive.

We expect automobile manufacturers will allocate a significant fraction of their ongoing research and development toward complying with potential GHG regulations. We have used an indirect cost adjustment factor, in part, to estimate the cost of this research and development for vehicles produced between 2010 and 2020. We have reduced the adjustment factor for vehicles produced after 2020 (2016 for A/C-related costs since the analyzed limits are fully implemented by 2016) to reflect the shift of ongoing research and development to other aspects of vehicle design not attributable to potential GHG limits. While we believe this is an appropriate method to estimate the overall cost for complying with potential regulations, including research and development costs, we do not believe the resulting incremental costs reflect the best method to estimate changes in vehicle prices. As we have already noted, the cost for research and development is already reflected in the current (and ongoing) price of a new vehicle. Hence, any estimate of an incremental price increase used to estimate market responses would ideally not include these research and development costs as those cost are already reflected in the baseline price. As our current analysis does in fact use the incremental cost including research and development to estimate potential incremental price increases, the resulting analysis almost certainly overstates the true incremental price increases and, hence, market responses.

[h] Final Peer Review Document NHTSA's Cost, Weight, and Lead Time Estimating Methodology for New Safety Initiatives DTNH22-02-D-02104, Task Order 09 October 23, 2006.
[i] Final Peer Review Document NHTSA's Cost, Weight, and Lead Time Estimating Methodology for New Safety Initiatives DTNH22-02-D-02104, Task Order 09 October 23, 2006.
[j] Vehicle price may increase due to more, or more valuable, hardware, but the baseline vehicle price has not increased in constant dollar terms.

We have more discussion of our indirect cost factor and the indirect costs it reflects in our recent Staff Technical Report. In particular, we discuss the limitations with the factor and the data behind it. We seek comment on all aspects of our indirect cost markup factor both as presented here and in our Staff Technical Report.

We have also considered the impacts of manufacturer learning on these cost estimates. Consistent with past EPA rulemakings, we have estimated that costs would decline by 10 to 20 percent after manufacturers have had the opportunity to find ways to improve upon their manufacturing processes or otherwise manufacture these technologies in a more efficient way. We have considered learning impacts on only a fraction of the technologies expected to be used because many of the expected technologies are already used rather widely in the industry and, presumably, learning impacts have already occurred. We have more discussion of our learning approach and the technologies to which we have applied learning in our recent Staff Technical Report.[k]

Table III-2 presents the fleet average incremental compliance cost per vehicle. The costs shown for the years 2015 and 2020 are taken from Table I-14 but include the $97 savings in 2015 and $177 savings in 2020 that result from trading between a given manufacturer's car and truck fleets (note that this does not include trading between different manufacturers). The costs shown for intermediate years are simple straight line interpolations beginning with $0 in 2010.

Table III-2. Compliance Costs Associated with the Tailpipe CO2 Standards
Costs Shown Include Trading between Cars & Trucks and Exclude A/C Costs
4% per Year Scenario
(2006 $/vehicle)

Calendar Year	Car	Truck	Average
2011	$64	$117	$91
2012	$127	$233	$183
2013	$191	$350	$274
2014	$254	$466	$366
2015	$318	$583	$457
2016	$514	$933	$734
2017	$711	$1,282	$1,011
2018	$907	$1,632	$1,287
2019	$1,104	$1,981	$1,564
2020	$1,300	$2,331	$1,841
2021+	$988	$1,772	$1,399

[k] "Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions," EPA420-R-08-008, March 2008.

For the analyzed A/C CO_2 efficiency program, we have estimated the compliance costs shown in Table III-3.[l] Not all vehicles would incur A/C CO_2 efficiency hardware costs. The analyzed program's implementation would result in an increasing percentage of vehicles adding the hardware each year until full implementation (the potential program would begin in 2012 and be fully implemented in 2015). The costs shown in Table III-3 reflect sales weighted average costs as though the costs were shared equally by all vehicles when, in reality, some vehicles would incur the full $70 near-term cost while others would not during the 2012 through 2014 model years. The cost reduces in years following 2018 due to the elimination of some indirect costs as discussed above.

Table III-3. Compliance Costs Associated with the A/C CO_2 Efficiency Program (2006 $/vehicle)

Calendar Year	Car	Truck
2011	$0	$0
2012	$18	$18
2013	$35	$35
2014	$53	$53
2015	$70	$70
2016	$54	$54
2017	$54	$54
2018	$54	$54
2019	$54	$54
2020	$54	$54
2021+	$54	$54

2. Compliance Costs and Maintenance Impacts Associated with A/C Leakage

For the analyzed A/C leakage program, we have estimated the compliance costs shown in Table III-4.[m] In contrast to the costs for CO_2 efficiency, most (if not all) of the vehicles would incur A/C leakage hardware costs since the standards phase in over time for all vehicles. The analyzed program's implementation would result in an increasing average cost per vehicle as they add hardware each year until full implementation (the analyzed program would begin in 2012 and be fully implemented by 2015). The costs shown in Table III-4 reflect the sales weighted average costs. The costs reduce in later years due to the elimination of some indirect costs as discussed above.

[l] We discuss the A/C program and its costs in Appendix IIIB of this memorandum.
[m] We discuss the A/C program and its costs in Appendix IIIB of this memorandum.

Table III-4. Compliance Costs Associated with the A/C Leakage Program
(2006 $/vehicle)

Calendar	Car	Truck
2011	$0	$0
2012	$2	$2
2013	$13	$13
2014	$26	$26
2015	$38	$38
2016	$29	$29
2017	$29	$29
2018	$29	$29
2019	$29	$29
2020	$29	$29
2021+	$29	$29

We expect that the approach manufacturers would use to comply with the potential A/C leakage program would result in reduced demand for maintenance on air conditioning components by owners of affected vehicles. We have estimated that one fewer maintenance event would occur during the typical vehicle lifetime. We have estimated the net present value of these savings to be $68 for compliant vehicles (this results in $17 per vehicle in 2012 when 25% of vehicles are compliant). These estimates consider both the timing of the maintenance event, the survival rate of the typical vehicle, and the phase in of the analyzed program. These maintenance savings are reflected in the annual cost table presented in Section III.A.3.

3. Annual Costs of the Potential Vehicle Program

This section presents the total per vehicle costs, projected vehicle sales, and the resultant annual costs associated with the analyzed vehicle program (tailpipe CO2, A/C CO2 efficiency, and A/C leakage). The annual costs are calculated by multiplying the hardware costs and maintenance savings presented above and summarized in Table III-5 by the appropriate vehicle sales in each year shown in Table III-6. Note that the costs presented in Table III-5 do not include the fuel-related savings that would occur as a result of the improvements to fuel efficiency. Those impacts are presented in Section III.B. Projected vehicle sales through 2030 are taken directly from AEO2007 except that we have added an additional one percent of AEO's truck sales back to AEO's truck sales to account for medium-duty passenger vehicle (MDPV) sales.[n] For 2031 to 2040, we have interpolated beyond 2030 by applying the growth in sales from 2029 to 2030 as reported in AEO2007. Table III-7 shows the resultant annual costs of the analyzed program.

[n] U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook 2007, Supplemental Table 47, can be found at http://www.eia.doe.gov/oiaf/archive/aeo07/index.html.

Table III-5. Compliance Costs Associated with the Vehicle Program
(2006 $/vehicle)

Calendar Year	Tailpipe CO2 Compliance	A/C CO2 Efficiency Compliance	A/C Leakage Compliance	Total Compliance Costs	A/C Maintenance[a]
2011	$91	$0	$0	$91	$0
2012	$183	$18	$2	$203	$0
2013	$274	$35	$13	$323	-$17
2014	$366	$53	$26	$444	-$34
2015	$457	$70	$38	$565	-$51
2016	$734	$54	$29	$816	-$68
2017	$1,011	$54	$29	$1,093	-$68
2018	$1,287	$54	$29	$1,370	-$68
2019	$1,564	$54	$29	$1,646	-$68
2020	$1,841	$54	$29	$1,924	-$68
2021+	$1,399	$54	$29	$1,481	-$68

[a] Negative values reflect a per vehicle present value lifetime savings to vehicle owners.

Table III-6. Projected Vehicle Sales Used in This Analysis

Calendar Year	Car	Truck	Total	% Car	% Truck
2011	8,577,555	8,376,304	16,953,859	51%	49%
2012	8,486,365	8,612,305	17,098,670	50%	50%
2013	8,412,005	8,829,008	17,241,013	49%	51%
2014	8,255,845	9,077,041	17,332,885	48%	52%
2015	8,182,902	9,175,941	17,358,843	47%	53%
2016	8,127,923	9,249,457	17,377,380	47%	53%
2017	8,141,646	9,366,614	17,508,260	47%	53%
2018	8,136,979	9,489,822	17,626,801	47%	53%
2019	8,302,527	9,662,728	17,965,256	47%	53%
2020	8,359,771	9,950,295	18,310,067	47%	53%
2021	8,402,483	10,119,722	18,522,205	45%	55%
2022	8,472,445	10,198,681	18,671,126	45%	55%
2023	8,431,680	10,407,903	18,839,583	45%	55%
2024	8,496,887	10,549,683	19,046,569	45%	55%
2025	8,569,630	10,678,085	19,247,715	45%	55%
2026	8,562,413	10,961,009	19,523,422	44%	56%
2027	8,620,084	11,116,441	19,736,525	44%	56%
2028	8,680,693	11,215,365	19,896,059	44%	56%
2029	8,691,355	11,397,771	20,089,127	43%	57%
2030	8,782,052	11,518,549	20,300,601	43%	57%
2031	8,873,694	11,640,607	20,514,301	43%	57%
2032	8,966,294	11,763,958	20,730,251	43%	57%
2033	9,059,859	11,888,616	20,948,475	43%	57%
2034	9,154,401	12,014,595	21,168,996	43%	57%
2035	9,249,929	12,141,909	21,391,838	43%	57%
2036	9,346,454	12,270,572	21,617,026	43%	57%
2037	9,443,986	12,400,599	21,844,585	43%	57%
2038	9,542,537	12,532,003	22,074,540	43%	57%
2039	9,642,115	12,664,800	22,306,915	43%	57%
2040	9,742,733	12,799,004	22,541,737	43%	57%

Note that AEO's projected sales result in a fleet mix of 43 percent cars and 57 percent trucks by 2029. Recent sales trends and the presumed impact of fuel prices on those recent trends would suggest that AEO's projections are perhaps skewed too heavily toward trucks. A future fleet mix comprised of more cars than trucks, or even a 50/50 weighting would reduce the projected long term annual costs of the analyzed future standards. It would also reduce the projected GHG emission reductions of the analyzed future standards since some of those impacts would be built into our reference case rather than our control case.

Table III-7. Quantified Annual Costs Associated with the Vehicle Program
4% per Year Scenario
($Billions of 2006 dollars)

Year	Tailpipe CO2 Efficiency Compliance	A/C CO2 Efficiency Compliance	A/C Leakage Compliance	A/C Leakage Maintenance[a]	Quantified Annual Costs
2011	$1.5	$0.0	$0.0	$0.0	$1.5
2015	$8.0	$1.2	$0.7	-$1.2	$8.7
2020	$34.1	$1.0	$0.5	-$0.9	$34.6
2030	$29.1	$1.1	$0.6	-$1.0	$29.7
2040	$32.3	$1.2	$0.6	-$1.2	$33.0
NPV, 7%	$208	$9.5	$4.9	-$9.1	$213
NPV, 3%	$407	$17.4	$9.1	-$16.7	$417

[a] Negative values reflect savings.

B. Reduction in Fuel Consumption and its Impacts

1. What Are the Projected Changes in Gasoline and Diesel Fuel Consumption?

The potential CO2 tailpipe standards and A/C efficiency requirements would result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles would see corresponding savings associated with reduced fuel expenditures. We have estimated the impacts on fuel consumption for both the analyzed tailpipe CO2 program and the A/C efficiency program. To do this, fuel consumption is calculated using both current CO2 emission levels and the potential CO2 standards including the improvements in A/C efficiency. The difference between these estimates represents the net savings from the potential CO2 standards.

The expected impacts on fuel consumption are shown in Table III-8. The gallons shown in the tables reflect impacts from the potential CO2 tailpipe standards, the A/C efficiency improvements, and include the off-setting increased consumption resulting from the rebound effect.

