Interim Joint Technical Assessment Report:

Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025

Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Office of International Policy, Fuel Economy, and Consumer Programs
National Highway Traffic Safety Administration
U.S. Department of Transportation

California Air Resources Board
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September 2010

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Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA, a modal administration within the Department of Transportation) ("the agencies") are collaborating with the California Air Resources Board (CARB) to build on the success of the first phase of the National Program to regulate fuel economy and greenhouse gas (GHG) emissions from U.S. light-duty vehicles. The strong and coordinated first phase of standards for model years (MY) 2012-2016 was completed in April 2010, ensuring that all manufacturers can build a single fleet of U.S. vehicles to meet the new harmonized standards.

On May 21, 2010, the President called on the agencies to take additional coordinated steps to bring about a new generation of clean vehicles.[1] Among other things, the agencies were tasked with researching and then developing standards for MY 2017 through 2025 that would be appropriate and consistent with EPA's and NHTSA's respective statutory authorities, in order to continue to guide the automotive sector along the road to reducing its fuel consumption and GHG emissions, thereby ensuring the corresponding energy security and environmental benefits. During the public comment period for the MY 2012-2016 proposed rulemaking, many stakeholders encouraged EPA and NHTSA to begin working toward standards for MY 2017 and beyond that would maintain a single nationwide program. Several major automobile manufacturers and CARB sent letters to EPA and NHTSA in support of a 2017 to 2025 MY rulemaking initiative outlined in the President's May 21st announcement.

In his May 2010 memorandum, the President recognized that, by acting expeditiously, our country could take a leadership role in addressing these global challenges. He stated that, "America has the opportunity to lead the world in the development of a new generation of clean cars and trucks through innovative technologies and manufacturing that will spur economic growth and create high-quality domestic jobs, enhance our energy security, and improve our environment." The effort described in the Presidential Memorandum represents a continuation of the National Program to control GHGs and reduce oil consumption from the transportation sector. As directed by the President, NHTSA and EPA, in close coordination with CARB are working together under a carefully coordinated set of steps to further control GHG emissions and reduce oil consumption from the transportation sector.

In response to the President's request and to craft a clear regulatory path for the automobile industry, the agencies have collaborated with CARB to prepare this joint Technical Assessment Report to inform the rulemaking process and provide an initial technical assessment for that work. In accordance with the Presidential Memorandum, the agencies are also issuing a joint Notice of Intent to Issue a Proposed Rulemaking (NOI). The NOI announces plans for initiating a joint rulemaking which will be designed to improve the fuel efficiency and reduce the

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[1] Presidential Memorandum: "Improving Energy Security, American Competitiveness and Job Creation, and Environmental Protection Through a Transformation of Our Nation's Fleet of Cars And Trucks," Issued May 21, 2010, published at 75 Fed. Reg. 29399 (May 26, 2010), also available at http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards.

GHG emissions of passenger cars and light-duty trucks built in MYs 2017-2025. The joint federal rulemaking will undergo a full notice-and-comment process, consistent with law and Administration policies on openness, transparency, and sound science.

EPA, NHTSA, and CARB are issuing this joint Technical Assessment Report in response to Section 2(a) of the Presidential Memorandum. Section 2(a) of the Presidential Memorandum requests that EPA and NHTSA "Work with the State of California to develop by September 1, 2010, a technical assessment to inform the rulemaking process, reflecting input from an array of stakeholders on relevant factors, including viable technologies, costs, benefits, lead time to develop and deploy new and emerging technologies, incentives and other flexibilities to encourage development and deployment of new and emerging technologies, impacts on jobs and the automotive manufacturing base in the United States, and infrastructure for advanced vehicle technologies." This report provides an overview of key stakeholder input and addresses the topics noted in the memorandum, and presents the agencies' initial assessment of a range of stringencies of future standards. Chapter 1 of this report provides a further introduction and overview of the light-duty vehicle related sections of the May 21, 2010 Presidential Memorandum, and also of the final rule establishing CAFE and GHG standards for MYs 2012-2016 light-duty vehicles.

During June through August 2010, EPA, NHTSA, and CARB held numerous meetings with a wide variety of stakeholders to gather input to consider in developing this Technical Assessment Report, and to ensure that the agencies had available to them the most recent technical information. These stakeholders included the automobile original equipment manufacturers (OEMs), automotive suppliers, non-governmental organizations, states and state organizations, infrastructure providers, and labor unions. The agencies sought these stakeholders' technical input and perspectives, consistent with the President's request, on the key issues that should be considered in assessing a national program to reduce greenhouse gas emissions and improve fuel economy for light-duty vehicles in model years 2017-2025.

The agencies requested the OEMs' input regarding several key areas including technology development, key regulatory design elements, infrastructure issues, perspective on the impacts on the U.S. manufacturing base and jobs, and potential regulatory incentives and flexibilities. The OEMs presented detailed and confidential technical information to the agencies addressing these topics. A common theme across the auto firms is they are all heavily investing in advanced technologies including hybrids, plug-in hybrid electric vehicles, electric vehicles, including fuel cell vehicles, next generation internal combustion engines, and mass reduction technologies, and companies expect to increase their offerings and sales of these technologies significantly in the future. The companies generally stated, however, that the degree to which these advanced technologies will penetrate the U.S. market in the 2017-2025 time frame depends upon a number of challenges and factors, as discussed in Chapter 2 of this report. EPA, NHTSA and CARB also met with a cross section of automotive suppliers to seek their input on the advanced technologies they are developing which could be implemented in the 2017-2025 time-frame. The agencies further received input from infrastructure providers. Many of the automakers and automotive suppliers provided input on the need for vehicle charging locations needed for the electrical charging of EVs and PHEVs to support their introduction into the market. Chapter 2 aggregates and summarizes information gathered from the OEM, automotive supplier, and infrastructure provider meetings and describes how the agencies used the information to inform this report.

The agencies also received input from numerous non-governmental organizations, including environmental organizations; representatives from the National Association for Clean Air Agencies (NACAA), the Northeast States for Coordinated Air Use Management (NESCAUM), and approximately 10 individual state and local governments; and the United Auto Workers (the UAW). All of these stakeholders strongly supported the President's call for continuing the National Program approach and setting new fuel economy and greenhouse gas standards for light-duty vehicles for the 2017-2025 model years. Chapter 2 also provides an overview of issues that were raised during discussions with the states, non-governmental organizations, and the UAW.

As discussed in Chapter 3, the agencies have conducted an initial technology cost, effectiveness and lead-time assessment for MYs 2017-2025. The agencies assessed the cost, effectiveness, and availability of over 30 vehicle technologies that manufacturers could use to improve the fuel economy and reduce CO_2 emissions of their vehicles during MYs 2017-2025. The chapter describes technologies that are readily available today, but also other technologies that are not currently in production but are beyond the research phase and under development, and which are expected to be in production in the 2017-2025 timeframe. The technologies considered in this report fall into five broad categories: engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, electric drive technologies including hybrid technologies and mass reduction.

Consistent with stakeholder input obtained over the summer, Chapter 3 identifies how electric drive vehicles can be an important part of the vehicle mix that will likely be used to meet increasingly stringent fuel economy and GHG emission standards. Electric drive vehicles including hybrid electric vehicles (HEV), battery electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs) and hydrogen fuel cell vehicles (FCVs), can dramatically reduce petroleum consumption and GHG emissions compared to conventional technologies. Additionally, given their use of fuels that can eventually be derived from entirely renewable and zero carbon resources, the agencies note that these technologies have significant potential to transform the vehicles of the future to a low carbon fleet.

Stakeholders, particularly the OEMs, emphasized to the agencies that the future rate of penetration of these technologies into the vehicle fleet is not only related to future GHG and CAFE standards, but also to future gasoline fuel prices, future reductions in HEV/PHEV/EV battery costs, the overall performance and consumer demand for the advanced technologies, access to electric vehicle recharging locations and, for fuel cell vehicles the development of a hydrogen refueling infrastructure. In the case of EVs and PHEVs, electric charging locations are needed in the form of charging systems, most often at home, but potentially also at the workplace and other locations such as stand-alone facilities and public parking locations in order to facilitate significant, wide-spread penetration of these vehicle technologies. In the case of FCVs, hydrogen fueling stations are needed to support commercialization. Chapter 4 provides a description and assessment of current activities and technologies, discussion of costs, and prospects for technology improvement, as well as a summary of needs for successful infrastructure deployment to support electric drive vehicle commercialization. The agencies worked closely with the Department of Energy (DOE) in our assessment of electric vehicle charging requirements and issues and DOE was a contributor to this Chapter, in addition to other technical aspects of this report.

The final rule for MYs 2012-2016 provides for several flexibilities, including averaging, banking and trading provisions for credit carry-forward and carry-back, various additional credits opportunities, and advanced technology incentives. The MYs 2012-2016 program also includes additional leadtime flexibilities under the CAA for smaller volume manufacturers. Several stakeholders provided input on the need to continue many of these flexibilities for the MYs 2017-2025 program. Chapter 5 provides an overview of these flexibilities as they exist in the MYs 2012-2016 rule as well as the stakeholder input the agencies have received regarding their potential applicability in the MYs 2017-2025 program. Also, Chapter 5 provides an overview of non-regulatory approaches that can promote the commercialization of low-GHG light-duty vehicle technologies.

Chapter 6 presents an analysis of future levels of control of GHG emissions conducted for this Technical Assessment Report.[2] Four scenarios of future stringency are analyzed for MYs 2020 and 2025, starting with a 250 gram/mile estimated fleet-wide level in MY 2016 and lowering CO_2 scenario targets at the rates of 3% per year, 4% per year, 5% per year, and 6% per year, respectively. For each of those rates of increase in stringency, the agencies considered the effects of the industry following four potential "technology pathways," "A," "B," "C," and "D." The agencies developed these different technology pathways in order to capture both the current levels of uncertainty regarding the potential rate of penetration of various advanced technologies and to illustrate more than one approach that the auto industry could take in responding to future targets. This approach was also informed by our meetings with the auto companies, whom are pursuing a range of different technology paths for the future, with different companies placing relative emphasis on different technologies. The agencies present the results of this assessment in terms of six broad metrics: per-vehicle cost increase, net lifetime vehicle owner savings, payback period to the consumer, net reduction in GHG emissions, net reduction in fuel consumption, and vehicle technology penetration mix, as shown in the tables below. Chapter 6 presents the results of this initial analysis for projected costs, emissions reductions, and lifetime fuel savings, and also provides the technology projections that were used in the analyses. Chapter 6 also discusses the fact that this preliminary assessment does not include consideration of all statutory requirements and other factors that will be assessed in the upcoming Federal rulemaking. Consideration of these factors is expected to affect cost assessments and may affect the proposed standards.

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[2] These GHG emissions levels can be translated to mpg-equivalent levels through simple math, but we note that they would not necessarily translate directly into equivalent CAFE standards due to their inclusion of credits for A/C improvements, which is permissible for CAA standards but not for CAFE standards.

The following summary tables show the fundamental quantitative conclusions from this initial assessment. As shown in Table ES-1, automotive technologies are available, or can be expected to be available, to support a reduction in greenhouse gas emissions, and commensurate increase in fuel economy, of up to 6 percent per year in the 2017-2025 timeframe. Greater reductions come at greater incremental vehicle costs. The per vehicle cost increase ranges from slightly under $1,000 per new vehicle for a 3 percent annual GHG reduction, increasing to as much as $3,500 per new vehicle to achieve a 6 percent annual GHG reduction. Consumer savings would increase with the lower GHG emissions and higher fuel economy. For the different scenarios analyzed, the net lifetime savings to the consumer due to increased vehicle efficiency range from $4,900 to $7,400. The initial vehicle purchaser will find the higher vehicle price recovered in 4 years or less for every scenario analyzed.

Table ES-1: Projections for MY 2025 Per-Vehicle Costs, Vehicle Owner Payback, and Net Owner Lifetime Savings [1, 2]

Scenario	New Fleet g/mile CO2 Target (MPGe)[2]	Tech Path	Per-Vehicle Cost Increase ($)	Payback Period (years)	Net Lifetime Owner Savings ($)
3%/year	190 (47)	A	$930	1.6	$5,000
		B	$850	1.5	$5,100
		C	$770	1.4	$5,200
		D	$1,050	1.9	$4,900
4%/year	173 (51)	A	$1,700	2.5	$5,900
		B	$1,500	2.2	$6,000
		C	$1,400	1.9	$6,200
		D	$1,900	2.9	$5,300
5%/year	158 (56)	A	$2,500	3.1	$6,500
		B	$2,300	2.8	$6,700
		C	$2,100	2.5	$7,000
		D	$2,600	3.6	$5,500
6%/year	143 (62)	A	$3,500	4.1	$6,200
		B	$3,200	3.7	$6,600
		C	$2,800	3.1	$7,400
		D	$3,400	4.2	$5,700

1. Per-vehicle costs represent the increase in costs to consumers from the MY 2016 standards. Payback period and lifetime owner savings use a 3% discount rate and AEO 2010 reference case energy prices. The gasoline price used for this estimate is $3.49/gallon in 2025 and increases over time to a maximum of $4.34/gallon in 2050. Per-vehicle costs represent the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.

2. The targets evaluated were CO2 targets which could be meet through reductions in CO2 as well as through air conditioning system hydroflurocarbon reductions converted to a CO2 equivalent value. MPGe is the equivalent MPG value if all of the CO2 reductions came from fuel economy improvement technologies. Real-world CO2 is

typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Thus, the 3% to 6% range evaluated in this assessment would span a range of real world fuel economy values of approximately 37 to 50 mpg, which correspond to the regulatory test procedure values of 47 and 62 mpg, respectively.

As shown in Table ES-2, the increased vehicle efficiency would result in substantial societal benefits in terms of the GHG emission reductions and the petroleum use reductions. In the analyzed scenarios for 2025 model year vehicles, lifetime GHG emissions would be reduced from 340 million metric tons (3 percent annual improvement scenario) to as much as 590 million metric tons for a 6 percent annual improvement scenario. For the same range of scenarios, lifetime fuel consumption for this single model year of vehicles would be reduced by 0.7 to 1.3 billion barrels.

Table ES-2: Estimated CO2e and Fuel Reductions for the Lifetime of MY 2025 Vehicles[1,2]

Scenario	Lifetime CO2e Reduction (million metric tons, MMT)	Lifetime Fuel Reduction (Billion Barrels)
3%/year	340	0.7
4%/year	410-440	0.9
5%/year	440-530	1.1
6%/year	470-590	1.3

1. Fuel reductions are the same for each of the four technology pathways, but CO2e reductions vary as a function of the penetration of EVs and PHEVs in each of the four technology pathways evaluated (due to an increase in upstream emissions).
2. For reference, the National Program in MY 2016 is projected to reduce 0.6 billion barrels of fuel and 325 MMT CO2e over the lifetime of MY2016 vehicles.

Table ES-3 illustrates the levels of technology required to achieve the different GHG and fuel economy levels that were analyzed by the agencies. The types of vehicle technologies sold in 2025 to meet more stringent emission and fuel economy standards depends on the stringency of the adopted standards, the success in fully commercializing at a reasonable cost emerging advanced technologies, and consumer acceptance. The analysis for this report illustrates a wide range of possible outcomes, and these will likely vary by vehicle manufacturer. The potential fleet penetrations for gasoline and diesel vehicles, hybrids, plug-in electric vehicles, or electric vehicles also may vary greatly depending on the agencies' assumptions about what technology pathways industry choose.

As shown in Table ES-3, at the 3 or 4 percent annual improvement scenarios, advanced gasoline and diesel powered vehicles that do not use electric drivetrains may be the most common vehicle types available in 2025. In the 3 percent to 4 percent annual improvement range, all pathways use advanced, lightweight materials and improved engine and transmission technologies. Table ES-3 also shows that hybrid vehicle penetration under the 3 and 4 percent annual improvement scenarios vary widely due to the assumptions made for each technology pathway, ranging from roughly 3 to 40 percent of the market in 2025.

Under the 5 or 6 percent annual improvement scenarios hybrids could make up from 40 percent to 68 percent of the market. In Paths A through C, PHEVs and EVs penetrate the market substantially only at the 6 percent annual improvement scenario. In Path D, where a manufacturer makes no improvement in gasoline and diesel vehicle technologies beyond MY 2016, PHEVs and EVs begin to penetrate the market at the 4 percent annual improvement rate and may have as high as a 16 percent market penetration under the 6 percent annual improvement scenario.

Table ES-3: Technology Penetration Estimates for MY 2025 Vehicle Fleet

		New Vehicle Fleet Technology Penetration				
Scenario	Technology Path	Mass Reduction[1]	Gasoline & diesel vehicles	HEVs	PHEVs[2]	EVs
3%/year	Path A	15%	89%	11%	0%	0%
	Path B	18%	97%	3%	0%	0%
	Path C	18%	97%	3%	0%	0%
	Path D	15%	75%	25%	0%	0%
4%/year	Path A	15%	65%	34%	0%	0%
	Path B	20%	82%	18%	0%	0%
	Path C	25%	97%	3%	0%	0%
	Path D	15%	55%	41%	0%	4%
5%/year	Path A	15%	35%	65%	0%	1%
	Path B	20%	56%	43%	0%	1%
	Path C	25%	74%	25%	0%	0%
	Path D	15%	41%	49%	0%	10%
6%/year	Path A	14%	23%	68%	2%	7%
	Path B	19%	48%	43%	2%	7%
	Path C	26%	53%	44%	0%	4%
	Path D	14%	29%	55%	2%	14%

1. Mass reduction is the overall net reduction of the 2025 fleet relative to MY 2008 vehicles.
2. This assessment considered both PHEVs and EVs. These results show a higher relative penetration of EVs compared to PHEVs. The agencies do believe PHEVs may be used more broadly by auto firms than indicated in this technical assessment.

Chapter 7 discusses other key factors for the MYs 2017-2025 light-duty vehicle rulemaking that the agencies are considering, including the potential impact on the employment and vehicle sales and upstream GHG emissions.

In conclusion, the three agencies have received important input from a range of stakeholders to inform the extension of the National Program to MYs 2017-2025. Auto manufacturers, states, environmental groups and the United Auto Workers have expressed support for a continuation of the National Program. All auto firms are heavily invested in developing advanced technologies which can reduce fuel consumption and GHGs significantly beyond the MYs 2012-2016 standards. Manufacturers are developing many technologies that would enable them to eventually achieve appreciable improvements in fuel economy levels, including advanced gasoline engines, hybrid electric vehicles, EVs, and PHEVs. The three agencies have performed an initial assessment of potential future standards (annual reductions in the range of 3 to 6% per year, or 47 to 62 mpg in 2025 if the industry achieved all of the increases through fuel economy improvements), which demonstrates that advanced technologies can be used to achieve substantial reductions in fuel consumption and GHGs. The agencies analyzed four technology pathway scenarios that the industry could pursue to achieve more stringent targets, recognizing there are a wide range of pathways individual manufacturers could pursue. One pathway scenario relied upon significant mass reduction and advanced next generation gasoline vehicles, the second focused on hybridization and electrification of the fleet (HEVs, PHEVs, EVs), and the third was a blend of the first two. The fourth pathway emphasizes an EV and PHEV focused approach, with a lesser degree of emphasis on advanced gasoline, HEV, and mass reduction approaches. Based on this analysis and the assumptions employed, the agencies found that the per-vehicle cost increases for a 2025 vehicle ranged from $770 to $3,500 across the range of stringency targets and technology pathways. The fuel savings achieved by MY 2025 vehicles meeting these more stringent targets would result in a net lifetime savings of between $4,900 and $7400. The GHG reductions ranged from 340 to 590 million metric tons and fuel reduction ranged from 0.7 to 1.3 billion barrels over the lifetime of MY 2025 vehicles. We emphasize that this Technical Assessment Report reaches no specific conclusions regarding the levels of stringency to propose for MYs 2017-2025. The report is an important step in a continuation of the National Program, but significant work remains to be done to support a future federal rulemaking.

1 Introduction

1.1 Purpose of this Report

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA, a modal administration within the Department of Transportation) ("the agencies") are collaborating with the California Air Resources Board (CARB) to build on the success of the first phase of the National Program to regulate fuel economy and greenhouse gas (GHG) emissions from U.S. light-duty vehicles. The strong and coordinated first phase of standards for model years (MY) 2012-2016 was completed in April 2010, ensuring that all manufacturers can build a single fleet of U.S. vehicles to meet the new harmonized standards.

On May 21, 2010, following the completion of the first phase of the National Program, the President called on the agencies to take additional coordinated steps to bring about a new generation of clean vehicles.[1] Among other things, the agencies were tasked with researching and then developing standards for MY 2017 through 2025 that would be appropriate and consistent with EPA's and NHTSA's respective statutory authorities, in order to continue to guide the automotive sector along the road to reducing its fuel consumption and GHG emissions, and to ensure the corresponding energy security and environmental benefits. Following the President's announcement, several major automobile manufacturers and CARB sent letters to EPA and NHTSA in support of a 2017 to 2025 rulemaking initiative as outlined in the President's Memorandum. In addition to the President's directive, many stakeholders in their comments during the MYs 2012-2016 rulemaking encouraged EPA and NHTSA to maintain a single nationwide program, and to extend the National Program beyond the first phase by beginning to work toward standards for MY 2017 as soon as practicable.

The President called on the agencies to begin the next phase of the National Program in response to the urgent and closely intertwined challenges faced by our nation of dependence on oil, energy security, and global climate change. Reducing total petroleum use by U.S. light-duty vehicles decreases our economy's vulnerability to oil price shocks. Reducing dependence on oil imports from regions with uncertain conditions enhances our energy security. The need to reduce energy consumption is more crucial today than it was when the Energy Policy and Conservation Act was enacted in the mid-1970s. Net petroleum imports now account for approximately 57 percent of U.S. domestic petroleum consumption,[2] and the share of U.S. oil consumption for transportation is approximately 72 percent.[3] Moreover, world crude oil production continues to be highly concentrated, exacerbating the risks of supply disruptions and their negative effects on both the U.S. and global economies. Light-duty vehicles also account for about 41 percent of all U.S. oil consumption,[B] making them the largest single oil-consuming transportation segment in the U.S. Light-duty vehicles emit four GHGs—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_X), and hydrofluorocarbons (HFCs) – and are responsible for nearly 60 percent of all mobile source GHGs and over 70 percent of Section 202(a) mobile source GHGs. In 2007, CO_2 emissions represented about 94 percent of total GHG emissions from light-duty vehicles (including HFCs), and the CO_2 emissions measured by EPA fuel economy compliance tests represented about 90 percent of all light-duty vehicle GHG emissions.[4,5]

In his May 2010 memorandum, the President recognized that by acting expeditiously, our country could take a leadership role in addressing these global challenges, stating that "America has the opportunity to lead the world in the development of a new generation of clean cars and trucks through innovative technologies and manufacturing that will spur economic growth and create high-quality domestic jobs, enhance our energy security, and improve our environment." NHTSA and EPA, in close coordination with CARB, have started the process, through this report, to evaluate the potential for cleaner and more efficient vehicles that would transform our nation's fleet of cars and trucks in the future. Our work would extend the National Program and would entail a carefully coordinated set of steps to further control GHG emissions and reduce oil consumption from the transportation sector.

To answer the President's call and to craft a clear regulatory path for the automobile industry, the agencies have collaborated with CARB to prepare this Technical Assessment Report to inform EPA's and NHTSA's upcoming rulemaking process and provide an initial technical assessment for that work. Section 2 of the President's Memorandum states that this Technical Assessment Report should reflect stakeholder input on relevant factors including: "viable technologies, costs, benefits, lead time to develop and deploy new and emerging technologies, incentives and other flexibilities to encourage development and deployment of new and emerging technologies, impacts on jobs and the automotive manufacturing base in the United States, and infrastructure for advanced vehicle technologies." This report provides an overview of key stakeholder input received to date, and addresses the applicable topics noted in the May 2010 Presidential Memorandum.

Section 2 of the President's Memorandum also states that EPA and NHTSA should issue a joint Notice of Intent to Issue a Proposed Rulemaking (NOI) following the Technical Assessment Report announcing plans to promulgate a next phase of standards for this sector, including plans for "gathering any additional information needed to support regulatory action." The NOI is also to include "potential standards that could be practicably implemented nationally for the 2017-2025 model years and a schedule for setting those standards as expeditiously as possible, consistent with providing sufficient lead time to vehicle manufacturers."[6] The joint federal rulemaking initiated with the NOI will be designed to improve the fuel economy and reduce the GHG emissions of passenger cars and light trucks built in MYs 2017-2025, and will follow the full notice-and-comment process, consistent with law and Administration policies on openness, transparency, and sound science.

1.2 National Program for Model Years 2012 - 2016

The National Program came about, in part, because of a historic agreement between diverse interests to set in motion a national fuel efficiency policy announced by the President on May 19, 2009.[7] Several automakers and their trade associations also announced their support for the National Program at that time. In collaborating between the public and private sector, the United States has already shown leadership through enactment of the first-ever harmonized GHG emissions and fuel economy standards for light-duty vehicles.

On April 1, 2010, NHTSA and EPA issued joint final rules establishing standards for GHG emissions and fuel economy for passenger cars, light-duty-trucks, and medium-duty passenger vehicles ("light-duty vehicles"), which we referred to collectively as the National Program.[8] The agencies found that this first phase of the National Program will achieve substantial reductions of GHG emissions and improvements in fuel economy from the light-duty vehicle part of the transportation sector, based on technology that is already being commercially applied in most cases and that can be incorporated at a reasonable cost.

EPA and NHTSA established two separate sets of standards, each under its respective statutory authority. EPA set national CO_2 emissions standards for light-duty vehicles under section 202 (a) of the Clean Air Act. These standards will require the fleet of vehicles to meet an estimated combined average emissions level of 250 grams/mile of CO_2 in model year (MY) 2016, which the agencies explained is equivalent to a fuel economy level of 35.5 miles per gallon if all the reductions were achieved through improvements in fuel economy, although the CO_2 standards also gave credit for air conditioning improvements that reduced GHGs other than carbon dioxide. NHTSA, in turn, set CAFE standards for passenger cars and light trucks under EPCA, as amended by EISA.[9] These standards will require manufacturers of those vehicles to meet an estimated combined average fuel economy level of 34.1 mpg in model year 2016, which is the maximum feasible amount of improvement that the agencies estimated could be required using fuel economy-improving technology alone, without regard to the A/C credits permitted by EPA under the CAA. The standards for both agencies begin with the 2012 model year, with standards increasing in stringency through model year 2016. They represent a harmonized approach that will allow industry to build a single national fleet that will satisfy both the GHG requirements under the CAA and CAFE requirements under EPCA/EISA.

The MY 2012-2016 standards are together expected to result in approximately 960 million metric tons of total carbon dioxide equivalent emissions reductions and approximately 1.8 billion barrels of oil savings over the lifetime of vehicles sold in 2012 through 2016. In total, the combined EPA and NHTSA 2012-2016 standards will reduce GHG emissions from the U.S. light-duty fleet approximately 21 percent by 2030 over the level that would occur in the absence of the National Program. These actions also will provide important energy security benefits, as light-duty vehicles are about 95 percent dependent on oil-based fuels and much of the petroleum consumed by the U.S. is imported.

The National Program for MYs 2012–2016 was developed in close coordination with many key stakeholders including California and several other states. In 2004, CARB approved standards for new light-duty vehicles, which regulate the emission of not only CO_2, but also other GHGs. Since then, thirteen states and the District of Columbia, comprising approximately 40 percent of the light-duty vehicle market, have adopted California's standards. On June 30, 2009, EPA granted California's request for a waiver of preemption under the CAA.[10] The granting of the waiver permits California and the other states to proceed with implementing the California emission standards. These standards apply to model years 2009 through 2016.

To promote the National Program for MYs 2012-2016, in May 2009, California agreed to accept compliance with the national standards as meeting its requirements. This action allows the single national fleet produced by automakers to meet the two Federal requirements and to meet California requirements as well.

The MYs 2012-2016 standards adopted by NHTSA and EPA for passenger cars and light trucks are attribute-based standards, specifically based on vehicle footprint. Each manufacturer will have a GHG and a CAFE standard unique to its each of its fleets, depending on the footprints of the vehicle models and the volumes produced by that manufacturer. A manufacturer will have separate footprint-based standards for cars and light trucks. With the footprint-based standard approach, EPA and NHTSA believe there should be no significant effect on the relative distribution of different vehicle sizes in the fleet, which should mean that consumers will still be able to purchase the size of vehicle that meets their needs.

As described in the final rule, EPA and NHTSA expect that automobile manufacturers will meet the MYs 2012-2016 CAFE and GHG standards by utilizing currently-available technologies. Although many of these technologies are available today, the emissions reductions and fuel economy improvements will involve more widespread use of these technologies across the light-duty vehicle fleet. These include improvements to engines, transmissions, and tires, increased use of start-stop technology, improvements in air conditioning systems, increased use of hybrid and other advanced technologies, and the initial commercialization of electric vehicles and plug-in hybrids. NHTSA's and EPA's assessment of likely vehicle technologies that manufacturers will employ to meet the MYs 2012-2016 standards is discussed in the final rule and in the Joint TSD for the final rule.

The MYs 2012-2016 standards also provide a number of compliance flexibilities to manufacturers. While the flexibilities vary in their compliance applicability based on whether the manufacturer is meeting the CAFE standard or the GHG standard, both standards also allow some of the same flexibilities. These flexibilities are discussed further in Chapter 5 below.

1.3 Standards for 2017 and Beyond

In response to the President's call to continue and expand a strong, coordinated National Program, and in order to achieve critical additional reductions in oil consumption and GHG emissions from light-duty vehicles, a number of stakeholders stepped up to offer their support and commitment to fulfilling the President's vision. After release of the President's May 2010 Memorandum, CARB issued a letter supporting the rulemaking process to establish MY 2017-2025 standards.[11] In its letter, CARB committed to work in partnership with EPA and NHTSA to: (1) evaluate technologies; (2) engage with manufacturers and other stakeholders to fully explore the capability of technologies; (3) evaluate possible approaches to increase in the marketplace the use of advanced technologies; and (4) identify potential GHG emissions standards with the expectation that the annual rate of improvement would be in the 3 to 6 percent range.

Several manufacturers also sent letters of support for the 2017-2025 rulemaking initiative following the President's announcement, committing to engaging in a process to continue a single national program beyond 2016.[12] The letters generally stated the manufacturers' agreement with a set of guiding principles, developed by the agencies, for the rulemaking process. These guiding principles include: (1) that EPA and NHTSA will work to develop strong, coordinated national GHG emissions and CAFE standards for light-duty vehicles manufactured in MY 2017-2025 that enable manufacturers to build a single light-duty national fleet that satisfies all federal and state requirements; (2) that EPA and NHTSA will seek input from an array of stakeholders including automobile manufacturers, infrastructure providers, labor unions, and environmental organizations, and the agencies will work with the State of California and other states in this process; (3) that the agencies and CARB will develop a technical assessment to inform the rulemaking process; (4) that a mid-term technology review would be appropriate; and, (5) that the future regulatory program should enable consumers to still have a full range of vehicle choices.

The guiding principles also included a description of the process for developing this Technical Assessment, including: (1) meeting with stakeholders individually to gather currently available information on viable technologies, costs, benefits, lead times, incentives and other flexibilities and to evaluate other relevant factors, such as infrastructure; (2) evaluating emerging technologies to further reduce GHG emissions and improve fuel economy; (3) identifying the capabilities to commercialize new and existing GHG and fuel economy technologies, including potential costs and market barriers associated with such technologies; and, (4) evaluating possible approaches to help establish in the marketplace an increase in the use of advanced technologies, including, but not limited to, plug-in hybrid, battery electric and fuel cell vehicles.

1.4 Future Technical Work and Analysis for the Joint Federal Rulemaking

This report represents EPA, NHTSA, and CARB’s initial assessment of the costs, effectiveness, and lead-time considerations for a range of advanced vehicle technologies that can significantly increase fuel economy and decrease GHG emissions and it includes new information that has been gathered since the 2012 – 2016 federal final rule. As discussed above, and presented in the Executive Summary and in detail in Chapter 6, the report also presents an analysis for a range of increasing levels of potential stringency for 2020 and 2025, along with costs and benefits for using certain advanced technologies for achieving those targets. This is an important first step for EPA and NHTSA in meeting the requirements of the President’s Memorandum, which will also include the agencies issuing a Joint Notice of Intent, a Joint Notice of Proposed Rulemaking, and a Joint Final Rule in the future.

Being the first step, it is important to note that this Technical Assessment must be viewed in the context of the additional work NHTSA and EPA will do going forward. The two agencies have a number of significant, on-going projects which will inform the future joint Federal rulemaking. As discussed in Chapter 3, these include: new technical assessments of advanced gasoline, diesel, and hybrid vehicle technology effectiveness being conducted with Ricardo, Inc.; several new projects to evaluate the cost, feasibility, and safety impacts of mass reduction from vehicles; and an on-going project with FEV & Munro to improve our cost estimations for advanced technologies; further consideration of battery life, durability, cost and safety; consideration of several technology cost factors including Indirect Cost Multiplier values, time based learning over extended periods of time; maintenance costs; and further review of the leadtime needed to implement advanced technologies. An analysis of the effects of mass reduction on vehicle safety has not been included in this Technical Assessment. For the 2017-2025 NPRM, NHTSA and EPA will conduct an analysis of the effects of the proposed rulemaking on vehicle safety, including societal effects. CARB is undertaking a study of the safety effects of a future vehicle designed for high levels of mass reduction, and CARB is coordinating with EPA and NHTSA on that study. In addition, EPA and NHTSA will continue to meet with and consider input from the full range of stakeholders as we develop the joint Federal rulemaking. All of this future information will enhance the accuracy of our technological assessment.

In addition, the assessment of scenarios and the accompanying results presented in Chapter 6 of this report should be considered an initial analysis because it does not consider the full range of factors which EPA and NHTSA must consider for a rulemaking under our respective statutory authorities. As discussed in Chapter 6, these include (but are not limited to): consideration of the full range of societal benefits, including consumer welfare effects, specific evaluation of potential safety implications of future standards, consideration of the costs and feasibility of the standards for individual automotive firms, and the development of separate attribute-based standards for passenger cars and light-duty trucks for each model year covered by the rulemaking.

Chapter 1 References

[1] Presidential Memorandum: "Improving Energy Security, American Competitiveness and Job Creation, and Environmental Protection Through a Transformation of Our Nation's Fleet of Cars And Trucks," Issued May 21, 2010, published at 75 Fed. Reg. 29399 (May 26, 2010), also available at http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards.

[2] Source; Transportation Energy Data Book Edition 28

[3] Source: EIA Annual Energy Outlook 2010 released May 11, 2010.

[4] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007. EPA 430-R-09-004.

[5] U.S. Environmental Protection Agency (2010). Regulatory Impact Analysis: Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, Chapter 2, page 2-4. EPA-420-R-10-009. Available at: http://www.epa.gov/otaq/climate/regulations.htm.

[6] Presidential Memorandum, *See* Note 1.

[7] Remarks by the President on National Fuel Efficiency Standards, May 19, 2009, available at http://www.whitehouse.gov/the-press-office/president-obama-announces-national-fuel-efficiency-policy, *see also* http://www.whitehouse.gov/the-press-office/remarks-president-national-fuel-efficiency-standards

[8] 75 FR 25324 (May 7, 2010).

[9] 49 U.S.C. 32902

[10] 74 FR 32744 (July 8, 2009).

[11] The California Air Resources Board commitment letter is available at: http://www.epa.gov/otaq/climate/regulations.htm.

[12] The manufacturer commitment letters are available at: http://www.epa.gov/otaq/climate/regulations.htm.

2 Technical Input from Stakeholders

2.1 Overview of Stakeholder Outreach Process

As mentioned above, the May 21, 2010 Presidential Memorandum requests that EPA and NHTSA, working with the State of California, develop a Technical Assessment to inform the rulemaking process "reflecting input from an array of stakeholders on relevant factors, including viable technologies, costs, benefits, lead time to develop and deploy new and emerging technologies, incentives and other flexibilities to encourage the development and deployment of new and emerging technologies, impacts on jobs and the automotive manufacturing base in the United States, and infrastructure for advanced vehicle technologies…."[13]

To fulfill that request, during June through August 2010, EPA, NHTSA, and CARB held numerous meetings with a wide variety of stakeholders to gather input to consider in developing this Technical Assessment Report, and to ensure that the agencies had available to them the most recent technical information directly from the stakeholders themselves. These stakeholders included many automobile original equipment manufacturers (OEMs), automotive suppliers, non-governmental organizations, states and state organizations, infrastructure providers, and labor unions. For many of the meetings with the OEMs, as well as labor unions, representatives from the federal Council of Environmental Quality and the White House Office of Energy and Climate Change also participated. The agencies sought these stakeholders' technical input and perspectives on the key issues that should be considered, as the President's memo identified, in assessing a national program to reduce greenhouse gas emissions and improve fuel economy for light-duty vehicles in model years 2017-2025. NHTSA and EPA anticipate continuing the productive dialogue with stakeholders as our joint federal rulemaking to develop the new national program proceeds, in order to continue to ensure that our analysis reflects the best available information.

2.2 Input from Various Stakeholder Groups

2.2.1 Automobile Original Equipment Manufacturers

EPA, NHTSA and CARB met with twenty different automotive OEMs to discuss the development of a national program for MYs 2017-2025. As discussed below, these include very large firms which sell large volumes of vehicles in the U.S. (and in most cases around the world), small and medium sized firms who sell relatively low volumes of vehicles in the U.S., and three relatively new "start-up" automotive firms whose business strategy for the U.S. market is focused on the production of all electric vehicles and/or plug-in hybrid electric vehicles. These meetings included senior management and staff from both the companies and the three agencies.