Table III-8. Fuel Consumption Impacts
4% per Year Scenario
(Billion gallons)

Calendar Year	Tailpipe CO2 Efficiency		A/C CO2 Efficiency		Total
	Gasoline	Diesel	Gasoline	Diesel	
2011	-0.2	0.0	0.0	0.0	-0.2
2015	-4.0	-0.2	-0.4	0.0	-4.5
2020	-17.0	-0.6	-1.1	0.0	-18.7
2030	-45.9	-1.4	-2.3	0.0	-49.7
2040	-62.3	-2.0	-3.0	-0.1	-67.3

[a] Fuel consumption impacts shown include increased fuel consumption resulting from the rebound effect.

2. What Are the Monetary Impacts Associated with Reduced Fuel Consumption?

Using the fuel consumption estimates presented in section III.B.1, we can calculate the monetized impacts associated with the CO2 tailpipe standards and A/C efficiency requirements. To do this, we multiply reduced fuel consumption in each year by the corresponding average fuel price in that year. For fuel prices, we have used the AEO2007 reference case projections. We then subtract taxes from those prices since the tax represents a transfer cost. These results are shown in Table III-9. (Note that we also present the monetized impacts from reduced fuel consumption in section III.F where we present the benefit-cost of the analyzed program and, for that reason, we present the monetized impacts as negative costs while here we present them as positive savings). Our projections for the future vehicle fleet do not include any shifting of sales between market segments, market-share shifts between companies, or changes to future vehicle projected sales as a result of the analyzed program. To the extent that these changes occur, the actual projected monetized fuel impacts due to the potential program may be different than what we have projected.

Table III-9. Estimated Societal Monetized Impacts
Associated with Reduced Fuel Consumption[a]
4% per Year Scenario
(Billions of 2006 dollars)

Calendar Year	AEO2007 Fuel Prices		
	Tailpipe CO2 Efficiency	A/C CO2 Efficiency	Total
2011	$0.4	$0.0	$0.4
2015	$6.7	$0.6	$7.3
2020	$29.8	$1.8	$31.6
2030	$87.6	$4.3	$92.0
2040	$119	$5.7	$125
NPV, 7%	$407	$21.7	$429
NPV, 3%	$917	$47.5	$965

[a] Monetized fuel consumption impacts using pre-tax fuel prices are presented in Section III.F as negative costs of the analyzed vehicle program. Monetized impacts include increased fuel expenditures resulting from the rebound effect but do not include the value placed on that additional driving as discussed in Section III.E.

As shown in Table III-9, we are projecting very large monetized impacts from reduced fuel consumption from the analyzed scenario. Since monetized fuel impacts accrue to vehicle owners, some would argue that fuel savings already have been taken into account when consumers purchase new vehicles, i.e., there are other tradeoffs associated with consumers rejecting greater vehicle efficiency and, therefore, fuel savings would be offset by other consumer losses. EPA believes that this is a complex issue and that there are a number of reasons why consumers undervalue fuel savings, including but not limited to: many vehicle purchasers only consider the fuel savings over the time they expect to own a vehicle and thus do not consider the entire savings that will occur over the life of the vehicle; many consumers have imperfect information on which to evaluate the overall economic impacts of more efficient technologies; the consumer's transaction costs associated with obtaining, processing, and calculating fuel savings may outweigh the benefits of lower fuel costs; and, finally, there are complex trade-offs involved in a new vehicle purchase, many of which are completely unrelated to, but may overwhelm cost-benefit decision making.[o,p]

3. VMT Rebound Effect

The rebound effect generally refers to the change in vehicles miles traveled (VMT) resulting from a change in the per mile cost of driving. This response may result from a number of factors, but the two sources usually considered are changes in fuel prices and vehicle fuel efficiency. Economic theory predicts that decreasing the cost of a good will increase demand for that good, assuming all other factors are held constant.
Many factors influence the magnitude of the rebound effect, including the population of adult drivers, the level of urbanization, income levels, and the amount of congestion. For this analysis, we have used a VMT rebound effect value of 15 percent and present the actual VMT rebound miles in Section II of this memorandum (see Table II-7).

C. Benefits of Reducing Green House Gas Emissions

Potential GHG emissions standards would result in GHG emissions reductions. CO2 and other GHGs mix well in the atmosphere, regardless of the location of the source, with each unit of emissions affecting global regional climates; and therefore, influencing regional biophysical systems. The effects of changes in GHG emissions are felt for decades to centuries given the atmospheric lifetimes of GHGs. Quantifying the monetary and non-monetary benefits of GHG emissions reductions over this spatial and temporal scale is challenging. We have a detailed discussion of our approach in a Technical Support Document published for the GHG ANPR.[q] Table III-10 summarizes our updated estimates of the societal benefits that would be possible. For the numbers shown in Table III-10, we have used a single point value for the social cost of carbon of $40 per metric ton (for emission changes in year 2007, in 2006 dollars, grown at a rate of 3% per year) that reflects potential international, including domestic, benefits of climate change mitigation. For this updated 4 % per year analysis, we utilized this single point value, which is the mean value from a global meta analysis for a 3% discount rate discussed in section III.G of the GHG Advance Notice, for illustrative purposes. Given the distribution of benefits over time, we believe that values associated with lower discount rates should also be considered. For example, for a 2% discount rate for year 2007, the mean value from the meta analysis is $68 per metric ton. As discussed in section III.G of the GHG Advance Notice, another approach to developing a value for the social coast of carbon is to consider only the domestic benefits of climate change mitigation. The two approaches – use of domestic or international estimates –

[o] For a discussion on consumer undervaluation of fuel savings, see Greene, David L., Patterson, Philip D., Singh, Margaret, and Li, Jia 2005. "Feebates, Rebates, and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy," Energy Policy, 33: 757-775.
[p] For a discussion on market failures associated with energy efficiency and consumer behavior, see Sanstad, Alan H. and Richard B. Howarth. 1994. "'Normal' Markets, Market Imperfections, and Energy Efficiency;" Energy Policy 22(10): 811-818.
[q] See the GHG ANPR Technical Support Document on Benefits of Reducing GHG Emissions.

are discussed in section III.G of the Advance Notice. There is considerable uncertainty regarding the valuation of the social cost of carbon, and in future analyses EPA would likely utilize a range of values (see section III.G of the GHG Advance Notice). The GHG Advance Notice asks for comment on the appropriate range of values to use to quantify the benefits of GHG emission reductions, including the use of a global, or international, value. While OMB Guidance allows for consideration of international effects, it also suggests that the Agency consider domestic benefits in regulatory analysis. Section III.G of the GHG Advance Notice discusses very preliminary ranges for U.S. domestic estimates with means of $1 and $4 per metric ton in 2007, depending on the discount rate. It should also be noted that the IPCC has concluded that current estimates of the social cost of carbon are very likely to underestimate the benefits of CO2 reductions. Table III-11 presents the estimated societal benefits of GHG reductions using the $1, $4, and $68 per metric ton values discussed here (again, these values are for emission changes in year 2007, in 2006 dollars, grown at a rate of 3% per year).

Table III-10. Estimated GHG Reductions & Monetized Benefits
4% per Year Scenario

Calendar Year	Tailpipe CO2 (MMT CO2)	A/C Efficiency (MMT CO2)	A/C Leakage (MMT CO2-equivalent)	Total (MMT CO2-equivalent)	Social Cost of Carbon ($/ton CO2)	GHG Benefit ($Billions)
2011	1.8	0.0	0.0	1.8	$45	$0.1
2015	33.3	3.2	7.2	43.8	$51	$2.2
2020	145.0	9.4	21.4	175.9	$59	$10.3
2030	395.4	20.6	50.0	466.0	$79	$36.8
2040	537.9	26.8	70.0	634.8	$106	$67.3
NPV, 7%						$171.7
NPV, 3%						$402.0

Note: MMT=Million Metric Tons

Table III-11. Estimated GHG Monetized Benefits at Different Social Cost of Carbon Values
Estimated GHG Reductions are as shown in Table III-10

Calendar Year	Social Cost of Carbon ($/ton CO2)	GHG Benefit ($Billions)	Social Cost of Carbon ($/ton CO2)	GHG Benefit ($Billions)	Social Cost of Carbon ($/ton CO2)	GHG Benefit ($Billions)
2011	$1	$0.0	$5	$0.0	$77	$0.1
2015	$1	$0.1	$5	$0.2	$86	$3.8
2020	$1	$0.3	$6	$1.0	$100	$17.6
2030	$2	$0.9	$8	$3.7	$134	$62.5
2040	$3	$1.7	$11	$6.7	$180	$114.5
NPV, 7%		$4.3		$17.2		$291.9
NPV, 3%		$10.1		$40.2		$683.5

D. Energy Security Impacts

One impact of the proposed vehicle standards in the U.S. is that it reduces U.S. oil imports. A reduction of U.S. oil imports reduces both financial and strategic risks associated with a potential disruption in supply or a spike in cost of a particular energy source. This reduction in risks is a measure of improved energy security. In Section VI of the LDV TSD of the GHG ANPR, we present our estimate of the impact of potential GHG emissions standards on the importation of oil and finished transportation fuels. We also describe a methodology for estimating the energy security benefits of reduced U.S. oil imports. Here, we present our latest estimate of the energy security benefits associated with potential GHG standards. We seek comment on all aspects of our energy security discussion.

Table III-12 presents the total benefits resulting from the reduction in U.S. imports of finished petroleum products and crude oil from the potential program. To develop these estimates, the volume reductions, from Table III-8, were multiplied by the energy security premium value of $12 per barrel ($0.295 per gallon in 2006 dollars; there are 42 gallons in a barrel).

Table III-12. Total Benefits from Reduction in Oil Imports
($2006 billion)

Calendar Year	Fuel Impact (Billion gallons)	Fuel Impact (Billion barrels)	Benefits ($Billion)
2011	-0.2	0.0	$0.1
2015	-4.5	-0.1	$1.3
2020	-18.7	-0.4	$5.2
2030	-49.7	-1.2	$13.9
2040	-67.3	-1.6	$18.9
NPV, 7%			$67.2
NPV, 3%			$149.6

EPA recognizes that as the world price of oil falls in response to lower U.S. demand for oil, there is the potential for an increase in oil use outside the U.S. This so-called international oil "take back" effect is hard to estimate. Given that oil consumption patterns vary across countries, there will be different demand responses to a change in the world price of crude oil. For example, in Europe, the price of crude oil comprises a much smaller portion of the overall fuel prices seen by consumers than in the U.S. Since Europeans pay significantly more than their U.S. counterparts for transportation fuels, a decline in the price of crude oil is likely to have a smaller impact on demand. In many other countries, particularly developing countries, such as China and India, oil is used more widely in industrial and even electricity applications, although China and India's energy picture is evolving rapidly. Evolving trends in worldwide oil consumption patterns illustrates the difficulty in trying to estimate the overall effect of a reduction in world oil price. In the GHG Advance Notice, we request comments on how to estimate the potential impact of a reduction in world oil price.

E. Other Economic Impacts

There are other impacts associated with CO2 emissions standards and reduced fuel consumption. Lower fuel consumption would, presumably, result in fewer trips to the filling station to refuel and, thus, time saved. The rebound effect produces additional benefits to vehicle owners in the form of consumer surplus from the increase in vehicle-miles driven, but may also increase the societal costs associated with traffic congestion, motor vehicle accidents, and noise. These effects are likely to be relatively small in comparison to the value of fuel saved as a result of new GHG standards, but they are nevertheless important to include. We present a detailed discussion of these impacts in Section VI of the LDV TSD of the GHG ANPR and present here a summary of our updated estimates of these impacts.[r]

[r] We have made one change worth noting since our analysis presented in the LDV TSD to the GHG ANPR) in that we have updated the estimates of noise, congestion, and accidents for cars. Our updated analysis uses $0.052 per mile for congestion, $0.023 per mile for accidents, and $0.001 per mile for noise. The truck values remain unchanged from those presented in the LDV TSD to the GHG ANRP. Our updated-car and truck values are consistent with NHTSA's May 2, 2008, CAFE proposal.