EPA, NHTSA and CARB met with eleven of the manufacturers with the largest U.S. vehicle sales volume to seek their input on both the key technical and policy issues that the agencies should consider in developing the MYs 2017-2025 technical assessment. The agencies met individually with the following companies: General Motors, Ford, Chrysler, Toyota, Honda, Nissan, Hyundai, Kia, Volkswagen, BMW, and Daimler. These manufacturers account for more than 90 percent of the vehicles produced for sale in the United States. While the views they expressed and the forecasts they shared for the future vehicle market covered a considerable range, especially in terms of specific details, the agencies view this range as unsurprising, considering uncertainty regarding key factors (*e.g.*, fuel prices) in the 2017-2025 time frame, the relatively long-time frame over which requested companies to consider (15 years into the future) and considering manufacturers' various strategies for competing in the automotive market. A number of messages were stressed by all or nearly all manufacturers and we have summarized those below. The agencies have carefully considered the information and views these manufacturers have shared, and NHTSA and EPA will continue to do so as part of the formal rulemaking process for post-2016 CAFE and GHG emissions standards.

In addition, the agencies met with several medium to smaller volume manufacturers, including Mitsubishi, Jaguar Land-Rover, Ferrari, Aston-Martin, Lotus, and McLaren. These medium and smaller volume manufacturers may face unique compliance challenges because they sell a limited number of vehicle types in the U.S., and/or they serve relative small market segments that tend to value highly priced luxury vehicles with very high levels of vehicle performance (e.g., vehicles with very rapid acceleration and top vehicle speeds) much more highly than fuel economy, such that fuel-saving technologies (*e.g.*, turbochargers), even when applied, are often used to increase performance rather than to increase fuel economy. Several of these manufacturers have traditionally been “fine-payers” under the CAFE system, and like all manufacturers—including those that do comply with CAFE standards—are required to pay “gas guzzler” taxes for specific models with especially low fuel economy levels. The input from these medium and smaller volume manufacturers will be important to the agencies in determining how to structure the national program for MYs 2017-2025.

The agencies also met with new entrants to the automotive industry who are focusing on development of electric vehicles and/or plug-in hybrid electric vehicles, including Fisker, Tesla, and BYD. These electric vehicle manufacturers provided input regarding the cost of key EV technologies (*e.g.*, batteries), the outlook for expanding the EV market, and the need for infrastructure and public incentives to support PHEV and EV purchase and operation.

The agencies requested the OEMs' input in the following key areas, consistent with the President's memorandum:

- Technology development status for MYs 2017-2025. For each major technology development area we requested details regarding effectiveness, costs, technology development and future product introduction plans, and the anticipated market penetration in the 2017-2025 timeframe. The major technology areas in which the agencies specifically sought information included powertrain improvement for advanced gasoline and diesel engines and transmissions, hybrid vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) (with a focus on battery technology for HEV/PHEV/EVs), fuel cell vehicles, and vehicle mass reduction, as well as thermal management technologies including air conditioning improvements.

- Key regulatory design elements
- Infrastructure issues
- Perspective on the impacts on the U.S. manufacturing base and jobs
- Potential incentives and flexibilites

In response, the automotive OEMs presented detailed technical information to the agencies addressing these topics, and requested confidential treatment for much of it. In order to respect these requests for confidentiality, the agencies cannot reveal specific details of the business information provided at these meetings, but taken in the aggregate, the following summarizes information gathered from the OEM meetings. It is important to note that while we requested information for the 2017-2025 time frame, nearly every manufacturer indicated that they do not have detailed product development and launch plans which extend 15 years into the future. In general, the firms' plans for 2010-2015 are fairly well defined, most firms do have product plans which extend into the 2016-2020 time frame, and no firm had product plans of any significant detail which cover the 2021-2025 time frame. Below we summarize the general trends we heard from the OEMs in the following broad areas: advanced gasoline/diesel engine and transmission technologies; vehicle mass reduction technologies; HEV, PHEV, EV technologies; fuel cell vehicle technologies; air conditioning and other technologies; regulatory program design; electric vehicle charging infrastructure, and; perspectives on US manufacturing and automotive-related jobs.

<u>Advanced gasoline/diesel engine and transmission technologies</u>

Nearly universally, the manufacturers agreed with the agencies' projections in the MYs 2012-2016 final rule that the following technologies will be much more prevalent in 2016 and beyond than they are today. These unclude more efficient turbocharged direct injection downsized gasoline engines (turbo-GDI engines) as well as, for larger displacement engines, a mix of turbo-GDI engines and some products with GDI coupled with cylinder deactivation and advanced valve timing control - all matched with more efficient 6+ speed automatic or dual-clutch transmissions.[C] However, beyond this particular combustion and transmission technologies, OEM feedback with regard to what technologies would be employed to meet future more stringent CAFE and GHG standards was mixed. Companies indicated that they intended to pursue a variety of different strategies, including diesel, lean burn gasoline direct injection, homogeneous charge compression ignition, high Brake Mean Effective Pressure (BMEP)[D] turbocharged/cooled exhaust gas recirculation systems, and

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[C] *See, e.g., id*. at 25621-25624.

[D] Brake Mean Effective Pressure is the average amount of pressure in pounds per square inch (psi) that must be exerted on the piston to create the measured horsepower. This indicates how effective an engine is at filling the other advanced engine configurations. Some of these technologies are still in development, and OEM comments usually noted that while they remain promising advanced powertrains, further development will still be needed to bring them to production. For example, while manufacturers were often optimistic about upcoming advanced gasoline engine technologies, some also cited concerns such as launch performance of highly-downsized turbocharged engines (though most of those manufacturers also stated they are working to resolve this issue), or the sensitivity of emission controls on lean-burn engines to gasoline sulfur content. Several manufacturers also indicated that nationwide increases in gasoline minimum octane levels could be important to attain the maximum potential fuel efficiency and GHG emissions improvements for advanced gasoline engines while avoiding driver dissatisfaction with not being able to use regular octane fuel. While there was general consensus that more can be done for gasoline engines, there was no general consensus, and in some cases no projections were provided, regarding the projected costs of these technologies in the 2020 to 2025 time frame.

Vehicle mass reduction technologies

Nearly all OEMs had strategies for reducing the mass of their vehicles, that in many cases were described as a new or improved technical approach. Some firms stated that they would also be taking advantage of opportunities to reduce engine size without compromising vehicle power/weight ratios and thus maintain or increase vehicle performance. The majority of manufacturers stated that they were making every effort to remove weight from their vehicles through careful redesigns, material substitution, and mass reduction compounding going forward. Nearly every automotive firm indicated that vehicle mass will actually decrease over the 2010 to 2025 time frame, though the level predicted level of mass decrease varied significantly across the firms. Nevertheless, several OEMs indicated that vehicle safety technologies, both those driven by regulation and those planned by the firms to meet internal company objectives or voluntary standards, would add mass to vehicles in the future and this would partially off-set the gains they would see if the focus were only on mass reduction and the current status-quo with respect to vehicle safety related technology. A few firms also speculated that future criteria pollutant emission standards may also result in a small increase in mass that would partially offset the other mass reduction technologies being considered by the companies.

Manufacturers cited varied plans to change vehicle designs and/or increase the use of high-strength steel (HSS), ultra-high strength steel, aluminum, composites, and/or other materials in order to offset these increases and achieve further mass reduction.

Manufacturers generally indicated that universal material substitution (such as a complete switch from steel to aluminum body-in white structures) would not be feasible to implement across the majority of their high volume vehicle product lines in the 2017-2025 time frame due to cost constraints as well as many other engineering and manufacturing challenges. Therefore, while more lighter-weight materials might be seen in the future, most

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combustion chamber with an air/fuel mixture, compressing it and achieving the most power from it. A higher BMEP value contributes to higher overall efficiency.

OEMs expressed that they still saw the need to continue utilizing steel on many of the structural components of vehicles. Also, most manufacturers indicated they either currently use significant levels of HSS and/or plan to increase use of HSS in response to recently-promulgated MYs 2012-2016 standards, which some emphasized could mean that further mass reduction through MYs 2017-2025 would necessitate more aggressive (and, therefore, potentially more expensive) strategies. Balancing all of these factors, most manufacturers generally estimated the potential to reduce actual vehicle mass ranges from 10% to 15% between today (2010) and 2025.

A number of firms also discussed the more advanced light-weight materials such as carbon fiber and magnesium. While these materials can offer very significant mass reduction, in general these materials are only used on more exotic luxury or high performance vehicles. There are, of course, examples of vehicles today which use carbon fiber, but they tend to be very expensive, ultra-high performance vehicles (such as the limited edition Ferrari Enzo, or the Mercedes SLR MacLaren) or in other cases the amount of carbon fiber in the vehicle is for a few select components (such as in the high performance Corvette ZR1 or the high performance Lexus ISF). A number of automotive firms are exploring the ability to produce a less expensive automotive grade carbon fiber, but in general companies did not see carbon fiber, or for that matter magnesium, as playing a major role in the 2017-2025 time frame.

HEV, PHEV, EV technologies

Virtually all of the manufacturers are planning for greater electrification of their fleet, although there were varying degrees of this: from 12 volt stop-start systems, to full hybrid electric vehicles (HEV), to plug-in HEVs (PHEV), to electric vehicles (EV). OEMs stated that the relative penetration of these technologies varied greatly depending on a number of factors, including, future gasoline fuel prices, future decreases in battery costs, anticipated regulatory fuel economy/GHG requirements. In particular for PHEV and EVs, OEMs also identified the charging infrastructure development and costs as well as external (federal, state and local) incentives, and consumer demand/acceptance of vehicles requiring recharging and which may have reduced range (in the case of EVs) as additional factors which will impact the future penetration of these technologies. For example, with regard to consumer demand, a number of OEMs expressed reservations regarding the potential, without government assistance, to increase significantly the market for PHEVs and EVs, much beyond the likely first-adopters who have already indicated interest in purchasing these vehicles. Nevertheless a number of the firms suggested that in the 2020 time frame their U.S. sales of HEVs, PHEVs, and EVs combined could be on the order of 15-20% of their production, and while not all firms provided forecasts out to 2025, some did indicate that this percent of production could grow to be on the order of 40-50%, depending on the factors described above. Other firms provided lower projections for the 2020 to 2025 time frame, or no projection at all.

All of the major OEMs recognize that for PHEV and EV vehicles, the battery costs are by far the most significant contributor to the cost increase over a gasoline vehicle. Universally the OEMs believe that large-format lithium-ion batteries offer the most promising trade-off between battery performance, weight, size, and costs. A large number of lithium-ion battery chemistries and designs are being explored and considered for commercialization. With respect to costs, there also was a wide range in OEM-projected battery-pack cost in the

2020 to 2025 timeframe, with the majority of estimates in the $300/kW-hour to $400/kW-hour range for 2020 and $250 to $300/kW-hour range for 2025.

Fuel cell vehicle technologies

A number of the larger automotive firms described active research and product development programs they have underway with respect to fuel cell vehicles. Several companies have planned limited product introductions for California within the next several years. The companies that discussed such programs identified two major challenges for fuel cell vehicles: reducing vehicle system costs and the development of a refueling infrastructure.

With respect to costs, several of the firms had specific technology development roadmaps which they estimated could significantly lower the costs of fuel cell vehicles over the next ten to fifteen years, which they indicated could potentially make fuel cell vehicle incremental costs competitive with all electric vehicles in the 2020 to 2025 time frame.

With respect to infrastructure, while the OEMs noted that California is actively working to develop and expand a hydrogen refuel infrastructure centered in Southern California, they also stressed that without a significant development in other regions of the U.S., fuel cell vehicles will not be able to penetrate the market beyond limited, centrally fueled fleet programs.

For the U.S. market, most major firms expressed a belief that fuel cell vehicles will play a significant role in the longer-term. Several firms expect that this will be in the time frame beyond 2025 for the nation as a whole, outside of specific geographic areas (such as California) where a refueling infrastructure is being developed.

Air conditioning and other technologies

Many of the OEMs stated that they were anticipating switching air conditioner (A/C) refrigerant from the current R134a (with its high global warming potential, GWP) to the much lower HFO1234yf as soon as they could, with most firms projecting this would occur between now and approximately 2018. Many OEMs noted, however, that this switch is dependent on EPA SNAP approval,[E] as well as availability and price from suppliers for the new refrigerant. Manufacturers noted that these two issues had the potential to delay much of the switchover to HFO1234yf, with the period of the delay depending upon the specifics of EPA's future action and how the market place forces play out with respect to the supply and demand for the new refrigerant..

With regard to other vehicle technologies, each of the companies had their own suite of other technologies that would improve efficiency based on their unique expertise and

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[E] The Significant New Alternatives Policy (SNAP) Program is EPA's program to evaluate and regulate substitutes for the ozone-depleting chemicals that are being phased out under the stratospheric ozone protection provisions of the Clean Air Act (CAA). Before any new or substitute refrigerant can be utilized in mobile A/C applications, EPA must receive a SNAP submission and reach a determination. If EPA finds the substitute acceptable, its use must comply with conditions set forth in the SNAP determination.

product plans. These included aerodynamic improvements, friction reduction, further reductions in tire rolling resistance, and a number of other technologies that cannot be described in detail given confidentiality restrictions.

Regulatory program design input

Specific company suggestions for the appropriate design of regulatory programs, often relating to OEM-specific strategies for coming into compliance under various scenarios and their particular desired program flexibilities, were considered to be confidential business information by all of the manufacturers. These suggestions varied greatly depending on the specific company, as did manufacturers' plans for future compliance. However, there was universal consensus that a national program should continue, and that a single national fleet should be able to comply with California and federal GHG standards as well as federal CAFE standards.

Several OEMs also discussed the importance of a mid-term technology review which would occur after the 2017-2025 standards are promulgated. The May 19, 2010 support letters from all of the OEMs and the two major automotive trade associations also supported the concept of a mid-term technology review. In addition, several OEMs were supportive of the continuation of attribute-based standards and of separate standards for cars and trucks.

Electric vehicle charging systems

A number of the automakers provided input on the electrical vehicle charging systems needed for EVs and PHEVs. The OEMs generally agreed that most charging will occur at home and will be Level 1 or Level 2, with a greater likelihood of Level 2 charging as vehicle range and size increases.[F] OEMs suggested that workplace charging, if available, could significantly increase the vehicle's daily driving range (under the assumption the vehicle can be charge two times in a day, once at home in the morning, and once at work during the day) and may help to increase market appeal of EVs and PHEVs. OEMs also indicated that public charging (Level 2 or Level 3 quick charging) could provide additional comfort to EV/PHEV owners and may help to facilitate the mass adoption of these vehicles. OEMs also generally agreed that costs of electric vehicle service equipment installation will vary widely by the age of the house, location of the charging equipment, and difficulty of installation. Some urban locations without dedicated parking, such as apartments and townhouses with street parking, may present charging challenges. These issues are discussed in more detail in Chapter 4 below.

A number of OEMs also indicated that they believe that federal and state incentives are helpful in encouraging charging system development and charge point deployment. In addition, stakeholders emphasized that standardization of charging facilities and codes for

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[F] Details regarding EV and PHEV charging levels are included in Chapter 4 of this report. In general, Level 1 charging uses a lower voltage than Level 2. Level 1 chargers require more time for battery charging than Level 2. As discussed in Chapter 4, there is also a Level 3 charging approach, sometimes called "quick charging", which uses even higher voltages and takes even less time than Level 1 or Level 2.

installing equipment will streamline and encourage the widespread deployment of charging infrastructure and promote the adoption of PHEVs and EVs. Some OEMs also suggested that so-called "smart metering" equipment and strategies could enable consumers and utilities to choose the best time to charge vehicles for the lowest cost while maintaining maximum vehicle availability.

Perspectives on US manufacturing and automotive-related jobs

Not all manufacturers discussed potential impacts on jobs and the U.S. manufacturing base, but of those that did, many were optimistic about the opportunities to build fuel-efficient cars in the United States and the concurrent boost to the U.S. job market. Most OEMs were predicting significant increase in sales after the drop in 2009, and further sales increases into 2017+, with concomitant increases in U.S. manufacturing jobs. Further, OEMs stated that increased technological content in vehicles will likely require more development, testing, and additional manufacturing requirements and thus potentially lead to more jobs in the supplier chain, both in the U.S. as well as abroad. Several manufacturers noted that Federal government stimulus bill investments, as well as additional incentives provided by a number of state and local governments, were an important factor in locating manufacturing operations for electrification components (including new battery, electric motor, and power electronic manufacturing facilities) in the U.S., and that continuation of this type of investment would be an important consideration to locating future facilities in the U.S.

2.2.2 Automotive Suppliers

EPA, NHTSA and CARB met with a cross section of automotive suppliers to seek their input on a number of key technical issues. Suppliers conduct their own research and development on a wide variety of automotive products that directly and indirectly influence the fuel economy and CO_2 emissions of vehicles. The agencies met individually with the following companies and associations: Delphi, Bosch, Denso, Borg Warner, Honeywell, Valeo, Johnson Controls, A123, BYD, Dupont, the American Iron and Steel Institute and a number of their member companies, the Aluminum Transportation Group (a part of the Aluminum Association) and a number of their member companies, and the Rubber Manufacturers Association and a number of their tire manufacturing company members. We note that there are a very large number of automotive suppliers, making it impossible to meet with even all of the major companies given the time frame for this technical assessment report. The companies and associations with whom we met represent a small but significant fraction of these suppliers, given their importance in the market and/or the uniqueness of their product offerings.

The agencies requested input in the following key areas: expected technology development status for MYs 2017-2025, cost, effectiveness, and potential limitations of technologies, and impact on jobs. In response, as with the automotive OEMs, the supplier companies presented detailed technical information to the agencies addressing these topics, and requested confidential treatment for much of it. In order to respect these requests for confidentiality, the agencies cannot reveal specific details of the business information provided at these meetings, but taken in the aggregate, the following summarizes information gathered from the supplier meetings.

In general, the suppliers were optimistic that supplier-developed advanced technologies could play a critical role in 2017-2025 vehicles, and they were actively engaged with OEMs for not only application of near-term technologies but also collaborative development of production road maps for technologies currently in the R&D phases within their organizations. Generally the suppliers stated that future R&D activities would allow them to decrease costs, increasing production capacity, and produce innovative solutions for OEM needs. However, suppliers also independently discussed some of OEMs key issues — such as the potential future penetration and challenges for large market adoption of HEVs, PHEVs, EVs, and FCVs. Some suppliers' cost estimates were more consistent with or even lower than the figures used by the agencies in the present analysis. The steel and aluminum industry emphasized that weight can be reduced in vehicles without sacrificing safety, although the agencies note that the assessment of safety identified by these industries does not include the type of detailed aggregate societal impacts assessment that NHTSA and EPA will conduct for the upcoming joint Federal rulemaking.

On the issue of potential job impacts, suppliers strongly supported the recent federal funding for advanced battery development. Suppliers stated that this has already led to many engineering and manufacturing jobs created in the U.S., in part due to Federal stimulus funding, and expressed confidence that this sector will continue to grow.

On the issue of infrastructure, some of the suppliers did discuss issues regarding EV/PHEV vehicle infrastructure. In general, their themes on this topic were consistent with what we also heard from the OEMs discussed above.

2.2.3 Non-Governmental Environmental Organizations

The agencies also received input from numerous environmental organizations, including the Natural Resources Defense Council, Union of Concerned Scientists, Environmental Defense, Sierra Club, the American Council for an Energy-Efficient Economy, Safe Climate Campaign, Environment America, and the National Wildlife Federation. These environmental organizations stated that they are very supportive of the President's call for setting new fuel economy and greenhouse gas standards for light-duty vehicles for the 2017-2025 model years. These groups believe this will help to cut U.S. oil dependency and move the nation toward a clean energy economy. The groups stated that they support setting standards at the maximum technically feasible level in order to bring new technologies to the marketplace, calling on the agencies generally to establish future standards which would push efficiency limits on conventional internal combustion engine vehicles, bring hybrids into mainstream commercial production, and pull advanced electric-drive vehicles into the market. These organizations requested that the agencies establish standards for 2017-2025 which would put light-duty vehicles on a path to achieve an 80 percent reduction (from 2005 levels) in global warming emissions by 2050. The groups also encouraged EPA and NHTSA to work quickly to propose and finalize the new standards.

The environmental groups emphasized that the rulemaking process be open and transparent to the public. They commended the transparency of the process thus far, and expect it to be continued moving forward. The environmental groups stated that transparency is critical in several specific areas, including manufacturers' compliance, test data, technology costs, modeling of technology adoption (*e.g.*, EPA's OMEGA model and NHTSA's Volpe model), vehicle safety assessments, assumptions of advanced vehicle adoption, and accounting for electric vehicle upstream emissions and other off-cycle factors.

Another issue raised by the environmental groups was the concept of a mid-term technology review, as indicated in the auto manufacturers' letters supporting the President's memorandum. The environmental groups emphasized that any mid-term technology review, if conducted, should not undermine innovation, should be very narrow in scope, and be a one-time review after 2020. They stated that a technology review should not create uncertainty regarding the requirements established by the agencies, or be considered an "escape route" to delaying requirements. They also stated that a technology review may be unnecessary if the 2017-2025 standards can be achieved by using multiple technology pathways, as opposed to a single, "silver-bullet" technology.

The environmental groups requested that EPA and NHTSA continue to rely on what they characterized as reasonable discount rates when evaluating the consumer benefits of fuel savings, so as to not undervalue the consumer benefits of higher fuel economy standards. The groups reiterated prior arguments that discount rates higher than the 3 and 7 percent rates recommended in OMB guidance documents are inappropriate, due to the highly imperfect automobile market, with limited information, uncertainty of future gasoline prices, and a limited set of options with regard to fuel economy. The groups expressed interest in working on the discount rate issue with EPA, NHTSA, and others during the upcoming joint federal rulemaking process.

These groups stated that the standards should rely on an updated and accurate safety analysis, consistent with EPA and NHTSA's discussion of this issue in the final rule for the MY2012-2016 standards. The environmental groups stated that their understanding of the analysis in the MYs 2012-2016 rule is that vehicle mass reduction can be applied in a way that saves lives while also cutting fuel consumption and GHG emissions. The groups expressed support for the commitments made by NHTSA in the MYs 2012-2016 final rule, as discussed below in Chapter 3, to collaborate with EPA, CARB and the Department of Energy, in conducting further safety and mass reduction research.

Finally, the environmental groups stated that the tailpipe compliance calculation for electric-drive vehicles should account for upstream GHG emissions due to electricity and hydrogen generation. Their concern is that if manufacturers are allowed to treat EVs (or the electric portion of a PHEV) as 0 grams of CO_2/mile for compliance purposes, they may be able to meet the standards through producing only a small number of electric-drive vehicles, while avoiding fuel economy improvements in conventional vehicles. Further discussion of this issue is contained in Chapter 7.

2.2.4 State and Local Government Organizations

The agencies met with representatives from the National Association for Clean Air Agencies (NACAA), the Northeast States for Coordinated Air Use Management (NESCAUM), and approximately 10 individual state and local governments. The state and local organization stressed broad objectives, and generally expressed strong support of the agencies' efforts to develop a national program for the 2017-2025 timeframe. The states emphasized, consistent with California's letter supporting the Presidential memorandum, that the agencies should evaluate a range of potential standards of 3 to 6 percent annual increases in stringency for the 2017-2025 time frame. The states expressed a strong preference toward the higher stringencies in that range, stating that the standards must be technology forcing in order to help them achieve their individual and regional GHG reduction goals.

The states also strongly supported the collaborative process in which EPA, NHTSA, and CARB are engaging in order to assess the technical information going into the 2017-2025 assessment. Several states mentioned activities they have underway to develop the infrastructure needed to support electrified vehicles. The states also expressed support for transparency in the process of developing the technical assessment, and the eventual proposed rulemaking, and an interest in continued dialogue.

2.2.5 Infrastructure Providers

The agencies met with representatives from the Electric Power Research Institute (EPRI) and charging infrastructure providers. EPRI believes the focus for EV and PHEV charging systems should be on home charging, with a goal of a seamless installation process (permitting, electrical installation, inspection) for homeowners. However, EPRI recognizes that home charging infrastructure is expensive, estimating an average cost of about $1,500 for home charging installations. Some charging infrastructure providers see a more important role for public charging, which could expand EV/PHEV markets to people who live in apartments, condominiums, or otherwise do not have garage access for convenient home charging. EPRI believes more work is needed to assess how workplace and public charging infrastructure should be developed, both in terms of where to best locate stations for consumers' convenience and who should own the them (e.g., municipalities, private sector, employers, utilities).

EPRI believes that overall electric utilities will be able to support the rollout of EVs and PHEVs. However, there is a possibility of isolated impacts on some residential transformers, particularly in neighborhoods with older distribution systems. To mitigate these potential impacts, EPRI suggests that early notification to the local utilities of EV/PHEV charging plans would help the utilities assess any potential need for upgrades to the electric power delivery system. EPRI also believes that potential stresses on power delivery systems can be mitigated by the wise application of smart charging, which has the potential to even out charging loads. Charging infrastructure providers generally agreed with this assessment. EPRI is currently examining these issues.

2.2.6 Labor Unions

EPA, NHTSA and CEQ met with representatives of the United Auto Workers (the UAW). The UAW was supportive of continuing the National Program for 2017 and beyond. The UAWs overarching concern was how the future development and market penetration of advanced vehicle technologies will impact automotive industry manufacturing employment in the United States. The UAW stated their general belief that a high percentage the sub-systems and vehicle assembly for hybrid electric vehicles sold in the U.S. today are not manufactured in the United States. The UAW is concerned that this trend could continue, and that the potential future introduction of plug-in hybrid electric vehicles and electric vehicles in addition to the potential future expansion of hybrid electric vehicles could results in an overall decline in the automotive manufacturing jobs in the United States. The UAW stated that the government funding for advanced technology vehicles had made an important difference in the past year, resulting in many companies deciding to manufacturer batteries, electric motors, and vehicle assembly plants in the U.S.; the UAW was concerned that without the continued economic support from the federal government, future manufacturing facilities for these advanced technology vehicles may not occur in the U.S.

In addition to this important issue, the UAW made two specific requests which they would like the federal government to consider in the development of the 2017-2025 joint federal rulemaking. The UAW believes it is important for the agencies to analyze and report the net domestic employment effects of any future proposed standards. In addition, the UAW requested that future regulations include provisions with respect to GHG emissions from automobiles other than the CO2 captured by the CAFE program for the eventual integration of those emissions regulations with any broader national GHG program that might be developed by Congress or that may be proposed by EPA under the Clean Air Act in the future. Specifically the UAW was referring to methane, nitrous oxide, and hydroflurocarbon emissions, as well as CO2 emissions related to a vehicles air conditioning system operation, which is not capture under today's CAFE test procedures. Finally, the UAW raised some concerns with the future projections contained in the Energy Information Administration's Annual Energy Outlook reports and the accuracy of those reports projections regarding future improvements in fuel economy absent new standards.

Chapter 2 References

[13] 75 Fed. Reg. 29399 (May 26, 2010).

3 Technology, Cost, Effectiveness and Lead-time Assessment

3.1 What technologies did the Agencies Consider?

The agencies assume, in this analysis, that manufacturers will add a variety technologies to each of their vehicle model platforms in order to improve their fuel economy and GHG performance. In order to analyze a variety of regulatory control scenarios (as we do in this report), it is thus essential to understand what is feasible within the timeframe of the rule. Technical feasibility of potential standards requires a thorough study of the technologies available to the manufacturers. This study includes an assessment of the cost, effectiveness, as well as the lead time of the technologies. The lead time relates to the availability, development time, and manufacturability of the technology within the normal redesign periods of a vehicle line (or in the design of a new vehicle). As we describe below, lead time issues can in turn affect the cost as well as the technology penetration rate (or caps) that are assumed in the analysis.

The agencies considered over 30 vehicle technologies that manufacturers could use to improve the fuel economy and reduce CO_2 emissions of their vehicles during the 2017-2025 timeframe. A majority of the technologies described in this chapter are readily available today, are well known, and could be incorporated into vehicles once product development decisions are made. These are “near-term” technologies and are identical to those applied in the 2012-2016 light-duty rule. Other technologies considered may not currently be in production, but are beyond the initial research phase, under development and are expected to be in production in the next few years. These are technologies which can, for the most part, be applied both to cars and trucks, and which are capable of achieving significant improvements in fuel economy and reductions in CO_2 emissions at reasonable costs in the 2017 to 2025 timeframe. The agencies did not consider technologies that are currently in an initial stage of research because of the uncertainty involved in the lead time available to implement the technologies with significant penetration rates for this assessment.

3.2 How did the Agencies Determine the Costs and Effectiveness of Each of These Technologies?

3.2.1 How are Cost and Effectiveness Estimates Different from the 2012-2016 Rule?

Virtually all of the technologies considered in this analysis are identical to those described in the 2012-2016 light-duty CAFE and GHG final rule. Those that are new or modified are described in greater detail in this chapter. In general, the costs of fuel consumption improvement technologies considered in this assessment are taken straight from the 2012-2016 light-duty CAFE and GHG final rule, with six exceptions that impact individual technology costs in different ways. The first exception is that the agencies have reconsidered the costs for several technologies for which extensive tear-down studies were completed during development of the MYs 2012-2016 final rule. These teardown studies were conducted under the continuing EPA contract with FEV and Munro in support of that rulemaking and were discussed in detail in the Technical Support Document.[14] The second exception is that the agencies have reconsidered the costs for hybrid electric vehicles (HEV), plug-in hybrid (PHEV), electric vehicles (EV), and fuel cell electric vehicles (FCEV), due in part to the rapid changes taking place in battery technology and cost estimation methods based on the expert judgment of the Department of Energy (DoE), EPA, CARB, and NHTSA and using updated costs as compared to the 2012-2016 light-duty rule. The third exception is that the agencies have updated the cost for mass reduction based on more recent studies. The fourth exception is that the indirect cost markups (ICM) used in the 2012-2016 light-duty rulemaking and have added an additional factor of 0.06 to each. This factor has been added to reflect return on capital of 6% in the automotive industry, described further below.[15] The fifth exception is that cost estimates have been updated to reflect 2008 dollars while the 2012-2016 light-duty rule expressed costs in terms of 2007 dollars. This update was done using a ratio of GDP price deflators in a manner consistent with the procedure used in the 2012-2016 light-duty rule. The sixth exception is that learning effects have been allowed to continue beyond the 2016 model year so that the individual piece costs in the 2017 and later model years will, in general, be lower than the costs estimated for the 2012-2016 model years. We note, however, that the type of learning – volume-based or time-based, as described in the 2012-2016 light-duty rule – has not changed. Each of these exceptions is discussed in more detail below and in Appendix B.

Most of the effectiveness numbers of the technologies have also not changed from the previous final rule. The few changes that were made are also described below. The agencies are pursuing additional work to update the effectiveness of virtually all of the technologies listed in this chapter.

3.2.2 Costs from Tear-down Studies

The agencies have updated costs of certain technologies that had been based on tear-down studies conducted during the 2012-2016 rulemaking. The agencies believe that the best method to derive technology cost estimates is to conduct studies involving tear-down and analysis of actual vehicle components. A “tear-down” involves breaking down a technology into its fundamental parts and manufacturing processes by completely disassembling vehicles and vehicle subsystems and precisely determining what is required for its production. More details about tear down studies can be found in the studies supporting the 2012-2016 light-duty rule as well as the FEV and Munro Associates report for EPA.[16,17] This tear-down method of costing technologies is often used by manufacturers to benchmark their products against competitive products. Historically, vehicle and vehicle component tear-down has not been done in large scale by researchers and regulators due to the expense required for such studies.

To-date, such tear-down studies have been completed on the six technologies listed below. These completed tear-down studies provide a thorough evaluation of the component or system cost relative to their baseline (or replaced) technologies. A more detailed description of these technologies can be found in the Technical Support Document prepared for the 2012-2016 light-duty final rule.[14] For these technologies, the agencies have relied on the tear-down data available and scaling methodologies used in EPA’s ongoing study with FEV. Note, this costing methodology has been published and has been peer reviewed.[18]

1. Stoichiometric[G] gasoline direct injection and turbo charging with engine downsizing (T-DS) for a large DOHC (dual overhead cam) 4 cylinder engine to a smaller DOHC 4 cylinder engine.
2. Stoichiometric gasoline direct injection and turbo charging with engine downsizing for a SOHC (single overhead cam) 3 valve/cylinder V8 engine to a SOHC V6 engine.
3. Stoichiometric gasoline direct injection and turbo charging with engine downsizing for a DOHC V6 engine to a DOHC 4 cylinder engine.
4. 6-speed automatic transmission replacing a 5-speed automatic transmission.
5. 6-speed wet dual clutch transmission (DCT) replacing a 6-speed automatic transmission.

In addition, FEV and EPA extrapolated the engine downsizing costs for the following scenarios that were based on the above study cases:

1. Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6.
2. Downsizing a DOHC V8 to a DOHC V6.
3. Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.
4. Downsizing a DOHC 4 cylinder engine to a DOHC 3 cylinder engine.

In the 2012-2016 light-duty rule, the agencies relied on the findings of FEV in part for estimating the cost of these technologies. However, for some of the technologies, NHTSA and EPA modified FEV's actual estimated costs. This was done because FEV based their costs on the assumption that these technologies would be mature when produced in large volumes (450,000 units or more). The agencies believed that there was some uncertainty regarding each manufacturer's near-term ability to employ the technology at the volumes assumed in the FEV analysis with fully learned costs. There was also the potential for near term (earlier than 2016) supplier-level Engineering, Design and Testing (ED&T)[H] costs to be in excess of those considered in the FEV analysis because existing equipment and facilities need to be converted to the production of new technologies and may lead to stranded capital [I] if done too rapidly. The agencies consider the FEV results to be generally valid for the 2017-2025 timeframe because the factors considered in the 2012-2016 light-duty rule should no longer exist and sales volumes of 450,000 units are likely due to, at least in part, the new GHG and fuel economy requirements. More detail on which specific technologies are

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[G] Stoichiometric Gasoline Direct Injection refers to a gasoline fueled spark-ignition internal combustion engine with direct fuel injection into the combustion chamber that is designed to operate primarily at a chemically balanced ratio of air and fuel thus allowing the effective use of standard precious-metal based (Rh combined with Pd and/or Pt) three-way exhaust catalysts for control of criteria pollutants

[H] Product Development Costs are the ED&T costs incurred for development of a component or system. These costs can be associated with a vehicle specific application and/or be part of the normal research and development (R&D) performed by companies to remain competitive. In the cost analysis, the product development costs for suppliers are included in the mark-up rate as ED&T suppliers.

[I] Stranded Capital is defined as manufacturing equipment and facilities owned by a vehicle manufacturer that cannot be used in the production of a new technology.

impacted by this change is presented in Appendix B. The agencies will continue to review the FEV results and methodology as necessary in the upcoming federal rulemaking.

3.2.3 Costs of HEV, PHEV, EV, and FCEV

The agencies have also reconsidered the costs for HEVs, PHEVs, EVs, and FCEVs as the result of two issues: The first issue is that there is a rapid development taking place on electrified vehicle technologies and an effort has been made to capture the results from the most recent analyses. The second issue is that the 2012-2016 rule employed a single $/kWhr estimate and did not consider the specific vehicle and technology application for the battery when we estimated the cost of the battery. Specifically, batteries used in HEVs versus EVs need to be considered appropriately to reflect the design differences and differences in cost per kW-hr as the power to energy ratio of the battery changes for different applications. For this assessment, the agencies have used a battery cost model developed by Argonne National Laboratory (ANL) for the Vehicle Technologies Program of the U.S. Department of Energy (DoE) Office of Energy Efficiency and Renewable Energy. The model developed by ANL provides unique battery pack cost estimates for each of the three major types of electrified vehicles. The DoE has established long term industry goals and targets for advanced battery systems as it does for many energy efficient technologies. ANL was funded by DoE to provide an independent assessment of Li-ion battery costs because of their expertise in the field as one of the primary DoE National Laboratories responsible for basic and applied battery energy storage technologies for future HEV, PHEV and EV applications. A basic description of the ANL Li-ion battery cost model and initial modeling results for PHEV applications were published in a peer-reviewed technical paper presented at EVS-24[19]. ANL has extended modeling inputs and pack design criteria within the battery cost model to include analysis of manufacturing costs for EVs and HEVs as well has PHEVs.[20] A complete peer-review of the model and its inputs and results for HEV and EV applications is pending, and ANL expects to have a peer review completed within 1 year. NHTSA and EPA will consider the results of the peer review as we develop the future joint federal notice of proposed rulemaking. The agencies expect to continue to work with DOE and ANL (as well as battery manufacturers, OEMs, and other stakeholders) to get the most up to date information for the upcoming NPRM.

The agencies have decided to use the ANL model for estimating large-format lithium-ion batteries for this assessment for the following reasons. The ANL model has been described and presented in the public domain and does not rely upon confidential business information (which would therefore not be reviewable by the public). The model was developed by scientists at ANL who have significant experience in this area. The model uses a bill of materials methodology which the agencies believe is the preferred method for developing cost estimates. The ANL model appropriately considers the vehicle applications power and energy requirements, which are two of the fundamental parameters when designing a lithium-ion battery for an HEV, PHEV, or EV. The ANL model can estimate high volume production costs, which the agencies believe is appropriate for the 2025 time frame. Finally, the ANL model's cost estimates, while generally lower than the estimates we received from the OEMs, is consistent with some of the supplier cost estimates the agencies received from large-format lithium-ion battery pack manufacturers. A portion of the data was received from on-site visits done by the EPA.