Table III-13 summarizes for the 4% per year scenario these other economic impacts assuming AEO2007 fuel prices. The fuel price is a factor in determining the value placed on additional driving as a result of the rebound effect.[s]

Table III-13. Estimated Economic Externalities Associated with the Analyzed GHG Program
4% per Year Scenario, AEO2007 Fuel Prices
($Billions of 2006 dollars)

Year	Reduced Refueling	Value of Increased Driving[a]	Congestion	Accidents	Noise	Annual Quantified Benefits
2011	$0.1	$0.1	$0.0	$0.0	$0.0	$0.1
2015	$1.1	$0.9	-$0.6	-$0.3	$0.0	$1.1
2020	$4.7	$3.7	-$2.6	-$1.3	$0.0	$4.4
2030	$12.4	$10.8	-$7.1	-$3.5	-$0.1	$12.5
2040	$16.8	$14.7	-$9.6	-$4.7	-$0.1	$17.1
NPV, 7%	$59.9	$50.5	-$33.9	-$16.6	-$0.5	$59.3
NPV, 3%	$133	$114	-$76.0	-$37.2	-$1.1	$133

[a] Calculated using pre-tax fuel prices.

F. Summary of Costs and Benefits

In this section we present a summary of costs, benefits, and net benefits of our updated 4% per year scenario. This section summarizes the information presented in Sections III.A through III.E. Here, we present fuel consumption impacts as negative costs of the potential vehicle program rather than presenting them as positive savings as we did in Section III.B.

[s] The term for the consumer surplus on the added driving that stems from the rebound effect is "travel value." It is calculated using the standard "rule of one-half" approximation in economics, which is one-half the reduction in fuel cost per mile driven times the resulting rebound miles driven. The value of additional driving as calculated here includes that consumer surplus and the dollars paid for the fuel burned over the rebound miles driven. Given the nature of this metric and the way it is calculated, it varies by fuel price.

Table III-14. Estimated Societal Costs of the Potential Vehicle CO_2 and A/C Efficiency Program
4% per Year Scenario, AEO2007 Fuel Prices[a]
(Billions of 2006 dollars)

Calendar Year	Tailpipe CO2 Compliance	AC CO2 Compliance	Tailpipe CO2 Fuel[a]	AC CO2 Fuel[a]	Quantified Annual Costs[a]
2011	$1.5	$0.0	-$0.4	$0.0	$1.2
2015	$8.0	$1.2	-$6.7	-$0.6	$1.9
2020	$34.1	$1.0	-$29.8	-$1.8	$3.4
2030	$29.1	$1.1	-$87.6	-$4.3	-$61.8
2040	$32.3	$1.2	-$119.0	-$5.7	-$91.1
NPV, 7%	$208	$9.5	-$407	-$21.7	-$212
NPV, 3%	$407	$17.4	-$917	-$47.5	-$540

[a] Fuel consumption impacts calculated using pre-tax fuel prices; negative values reflect savings.

Table III-15. Estimated Societal Costs of the Analyzed AC Leakage Program
(Billions of 2006 dollars)

Calendar Year	AC Leakage Compliance	AC Leakage Maintenance[a]	Quantified Annual Costs[a]
2011	$0.0	$0.0	$0.0
2015	$0.7	-$1.2	-$0.5
2020	$0.5	-$0.9	-$0.4
2030	$0.6	-$1.0	-$0.5
2040	$0.6	-$1.2	-$0.5
NPV, 7%	$4.9	-$9.1	-$4.2
NPV, 3%	$9.1	-$16.7	-$7.6

[a] Negative values reflect savings.

Table III-16. Summary of Societal Costs of the Analyzed Tailpipe CO_2 & AC Programs
(Billions of 2006 dollars) [a]

Calendar Year	AEO2007 Fuel Prices
2011	$1.2
2015	$1.4
2020	$3.0
2030	-$62.3
2040	-$91.6
NPV, 7%	-$216
NPV, 3%	-$548

[a] Negative values reflect savings.

Table III-17. Estimated Societal Benefits of the Analyzed Tailpipe CO_2 & AC Programs
4% per Year Scenario, AEO2007 Fuel Prices[a]
(Billions of 2006 dollars)

Calendar Year	Reduced GHG Emissions	Reduced Oil Imports	Reduced Refuel-ing	Value of Increased Driving[b]	Conges-tion	Acci-dents	Noise	Quanti-fied Annual Benefits
2011	$0.1	$0.1	$0.1	$0.1	$0.0	$0.0	$0.0	$0.2
2015	$2.2	$1.3	$1.1	$0.9	-$0.6	-$0.3	$0.0	$4.6
2020	$10.3	$5.2	$4.7	$3.7	-$2.6	-$1.3	$0.0	$20.0
2030	$36.8	$13.9	$12.4	$10.8	-$7.1	-$3.5	-$0.1	$63.2
2040	$67.3	$18.9	$16.8	$14.7	-$9.6	-$4.7	-$0.1	$103
NPV, 7%	$172	$67.2	$59.9	$50.5	-$33.9	-$16.6	-$0.5	$298
NPV, 3%	$402	$150	$134	$114	-$76.0	-$37.2	-$1.1	$684

[a] Note that impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. For example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics). Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.
[b] Calculated using pre-tax fuel prices.

Table III-18. Estimated Societal Benefits of the Analyzed Tailpipe CO_2 & AC Programs
Excluding the Social Cost of Carbon
4% per Year Scenario, AEO2007 Fuel Prices[a]
(Billions of 2006 dollars)

Calendar Year	Reduced GHG Emissions	Reduced Oil Imports	Reduced Refuel-ing	Value of Increased Driving[b]	Conges-tion	Acci-dents	Noise	Quanti-fied Annual Benefits
2011	$0	$0.1	$0.1	$0.1	$0.0	$0.0	$0.0	$0.1
2015	$0	$1.3	$1.1	$0.9	-$0.6	-$0.3	$0.0	$2.4
2020	$0	$5.2	$4.7	$3.7	-$2.6	-$1.3	$0.0	$9.6
2030	$0	$13.9	$12.4	$10.8	-$7.1	-$3.5	-$0.1	$26.4
2040	$0	$18.9	$16.8	$14.7	-$9.6	-$4.7	-$0.1	$35.9
NPV, 7%	$0	$67.2	$59.9	$50.5	-$33.9	-$16.6	-$0.5	$127
NPV, 3%	$0	$150	$134	$114	-$76.0	-$37.2	-$1.1	$282

[a] Note that impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. For example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics), and have not included a monetized value for the social cost of carbon. Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.
[b] Calculated using pre-tax fuel prices.

Table III-19. Quantified Net Benefits of the Analyzed Tailpipe CO_2 & AC Programs
4% per Year Scenario, AEO2007 Fuel Prices[a]
(Billions of 2006 dollars)

Calendar Year	Quantified Annual Costs[b]	Quantified Annual Benefits[b]	Quantified Net Benefits[b]
2011	$1.2	$0.2	-$1.0
2015	$1.4	$4.6	$3.2
2020	$3.0	$20.0	$16.9
2030	-$62.3	$63.2	$126
2040	-$91.6	$103	$195
NPV, 7%	-$216	$298	$514
NPV, 3%	-$548	$684	$1,232

[a] Note that impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. For example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics). Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.
[b] Fuel impacts were calculated using pre-tax fuel prices.

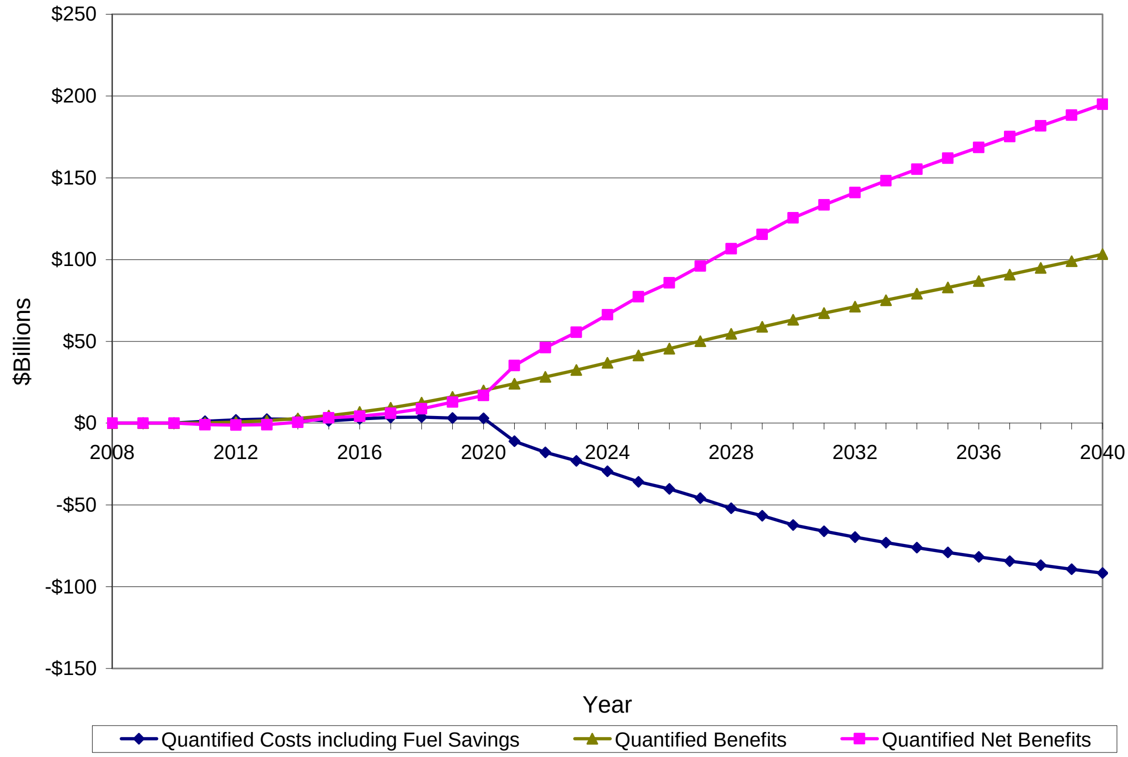
Table III-20. Quantified Net Benefits of the Analyzed Tailpipe CO_2 & AC Programs
Excluding the Social Cost of Carbon
4% per Year Scenario, AEO2007 Fuel Prices[a]
(Billions of 2006 dollars)

Calendar Year	Quantified Annual Costs[b]	Quantified Annual Benefits[b]	Quantified Net Benefits[b]
2011	$1.2	$0.1	-$1.0
2015	$1.4	$2.4	$1.0
2020	$3.0	$9.6	$6.6
2030	-$62.3	$26.4	$88.7
2040	-$91.6	$35.9	$128
NPV, 7%	-$216	$127	$343
NPV, 3%	-$548	$282	$830

[a] Note that impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. For example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics), and have not included a monetized value for the social cost of carbon. Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.
[b] Fuel impacts were calculated using pre-tax fuel prices.

Figures III-1 and III-2 present the quantified costs and benefits for the 4% per year scenario with and without the social cost of carbon, respectively. These figures present the same information presented in Tables III-19 and III-20, respectively. As such, the same cautions as regards the quantification of all benefits—as noted by footnote a to Tables III-19 and III-20—apply to the figures as well.

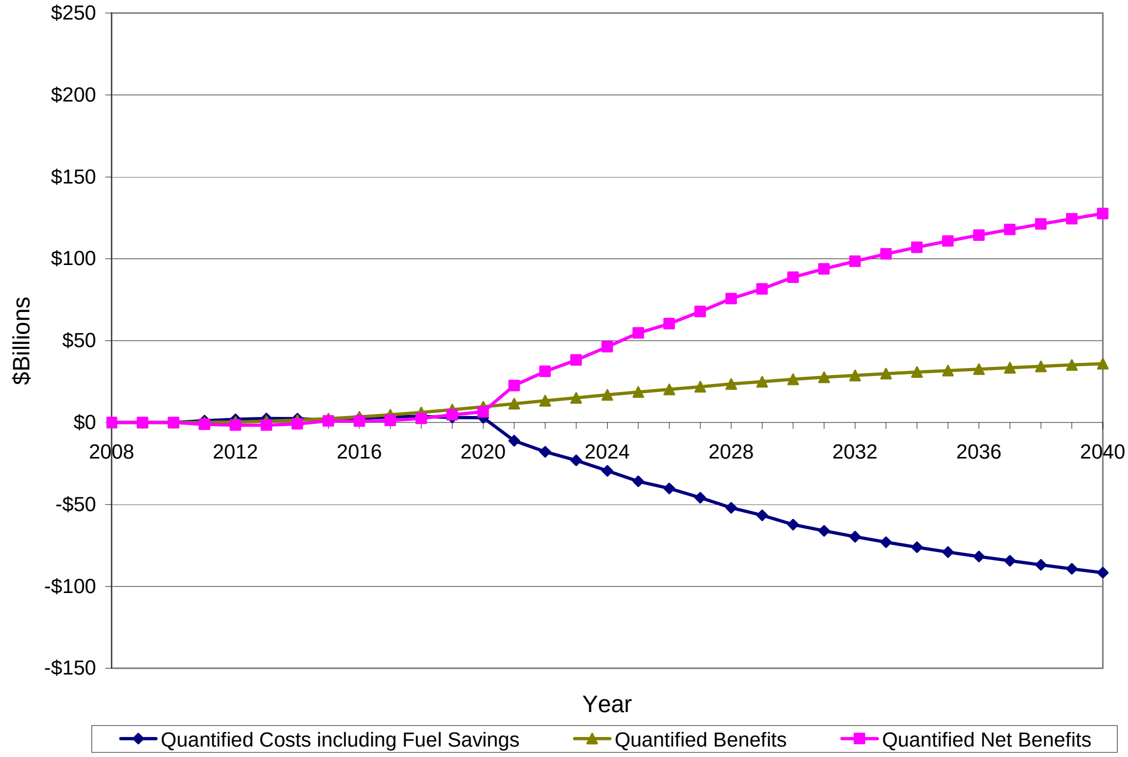
Figure III-1. Quantified Net Benefits of the Analyzed Tailpipe CO_2 & AC Programs
4% per Year Scenario, AEO2007 Fuel Prices[a, b]



[a] Note that impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. For example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics). Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.