The ANL battery cost model is based on a bill of materials approach in addition to specific design criteria for the intended application of a battery pack. The costs include materials, manufacturing processes, the cost of capital equipment, plant area and labor for each manufacturing step as well as the design criteria include a vehicle application's power and energy storage capacity requirements, the battery's cathode and anode chemistry, and the number of cells per module and modules per battery pack. The model assumes use of a laminated multi-layer prismatic cell and battery modules consisting of double-seamed rigid containers. The model also assumes that the battery modules are air-cooled. The model takes into consideration the cost of capital equipment, plant area and labor for each step in the manufacturing process for battery packs and places relevant limits on electrode coating thicknesses and other processes limited by existing and near-term manufacturing processes. The ANL model also takes into consideration annual pack production volume and economies of scale for high-volume production.

The cost outputs from the ANL model used by the Agencies to determine 2025 HEV, PHEV and EV battery costs were based upon 500,000 packs/year production volume and the use of a common cathode and anode chemistry, LiMn2O4-spinel for the cathode and graphite for the anode. The agencies assumed a change in battery state of charge (% SOC) of 50% for HEVs, 70% for PHEVs and 80% for EVs in 2025. The agencies also estimated 2020 HEV, PHEV and EV battery costs based upon the same battery chemistry and a production volume of 100,000 packs/year. EPA considered one other battery chemistry, LiFePO4-graphite. While it is expected that other Li-ion battery chemistries with higher energy density, higher power density and lower cost will likely be available in the 2017-2025 timeframe, the specific chemistry used for the cost analysis was chosen due to its known characteristics and to be consistent with publicly available information on current and near term HEV, PHEV and EV product offerings from Hyundai, GM and Nissan.[21,22,23,24] The cost of active materials is somewhat higher for LiMn2O4-spinel than for LiFePO4, but battery pack costs are generally higher for LiFePO4 when comparing battery packs with the same energy and power requirements. This is due primarily to the lower energy density of LiFePO4 relative to LiMn2O4-spinel. We expect that incremental improvements in battery energy density will continue through 2025 and thus the higher energy density represented by the choice of a LiMn2O4-spinel cathode/graphite anode within the ANL cost model is more appropriate for determining the future cost of batteries in the 2017-2025 timeframe. Examples of the cost outputs from the ANL model used by the agencies in this analysis are shown in Table 3.2-1 and Table 3.2-2. A more detailed discussion of battery pack costs is contained in Appendix B. The agencies note that costs used in the analysis are lower than the costs generally reported in stakeholder meetings, which ranged from $300/kW-hour to $400/kW-hour range for 2020 and $250 to $300/kW-hour range for 2025. Because of uncertainty with regard to future battery costs, the agencies also conducted a sensitivity study using PHEV and EV battery pack costs approximately $100/kW-hr higher and $50/kW-hr lower than the costs estimates from the ANL battery cost model. Further details regarding the sensitivity analysis are described Chapter 6 of this report and in Appendix B, section B4.2.1.3.

Table 3.2-1: Direct Manufacturing Costs on a $/kWh-basis for Large Car HEVs, PHEVs and EVs (2008 dollars, markups not included).

Application	Direct Manufacturing Cost, MY2020 (100,000 packs/year volume)		Direct Manufacturing Cost, MY2025 (500,000 packs/year volume)	
	$	$/kW-hr	$	$/kW-hr
P2 HEV Battery Pack	$801	$1,214	$641	$971
PHEV20 Battery Pack	$2,916	$324	$2,333	$259
PHEV40 Battery Pack	$4,285	$238	$3,428	$190
EV75 Battery Pack	$5,847	$217	$4,678	$173
EV100 Battery Pack	$7,443	$191	$5,954	$153
EV150 Battery Pack	$11,005	$175	$8,804	$140

Table 3.2-2: Direct Manufacturing Costs on a $/kWh-basis for subcompact HEVs, PHEVs and EVs (2008 dollars, markups not included).

Application	Direct Manufacturing Cost, MY2020 (100,000 packs/year volume)		Direct Manufacturing Cost, MY2025 (500,000 packs/year volume)	
	$	$/kW-hr	$	$/kW-hr
P2 HEV Battery Pack	$541	$1,177	$433	$941
PHEV20 Battery Pack	$2,187	$347	$1,749	$278
PHEV40 Battery Pack	$3,244	$251	$2,595	$201
EV75 Battery Pack	$4,013	$197	$3,211	$157
EV100 Battery Pack	$5,143	$184	$4,115	$147
EV150 Battery Pack	$7,666	$170	$6,133	$136

The potential for future reductions in battery cost and improvements in battery performance will play a major role in determining the overall cost and performance of future PHEVs and EVs. The U.S. Department of Energy manages major battery-related R&D programs and partnerships, and has done so for many years, including the ANL model utilized in this report. DOE has reviewed the battery cost projections underlying today's TAR. DOE supports the cost projections, and while the overall projections are in some cases optimistic, DOE believes they are reasonable for a long-term, technology-based assessment as utilized in this report. In addition, as discussed above, DOE intends to work with ANL to ensure the ANL model undergoes a thorough peer review. Finally, DOE recommends that the agencies consider evaluating a range of assumptions for rulemaking, including the evaluation of other battery cost estimation models as appropriate. NHTSA and EPA intend to conduct additional analysis for the NPRM and final rule that is consistent with these recommendations from DOE.

The agencies have also carefully reconsidered the power and energy requirements for each electrified vehicle type, which has a significant impact on the cost estimates for HEVs, PHEVs, and EVs as compared to the estimates used in the 2012-2016 rulemaking. In addition, the agencies have considered battery pack costs separately from the remainder of the systems added to each type of electrified vehicle. The advantage of separating the battery pack costs from other system costs is that it allows each to carry unique indirect cost multipliers and learning effects which are important given that battery technology is an emerging technology, while electric motors and inverters are more stable technologies. We note that, for this analysis, the agencies have assumed batteries will be capable of lasting the lifetime of the vehicle[J], which is consistent with what manufacturers have shared with us are the expected customer demands from this technology. Manufacturers have acknowledged, however, that there may be some performance degradation in the batteries over time. For the NPRM, the agencies may analyze the maintenance cost differences among technologies, including batteries. Lastly, the agencies have focused attention on an emerging HEV technology known as a P2-hybrid, a technology not considered in the 2012-2016 light-duty rule.

A P2 hybrid is a vehicle with an electric drive motor coupled to the engine crankshaft via a clutch. The engine and the drive motor are mechanically independent of each other, allowing the engine or motor to power the vehicle separately or combined. This is similar to the Honda HEV architecture with the exception of the added clutch, and larger batteries and motors. Examples of this include the soon-to-be sold Hyundai Sonata, Elantra and the Nissan Fuga (expected to be rebadged as an Infiniti product for the North American market). The agencies believe that the P2 is an example of a “strong” hybrid technology that is typical of what we will see in the timeframe of this rule. The agencies could have equally chosen the power-split architecture as the representative HEV architecture. These two HEV’s have similar average effectiveness values (combined city and highway fuel economy), though the P2 systems may have lower cost due to the lower number of parts and complexity.

The effectiveness used for vehicle packages with the P2-hybrid configuration within this analysis reflects a conservative estimate of system performance. Vehicle simulation modeling of technology packages using the P-2 hybrid configuration is currently underway under contract with Ricardo Engineering. The agencies plan to update the effectiveness of hybrid electric vehicle packages using the new Ricardo vehicle simulation modeling runs prior to the NPRM.

The agencies have also considered, for this analysis, the costs associated with in-home chargers expected to be necessary for PHEVs and EVs. Further details on in-home chargers and their estimated costs are presented in Section 4.2.3 and Appendix B. Details of the updated HEV, PHEV, EV and FCEV costs are presented in Appendix B.

3.2.4 Mass Reduction Impacts and Costs

Mass reduction encompasses a variety of techniques ranging from improved design, and increased component integration to the application of lighter and higher-strength materials. Initial mass reduction can be further compounded by reductions in engine power and ancillary systems (transmission, steering, brakes, suspension, etc.) to provide increased vehicle mass reduction overall. The agencies recognize there is a wide diversity and range of complexity

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[J] Median life of a passenger vehicle is 13.8 years and 14.5 years for light trucks. Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, “Vehicle Survivability and Travel Mileage Schedules,” DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf (last accessed March 1, 2010).

for mass reduction and material substitution technologies, and that there are many techniques that automotive and other industry suppliers and manufacturers are using or plan to use to achieve the levels of this technology that the agencies model in our analysis. Manufacturers' opinions in stakeholder meetings over the summer varied widely as to how much mass reduction could be realized and at what cost in the time frame of 2017-2025, ranging from some mass increase to 10-15 percent mass reduction. While the agencies limited the amount of mass reduction in our analysis for the MYs 2012-2016 final rule to 10 percent, for the purposes of this Technical Assessment Report the agencies have considered three levels of mass reduction that could be achieved in 2025 compared to a baseline 2008 vehicle: one pathway with less aggressive mass reduction of 15 percent, one with 20 percent mass reduction, and one with technology forcing mass reduction of 30 percent. The agencies assume, as part of these reduction amounts, that vehicle size and full functionality are maintained. We note the ability of the industry to reduce mass beyond 20% while maintaining vehicle size and functionality is an open technical issue, which the agencies are carefully evaluating and will continue to as we move forward. We also note, as discussed in the MYs 2012-2016 final rule, that the agencies believe that the effects of vehicle mass reduction on safety should be evaluated from a societal perspective (including an analysis or fatalities and casualties), which could affect the maximum levels used for rulemaking. This analysis has not been included in this report. NHTSA and EPA will include a thorough safety assessment of mass reduction for the upcoming joint federal NPRM and final rule.

With respect to the feasibility of reducing mass by 15-30 percent by 2025, the agencies discussed the application of mass reduction technologies at length in meetings with vehicle manufacturers in preparation for this Technical Assessment Report. One of the challenges the manufacturers identified with respect to mass reduction was the feasibility of substituting some lower density materials for higher density materials. These material substitution issues included material availability, forming, joining, painting, corrosion, reparability, and impact performance. The agencies have established a collaborative team among DOT/NHTSA, DOE and EPA to address vehicle mass reduction and mass/safety issues generally, and have undertaken work on several tasks to begin addressing these particular issues identified by the manufacturers, including 1) a peer review of the Lotus Engineering report[25] regarding holistic vehicle mass reduction opportunities, 2) a 2nd phase of analysis by Lotus Engineering using computer aided engineering (CAE) to assess phase 1 designs for functional and safety performance, to modify designs as necessary to achieve performance levels similar to the baseline vehicle, and to determine the mass reduction that is feasible, 3) a DOE funded project investigating the amount of mass reduction that is technologically feasible, and 4)a DOE funded project consisting of an actual vehicle build (Multi Material Vehicle – MMV[K]). NHTSA and EPA may fund other studies to explore the feasible amount of mass reduction and cost for MY 2017-2025 separately from the study contracted to Lotus engineering by CARB. Computer Aided Engineering (CAE) tools would be used to analyze the structure of the vehicle. The proposed design should meet at least the

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[K] DOE Notice of Intent to Issue Funding Opportunity Announcement N.:DE-FOA-000239. http://www.netl.doe.gov/business/solicitations/NOTICE%20OF%20INTENT.pdf same functional objectives as the baseline vehicle. If funded, this study would be finished in time for the final rule for MYs 2017-2025.

With respect to cost, in the MYs 2012-2016 final rule, NHTSA and EPA applied a cost of $1.32 per pound of mass reduction, and the limit of mass reduction (penetration cap) was set to 10%[14]. This cost estimate was based on three studies: 2002 NAS report[26], Sierra Research[27], and MIT[28]. For the purposes of this Technical Assessment Report, however, the agencies expect based on the meetings this summer with OEMs, that manufacturers will be capable of mass reduction levels greater than 10 percent net in the 2017-2025 timeframe. The agencies recognize that higher percentages of mass reduction may result in higher costs and that these costs are likely to increase non-linearly with increasing mass reduction levels. Furthermore, the agencies and OEMs also recognize that there is some initial amount of mass reduction which can be accomplished with zero or very little cost (much lower than that estimated in the 2012-2016 rule). Thus, in this report, the agencies have begun updating their mass reduction cost model to reflect this progressively increasing level of cost. A preliminary non-linear cost model employed for this current analysis is shown in the figure below. The figure shows the present cost model in comparison to the costs used for the 2012-2016 final rule. The agencies have relied on a parabolic shape for the cost curve – where the cost per pound increases as the square of the percentage mass reduction. The endpoint of the model is based on an average of the final rule costs and the results from the Lotus Engineering mass reduction study. A more complete description of how this cost model was developed is described in Appendix B. For the purposes of the upcoming federal rulemaking, the agencies intend to improve the model using additional studies that are expected to be complete before the NPRM and final rule – the agencies do not intend for this preliminary model to be the final cost model used. The federal interagency mass/safety team has initiated several work tasks to inform and update the cost model, including meeting with vehicle manufacturers, updating DOE's 2007 study on feasibility and cost, and EPA funding a 3rd party cost assessment of the Lotus Report.

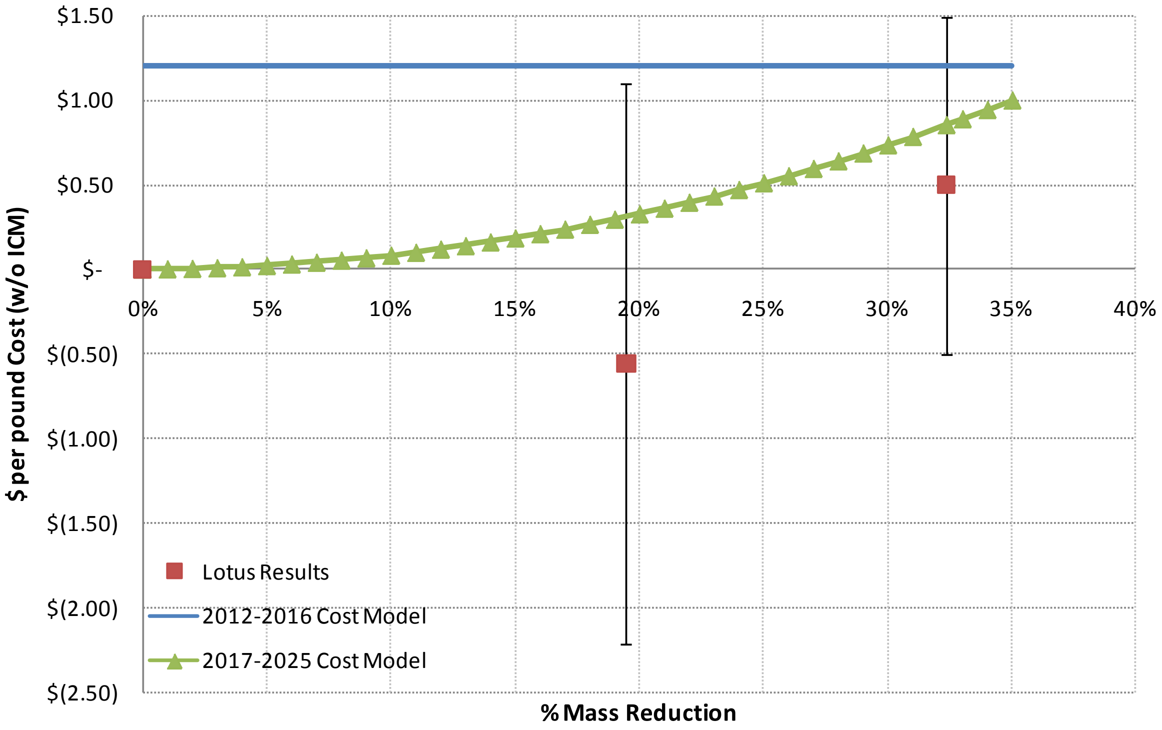

Figure 3.2-1: Mass Reduction Cost Model in Dollars per Pound in Model Year 2020 Compared to the Lotus Results and 2012-2016 Final Rule Cost.

With respect to the effects of net vehicle mass reduction amounts of 15-30 percent on overall societal safety, the federal interagency mass/safety group has been meeting several times a week since shortly after the MY 2012-2016 rule was released to coordinate study of the effects of mass reduction and vehicle size on societal safety. This work will be used to update the safety model for future federal rulemaking. The agencies are conducting several statistical studies using a common database with updated historical crash data (MY 2000-2007 FARS data, common state accident data and updated vehicle attributes). The studies include an updated NHTSA study of the relationship between vehicle mass, size and safety, two separate DOE funded fatality and casualty vehicle mass, size and safety analyses to be performed by Lawrence Berkeley National Laboratory, and peer reviews of the methodologies used in over 20 significant reports published.

NHTSA is also looking into conducting two additional studies of crash compatibility that may help inform the effects of mass reduction and design on societal safety. If conducted, these studies may use vehicle models developed for the CARB funded Lotus phase 2 study and/or the potential NHTSA and EPA study for the feasible amount of mass reduction and cost for MY 2017-2025. These studies may inform how designs that incorporate lower density or higher strength materials, meet FMVSS regulations, and perform well in NCAP and IIHS tests, affect vehicle crash compatibility. The findings may be used to help inform the effects of mass reduction on societal safety. Because this study cannot begin until the Lotus or NHTSA/EPA studies have been completed, and this study requires significant modeling work, there is some risk the study will not be completed in time to inform a final rule.

3.2.5 Indirect Cost Multipliers

Since the 2012-2016 rulemaking, the agencies have reconsidered the indirect cost multiplier approach and believe it to be more appropriate to include in the ICM a factor to reflect return on invested capital. In the automotive industry, this is on the order of 6%.[29] To account for this, the agencies added a 0.06 factor added to the ICMs used in the rulemaking. These values are shown in Table 3.2-3. A note of clarification on the table, the low, medium and high complexity levels are meant to account for the complexity of integrating a technology into a vehicle. For example, adding variable valve timing to an engine is relatively not difficult and, for that reason, we would consider it a low complexity technology. By contrast, converting to a hybrid powertrain is considerably more complex to do and, for that reason, we would consider it a high complexity technology. The indirect costs are higher for the high complexity technology given the higher level of effort (and therefore costs) that would be incurred to implement the technology. The near term and long term values reflect the way that indirect costs are expected to change over time as new technologies are implemented. In the near term, the indirect costs are highest because the development effort is underway, the warranty costs are higher, etc. In the long term, many of these costs are no longer attributable to regulatory changes and, therefore, are no longer applied. Similarly, the warranty costs, while still present, have come down because the technology has achieved mature status and those costs have returned to an average level. For this assessment, the near term and long term cutoff points are different for different technologies. In short, conventional gasoline technologies are considered long term beginning in 2017, hybrid technologies are considered long term beginning in 2020, advanced gasoline technologies and both range extended and full electric vehicles are considered long term beginning in 2022.

Table 3.2-3 Comparison of Indirect Cost Multipliers used in the 2012-2016 Rulemaking versus this Assessment Report

Complexity	2012-2016 Rulemaking		Assessment Report	
	Near term	Long term	Near term	Long term
Low	1.11	1.07	1.17	1.13
Medium	1.25	1.13	1.31	1.19
High 1	1.45	1.26	1.51	1.32
High 2	1.64	1.39	1.70	1.45

For this analysis, the indirect costs are estimated by applying indirect cost multipliers (ICM) to direct cost estimates. ICMs were developed by EPA during the 2012-2016 light-duty rulemaking as a basis for estimating the impact on indirect costs of individual vehicle technology changes that would result from regulatory actions. Separate ICMs were derived for low, medium, and high complexity technologies, thus enabling estimates of indirect costs that reflect the variation in research, overhead, and other indirect costs that can result from the application of various technologies in direct response to a regulatory action.