[b] Fuel impacts were calculated using pre-tax fuel prices.

Figure III-2. Quantified Net Benefits of the Analyzed Tailpipe CO2 & AC Programs
Excluding the Social Cost of Carbon
4% per Year Scenario, AEO2007 Fuel Prices[a, b]



[a] Note that impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. For example, we have not quantified the co-pollutant impacts (PM, ozone, and air toxics), and have not included a monetized value for the social cost of carbon. Societal benefits exclude all fuel taxes because they represent transfer payments. In addition, we have not included the increased costs nor the GHG emissions of electricity associated with the use of plug-in electric hybrid vehicles. We have also not quantified the costs and/or benefits associated with changes in consumer preferences for new vehicles.
[b] Fuel impacts were calculated using pre-tax fuel prices.

Appendix IIIA. Automotive Dealer Inventory Costs

For our analysis, we assume a dealership's inventory cost consists primarily of the floor-plan interest expense. Property tax and insurance costs will have a small influence on the overall expense, but each significantly varies depending on the dealership's physical location and method of insurance.

The floor-plan interest expense is determined by the value of the new and used vehicle inventory and interest rates. The dealership can influence the value of their inventory through inventory levels but they have little control over interest rates. Vehicle manufacturers often provide financial support to dealerships for floor-plan interest expenses. For this analysis, we will use the total interest expense and will not account for manufacturer support.

In summary, we will conservatively set the automotive dealer inventory expense ratio at 0.9% of vehicles sales revenue. This value is determined from the National Automotive Dealers Association (NADA) Average Dealership Profiles and financial statements from AutoNation Annual Reports. The expense ratios fluctuate depending on interest rates and inventory levels, but we expect future ratios to remain relatively constant because dealers have a stronger incentive to manage their inventory levels as interest rates rise. Figure IIIA-1 below summarizes our analysis.

Table IIIA-1. Automotive Dealer Inventory Costs

AutoNation Annual Reports (1)			
2001	New Vehicle Sales	$	11,695,000
	Used Vehicle Sales	$	3,787,000
	Floor-plan Inventory Costs	$	126,700
	Inventory Cost % of Sales		0.8%
2002	New Vehicle Sales	$	12,000,000
	Used Vehicle Sales	$	3,883,000
	Floor-plan Inventory Costs	$	74,800
	Inventory Cost % of Sales		0.5%
2006	New Vehicle Sales	$	11,163,000
	Used Vehicle Sales	$	4,518,000
	Floor-plan Inventory Costs	$	142,000
	Inventory Cost % of Sales		0.9%
2007	New Vehicle Sales	$	10,995,000
	Used Vehicle Sales	$	4,206,000
	Floor-plan Inventory Costs	$	142,000
	Inventory Cost % of Sales		0.9%
NADA Average Dealership Profile (2)			
2001	New Vehicle Sales	$	18,808,644
	Used Vehicle Sales	$	9,187,234
	Floor-plan Inventory Costs	$	101,800
	Inventory Cost % of Sales		0.4%
2006	Floor-plan Inventory Cost per Vehicle (3)	$	160
	Used Car Average Selling Price	$	15,518
	New Car Average Selling Price	$	28,451
	% Used Vehicle Sales		33%
	% New Vehicle Sales		67%
	Weighted Avg. Selling Price	$	24,181
	Inventory Cost % of Sales		0.7%

(1) http://www.corporate-ir.net/ireye/ir_site.zhtml?ticker=AN&script=700
(2) www.nada.org
(3) Henry, Jim. *Are Model-Year Closeouts a Good Buy?* August 15, 2007. http://www.msnbc.msn.com/id/20247967/page/2/ (May 21,2008)

Appendix III.B. Air Conditioning Leakage and Indirect Emissions Reductions and Relevant Costs/Savings

Current Impact of A/C Use on Fuel Consumption

Three studies have been performed in recent years that estimate the impact of A/C use on the fuel consumption of motor vehicles. In the first study, the National Renewable Energy Laboratory (NREL) and the Office of Atmospheric Programs (OAP) within EPA have performed a series of A/C related fuel use studies.[t] The energy needed to operate the A/C compressor under a range of load and ambient conditions was based on testing performed by Delphi, an A/C system supplier. They used a vehicle simulation model, ADVISOR, to convert these loads to fuel use over the EPA's FTP test cycle. They developed a personal "thermal comfort"-based model to predict the percentage of drivers which will turn on their A/C systems under various ambient conditions. Overall, NREL estimated A/C use to represent 5.5% of car and light truck fuel consumption in the U.S.

In the second study, ARB estimated the impact of A/C use on fuel consumption as part of their GHG emission rulemaking.[u] The primary technical analysis utilized by ARB is summarized in a report published by NESCCAF for ARB. The bulk of the technical work was performed by two contractors, AVL Powertrain Engineering and Meszler Engineering Services. This work is founded on that performed by NREL-OAP. Meszler used the same Delphi testing to estimate the load of the A/C compressor at typical ambient conditions. The impact of this load on onroad fuel consumption was estimated using a vehicle simulation model developed by AVL, the CRUISE model, which is more sophisticated than ADVISOR. These estimates were made for both the EPA FTP and HFET test cycles. (This is the combination of test cycle results used to determine compliance with NHTSA's current CAFE standards.) NREL's thermal comfort model was used to predict A/C system use in various states and seasons.

The NESCAFF results were taken from Table 3-1 of their report and are summarized in Table III.B-1.

Table III.B-1. CO2 Emissions Over 55/45 FTP/HFET Tests and From A/C Use (g/mi)

	Small Car	Large Car	Minivan	Small Truck	Large Truck
55/45 FTP/HFET	278	329	376	426	493
Indirect A/C Fuel Use	16.8	19.1	23.5	23.5	23.5
Total	294.8	348.1	399.5	449.5	516.5
Indirect A/C Fuel Use	5.7%	5.5%	5.9%	5.2%	4.6%

[t] Johnson, Valerie H., "Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach," SAE 2002-01-19574, 2002. And
Rugh, John P, Valerie Hovland, and Stephen O. Andersen, "Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning," Mobile Air Conditioning Summit, Washington DC., April 14-15, 2004.
[u] California Environmental Protection Agency Air Resources Board, "STAFF REPORT: Initial statement of reasons for proposed rulemaking, public hearing to consider adoption of regulations to control greenhouse gas emissions from motor vehicles," 2004.

NESCAFF estimated that nationwide, the average impact of A/C use on vehicle fuel consumption use ranged from 4.6% for a large truck or SUV to 5.9% for a minivan of total CO2 emissions over a 55%/45% weighting of CO2 emissions over EPA's FTP and HFET tests plus the A/C fuel use (hereafter referred to simply as FTP/HFET). .For the purposes of this analysis of A/C system fuel use, the percentage of CO2 emissions and fuel use are equivalent, since the type of fuel being used is always gasoline.[v]

In order to compare the NESCCAF and ARB estimates to that of NREL-OAP, we developed weighting factors for the five vehicle classes. NESCCAF presented sales percentages for the five vehicle classes in Table 2-1 of their report. These are shown below in Table A.I-2. (Since these sales percentages do not sum to 100% (possibly due to round-off or because some vehicles do not fit into any of the five categories) we normalized these percentages so that they summed to 100%.) We then weighted the car and truck categories by their lifetime VMT, normalized to that of cars. [w] This meant a relative weighting factor for the three truck categories of 1.11 relative to a factor of 1.0 for cars. We then determined the percentage of lifetime VMT represented by each vehicle class. These estimates are shown on the last line of Table III.B-2.

Table III.B-2. Sales and VMT by Vehicle Class

	Small Car	Large Car	Minivan	Small Truck	Large Truck
NESCCAF sales	22%	25%	7%	23%	21%
Normalized NESCCAF sales	22.4%	25.5%	7.1%	23.5%	21.4%
Lifetime VMT weighting factor	1.00	1.00	1.11	1.11	1.11
VMT	21.2%	24.1%	7.5%	24.6%	22.5%

Using the percentages of VMT represented by each vehicle class, we weighted the A/C fuel use impacts of NESCCAF and ARB and determined that they represent 5.3% and 4.2% of fuel use over the FTP/HFET, respectively, including the A/C fuel use.

In the final study, EPA evaluated the impact of A/C use on fuel consumption as part of its recent rulemaking which revised the onroad fuel economy labeling procedures for new motor vehicles[x]. EPA estimated the impact of the A/C compressor on fuel consumption from vehicle emission measurements taken over its SC03 emissions test. SC03 is a 10 minute test where the vehicle is operated at city speeds, at 95 degrees F, 40% relative humidity and a solar load of 850 Watts/m^2. In addition, prior to the test, the vehicle has been pre-heated for 10 minutes under these conditions, so the interior cabin starts the test at an elevated temperature. Testing of 500 late model vehicles over both the FTP and SC03 test cycles indicated that fuel consumption was

[v] Because NESCCAF estimated A/C fuel use nationwide, while ARB focused on that in California, we will focus on comparing the NESCCAF and EPA methodologies and results below.

[w] Based on annual mileage per vehicle from the Volpe Model discounted at 7% per year. Discounted lifetime mileages are 102,838 for cars and 114,350 for trucks.

[x] Fuel Economy Labeling of Motor Vehicles: Revision to Improve Calculation of Fuel Economy Estimates; Final Rule, 71 FR 77872, December 27, 2006.

27% higher on the SC03 test than over a combination of Bag 2 and Bag 3 fuel consumption designed to match the vehicle load of the SC03 test. EPA assumed that the A/C compressor was engaged 100% of the time over SC03 due to the high ambient temperature, short duration and vehicle pre-heating test conditions.

EPA does not measure A/C emissions at highway speeds. Thus, this impact had to be estimated based on the city-like SC03 test. EPA tested six vehicles (four conventional and two hybrid) over the FTP, SC03, and HFET emission tests in a standard test cell at 60 F, 75 F, and 95 F with and without the A/C system operating in order to assess the relative impact of A/C use at city and highway speeds. The data indicated that it was more accurate to assume that the impact of the A/C compressor on fuel consumption was the same at city and highway speeds when compared in terms of fuel burned per unit time than when compared in terms of fuel use per mile. Thus, EPA estimated the impact of A/C in terms of fuel use per mile at highway speeds by multiplying the A/C related fuel use at city speeds by the ratio of the speed of the city test to that of the highway test. For average driving in the U.S., this ratio was estimated to be 0.348. The result was that the impact of engaging the A/C compressor 100% of the time at highway speeds increased fuel use by 9.7%, versus 27% at city speeds. These percentages are based on the assumptions that fuel is only consumed during warmed up driving, hence ignoring cold start fuel use.

EPA's estimate in the Fuel Economy Labeling rule of in-use A/C compressor engagement was based on a test program covering 1004 trips made by 19 vehicles being operated by their owners in Phoenix, Arizona.[y] The results of this testing were correlated against heat index, a function of temperature and humidity, and time of day, to represent solar load. Nationwide, EPA estimated that the A/C compressor was engaged 15.2% of the time. However, much of this time, the ambient conditions are less severe than those of the SC03 test. Therefore, EPA reduced this percentage to 13.3% to normalize usage to the load experienced during SC03 conditions. Nationwide, EPA estimated that the A/C system was turned on an average of 22.9% of the time.

This estimate does not include defroster usage, while the NREL-OAP and ARB-NESCCAF estimates do include this. EPA considered adding the impact of defroster usage based in large part on NREL-OAP estimates. NREL-OAP estimates that the defroster is in–use 5.4% of the time. However, the load of the compressor under defrosting conditions is very low. EPA estimated that including defroster usage would increase the percentage of time that the compressor was engaged at a load equivalent to that over SC03 from 13.3% to 13.7%. While this defroster impact was quantified, EPA decided not to include it in its final 5-cycle fuel economy formulae. Based on the A/C usage factor of 13.3% and EPA's 5-cycle formulae, A/C system use increases onroad fuel consumption by 2.4%. Including defroster use increased this value to 2.5%.

Comparing the results of the three studies, the EPA estimate gives the smallest A/C system impact, while the NREL-OAP estimate is the highest. The NESCCAF and NREL-OAP

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[y] Koupal, J., "Air Conditioning Activity Effects in MOBILE6" EPA Report Number M6.ACE.001, 1998

studies give very similar results. The overall difference between the estimates is more than a factor of two.

It is difficult to directly compare the three estimates. The NREL-OAP and ARB-NESCCAF methodologies are very similar. However, the EPA methodology is quite different, as will be discussed further below. This complicates the comparison, making it difficult to compare smaller segments of each study directly. In addition, as will be seen, each study utilizes assumptions or estimates which contain uncertainties. These uncertainties are not well characterized. We conclude that it is not possible to determine a single best estimate of A/C fuel use from these studies. However, we were able to identify a couple of aspects of the studies which could be improved for the purpose of this analysis. Doing so, we were able to reduce the overall difference between the studies by roughly one half. This process is described below.

The first step in this comparison will reduce the number of studies from three to two. The NREL-OAP and ARB-NESCCAF methodologies are very similar, since both utilize the NREL-OAP comfort model to estimate A/C usage onroad. They also both use essentially the same estimate of A/C compressor load from Delphi to estimate the load which the compressor puts on the engine. ARB-NESCCAF utilized the vehicle simulation tool, AVL's CRUISE model, to estimate the impact of A/C load on fuel economy, while NREL employed the ADVISOR model (both models assumed a rather simple A/C system load). In addition, ARB-NESCCAF modeled both city and highway driving (i.e., the 55/45 FTP/HFET), while NREL-OAP only modeled the FTP. Thus, we will focus on the NESCCAF estimate over that of NREL-OAP, though as mentioned above, their overall estimates are very similar. Also, because NESCCAF estimated A/C fuel use nationwide, while ARB focused on that in California, we will focus on comparing the NESCCAF and EPA methodologies and results below. With respect to EPA's estimates from the 2006 rulemaking, we will focus on its estimate including defroster use, since NESCCAF considered defroster use, as well. As way of reminder, on a nationwide average basis, the NESCAFF estimates indicate that A/C use represents 5.3% of total fuel consumption, while EPA estimates this at 2.5%.

NESCCAF and EPA break down the factors which determine the impact of A/C use on onroad fuel consumption differently. NESCCAF breaks down the process into three parts. The first is the frequency that drivers turn on their A/C system. The second is the average load of the A/C compressor at various ambient conditions, including compressor cycling. The third is the impact of this average A/C compressor load on fuel economy over various driving conditions.

In contrast, in the fuel labeling rulemaking, EPA breaks down the process into two parts. The first is the frequency that the A/C compressor is engaged at various ambient conditions. This includes both the frequency that the driver turns on the A/C unit and the frequency that the compressor is engaged when the system is turned on. The second is the impact of the A/C compressor on fuel economy over various driving conditions when the compressor is engaged.

The most direct comparison that can be made between the two studies is the estimate of A/C system use. Because EPA measured both A/C system on/off condition as well as compressor engaged/disengaged condition in the Phoenix test program, it is possible to compare the percentage of A/C system use as measured in the Phoenix study and extrapolated to the U.S. to that of the NREL-OAP comfort model.

In its rulemaking analysis, based on its Phoenix study and extrapolation procedure, EPA estimated that on average, the A/C unit was turned on 22.9% of the time. This does not include defroster use. There, EPA also determined that the NREL-OAP thermal comfort model predicts a higher percentage of 29%, again ignoring defroster use. Since EPA utilized NREL-OAP's estimate of defroster use in its analysis, this estimate does not contribute to the difference in the two estimates. Also, fuel use is very low during defroster use compared to air conditioning at high ambient temperatures, so the difference between the 22.9% and 29% estimates is the most relevant factor. By itself (ignoring fuel use during defrosting), this difference would cause the NESCCAF A/C fuel use estimate to be 27% higher than that of EPA. The overall difference between the 5.3% and 2.5% estimates is 112%. Thus, the difference in estimated A/C system use explains about one-fourth of the overall difference between the two studies.

NREL's thermal comfort model for vehicle A/C use is based on a model designed to the represent the comfort of a person walking outside and wearing one of two different sets of clothes. A number of assumptions had to be made in order to extrapolate this outdoor model to a person sitting in a vehicle. The predictions of NREL-OAP's thermal comfort model have not been confirmed with any vehicle/occupant testing and their air conditioner settings. Therefore, its predictions, while reasonable, are of an unknown accuracy.

EPA's Phoenix study was performed over a relatively short period of time, roughly seven weeks. It was conducted in only one city, Phoenix. Thus, the variation in climate evaluated was limited. The number of vehicles tested was also fairly small, nineteen. However, over 1000 trips were monitored by these 19 vehicles. EPA extrapolated the measured A/C compressor engagement under these limited ambient conditions to other conditions using a metric called the heat index, which combines temperature and humidity into a single metric. Heat index is conceptually similar to NREL-OAP's comfort model. This allowed the results found in the generally dry climate of Phoenix to be extrapolated to both cooler and more humid conditions typical of the rest of the U.S. No testing has yet been performed to confirm the accuracy of this extrapolation.

Given the two very different approaches to estimating vehicle A/C system use, it is notable that the difference in the two estimates is only a relative 27%. As both the EPA and NREL-OAP models of A/C system use involve assumptions or extrapolations which have not been verified, it is not possible to determine which one is more accurate. Thus, the differences in the EPA and ARB estimates of the impact of A/C use on onroad fuel consumption due to these two different sources of A/C usage cannot be resolved at this time.

With respect to the operation of the A/C compressor at various ambient and driving conditions, EPA bases its estimate on the Phoenix vehicle test study. This is subject to the same uncertainties described above, due mainly to the limited scope of the data. NREL-OAP relies on test results published by W.O. Forrest of Delphi. Forrest describes the factors which affect the load of the A/C system on the engine: the percentage of time the compressor is engaged, compressor displacement, compressor speed, air flow across the evaporator, engine operating condition and ambient conditions. The load curves presented by Forrest apply to a 210 cc compressor and show load as a function of compressor speed for six sets of ambient conditions. The loads include the effect of compressor cycling. However, no mention is made of airflow rates across the evaporator, which would vary with engine speed. It is not clear whether these curves were based on bench testing or onroad vehicle testing. Also, only one A/C system appears to have been tested. It is not clear how well these curves would apply to other manufacturers' systems, nor even to others produced by Delphi. Forrest states that the loads for other compressor displacements can be approximated by assuming that the load is proportional to compressor displacement. However, this is clearly an approximation and does not address differences inherent in particular A/C system applications. The fact that the NESCCAF analysis is based on the testing of only a single A/C system and does not address the effect of varying airflow rates under different driving conditions appears to be the largest sources of uncertainty in their estimate.

It is not possible to directly compare these two estimates of compressor operation. EPA's Phoenix study provides an estimate of the percentage of time that the compressor is engaged when the A/C system is on. On the other hand, compressor cycling is implicitly included in the Delphi load curves. Since the load curves of a continuous operating compressor were not presented, the degree of cycling cannot be determined. Thus, the effect of any differences in the NESCCAF and EPA estimates of compressor engagement cannot be quantified.

With respect to the impact of the A/C compressor load on fuel economy, EPA relies on a comparison of measured fuel economy over the two warmed up bags of its FTP test (when the A/C system is inoperative) and its SC03, A/C emissions test. The vehicles on both tests are run at city speeds. EPA based its estimates on the testing of over 600 recent model year vehicles. Thus, for the conditions addressed by the SC03 test, EPA's estimate of the impact of A/C system load on fuel economy is well supported. However, in order to combine this measurement with the Phoenix study, EPA needed an estimate of the percentage of time that the compressor was engaged during the SC03 test. The SC03 test does not include a measurement of this factor, so EPA had to estimate the percentage of time that the compressor was engaged during the test. As noted above, EPA assumed that the A/C compressor was engaged 100% of the time during the SC03 test given its short duration and the pre-heating of the vehicle. Thus, for a given ambient condition, if the compressor was estimated to be engaged 25% of the time, then the incremental amount of fuel used due to A/C system was 25% of the difference between the fuel use over the SC03 test and a 39%/61% weighting of the fuel use over Bags 2 and 3 of the FTP, respectively.

EPA has evidence to show that most vehicles' A/C compressors are engaged 100% of the time over SC03[z]. The vehicle pre-heating, short test duration and the requirement that the driver window be rolled down, make it extremely likely that the vehicle compartment never reaches a comfortable temperature by the end of the test. However, it is possible that the compressor still cycled to some degree during the test. All compressors shut down when the heat exchanger nears 32 F in order to avoid icing. The cold heat exchanger continues to cool the refrigerant

[z] Nam, E.K., "Understanding and Modeling NOx Emissions from Automobiles During Hot Operation," PhD Thesis, University of Michigan, 1999.

while the compressor is shut down, but the compressor is not putting an additional load on the engine and increasing fuel consumption. As it is impossible for the compressor to operate more than 100% of the time, any error in EPA's assumption can only lower the actual compressor use below 100%. If compressor engagement was lower than 100%, this would mean that fuel use at 100% compressor engagement would be higher than currently estimated. Thus, it is possible that this assumption that the A/C compressor is engaged 100% during SC03 is causing EPA's estimate of A/C fuel use to be under-estimated to some degree.

There are additional uncertainties involved in EPA's assumption that a vehicle's A/C fuel use is constant in terms of gallons per hour, and thus inversely proportional to vehicle speed when presented in terms of gallons per mile. EPA testing of six vehicles as part of the Fuel Economy Labeling rulemaking (used to estimate A/C compressor usage in highway driving conditions, as noted above) confirmed that A/C fuel use was roughly constant in terms of gallons per hour. However, this testing was performed in a standard emission test cell. Air flow through the engine compartment was the same at city and highway speeds. The city test was only 20 minutes long and the highway test was only 10 minutes long. There was also significant variability in the individual vehicle test results. Thus, while the testing showed that EPA's assumption was reasonable, there is an unknown degree of uncertainty associated with extrapolating the measured A/C fuel use at city speeds to highway speeds. One could attempt to quantify the uncertainty using the test results of the six vehicles. However, these vehicles were not randomly selected and two of the six vehicles were Prius hybrids. Thus, it is not clear how representative the results of a statistical analysis of these data would be.

An A/C load adjustment factor is also applied to account for the change in compressor load which occurs when the compressor is engaged at different temperatures. The study which developed this data data is based on an A/C model developed by Nam (2000)[aa].

NESCCAF starts with A/C compressor load curves which describe the A/C compressor load as a function of compressor speed for six ambient conditions. These curves, along with A/C - on percentages from the thermal comfort model, were used to interpolate between the six compressor load curves to estimate the load curves applicable to the ambient conditions existing during driving times for a large number of cities across the U.S. The resulting curves are averaged using the VMT estimated to occur in each city to produce a single load curve representing the entire U.S.