Previous NHTSA and EPA rulemakings applied a retail price equivalent (RPE) factor to estimate indirect costs and mark up direct costs to the retail level. Retail Price Equivalents are estimated by dividing the total revenue of a manufacturer by their direct manufacturing costs. As such, it includes all forms of indirect costs for a manufacturer, regardless of whether all of those costs change in response to the regulatory action and assumes that the ratio applies equally for all technologies. ICMs, in contrast, are based on RPE estimates that are then modified to reflect only those elements of indirect costs that would be expected to change in response to a regulatory action. For example, warranty costs would be reflected in both RPE and ICM estimates since new technologies, whether added in response to a regulatory action or other reason, will almost always incur some level of warranty expense. In contrast, marketing costs might only be reflected in an RPE estimate and not an ICM estimate for a particular technology if the new technology added in response to a regulatory action is not one expected to be expressly marketed to consumers. Because the ICMs developed for the 2012-2016 rulemaking are for individual technologies, many of which are relatively simple to implement (e.g., variable valve timing), they often reflect a subset of RPE costs; as a result, the RPE is typically higher than an ICM. This is not always the case, as ICM estimates for complex technologies may reflect higher than average indirect costs due perhaps to increased R&D and/or integration demands, with the resulting ICM larger than the averaged RPE for the industry.

Precise association of ICM elements with individual technologies based on the varied accounting categories in company annual reports is difficult. Hence, there is a degree of uncertainty in the ICM estimates. The agencies are continuing to study ICMs and the most appropriate way to apply them, and it is possible revised ICM values may be used for the upcoming NPRM. For that reason, the agencies have considered the range of data in the survey responses used to develop the ICMs used in the 2012-2016 rule.[30] The survey data showed a standard deviation of 0.14 to 0.21 on the short term ICMs against average values ranging from 1.16 (for the low ICM) to 1.64 (for the high ICM). The coefficient of variance (the standard deviation divided by the average) would then be roughly 12% for the low ICM and 13% for the high ICM. Based on these results, the ICM values could range from 13% lower to 13% higher than the primary ICM values. Using the range of cost estimates presented in Chapter 6 for future potential scenarios, this range of ICMs could result in an approximate change in 2025 costs between +/- $100 to as much as +/- $450, depending on the overall level of the 2025 targets analyzed.

As mentioned earlier, the agencies have also conducted some sensitivity surrounding the issue of battery costs. A more complete discussion of this is presented in Chapter 6.

3.2.6 Cost Adjustment to 2008 Dollars

As noted above, the costs presented in the 2012-2016 rule have been updated from 2007 dollars to 2008 dollars using the Gross Domestic Product (GDP) Price Deflator. The GDP Price Deflator is one means of adjusting the value of the dollar in different years. The data we have used, which is indexed to 2005, shows that it takes $1.062 in 2007 dollars and $1.085 in 2008 dollars to purchase a $1 item in 2005.[31] Therefore, we have adjusted all of the 2012-2016 costs, valued in 2007 dollars, by a factor of 1.022 (1.085/1.062) to express costs in 2008 dollars.

3.2.7 Costs Effects due to Learning

The agencies have also reconsidered learning effects. For this assessment, we continue to reflect the phenomenon of volume-based learning curve cost reductions in our modeling using two algorithms – “volume-based” for newer technologies and “time-based” for mature technologies. The observed phenomenon in the economic literature which supports manufacture learning cost reductions are based on reductions in costs as production volumes increase, and the economic literature suggests these cost reductions occur indefinitely, though the absolute magnitude of the cost reductions decrease as production volumes increase (with the highest absolute cost reduction occurring with the first doubling of production).[32] The agencies use the terminology “volume-based” and “time-based” to distinguish among newer technologies and more mature technologies, and how we apply learning cost reductions in our assessment. Our volume-based learning algorithm applies for the early, steep portion of the learning curve and is estimated to result in 20 percent lower costs after two full years of implementation (i.e., a 2014 MY cost would be 20 percent lower than the 2012 and 2013 model year costs for a new technology being implemented in 2012). Our time-based learning algorithm applies for the flatter portion of the learning curve and is estimated to result in 3 percent lower costs in each of the five years following first introduction of a given technology. Once two volume-based learning steps have occurred (for technologies having volume-based learning applied), time based learning would begin. For technologies to which time based learning is applied, learning would begin in year 2 at 3 percent per year for 5 years. Beyond 5 years of time-based learning at 3 percent per year, 5 years of time-based learning at 2 percent per year, then 5 at 1 percent per year become effective. Going forward, the agencies intend to investigate industry learning curves in more detail including to what extent “volume-based” and “time-based” come from the same observed phenomenon and whether learning should continue to be applied indefinitely, or whether cost reductions due to learning should go to zero after some period of time. The learning curve used in this assessment may be modified for the rule making.

3.2.8 Cooled EGR Cost and Effectiveness

While not considered in the 2012-2016 light-duty rule, the agencies have considered an emerging technology referred to as cooled exhaust gas recirculation (cooled-EGR) as applied to downsized, turbocharged GDI engines. The agencies have considered this technology as an advanced gasoline technology since, as noted, it is emerging and not yet available in the light-duty gasoline market. While a cooled or “boosted” EGR technology was discussed in the 2012-2016 light-duty rule, the technology considered here is comparatively more advanced than the one considered previously, and as such, the agencies have considered new costs and new effectiveness values for it. The details behind those updated costs and effectiveness values are presented in Appendix B. The effectiveness values used for vehicle packages with cooled EGR within this analysis reflect a conservative estimate of system performance at approximately 24-bar BMEP. Vehicle simulation modeling of technology packages using the more highly boosted and downsized cooled EGR engines (up to 30-bar BMEP) with dual-stage turbocharging is currently underway as part of EPA’s contract with Ricardo Engineering as described below. The agencies plan to update the effectiveness of vehicle packages with cooled EGR using the new Ricardo vehicle simulation modeling runs prior to the NPRM.

3.2.9 HEV Effectiveness

At time of this publication, the effectiveness of HEVs requiring equivalent towing capacity to their traditional, gasoline powered counterpart (large pick-up trucks for example) is similar to those used in the 2012-2016 light-duty rule for vehicles. For several other subclasses, the agencies increased HEV effectiveness by approximately 2% based on published data for new HEVs that have entered production since the last study was complete (including the new Toyota Prius, Ford Fusion hybrid and others[L]). In addition, for the Large Car, Minivan and Small Truck subclasses, the agencies further increased HEV effectiveness by assuming that towing capacity could be reduced from their current rating[M] to approximately 1,500 pounds for some vehicles in these subclasses without significantly impacting consumers' need for utility in these vehicles.[N] The agencies believe that the towing capacity in these HEV classes was maintained at an overly stringent performance level in the technical analysis of the 2012-2016 rule. The agencies believe that consumers who require higher towing capacity could acquire it by purchasing a vehicle with a more capable non-hybrid powertrain (as they do today).[O] Moreover, it is likely that some fraction of consumers who purchase the larger engine option do so for purposes of hauling and acceleration performance, not just maximum towing.

A reduction in towing capacity allows greater engine downsizing, which increases estimated overall HEV system incremental effectiveness by 5 to 10 percent and brings estimated absolute HEV system effectiveness to approximately 30 percent for Large Cars, Minivans, and Small Trucks, similar to the HEV effectiveness value assumed for Small Cars and Compact Cars.[P] Refer to Appendix B for a more detailed summary of the effectiveness values assumed for both towing and relaxed towing HEVs.

[L] The agencies will continue to evaluate hybrid effectiveness estimates through vehicle simulation research currently underway but will not be completed as of the publication of this NOI and TAR.

[M] Current small SUVs and Minivans have an approximate average towing capacity of 2000 lbs (without a towing package), but range from no towing capacity to 3500 pounds.

[N] We note that there are some gasoline vehicles in the large car/minivan/small truck segments sold today which do not have any towing rating.

[O] The agencies recognize that assuming that certain consumers will choose to purchase non-hybrid vehicles in order to obtain their desired towing capacity could lead to some increase in fuel consumption and CO_2 emissions as compared to assuming that towing capacity is maintained for hybrid vehicles across the board and all vehicles are therefore hybrids. However, the agencies think it likely that the net improvement in fuel consumption and CO_2 emissions due to the increased numbers of hybrids available for consumers to choose will offset any potential increase in fuel consumption and CO_2 emissions resulting from consumers selecting the higher-performance non-hybrid powertrain vehicles.

[P] The effectiveness of HEVs for heavier vehicles which require conventional towing capabilities is markedly less because the rated power of the IC engine must be similar to its non-hybrid brethren. As such, there is less opportunity for downsizing with these vehicles.

3.2.10 Ongoing Vehicle Simulation to Update Effectiveness

The other critical factor in the assessment of the cost-effectiveness of technologies is the effectiveness value[Q] associated with a particular technology. The agencies have, in general, used the same effectiveness estimates used in the 2012-2016 light-duty rule.

To assess the effectiveness of emerging technologies and advances in conventional technologies in the 2017 to 2025 timeframe, EPA also commissioned an extension of earlier vehicle simulation modeling work with Ricardo, Inc. Besides updating the technology effectiveness estimates of the previous work, the present study substantially broadened the scope to include two new vehicle classes and several advanced technologies, including P2 and other HEVs. Among the major additions:

1. Two new vehicle classes intended for use in EPA's OMEGA model: a subcompact car and a light heavy-duty truck
2. Highly-boosted and significantly downsized direct injection gasoline engines, including lean-burn[R] and stoichiometric/cooled-EGR variants
3. 8-speed automatic and dual-clutch transmissions
4. Advanced hybrids, including P2 and powersplit[S] hybrids
5. Vehicle mass reduction, in conjunction with engine downsizing

The Ricardo study has not been completed to a degree that allow results to be used for this analysis, but EPA and NHTSA expect to use the findings from this work to inform the estimates of technology effectiveness used for the model year 2017-2025 NPRM.

3.3 Vehicle Manufacturer Lead Time

With respect to the practicability of the standards in terms of lead time, during MYs 2017-2025 manufacturers are expected to go through the normal automotive business cycle of redesigning and upgrading their light-duty vehicle products, and in some cases introducing entirely new vehicles not in the market today. This assessment allows manufacturers the time needed to incorporate technology to achieve GHG reductions and improve fuel economy during the vehicle redesign process. This is an important aspect of the assessment, as it avoids the much higher costs that would occur if manufacturers need to add or change technology at times other than their scheduled redesigns. This time period also provides manufacturers the opportunity to plan for compliance using a multi-year time frame, again consistent with normal business practice. Over these 9 model years, there will be an opportunity for manufacturers to evaluate, presumably, every one of their vehicle model platforms and add technology in a cost effective way to control GHG emissions and improve fuel economy. This includes all the technologies considered here and redesign of the air

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[R] Lean-burn simply means less fuel per unit air than would be used under stoichiometric combustion. Lean burn operation is a way to reduce throttling losses and allows for higher compression ratios and, thus, better performance and/or fuel efficiency.

[S] This is the HEV architecture initially developed by Toyota and now more widely used in several models.

conditioner systems in ways that will further reduce GHG emissions and improve fuel economy. Most vehicles would likely undergo two redesigns during this period.

Even with multiple redesign periods, it is still likely that some of the more advanced and costly technologies (such as cooled boosted EGR engines, or advanced (P)HEVs) may not be able to be fully implemented within the timeframe of this rule. These limitations are captured in "maximum technology penetration rates" within the modeling analysis.

In order to assess the four technology pathways, we developed "Maximum Technology Penetration Rates" which we could implement within the OMEGA model in order to represent the four pathways. Each technology path was defined by these maximum technology penetration rates, which were specified as the maximum modeled fleet penetration of classes of technology into the new vehicle fleet in MY 2020 and MY 2025 (these broad classes of technology as described in detail below). We developed these penetration rates based on agency expert judgment with regard to a number of factors such as manufacturer production capacity, vehicle suitability, technical feasibility considerations, as well as our goal of purposely analyzing multiple potential pathways for this technical assessment. The maximum technology penetration rates serve as exogenous limits on technology application within the OMEGA model and are shown in Table 3.3-1.

Table 3.3-1 Scenario Maximum Technology Penetration Rates

Technology	MY 2020[3]			MY 2025			
	Path A	Path B	Path C	Path A	Path B	Path C	Path D
Conventional SI	100%	100%	100%	100%	100%	100%	100%
Advanced SI	10%	30%	40%	50%	75%	100%	0%
Hybrid vehicles	40%	30%	40%	75%	50%	75%	60%
Electric Vehicle	4%	4%	8%	8%	8%	15%	20%
Plug-in Hybrid	4%	4%	8%	8%	8%	15%	20%
Mass Reduction[1,2]	15%	15%	25%	15%	20%	30%	15%

[1] The mass reduction shown is with respect to the 2008 MY.
[2] The mass reduction shown is not an actual phase-in cap, but the maximum amount of mass reduction which could be allowed on any vehicle.
[3]Technology Path D was not run in MY 2020, please see chapter 6 for a discussion of this topic.

The broad technology classes evaluated for purposes of this analysis are defined below and a brief discussion of the limiting factors considered are presented. For a more detailed discussion of any individual technology, please see the joint Technical Support Document for the 2012-2016 rule and Appendix B of this report:

- Conventional Spark Ignition (SI) - This technology category includes all technologies that are not contained in other categories such as gasoline direct injection engines, cylinder deactivation, six and eight speed automatic and dual clutch transmissions, and start-stop micro-hybrid technology. Most of these technologies were anticipated as being available in the MY 2012-2016 time frame in the recent NHTSA and EPA final rule, and it is expected manufacturers could expand production to all models by model year 2025, and therefore the maximum technology penetration rate is set at 100% for all four pathways.

- Advanced SI - This technology includes gasoline spark ignition engines which are currently under development by OEMs and suppliers and are not anticipated to be widely used in the 2012- 2016 time frame. For purposes of this analysis, based on agency expert judgment to define these advanced SI engines, we modeled a direct injection gasoline engine with cooled exhaust gas recirculation, and with a larger degree of engine downsizing and higher level of turbocharging as compared to the turbo-downsized engines included in our analysis for the MYs 2012-2016 final rule. This technology is discussed in more detail above and the appendix B, and is similar to the technologies that many OEMs indicated were underdevelopment and which they anticipate will be introduced into the market in the 2017-2025 time frame. As there are no production vehicles presently using these technologies, we set the maximum technology penetration rate for these technologies at less than 100% in MY 2025 for Paths A and B.

- Hybrid – While the agencies recognize there are many types of full-hybrids either in production or under development, for the purposes of this analysis we have specifically modeled two types of hybrids, P-2 and 2-Mode type hybrids. These technologies are discussed in detail in Chapter 3. While the agencies expect the proliferation of these vehicles to increase in this timeframe, the maximum technology penetration rate are set at less than 100% due to potential battery supply constraints, as well as industry-wide engineering and capacity constraints, for converting the entire new vehicle fleet to strong hybrids in this time frame. The four path ways using varying levels in order to capture both the current uncertainty with how rapidly these technologies can penetrate into the new vehicle fleet in the 2017-2025 time frame as well as the potentially different strategies auto companies may choose with respect to the degree of HEV penetration they may pursue.

- Plug-in Hybrid (PHEV) - This technology includes PHEV's with a range of 20 and 40 miles and is discussed above. The maximum technology penetration rates are set at less than 100% due to the same general potential constraints as listed for the HEVs, but are lower for PHEVs due to the current status of the development of these advanced vehicles. Further, as discussed in Appendix B, we project that PHEV technology is not available to some vehicle types, such as large pickup. While it is possible to electrify such vehicles, there are tradeoffs in terms of cost, electric range, and utility that would reduce the appeal of the vehicle to a narrower market.

- Electric Vehicle (EV) - This technology includes vehicles with actual on-road ranges of 75, 100, and 150 miles. The actual on-road range was calculated using a projected 30% gap between two-cycle and on-road range. These vehicles are powered solely by electricity and are not powered by any liquid fuels. The maximum technology penetration rates are set at less than 100% due to the same general potential constraints as discussed for PHEVs. Further, as with PHEVs, and as discussed in Appendix B, we assume that EV technology is not available to some vehicle types, such as large pickups. While it is possible to electrify such vehicles, there are tradeoffs in terms of cost, range, and utility that would reduce the appeal of the vehicle to a narrower market. These trade-offs are expected to reduce the market for other vehicle types as well, and for this analysis we have considered this in the development of the maximum technology penetration rates we use for the four pathways. Although the agencies have assumed that range limitations would entail no loss in value to EV owners, we will further consider the reasonableness and applicability of this assumption, and will conduct our analyses for the forthcoming NPRM accordingly.[T]

- Mass Reduction - This technology includes material substitution, smart design, and mass reduction compounding. The actual amount of reduction from the 2008 baseline was determined based on confidential business information provided by vehicle manufacturers, assessments provided by material suppliers, and existing studies in the literature, including the 2010 report from Lotus Engineering. As discussed above as well as in Chapter 1 and Appendix B, NHTSA and EPA intend to conduct a thorough

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[T] If the agencies determine that the loss of range does entail some loss in value to vehicle owners, we anticipate that accounting for this loss in value would affect our estimates of potential EV application rates and our estimates of the private and social benefits of new standards that could lead to increases in EV application rates.

assessment of the levels of the levels of mass reduction that could be achieved which is both technologically feasible and which can be implemented in a safe manner for the joint federal NPRM.

3.4 Other Technologies Assessed

In addition to the technologies already mentioned, the technologies generally considered in the agencies' analysis are briefly described below. They fall into five broad categories: engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, hybrid technologies and mass reduction. For a more detailed description of each technology and their costs and effectiveness, we refer the reader to Chapter 3 of the Joint TSD, Chapter III of NHTSA's FRIA, and Chapter 1 of EPA's final RIA.[33] Technologies to reduce CO_2 and HFC emissions from air conditioning systems are discussed in Appendix D. We note that not all of these technologies were actually modeled in the analysis for this Technical Assessment Report given the agencies' decision to simplify that analysis as discussed further below in Section 3.5 and in Chapter 6, but all of the technologies will be available for the models in the upcoming rulemaking analysis.

3.4.1 Types of engine technologies that improve fuel economy and reduce CO_2 emissions include the following:

- Low-friction lubricants – low viscosity and advanced low friction lubricants oils are now available with improved performance and better lubrication. If manufacturers choose to make use of these lubricants, they would need to make engine changes and possibly conduct durability testing to accommodate the low-friction lubricants. The cost and GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule.

- Reduction of engine friction losses – can be achieved through low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, piston surface treatments, and other improvements in the design of engine components and subsystems that improve engine operation. The cost and GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule.