NESCCAF then input this national average load curve into AVL's CRUISE model to estimate the effect of A/C on fuel consumption over the FTP and HFET cycles. The CRUISE model simulates vehicle operation and fuel consumption over specified driving conditions. The load of the A/C compressor (based on bench testing) was added to the other loads being placed on the vehicle, such as inertia, friction, aerodynamic drag, etc. The A/C loads included the cycling of the compressor as a function of ambient condition. In actuality, the engine will experience the full load of the compressor at some times and no load at other times. This could produce a slightly different fuel use impact than applying the average load of the compressor all

[aa] Nam, E. K., "Understanding and Modeling NOx Emissions from Air Conditioned Automobiles," SAE Technical Paper Series 2000-01-0858, 2000.

of the time. However, this error is likely very small. The A/C load curves vary as a function of engine speed, but not vehicle speed. However, as air flow by the heat exchanger will vary as a function of vehicle speed, compressor cycling and evaporator cooling efficiency is likely to vary, as well. However, the degree of error associated with any of these simplifications is unknown.

A detailed comparison of this aspect of the two analyses would require reconstructing both models to produce A/C fuel use estimates for specific ambient conditions. This is beyond the scope of the study. Also, once the differences were known, it would still be difficult to decide which estimate was superior.

There is one aspect of each analysis which appears to be an improvement over the other. In addition to A/C, EPA evaluated a number of other reasons why onroad fuel economy differs from that measured over the FTP and HFET cycles. Among these were higher speed and more aggressive driving, ambient temperatures below 75 F, short trips, wind, under-inflated tires, ethanol containing fuel, etc. This does not affect the absolute volume of fuel used by the A/C system, but it does raise the total amount of fuel consumed onroad, effectively lowering the percentage of fuel due to A/C use.

NESCCAF estimated the impact of the A/C compressor load on fuel use during city and highway driving using the CRUISE model. While it is not clear that this is superior to EPA's SC03 data, the CRUISE model is likely more accurate for highway driving than an extrapolation of the SC03 data (i.e. EPA's six vehicle study described above). While CRUISE was not able to represent all aspects of vehicle operation, such as airflow across the evaporator, it does simulate the difference in engine speed and load between city and highway driving. This allows a detailed simulation of the A/C compressor speed during this driving, which is a primary factor in estimating A/C compressor load. EPA's extrapolation of the impact over SC03 essentially assumes that engine speed and airflow over the evaporator are the same during both city and highway driving, or that any differences cancel each other. This is unlikely. Therefore, NESCCAF's highway estimates are likely more accurate than EPA's.

Since the two analyses were performed so differently, the CRUISE results for highway driving cannot be simply substituted for EPA's estimates. However, one way to utilize the CRUISE highway results is to determine the ratio of the impact of the A/C load on fuel use over the HFET to that over the FTP. This ratio can then be substituted for EPA's assumption that the impact of A/C load is constant with time (inversely proportional to vehicle speed in terms of gallons per mile.

Adjusting the NESCCAF estimates for the other factors reducing onroad fuel economy relative to the FTP/HFET is straightforward. EPA found that all such factors, including A/C, reduced onroad fuel economy to 80% of the FTP/HFET. In other words, onroad fuel consumption is 25% higher (1/0.8) than over the FTP/HFET. Thus, the CO2 emissions over the FTP/HFET shown above in Table xxx are multiplied by a factor of 1.25 to represent onroad CO2 emissions. A/C fuel use is unaffected. A/C fuel use as a percentage of onroad fuel use is simply the ratio of the A/C fuel use divided by the estimated onroad fuel use. These figures are shown in Table III.B-3 below. The VMT weighted average of these percentages is 4.4%, 0.9% lower than the estimate presented above.

Table III.B-3. Adjusted NESCCAF CO2 Emissions Over 55/45 FTP/HFET Tests and From A/C Use (g/mi)

	Small Car	Large Car	Minivan	Small Truck	Large Truck
55/45 FTP/HFET	349	413	472	535	619
Indirect A/C Fuel Use	16.8	19.1	23.5	23.5	23.5
Indirect A/C Fuel Use	4.8%	4.6%	5.0%	4.4%	3.8%

Incorporating the relative impact of A/C load on fuel consumed over the HFET versus FTP cycles from CRUISE requires a few steps. Table III.B-3 shows the incremental CO2 emissions from the A/C compressor load from the CRUISE simulations of the FTP and HFET cycles. The top half of the table shows the incremental fuel use in terms of grams CO2 per mile. These figures were taken from Tables B-20 through B-23 of the NESCCAF report. For the large car, two base vehicles were simulated. We selected the vehicle with the conventional gasoline engine with variable valve timing and lift. The large truck was not modeled using CRUISE. Further in the study, Meszler assumed that the A/C fuel impact was proportional to compressor displacement. The large truck is assumed to have the same compressor displacement as the minivan and small truck. Thus, we estimated the A/C fuel impact for the large truck as the average of the impacts for the minivan and small truck. The bottom half of the table shows the incremental fuel use in terms of grams CO2 per minute. These figures were calculated by multiplying the A/C fuel impacts in grams per mile by the average speeds of the FTP and HFET cycles: 19.6 and 48.2 mph and converting hours to minutes. The final line of the table shows the ratio of the incremental fuel use in terms of grams CO2 per minute for the HFET cycle to that over the FTP.

Table III.B-4. Impact of A/C on Fuel Use: System

	Small Car	Large Car	Minivan	Small Truck	Large Truck
A/C impact: 100% A/C System On Time (g/mi)					
FTP	67.4	56.6	81.8	89.7	85.8
HFET	32.3	31.9	45.0	47.4	46.2
A/C impact: 100% A/C System On Time (g/minute (g/min))					
FTP	22.02	18.49	26.7	29.3	28.0
HFET	25.95	25.63	36.2	38.1	37.1
HFET/FTP (g/min)/(g/min)	1.18	1.39	1.35	1.30	1.32

As can be seen in the last line of Table III.B-4, the ratio of A/C CO2 emissions over the HFET to that over the FTP is greater than 1.0 for each of the five vehicles. VMT weighting the CO2 emissions for each of the five vehicle groups produces an average ratio of 1.30. EPA assumed that this ratio was 1.0. Thus, EPA likely underestimated the impact of A/C fuel use during highway driving by 30%. For the purposes of EPA's onroad fuel economy labeling rule, this under-estimation is small, because the impact of A/C on highway fuel economy is small. However, when estimating the impact of A/C fuel use, the difference is more significant. We adjusted EPA's five cycle formulae for estimating onroad fuel economy to reflect this 1.32

factor. The impact of A/C fuel use on onroad fuel economy including defrosting increased from 2.5% to 2.8%. Thus, instead of a range of 2.5-5.3% for the impact of A/C on onroad fuel consumption, we now have a range of 2.8-4.4%. The difference between the two estimates has been cut almost in half.

There is one more adjustment that should be made to both estimates. Both EPA and NESCCAF assume that all A/C systems are in working condition. However, as discussed elsewhere in this DRIA, A/C systems leak refrigerant, sometimes to the point where the system no longer works. The cost of repairing a leak can be significant, so vehicle owners do not always choose to repair the system. For its MOBILE6 emission model, EPA estimated the percentage of vehicles on the road with inoperative A/C systems as a function of vehicle age. Coupling these estimates with the amount of VMT typically driven by vehicles as a function of age, we estimate that 8% of all the VMT in the U.S. is by vehicles with inoperative A/C systems. These systems do not impact fuel consumption. Thus, both the NESCCAF and EPA estimates should be multiplied by 0.92. Doing this, we find that the impact of A/C on onroad fuel consumption is estimated to be 2.6-4.1%. The single best estimate is a simple average of this range, or 3.35%.

A/C refrigerant leakage emission rates and impacts

There have been several studies in the literature which have attempted to quantify the emissions (and impact) of air conditioner HFC emissions from light duty vehicles. We briefly discuss these in turn, and then describe the estimates used in the LDV TSD of the advance notice, and in the updated 4% per year scenario presented in the GHG ANPR, and in this memorandum.

Based on measurements from 300 European vehicles collected in 2002 and 2003, Schwarz and Harnisch estimate that the average HFC direct leakage rate from modern A/C systems was estimated to be 53 g/yr[bb]. This corresponds to a leakage rate of 6.9% per year. This was estimated by extracting the refrigerant from recruited vehicles and comparing the amount extracted to the amount originally filled (as per the vehicle specifications). The fleet and size of vehicles differs from Europe and the United States, so it is conceivable that vehicles in the United States could have a different leakage rate. The authors measured the average charge of refrigerant at initial fill to be about 747 grams (it is somewhat higher in the U.S., 770g), and that the smaller cars (684 gram charge) emitted less than the higher charge vehicles (883 gram charge). Moreover, due to the climate differences, the usage patterns vary between the two continents, which may influence leakage rates.

Vincent et al.(from the California Air Resources Board) estimated the in-use refrigerant leakage rate to be 80 g/yr[cc]. This is based on consumption of refrigerant in commercial fleets,

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[bb] Schwarz, W., Harnisch, J. 2003. "Establishing Leakage Rates of Mobile Air Conditioners." Prepared for the European Commission (DG Environment), Doc B4-3040/2002/337136/MAR/C1.
[cc] Vincent, R., Cleary, K., Ayala, A., Corey, R. 2004. "Emissions of HFC-134a from Light-Duty Vehicles in California." SAE 2004-01-2256.

surveys of vehicle owners and technicians. The study assumed an average A/C charge size of 950 grams and a recharge rate of 1 in 16 years (lifetime). The recharges occurred when the system was 52% empty and the fraction recovered at end-of-life was 8.5%.

The EPA publishes an inventory of greenhouse gases and sinks on an annual basis. The refrigerant emissions numbers that are used here, are from the model used to generate the emissions included in this EPA inventory source. The HFC refrigerant emissions from light duty vehicle A/C systems was estimated to be 53 Tg CO2 equivalent in 2005[dd]. The model used to estimate these values is called the Vintaging Model[ee]. The emissions estimated are checked based on the difference between the quantity of refrigerant produced and consumed through sales, service and retirement. The inventory of refrigerant emissions estimates (in metric tons and Tg CO2 equivalent) over a few calendar years are presented in the following table.

Table III.B-5. Annual HFC 134a refrigerant emissions from all light-duty vehicles in the United States. HFC emissions can be converted to CO2 equivalent by multiplying by 1300 GWP

Calendar Year	HFC Emissions (metric tons)	HFC emissions (Tg CO2 eq)
2005	40,851	53.1
2007	38,289	49.8
2017	39,561	51.4
2020	42,737	55.6
2030	55,279	71.9

In 2005, the refrigerant emissions account for about 4.3% of total greenhouse gases from light duty sources. The following table shows the breakdown of greenhouse gases as broken down by the different emissions processes in 2005. The emissions for the other pollutants on this table are described in other portions of this RIA. The baseline tailpipe CO2, N2O and CH4 emissions are from MOVES, the refrigerant emissions are from the Vintaging model, and the A/C CO2 emissions are from EPA and the National Renewable Energy Laboratory (NREL).

Table III.B-6. CO2 equivalent emissions from light duty vehicles broken up by source or process

Emissions source or process	Tg CO2 (equivalent)	Percentage of total
Tailpipe CO2 (w/o A/C)	1,097.3	89.7%
CO2 from A/C	38.0	3.1%
HFC134a (Leakage)	53.1	4.3%
N2O	33.4	2.7%
CH4	1.9	0.2%
Total	1,223.7	

From a vehicle standpoint, the Vintaging model assumes that 42% of the refrigerant emissions is due to direct leakage (or "regular" emissions), 49% for service and maintenance (or

[dd] EPA, 2007, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005. http://www.epa.gov/climatechange/emissions/usinventoryreport.html
[ee] Ibid, Annex 3.8.

"irregular" emissions), and 9% occurs at disposal or end-of-life as shown in the following table. These are based on assumptions of the average amount of chemical leaked by a vehicle every year, how much is lost during service of a vehicle (from garages and do-it-yourself practices), and the amount lost at disposal. These numbers vary somewhat over time based on the characteristics (e.g. average charge size and leakage rate) of each "vintage" of A/C systems, assumptions of how new A/C systems enter the market, and the number of vehicles disposed of in any given year.

Table III.B-7. Light duty vehicle HFC134a emissions in 2005 from Vintaging model. HFC emissions can be converted to CO2 equivalent by multiplying by 1300 GWP

Emission Process	HFC emissions (metric tons)	Fraction of total
Leakage	17,250	0.42
Maintenance/servicing	19,928	0.49
Disposal/end-of-life	3,672	0.09
Total	40,851	1.0

The Vintaging model assumes a leakage + servicing rate of 18% per year for modern vehicles running with HFC134a refrigerant. Applying the percentages above, this corresponds to a leakage rate of 7.6% per year and a servicing loss rate of 8.8% per year. The model also assumes an average refrigerant charge of 770 grams for vehicles sold in 2002 and later. The model does not currently assume that this charge size will change in the future; however, the model may be updated as new information becomes available. The emission rates are presented on the following table.