- Conversion to dual overhead cam with dual cam phasing – as applied to overhead valves designed to increase the air flow with more than two valves per cylinder and reduce pumping losses. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Cylinder deactivation – deactivates the intake and exhaust valves and prevents fuel injection into some cylinders during light-load operation. The engine runs temporarily as though it were a smaller engine which substantially reduces pumping losses. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Variable valve timing – alters the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control residual gases. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Discrete variable valve lift – increases efficiency by optimizing air flow over a broader range of engine operation which reduces pumping losses. Accomplished by controlled switching between two or more cam profile lobe heights. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Continuous variable valve lift – is an electromechanical or electrohydraulic system in which valve timing is changed as lift height is controlled.[34,35,36,37] This yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve throttled. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Stoichiometric gasoline direct-injection technology – injects fuel at high pressure directly into the combustion chamber to improve cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The costs for this technology differ from those used in the 2012-2016 light-duty rule (refer to Table 3.2-1).

- Turbocharging and downsizing – increases the available airflow and specific power level, allowing a reduced engine size while maintaining performance. Engines of this type use gasoline direct injection (GDI) and dual cam phasing. This reduces pumping losses at lighter loads in comparison to a larger engine. The GHG and fuel economy effectiveness changed from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The current estimates reflect engines that are now entering the light-duty vehicle market[38] or are under advanced development.[39,40,41] We now estimate an effectiveness of approximately 15% relative to a 2008 baseline engine technology. The costs for this technology also differ from those used in the 2012-2016 light-duty rule (refer to Table 3.2-1).

- Turbocharging and downsizing with cooled exhaust-gas recirculation (EGR) – additional charge dilution reduces the incidence of knocking combustion and obviates the need for fuel enrichment at high engine power. This allows for higher boost pressure and/or compression ratio and further reduction in engine displacement and both pumping and friction losses while maintaining performance. Engines of this type use GDI and both dual cam phasing and discrete variable valve lift. The EGR systems considered in this assessment would use a dual-loop system with both high and low pressure EGR loops and dual EGR coolers. The engines would also use single-stage, variable geometry turbocharging with higher intake boost pressure available across a broader range of engine operation than conventional turbocharged SI engines. Such a system is estimated to be capable of an additional 5% effectiveness relative to a turbocharged, downsized GDI engine without cooled-EGR.[39, 42,43] The agencies are also considering a more advanced version of such a cooled EGR system that would employ very high combustion pressures by using dual stage turbocharging. The agencies have at our disposal only very preliminary effectiveness estimates for this approach as modeling efforts are ongoing via vehicle simulation modeling by Ricardo Engineering. The simulation modeling is similar to work that Ricardo conducted for EPA for its 2008 staff report on GHG effectiveness of light-duty vehicle technologies.[44] The agencies will reconsider this more advanced cooled EGR approach in the upcoming NPRM when the Ricardo simulation work should be complete. The costs for the cooled EGR system considered in this assessment (i.e., single stage turbocharging) are presented in Appendix B.

- Diesel engines – have several characteristics that give superior fuel efficiency, including reduced pumping losses due to lack of (or greatly reduced) throttling, and a combustion cycle that operates at a higher compression ratio and with a very lean air/fuel mixture relative to an equivalent-performance gasoline engine. This technology requires additional enablers, such as a NOx adsorption catalyst system or a urea/ammonia selective catalytic reduction system for control of NOx emissions during lean (excess air) operation. For purposes of this current assessment, we have not included advanced diesel engines in our modeling scenarios. During our meetings with the automotive companies, a few companies did indicate that diesel technology would represent a meaningful portion of their future product offerings in the US, and these companies commented that there are opportunities for improving the fuel economy/reducing CO_2 from diesel in the 2017 to 2025 time frame which they are pursuing. For today's assessment, the three agencies did not have sufficient time to further investigate these potential improvements for diesels, both the improvements in effectiveness and the potential costs associated with those improvements. Therefore, we did not include diesel engines in our modeling assessment presented in Chapter 6. This does not mean that the agencies do not see a role for diesels in the future fleet since we fully expect some manufacturers will rely on diesels as part of their future strategy. We intend to continue to work on this area of our assessment and expect to perform additional evaluations in the future regarding diesel engine technology.

3.4.2 Types of transmission technologies considered include:

- Improved automatic transmission controls – optimizes shift schedule to maximize fuel efficiency under wide ranging conditions, and minimizes losses associated with torque converter slip through lock-up or modulation. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Six-, seven-, and eight-speed automatic transmissions – the gear ratio spacing and transmission ratio are optimized to enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions. While a six speed transmission application was most prevalent for the 2012-2016 final rule, eight speed transmissions are expected to be readily available and applied in the 2017 through 2025 timeframe. We applied the six speed transmission GHG and fuel economy effectiveness estimates used from 2016 model year vehicles in the 2012-2016 final rule. We plan to conduct further analysis to determine the effectiveness of increasing the number of available gear ratios beyond six speeds and increasing the ratio spread prior to the 2017-2025 notice of proposed rulemaking. The costs for a 6-speed automatic transmission differ from those used in the 2012-2016 light-duty rule (refer to Table 3.2-1). The agencies have estimated new costs for an 8-speed automatic transmission, which are presented in Appendix B.

- Dual clutch or automated shift manual transmissions – are similar to manual transmissions, but the vehicle controls shifting and launch functions. A dual-clutch automated shift manual transmission uses separate clutches for even-numbered and odd-numbered gears, so the next expected gear is pre-selected, which allows for faster and smoother shifting. The 2012-2016 final rule limited DCT applications to a maximum of 6-speeds. We applied the GHG and fuel economy effectiveness estimates used from 2016 model year vehicles in the 2012-2016 final rule. We plan to conduct further analysis to determine the effectiveness of increasing the number of available gear ratios beyond six speed and increasing the ratio spread prior to the 2017-2025 notice of proposed rulemaking. The costs for a DCT differ from those used in the 2012-2016 light-duty rule (refer to Table 3.2-1).

- Continuously variable transmission – commonly uses V-shaped pulleys connected by a metal belt rather than gears to provide ratios for operation. Unlike manual and automatic transmissions with fixed transmission ratios, continuously variable transmissions can provide fully variable and an infinite number of transmission ratios that enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions. CVTs have not been considered in this assessment.

- Manual 6-speed transmission –offers an additional gear ratio, often with a higher overdrive gear ratio, than a 5-speed manual transmission. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

3.4.3 Types of vehicle technologies considered include:

- Low-rolling-resistance tires – have characteristics that reduce frictional losses associated with the energy dissipated in the deformation of the tires under load, thereby improving fuel economy and reducing CO2 emissions. The costs and GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. This is conservative as reducing rolling resistance in tires is something that can likely continue to improve. The agencies may consider adding a second level of improvement in tire rolling resistance for the upcoming NPRM.

- Low-drag brakes – reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotors. The costs and GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule.

- Front or secondary axle disconnect for four-wheel drive systems – provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle. This results in the reduction of associated parasitic energy losses. The costs and GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule.

- Aerodynamic drag reduction – This can be achieved via two approaches, either reducing the drag coefficients or reducing vehicle frontal area. To reduce drag coefficients, skirts, air dams, underbody covers, and more aerodynamic side view mirrors can be applied. In addition to the standard aerodynamic treatments, the agencies have included a second level of aerodynamic technologies which could include active grille shutters, rear visors, and larger under body panels. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. This second level of aerodynamic technologies was not considered in the 2012-2016 light-duty rule and, as such, the estimated costs are new and are presented in Appendix B.

- Mass Reduction – Already mentioned above.

Types of electrification/accessory and hybrid technologies considered include:

- Electric power steering (EPS)/ Electro-hydraulic power steering (EHPS) – is an electrically-assisted steering system that has advantages over traditional hydraulic power steering because it replaces a continuously operated hydraulic pump, thereby reducing parasitic losses from the accessory drive. Manufacturers have informed the agencies that full EPS systems are being developed for all light-duty vehicles applications, including large trucks. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Improved accessories (IACC) – may include high efficiency alternators, electrically driven (i.e., on-demand) water pumps and cooling fans. This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Air Conditioner Systems – These technologies include improved hoses, connectors and seals for leakage control. They also include improved compressors, expansion valves, heat exchangers and the control of these components for the purposes of improving tailpipe CO2 emissions and fuel economy as a result of A/C use. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. We have estimated new costs for A/C systems which are presented in Appendix D.

- 12-volt micro-hybrid (MHEV) – also known as idle-stop or start-stop and commonly implemented as a 12-volt belt-driven integrated starter-generator, is the most basic hybrid system that facilitates idle-stop capability. Along with other enablers, this system replaces a common alternator with a belt-driven enhanced power starter-alternator, and a revised accessory drive system. These systems incorporate an additional battery, ELDC or other subsystems to prevent voltage-droop on restart, one of the shortcomings of previous 12V micro-hybrid sytems relative to higher voltage systems. Such a system is estimated to be capable of roughly 1.5% to 2.5% effectiveness. The cost has changed only in that learning effects have continued to decrease piece costs.

- Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG) – provides idle-stop capability and uses a higher voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator, that is belt driven and that can recover braking energy while the vehicle slows down (regenerative braking). The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- Integrated Motor Assist (IMA)/Crank integrated starter generator (CISG) – provides idle-stop capability and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the wiring harness. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator that is crankshaft mounted and can recover braking energy while the vehicle slows down (regenerative braking). The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. The cost has changed only in that learning effects have continued to decrease piece costs.

- P2 Hybrid – A newly emerging hybrid technology that uses a transmission integrated electric motor placed between the engine and a gearbox or CVT, much like the IMA system described above except with a wet or dry separation clutch which is used to decouple the motor/transmission from the engine. In addition, a P2 Hybrid would typically be equipped with a larger electric machine. Engaging the clutch allows all-electric operation and more efficient brake-energy recovery. Disengaging the clutch allows efficient coupling of the engine and electric motor and, when combined with a DCT transmission, reduces gear-train losses relative to PSHEV or 2MHEV systems. This technology was not included in the 2012-2016 GHG and CAFE rulemaking technical analysis. We have estimated new costs for this technology which are presented in Appendix B.

- 2-mode hybrid (2MHEV) – is a hybrid electric drive system that uses an adaptation of a conventional stepped-ratio automatic transmission by replacing some of the transmission clutches with two electric motors that control the ratio of engine speed to vehicle speed, while clutches allow the motors to be bypassed. This improves both the transmission torque capacity for heavy-duty applications and reduces fuel consumption and CO2 emissions at highway speeds relative to other types of hybrid electric drive systems. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. We have estimated new costs for this technology which are presented in Appendix B.

- Power-split hybrid (PSHEV) – a hybrid electric drive system that replaces the traditional transmission with a single planetary gearset and a motor/generator. This motor/generator uses the engine to either charge the battery or supply additional power to the drive motor. A second, more powerful motor/generator is permanently connected to the vehicle's final drive and always turns with the wheels. The planetary gear splits engine power between the first motor/generator and the drive motor to either charge the battery or supply power to the wheels. Power-split hybrids have not been considered in this assessment.

- Plug-in hybrid electric vehicles (PHEV) – are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (usually the electric grid). These vehicles have larger battery packs with more energy storage and a greater capability to be discharged than other hybrid electric vehicles. They also use a control system that allows the battery pack to be substantially depleted under electric-only or blended mechanical/electric operation and batteries that can be cycled in charge sustaining operation at a lower state of charge than is typical of other hybrid electric vehicles. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. We have estimated new costs for this technology which are presented in Appendix B along with estimates of their electricity usage per mile. Battery costs assume that battery packs for PHEV applications will be designed to last for the full useful life of the vehicle at a useable state of charge equivalent to 70% of the nominal battery pack capacity.

- Electric vehicles (EV) – are vehicles with all-electric drive and with vehicle systems powered by energy-optimized batteries charged primarily from grid electricity. While the 2016 FRM did not anticipate a significant penetration of EV's, in this analysis, EV's with several ranges have been included. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule. We have estimated new costs for this technology which are presented in Appendix B along with estimates of their electricity usage per mile. Battery costs assume that battery packs for EV applications will be designed to last for the full useful life of the vehicle at a useable state of charge equivalent to 80% of the nominal battery pack capacity.

- Fuel cell electric vehicles (FCEVs) – utilize a full electric drive platform but consume electricity generated by an on-board fuel cell and hydrogen fuel. Fuel cells are electro-chemical devices that directly convert reactants (hydrogen and oxygen via air) into electricity, with the potential of achieving more than twice the efficiency of conventional internal combustion engines. High pressure gaseous hydrogen storage tanks are used by most automakers for FCEVs that are currently under development. The high pressure tanks are similar to those used for compressed gas storage in more than 10 million CNG vehicles worldwide, except that they are designed to operate at a higher pressure (350 bar or 700 bar vs. 250 bar for CNG). We have estimated new costs for this technology which are presented in Appendix B. Due to the uncertainty of the future availability for this technology, FCEVs were not included in any OMEGA runs.

3.5 Technology Packages in OMEGA

The large number of possible technologies to consider and the breadth of vehicle systems that are affected mean that consideration of the manufacturer's design and production process plays a major role in assessing the ability of the US fleet to achieve various GHG levels and fuel economy, and the costs associated with achieving those levels. Vehicle manufacturers typically develop their many different individual vehicle models by basing them on a limited number of vehicle platforms. Several different models of vehicles may be produced using a common platform, allowing for efficient use of design and manufacturing resources. The platform typically consists of common vehicle architecture and structural components, such as the underbody, chassis and suspension. Given the very large investment put into designing and producing each vehicle model, manufacturers cannot reasonably redesign any given vehicle every year or even every other year, let alone redesign all of their vehicles every year or every other year. At the redesign stage, the manufacturer will typically upgrade or add all of the technology and make all of the other changes needed so the vehicle model will meet the manufacturer's plans for the next several years. This includes meeting all of the fuel economy, emissions, safety, and other requirements that would apply during the years before the next major redesign of the vehicle. This is in contrast to what would be a much more costly approach of trying to achieve small increments of reductions over multiple years by adding technology to the vehicle piece by piece outside of the redesign process.

However, making all of these changes at once typically involves significant engineering, development, manufacturing, and marketing resources to create a new product with multiple new features. In order to leverage this significant upfront investment, manufacturers plan vehicle redesigns with several model years' of production in mind.

That said, vehicle models are not completely static between redesigns as limited changes are often incorporated for each model year. This interim process is called a "refresh" of the vehicle. It generally does not allow for major technology changes although more minor ones can be done (e.g., aerodynamic improvements, valve timing improvements), usually aimed at improving the vehicle's market appeal. We note, though, that more major technology upgrades that affect multiple systems of the vehicle thus occur at the vehicle redesign stage and not in the time period between redesigns.

In determining the projected technology needed to meet the standards, and the cost of those technologies, EPA is using an approach that accounts for and builds on this redesign process and bundles technologies into "packages" to capture synergistic aspects and reflect progressively larger CO_2 reductions with additions or changes to any given package. As an input to this approach, EPA groups technologies into packages of increasing estimated cost and effectiveness. EPA determined that 19 different vehicle types provided adequate resolution required to accurately model the entire fleet. We discuss the approach to developing packages and how those packages are used in the OMEGA model in Appendix B.

For the reader's reference, we note that NHTSA's CAFE Compliance and Effects Model (often referred to as "the Volpe model"), which NHTSA uses for CAFE rulemaking analysis was not used for purposes of this Technical Assessment Report, also assumes manufacturers add most technology to vehicles as part of the vehicle redesign and freshening process. While the CAFE model considers technologies similar to those considered by EPA's OMEGA model, the CAFE model accumulates discrete technologies incrementally, taking into account model-estimated cost effectiveness, as well as engineering and other constraints. While the CAFE model does not require that packages be determined exogenously, in the analysis supporting the MYs 2012-2016 CAFE standards, the CAFE model often formed packages similar to those included in EPA's analysis supporting the MYs 2012-2016 GHG emissions standards. Although NHTSA is not, in today's report, presenting analysis performed using the CAFE model, the agency will do so in support of the upcoming NPRM for post-MY 2016 CAFE standards.

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4 Infrastructure Assessment

4.1 Overview

The May 21, 2010 Presidential Memorandum specifically requests that the EPA, NHTSA, and CARB's joint technical assessment include an assessment of infrastructure for advanced technology vehicles. Section 3 of the Memorandum requests the Department of Energy (DOE) to promote the deployment of advanced technology vehicles by providing technical assistance to cities preparing for deployment of electric vehicles, including plug-in hybrids and electric vehicles. The Memorandum also asks DOE to work with stakeholders on the development of voluntary standards to facilitate the robust development of advanced vehicle technologies and coordinate these efforts with DOT/NHTSA and EPA. Because of DOE's key role in these areas, EPA, NHTSA, and CARB have closely collaborated with DOE in developing our assessment of infrastructure issues, and DOE contributed significantly to this chapter.

This technical assessment report identifies electric drive vehicles as an important part of the vehicle mix that will likely be used to meet fuel economy and GHG emission reduction standards. Electric drive vehicles, including battery electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen-fueled fuel cell electric vehicles (FCEVs), have the potential to dramatically improve fuel economy and reduce GHG emissions compared to conventional technologies. Further, given their use of fuels that eventually could be derived from entirely renewable and zero carbon resources, they have a large potential to transform the vehicle future to a low carbon fleet and significantly reduce U.S. petroleum imports.

These technologies require new infrastructure to become a significant part of the vehicle fleet. In the case of EVs and PHEVs, electric charging infrastructure is needed in the form of charging stations, most often at home, but also at the workplace or other public locations, such as parking lots or retail stores. While at present, few public charging points are available, there are significant projects underway to deploy new electric-drive vehicle charging infrastructure across the U.S. and to collect data to facilitate analyses of future needs. In the case of FCEVs, hydrogen fueling stations analogous to gasoline stations are needed to support commercialization.

DOE has begun efforts to support a shift to electric-drive vehicles by coupling a long history of advanced vehicle research and development with more recent efforts to develop a holistic view of electric-vehicle infrastructure by compiling internal expertise, seeking input from outside experts and stakeholders and identifying areas where further investigation is needed. These combined efforts indicate that most electric vehicle owners will charge at home using equipment they pay to install and electricity from a grid that utility providers are capable of upgrading, where necessary, to meet charge demand. It is expected that 97 to 99% of charging energy will be delivered at home.[45] Home charging capability is not seen as a hurdle to electric vehicles in the near future. However, driver demand for and interaction with public infrastructure is not as well understood, so several DOE-supported projects will deploy public charging stations and collect data to inform an analyses of the role that public infrastructure will play nationally. These projects are currently underway and will be completed within the next 3-4 years. Additionally, DOE is coordinating government interaction with cities to share best practices. DOE is further coordinating with both national and international organizations, and with other federal agencies, to ensure that the development of codes and voluntary standards for electric-vehicles and support infrastructure happens as smoothly and quickly as possible.