Table III.B-8. Annual in-use vehicle HFC134a emission rate from Vintaging model

Emission Process	Leak rate (%/year)	Leak rate (g/yr)
Leakage	7.6%	59
Servicing/maintenance	8.8%	68

The in-use leakage emissions rate of 59 g/yr is higher than Schwarz's European study and lower than CARB's study. Thus, it is within the range of results in the literature.

More recent research has shown that newer vehicle leakage emissions can be significantly lower than this amount. Measurements from relatively new (properly functioning and manufactured) Japanese vehicles indicated the leakage rate to be closer to 8.6 g/yr for single evaporator systems and 13.3 g/yr for dual evaporator systems[ff]. A weighted (test) average gives 9.9 g/yr. This study is based on 78 in-use vehicles (56 single evap, 22 dual evap) from seven Japanese auto makers driven in Tokyo and Nagoya from April, 2004 to December, 2005. The study also measured a higher emissions level of 16 g/yr for 26 vehicles in a hotter climate (Okinawa).

[ff] Ikegama, T., Kikuchi, K.. 2006. "Field Test Results and Correlation with SAEJ2727." Proceedings of the SAE 7th Alternative Refrigerant Systems Symposium.

We compared the Japanese results with emissions measured from European vehicles[gg]. The European vehicle emission rates were slightly higher than the Japanese fleet, but were consistent overall. To these emission rates, Atkinson et al, (2006) added a factor slightly increasing the emissions for the occasional defective parts and improper assembly to calibrate the revised SAE J2727 standards. The average emission rate from this analysis is 17.0 g/yr with a standard deviation of 4.4 g/yr. We adjust this rate up slightly by a factor proportional to the average European refrigerant charge to the average United States charge (i.e. 770/747 from the Vintaging model and Schwarz studies respectively). The newer vehicle emission rate is thus 18 g/yr for the average newer vehicle emissions.

The discrepancy between the new vehicle measurements and the in-use measurements is likely due to the normal wear and tear on components (deterioration), malfunctioning systems, and a few "high-emitters". High emitters are vehicles that emit large amount of R134a because the owner recharges the refrigerant frequently without repairing the cause of the leak or develops new leaks frequently (e.g., due to abnormal temperature extremes, driving conditions, etc.).

This naturally leads to the construction of a simple linear deterioration estimate for HFC leakage emissions over time, which is discussed in the following section.

[gg] Atkinson, W., Baker, J., Ikegami, T., Nickels, P. 2006. "Revised SAEJ2727: SAE Interior Climate Control Standards Committee Presentation to the European Commission."

A/C leakage deterioration

There are two mechanisms of deterioration that we model: the normal deterioration that results in increasing leakage and the "avoidable" deterioration of the condenser & compressor components.

Normal deterioration occurs throughout all components of the A/C system. Hoses, fittings, compressors, etc all wear with age and exposure to heat (temperature changes), vibration, and the elements. We assume that the system deterioration rates decrease proportionally as the base leakage rates are decreased with the use of improved parts and components. The base deterioration rate is defined such that the (new vehicle) leakage rate is 18 g/yr at age zero and 59 g/yr at the "average" age of 5 years old. This model is presented in the following figure with the assumption that the average vehicle (A/C system) last about 10 years. Technically, the assumption is that the A/C system lasts 10 years and not the vehicle per se. Inherent in this assumption is that the vehicle owner will not repair the A/C system on an older vehicle due to the expensive nature of most A/C repairs late in life relative to the value of the vehicle. We also assume that the refrigerant requires a recharge when the state of charge reaches 50% for the analysis in this section. This deterioration/leakage model approach will be used later to estimate the cost of maintenance savings due to low leak technologies (from refills) as well as the benefits of leakage controls.

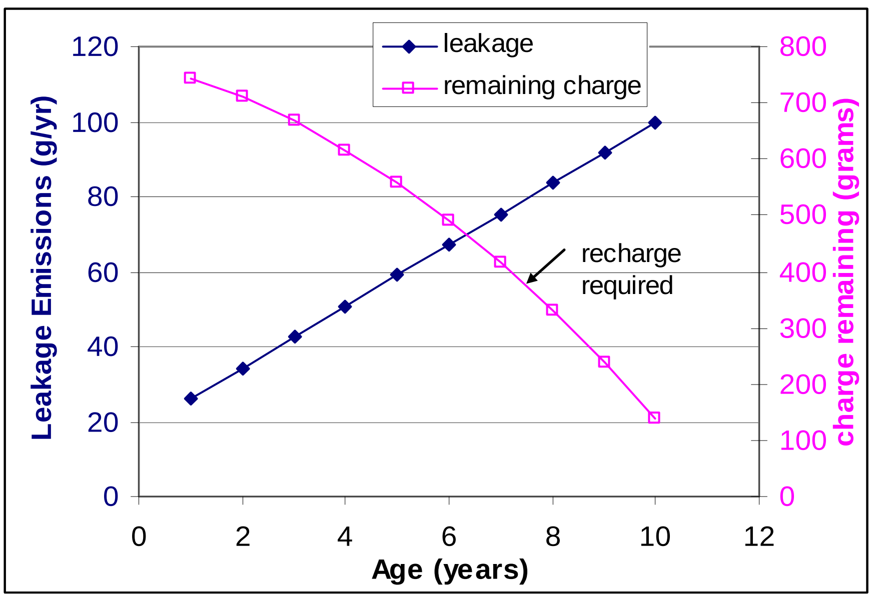

Figure III.B-1. Deterioration rate of refrigerant leakage

The Figure III.B-2 shows how the leakage rates vary with age as the initial leakage rates are decreased to meet new proposed standards (with improved components and parts). The deterioration lines of the lower leakage rates were determined by applying the appropriate ratio to the 18 g/yr base deterioration rate. Figure 3 shows the refrigerant remaining, which includes a line indicating when a recharge is required (50% charge remaining out of an initial charge of

770g). So a typical vehicle meeting a leakage score of 9 g/yr (new) will not require a recharge until it is about 12 years old.

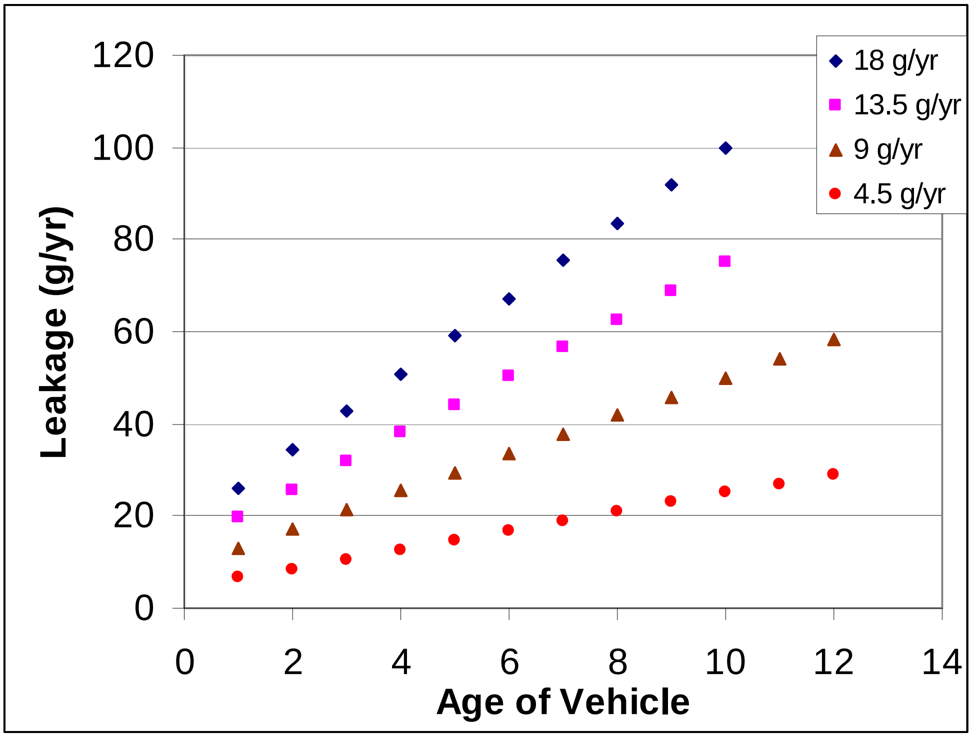

Figure III.B-2. A/C refrigerant leakage rate as vehicles age

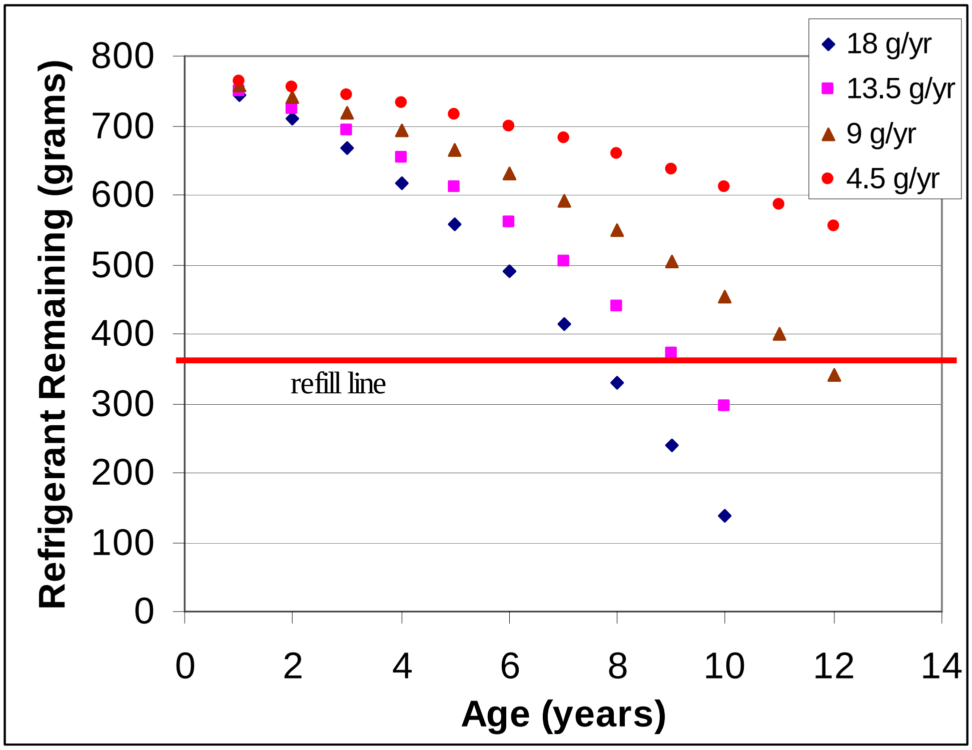

Figure III.B-3. A/C refrigerant remaining in a typical system as vehicles age and deteriorate

We now model two components separately that have avoidable deterioration paths. This mainly involves the condenser, but may also include the compressor. We model the deterioration of the condenser explicitly because the condenser is exposed to salt water and physical impacts from stones and road dust/dirt due to its placement at the front of the vehicle (behind the grill). The exposure to the elements accelerates the corrosion of the metals and the joints, while the stone impacts have the obvious effects on leakage from a high pressure system. It is also the component likely to be damaged in a front-end collision. While this component deterioration rate is already captured in the previous system deterioration curves, in order to calculate the savings due to improved condenser designs, we require an explicit deterioration model for this component, which will be helpful in estimating the benefits from the improved (and robust) technologies.

A European study conducted in 2001 (by Schwarz) found that the condenser is the component most likely to fail and result in a total leak[hh]. The study also found that the compressor component was the most likely culprit when other malfunctions were present (other than total loss). A more recent (and larger) study found that condensers required replacement at half the rate of a compressor (10% vs 19% of all of the part replacement rate), and that evaporators and accumulators failed more often[ii]. The same study also found that many of the repairs occurred when the vehicles were aged 5-10 years. Both these studies indicate that the

[hh] Schwarz, W., "Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems," Study conducted for the German Federal Environmental Office, September, 2001.

[ii] Hoffpauir, E. "By the Numbers" www.goHTSN.com

condenser and compressor are among the major causes of failure in an A/C system (we will not address evaporator and accumulator failures explicitly).

Schwarz estimates that the total annual rate of normal, irregular and disposal leakage emissions from passenger cars (up to seven years old) is 10.2%. "Normal" emissions are those that occur during the normal operation of the A/C system, such as those leaks attributable to the J2727 components and processes. These emissions account for 6.3% of the 10.2% leakage rate. "Irregular" emissions are those that occur because of externally caused physical damage to the system, or an unusual component defect and usually result in a near total loss of refrigerant. These emissions account for 1.9% of the 10.2% leakage rate. Emissions occurring during disposal of A/C components (beyond the scope of this discussion, and addressed by Title VI of the CAA) account for the remaining 2%. In this analysis we are mainly concerned with how much of the 1.9% of the irregular emissions is due to "avoidable" condenser and compressor failure. The next step is to estimate how much of this fraction may be avoided with improved and robust technologies.

According to Schwarz, of the 1.9% irregular leakage, 38/61 of the repaired systems had a total loss of refrigerant. 45% of these were attributable to "minor collisions, stone impact or internal emissive component defects". A further 50% of these were due to condenser and compressor failure. Altogether, these avoidable leaks amount to a leakage rate of approximately 0.266% per year. We interpret this to mean that out of 100 vehicles, 0.266 of them will experience total leakage in the first year due to these avoidable irregular emissions. After 10 years, 2.6 vehicles will have experienced a total loss. In the following section, we use this leak percentage to estimate the benefit of improved technologies.

Cost estimates for vehicle air conditioning improvements

This section describes the cost estimates for reductions in air conditioner related GHG emissions as well as the cost savings that result from improved technologies. These estimates are largely determined from literature reviews of publications and public presentations made by parties involved in the development and manufacture of A/C systems as well as from EPA analyses. The cost savings are estimated from the literature as well as estimates based on the deterioration models described above.

For (indirect) CO2 emissions due to A/C, it has been estimated that a 25-30% reduction can be achieved at a manufacturer price of 40€[kk]. The IMAC Efficiency Improvement team realized an efficiency improvement of 36.4% based on existing technologies and processes[jj]. For the idle test, we estimate that further reductions with software controls can achieve a total reduction of 40%. Using a conversion factor of 0.87 euro to the dollar, and adding $1 for software changes to the idle A/C controller (with a 1.5 indirect cost multiplier) gives a total retail price equivalent of $47.

[jj] SAE IMAC Team 2 – Improved Efficiency Report. April, 2007.

We assume a reference 2010 fuel economy of 30 mpg for cars and 24 for trucks. With a 20% real-world shortfall, this becomes 24 and 19 mpg respectively. As described in the LDV TSD of the GHG advance notice, we assume that A/C impacts fuel consumption by 3.35%, and an ultimate efficiency improvement of 40% is achievable. We use the same AEO 2008 fuel price, discount values, vehicle scrappage and VMT figures employed elsewhere in the advanced proposal to calculate a $96 cost savings for cars and $130 for trucks for the life of the vehicle. Assuming the same 0.23 to account for rebound and emissions, these savings increase to $118 for cars and $159 for trucks. This is a significant cost savings for the vehicle owner compared to the cost of the efficiency improvements.

For leakage (or direct) emissions, we assume that reductions can be achieved without a change in refrigerant, though it is possible that by 2020 a new technology and refrigerant will be a much more viable option than it is today. For example, an alternative refrigerant with a GWP less than 150 (like R152), which can directly replace R134a in current systems will be able to meet the leakage standards without significant engineering changes or cost increases. However, in order to reduce the leakage in conventional R134a systems by 50%, it has been estimated that the manufacturer cost would increase by $15 per vehicle employing existing off-the-shelf technologies such as the ones included in the J2727 leakage charts[kk]. We have estimated that even further reductions can be achieved and linearly estimate the costs such that a 75% reduction in emissions will cost 25% more, or $22.50. Furthermore, we believe that some credits will be required (above and beyond those available in the J2727 sheet) in order to meet the full reduction, so we assume an additional cost of $1.50 for an on-board diagnostic system that monitors the state of charge of the AC system[ll]. This is not much different from the price of the R152a alternative refrigerant system proposed in the previous study (which would comply with a 75% reduction with an additional wide compliance margin). “With the indirect cost markup factor of 1.5 applied, the compliance cost of leakage reduction technologies is estimated at $36 per vehicle. The following section describes how these costs may be distributed on a year by year basis as the program phases in over 4 years.

We expect that a reduction in leakage will lead to fewer servicing events for refrigerant recharge. The savings to the vehicle owner of a recharge maintenance visit is approximately $100.

The savings to the vehicle owner for avoiding a condenser or compressor replacement due to corrosion, stone chip, or defective manufacturing (avoidable replacements) is estimated using the component deterioration model above. We approximate that the cost of replacing a compressor or condenser is approximately $800, and that after 10 years, owners will be less likely to make this investment. On average, we estimate that more robust compressors and condensers will result in a cost savings of approximately $21 to the average vehicle owner (2.6% of $800) if the manufacturers qualify for the credits for more robust components.

[kk] Alternative Refrigerant Assessment Workshop, SAE Automotive Alternative Refrigerant Symposium, Arizona, 2003.

[ll] OBD costs determined from previous rulemaking (MSAT Rule CFR)

Combined with recharge savings, we believe that the average vehicle owner can save $121 in A/C maintenance charges in the first 10 years of ownership. We discount this rate 93%/yr out 8 years (to simplify our calculations to approximately when the repair would be required). This comes to $68 in discounted savings, which exceeds the cost to the consumer for reduced leakage and more robust A/C systems.

Annual cost estimates during the phase-in period

The cost estimates for reducing leakage described above only estimates the cost for a total 75% reduction in leakage emissions. The potential A/C efficiency limits analyzed in the advance notice are fleet average limits, whereas the leakage standards are caps (similar to existing vehicle evaporative emissions standards). In order to estimate the annual costs of a program, we require a methodology for estimating costs associated with converting from an average level to a cap standard.

The determination of the mean emission rate of 18 g/yr is described above. The estimation of the width of the distribution (standard deviation) comes from the European J2727 scores[gg], which has a standard deviation of 4.5. This distribution is shown in the following figure. In order for the non-compliant A/C systems to meet the standard, they must shift their leakage scores from their current level to 18. We assume a linear cost curve to estimate the total cost of reducing all the non-compliant systems to 18 g/yr levels.

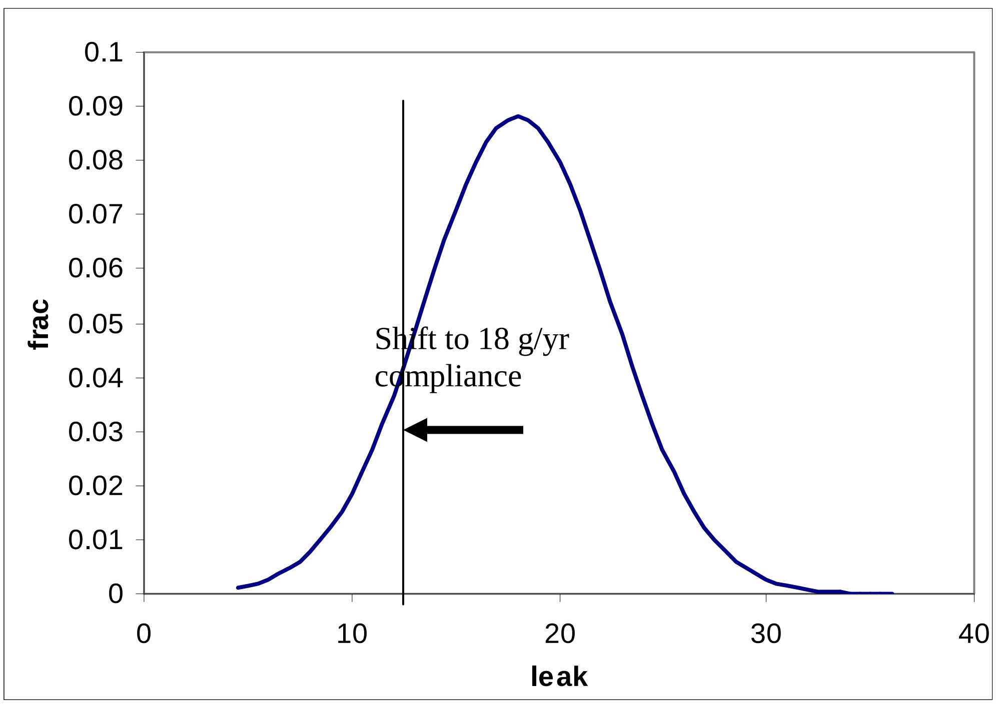

Figure III.B-4. A histogram of leakage scores

The cost for emissions reduction to 18 g/yr standard differs for each leak level. So the total cost of reduction is the sum product of the fraction and the cost to reduce to 18 g/yr. For example, the cost to reduce a 36 g/yr system to 18 g/yr is $24, consistent with a 50% reduction described above. Systems that have a leakage score of 18 g/yr or less already need not incur any additional cost to meet the cap standard. The sum product cost to shift all the non-compliant >18 g/yr systems to 18 g/yr levels is $2.14 on average per vehicle.

We can continue this analysis each year for each of the new stringency levels. For example, all of the vehicles whose leakage scores range from 13.5 to 18 g/yr the next year must comply with a new 13.5 g/yr standard. These costs are calculated in the same way as before. This shift is shown in the following figure. This analysis is repeated for the 9 and 4.5 g/yr standards. The costs for each year of the analyzed limits is displayed in table 5 below.

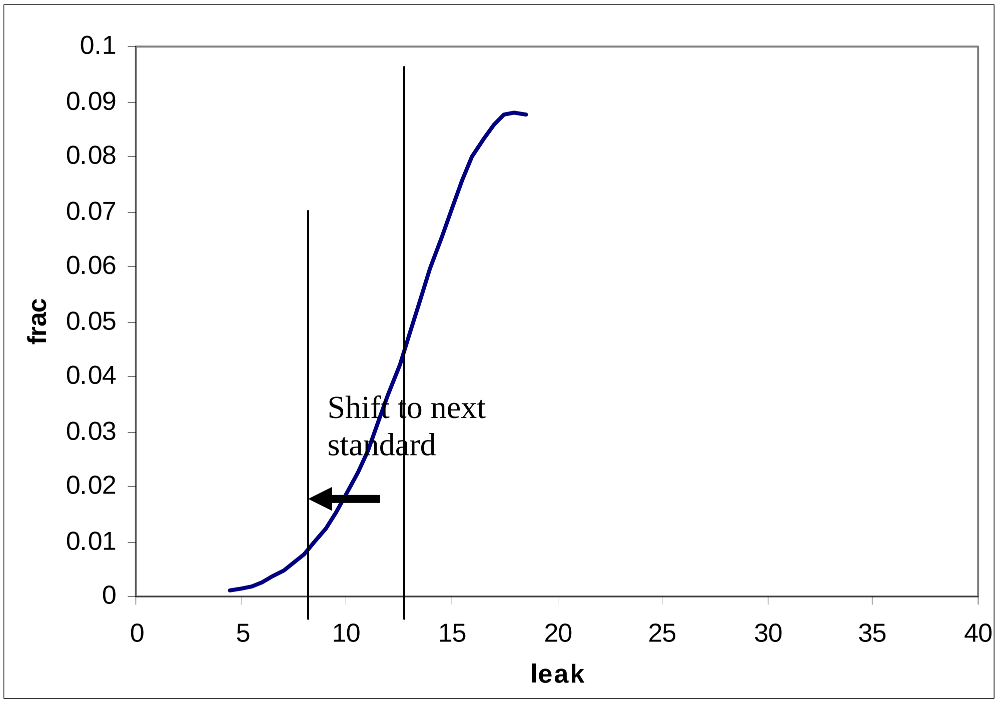

Figure III.B-5. A histogram of leakage scores in the 2nd year of the analyzed program

Table III.B-8. Costs associated with each year of the phase-in for refrigerant leakage reduction.

Leakage std	18	13.5	9	4.5
interval cost		$ 4.93	$ 2.36	$ 0.44
shifting the rest (peak)		$ 6.00	$ 9.91	$ 11.68
incremental cost	$ 2.41	$ 10.93	$ 12.27	$ 12.12
ttl cumulative cost	$ 2.41	$ 13.34	$ 25.60	$ 37.72