This chapter provides an assessment of both electric charging infrastructure needed to support electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) and the hydrogen infrastructure needed to support fuel cell electric vehicles (FCEVs). The electric vehicle infrastructure section summarizes current activities to demonstrate and deploy electric recharging infrastructure, the current availability and future potential of home recharging, the costs of charging systems, the potential impacts on the electric grid and distribution network, and government cooperation in developing voluntary codes and standards. The hydrogen infrastructure section discusses the current status of hydrogen fueling stations, the costs of hydrogen and refueling stations, prospects for cost and technology improvement, a strategy for how a hydrogen infrastructure could roll out to support fuel cell vehicle introductions, and potential policies and public/private partnerships that could further facilitate infrastructure development.

4.2 Electric Vehicle Infrastructure

A shift from petroleum-powered to electric-drive vehicles will involve a parallel shift in refueling: Where gasoline and diesel fuel vehicles refill at a gas station, electric-drive vehicles recharge at a charging station. Three charging levels are currently under consideration.[46] Level 1 charging uses a standard 120 volt (V), 15-20 amps (A) rated (12-16 A usable) circuit and is available in standard residential and commercial buildings. Level 2 charging uses a single phase, 240 V, 20-80 A circuit and allows much shorter charge times. Level 3 charging—sometimes colloquially called “quick” or “fast” charging—uses a 480 V, three-phase circuit, available in mainly industrial areas, typically providing 60-150 kW of off-board charging power.

This electric vehicle infrastructure section summarizes current activities to demonstrate and deploy electric recharging infrastructure, the current availability of home recharging, the cost of electric vehicle support equipment (EVSE), the potential impacts on the electric grid and distribution network, and government cooperation in developing industry-recognized electric vehicle support equipment standards.

4.2.1 DOE Charging Infrastructure Projects Underway

The Department of Energy (DOE) recognizes the importance of the variety of factors that will contribute to the success of grid-connected vehicles and is currently undertaking numerous activities to study and address them. Through the American Recovery and Reinvestment Act of 2009 (ARRA), DOE has awarded cost-shared grants to companies under the Transportation Electrification Initiative to establish development, demonstration, evaluation, and education projects to accelerate the market introduction and penetration of advanced electric drive vehicles. The Transportation Electrification Initiative, its component projects, and other DOE electric-drive vehicle infrastructure activities are discussed below.

4.2.1.1 American Recovery and Reinvestment Act: Transportation Electrification Initiative

Funded through the ARRA, the Transportation Electrification Initiative provides approximately $400 million in federal funding, leveraged through cost-shared grants with industry and educational institutions, to develop, demonstrate, and evaluate electric drive vehicles and charging infrastructure. Through the projects funded under this activity, over 13,000 electric-drive vehicles will be deployed in conjunction with nearly 23,000 charging stations, starting in 2010 and to be completed in the next 3-4 years, in residential, commercial, and public locations, in numerous and diverse geographic locations nationwide.

The majority of the vehicles deployed through Transportation Electrification projects will be privately-owned light-duty vehicles; however, many medium-duty trucks incorporating advanced electric and plug-in hybrid electric powertrains will be developed and demonstrated in a wide range of geographic, climatic, and operating environments. Additionally, the vast majority of electric vehicle charging infrastructure deployed through these projects will be Level 2 (220V), 3.3-6.6 kW charging stations, though several hundred Level 3 DC “fast” chargers will also be deployed along corridors linking cities within deployment areas. For privately-owned vehicles and commercial fleet vehicles, Level 2 chargers will be installed at the vehicle owners’ residences or the central fleet parking area, where the vehicles will most likely be domiciled for overnight charging. Many more Level 2 charging stations will be deployed in commercial and public locations, which may provide vehicle owners the opportunity to travel in expanded geographic areas without the “range anxiety” that could otherwise limit electric vehicles’ utility. The effect of charging station availability (Level 1, 2 and 3) on driver behavior will be studied as part of this initiative. Some researchers believe the duration of a driver’s experience with an EV has more to do with reducing range anxiety than public charging, and that public charging may reduce “purchase anxiety” instead.[47]

The coordinated deployment of electric drive vehicles and charging infrastructure under the Transportation Electrification Initiative will facilitate DOE’s collection and analysis of a comprehensive set of data from both the vehicles and the charging stations.[U] Vehicle data collected will include parameters such as vehicle miles driven, battery state-of-charge, GPS location, and, in the case of PHEVs and FCEVs, the liquid fuel consumption. Infrastructure data collected will include parameters such as charger connect/disconnect times, charge event start/stop times, average and peak power delivered, and total energy delivered per charge event. Evaluation of this data, managed by Idaho National Laboratory, will provide critical information regarding the influences on vehicle and charging infrastructure use, performance, and location suitability. These data collection and analysis activities will identify how consumers use electric drive vehicles; where, when, and how frequently they charge the vehicles; how usage and charging behavior impact the performance of the vehicle; what the impacts are to the electric grid; how consumers respond to pricing signals with respect to vehicle charging; and a myriad of other questions related to consumer

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[U] A condition of participating in the program will be that participants agree to data collection.

acceptance and market viability of grid-connected vehicles. After the projects are completed in the 2013-2014 timeframe, this information will then be used to guide the much broader deployment of electric drive vehicles and charging infrastructure in the future.

A summary of infrastructure-related projects funded through the Transportation Electrification Initiative follows in Table 4.2-1, which shows, for each project: the number of charging stations and electric vehicles to be deployed, the targeted locations and timeframe for deployment and data collection, and the intended benefit of the data to be collected. Additional information about each of these projects is in Appendix G.

Table 4.2-1 ARRA Transportation Electrification Initiative and Clean Cities Projects Summary

Project	Level 2 Charging Stations Deployed	Vehicles	Location	Time-frame[a]	Data Collected
ECOtality North America ($115M)	14,850 (and 320 Level 3)	8,500 light-duty cars	AZ, CA, DC, OR, TN, TX	2010-2013	operational and charging behavior of electric-drive vehicle owners
Coulomb Technologies ($15M)	5,000	2,600 light-duty cars	CA, DC, FL, MI, NY, TX, WA	2010-2014	operational and charging behavior of electric-drive vehicle owners
Navistar ($39M)	950	950 medium-duty trucks	CA	2010-2013	performance and suitability of medium-duty electric vehicles and support infrastructure required
General Motors ($30M)	650	125 light-duty cars	CA, FL, MI, NY, NC, SC, TX, VA, DC	2010-2013	light-duty vehicle usage and operational needs, supporting vehicle design and infrastructure planning
Smith Electric Vehicles ($32M)	500	500 medium-duty trucks	CA, GA, MO, NJ, NY, OH, OR, TX, DC	2011-2013	applicability of electric-drive powertrains in vocational medium-duty trucks
South Coast Air Quality Management District ($45M)	378	378 medium-duty trucks and shuttle	CA, CT, GA, HI, KY, LA, MD, MI, MO, NJ, NY, OH, OR, PA, TN, TX, WI, DC	2010-2013	PHEV technologies for Class 4/5 vehicles

		buses			
Chrysler Group LLC ($48M)	153	153 light-duty trucks	AZ, CA, CO, HI, MA, MI, MO, NV, NY, ND, TX	2011-2013	real-world product viability and quantified benefits
Clean Cities ($115M)	500-550	100 light-duty and 280 heavy-duty vehicles	CT, IL, MI, MO, NC, NY, OH, TX, UT, WA, WI	2010-2011	charging station usage

[a] Timeframe is approximate. More details about all Transportation Electrification Initiatives are found in Appendix G.

Smart Grid

The ARRA authorizes DOE's Office of Electricity to administer the Smart Grid Investment Grant (SGIG), which supports projects to update today's electric grid to a "smart grid"—a modernized electric grid utilizing real-time two-way communication for improved reliability, efficiency, security, and safety and the possibility of dynamic pricing and even vehicle-to-grid energy exchange (in which a charged vehicle battery provides energy to the grid). As part of the projects supported with these grants, 12 awardees plan to deploy approximately 100 charging stations. Additionally, under DOE's Smart Grid Regional Demonstrations, electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) are part of several smart grid technology demonstrations projects. In most of the regional demonstration projects, grid-connected vehicles are integrated in broader smart grid technology deployment activities. Because EV/PHEVs are a relatively nascent technology, their contribution to the overall smart grid technology deployment and regional demonstration activities is likely to be small, particularly in the early years of the multi-year deployment and demonstration programs.

4.2.1.2 Other Projects

Through its national laboratories, DOE also supports other various projects aimed at overcoming barriers related to electric drive vehicles and their interaction with the electric grid. These projects target the development of codes and standards that govern the vehicle-grid interface, including communications between the vehicle, the charging infrastructure, and the electric grid. Additional projects are intended to streamline the process of deploying electric vehicle charging infrastructure and minimize the impact on electricity generation, transmission, and distribution resources. Together, activities conducted through the national laboratories will help speed the wide-spread adoption of electric drive transportation technologies.

Many stakeholders have expressed the need for timely and standardized local permitting procedures for installing electrical vehicle supply equipment. The National Electric Vehicle Infrastructure Permitting Project at the National Renewable Energy Lab (NREL) seeks to standardize local permitting procedures to speed the deployment of EVSE across the U.S. NREL has drafted a National Electric Vehicle Charging Station Permit template,[48] which conforms to Article 625 of the National Electric Code, and is engaging select cities to promote the use of this permit to streamline the process of installing electric vehicle supply equipment. This draft permit is intended to establish a mechanism for local jurisdictions to provide a simplified approval process for the installation and operation of electric vehicle charging equipment, rather than the existing wide variety of permitting procedures that currently exist at the local level. Adoption of the draft permit could reduce the typical administrative delays that might otherwise impede the deployment of charging infrastructure and slow the market adoption of grid-connected vehicles. This draft permit was created with input from industry and electrical contractors, and will allow electric vehicle charging stations to be installed quickly and safely in the municipalities where the process is adopted. Other organizations have published similar documents: Pacific Gas & Electric's (PG&E) released an "Electric Vehicle Infrastructure Installation Guide" in 1999,[49] and the Electric Power Research Institute (EPRI) published "Plug-in Electric Vehicle Infrastructure Installation Guidelines" in 2009.[50]

4.2.2 Home Charging Adequacy

Charging availability affects consumer value and the development of the EV/PHEV market.[51,52] Understanding the number of American consumers who can plug-in a vehicle at home is instructive in estimating the number of who might choose to own an electric drive vehicle. More charging points enable more potential EV/PHEV buyers, but the role of an additional charging point depends on whether it is attached to a home, a workplace or a public place. A home charging point may enable a new EV/PHEV buyer, while a workplace charge point may make the prospective car buyer who already has home charging availability more determined to own a PHEV or EV. Availability of adequate home recharging will likely have the most impact on deployment, because home is usually where a vehicle parks the most often and longest, resulting in more recharging energy and fuel-saving benefit. Based on past experience, 97%-99% of charging energy is delivered at home.[53] Even with available workplace or public charging, consumers will probably feel it is more convenient and less stressful to charge at home. Surveys show that consumers state stronger preferences for home recharging.[54] Other surveys show that EV users with home recharging rarely use public recharging[55] and some PHEV users choose not to use available public recharging during weekdays because of the inconvenience they perceive.[56]

There may be opportunities for supplemental charging outside the home. Public charging stations with Level 2 or Level 3 charging, possibly offered by restaurants, supermarkets, gyms, or health centers, can extend the electric range in an equivalent sense, which may be especially important for a EV driver in an unexpected long distance trip. The ability of a charging point to extend the electric range depends on both the length of available charging time and the charging speed. Higher charging speed may be more necessary in public places where consumers usually do not park their vehicles as long as at home or the workplace. But for consumers with home charging and typical driving patterns, topping off partially a depleted battery can be more desirable than recharging a fully depleted one, which reduces the need for high charging speed. For home or workplace charging, the usual long parking time makes expensive upgrades to faster charging less necessary, especially for PHEVs with a small battery.

As described above, three charging levels are currently under consideration.[57] Level 1 charging uses a standard 120 V, 15-20 amps (A) rated (12-16 A usable) circuit and is available in standard residential and commercial buildings. Level 1 charging for 7-9 hours of home nighttime is sufficient to fully charge a small PHEV20.[V,W] Level 2 charging uses a 240 V, 20-80 A circuit, enabling a much shorter charge time. With Level 2 charging, a full recharge requires less than 4 hours for a PHEV40 SUV and about half hour for a PHEV10 small car. Level 3 charging uses a 480 V, three-phase circuit, typically providing 60-150 kW of off-board charging power. Level 3 charging for PHEVs is probably not necessary due to small battery capacity and the vehicles' internal combustion engine range extended design. For this reason, it is not envisioned that manufacturers will equip all PHEVs with capability for accepting Level 3 charging. In addition, due to the relatively small battery when compared to an EV, battery charge can be completed at home or workplace where vehicle parking duration is normally long. High cost, lack of 3-phase power, and potential safety concerns also make Level 3 implementation in these places unlikely, at least for the near term.

Nevertheless, Level 3 charging may be more beneficial to EV owners who lack the hybrid-drive backup of a PHEV. An EV midsize car with 150-mile driving range will likely require more than 10 hours of Level 2 charging to reach a full recharge, but only 2-3 hours with Level 3 charging. Fast-charging an EV with 100-mile driving range can provide 80 miles of urban-driving range in less than 30 minutes.[58] In commercial places where drivers park and conduct personal or business activities, 1-2 hours of Level 3 charging is sufficient to provide an 80% recharge[X,59] for most EVs.

Level 1 charging may prove to be appropriate for a significant fraction of the initial EV market. Tesla has reported that, based on their experience, there is potential for approximately 25% of the 244-mile range Tesla Roadster EV to make use of Level 1 charging.[60] It may also be more appropriate to consider average charge times that correspond to normal daily use instead of what is required for the exceptional circumstance to charge a fully depleted EV. At the national average of 28 miles of driving per day, a small EV would only require ~7 kWh to charge. This would require less than 5 hours with a standard Level 1 cordset. An important feature available on many Level 1 cordsets or grid-connected vehicles is the ability for the user to select a lower-than-usual charge rate so that users may make use of lower-capacity, non-dedicated Level 1 circuits until a dedicated circuit is installed.

[V] For the purposes of estimating charging times, it is assumed that a small EV consumes ~200 AC Wh/mile, mid-size EV or PHEV is 300 AC Wh/mile, and larger PHEV SUV is 350 AC Wh/mile; Level 1 charging power is assumed to be 1.44 kW nominal; Level 2 is 3.3 kW nominal on 20 A rated circuits (208 x 16); and Level 2 charging is 6.6 kW nominal on 40 A circuits (208 x 32).

[W] A PHEV20 is a PHEV with a 20-mile charge-depleting range, or, the range of battery operation over which energy is consumed from the battery at a greater rate than it is recharged through regenerative breaking. Once the battery is sufficiently depleted, the vehicle operates in charge sustaining mode, during which time the energy captured through regenerative breaking is roughly equivalent to the rate of battery energy consumption; this mode is identical to the operation of a grid-independent HEV. The nomenclature is analogous for PHEV with larger (e.g., PHEV40 has a 40-mile charge-depleting range) or smaller (PHEV10 has a 10-mile charge-depleting range) batteries.

[X] OEMs have indicated that fast charging is expected to replace 80% of max state-of-charge

Currently, there are approximately 1,000 charging stations in the United States.[61] Most of these stations allow public access, while the rest are restricted for workplace use. Home charging, which is not included in this count, is considered more important for EV/PHEV market success,[62] which is understandable since home is where a vehicle parks the most often and longest.

Although there is not clear data indicating home charging capacity, two indicators of charging readiness are the availability of a garage or carport, where the electric circuit is usually equipped, and the proximity of an electrical outlet. Having a garage or carport does not necessarily mean charging readiness, as a garage may lack parking functionality.[Y] For example, garages in old homes can be too small to hold today's large vehicles, forcing the owners to park their vehicles on the driveway, and some garages may mainly be used for non-parking purposes. One alternative measurement of home charging readiness is the availability of an electric outlet where the vehicle is usually parked when arriving home. According to a survey conducted by University of California, Davis (UCD),[63,64] 61%, 52%, 44%, and 36% of the U.S. new vehicle buying households have an electric outlet within 50, 25, 15, and 10 feet, respectively, from the home parking location.[Z] These percentages are slightly lower than the garage ownership share in the American Housing Survey or the share of detached single house in the 2001 National Household Travel Survey data.

The home charging availability for a specific consumer will need to be differentiated among EV/PHEVs with different battery capacity. The electric outlets in existing homes are most likely ready for Level 1 charging, which is about sufficient for fully recharging a PHEV20 SUV during normal nighttime, provided the outlet is not being heavily utilized by other loads. Shorter available charging time or owning a vehicle with a larger battery make the capability to fully charge overnight with a Level 1 system less likely, but upgrading to a Level 2 system in such cases will allow full recharge to happen more quickly.

The DOE-supported infrastructure projects described above in section 4.2.1 will collect data that significantly improve the understanding of how consumers interact with electric-vehicle support infrastructure. With respect to the availability of home charging, these data collection and analysis activities will identify how consumers use electric drive vehicles and infrastructure and how consumers respond to pricing signals with respect to vehicle charging as well as a myriad of other questions related to consumer acceptance and market viability, which can eventually be used to guide the much broader deployment of electric drive vehicles and charging infrastructure in the future.

[Y] Based on the 2001 National Household Travel Survey (NHTS), 63.8% of the U.S. households live in detached single houses. According to the American Housing Survey (AHS), 62.5% of homes in the U.S., regardless of home type, include a garage or carport. The share is a little higher (65.4%) for year-round occupied homes, much lower (45.1%) for vacant homes and much higher (81.5%) for new constructions up to 4 years old. The closeness between the share of detached single houses from the 2001 NHTS data and the share of garage ownership from the AHS data should not be interpreted as that the form of detached single house is an equivalent indicator of garage ownership. The estimation closeness is more likely a coincidence, since not all detached houses include a garage or carport, and some homes with a garage or carport are attached homes.

[Z] These estimates are based on the one-day 24-hour travel diary completed by respondents from 2,373 U.S. households that represent U.S. new vehicle buying households.

4.2.3 Charging System Cost

Charging an electric vehicle or plug-in hybrid will generally require specialized equipment, including:

A **charger** that converts electricity from alternating current (AC) from the electricity source to direct current (DC) required for the battery, and also converts the incoming 120 or 240 volt current to 300 or higher volts. Grid-connected vehicles carry an on-board charger capable of accepting AC current from a wall plug (Level 1 circuit) or, from a Level 2 charging station. On-board charger power capability ranges from 1.4 to 10 kW and is usually proportional to the vehicle's battery capacity.[AA] The lowest charging power,[BB] 1.4 kW, is expected only when grid-connected vehicles are connected to 120 volt (Level 1) outlets, and all currently known PHEV and EV on-board chargers are expected to provide at least 3.3 kW charging when connected to a Level 2 (220 volt, 20+ A) charging station. The latest SAE connection recommended practice, J1772, allows for delivery of up to ~19 kW to an on-board vehicle charger. For higher capacity charging, a charging station that delivers DC current to the vehicle is incorporated off-board in the wall or pedestal mounted.

The **charging station** needed to safely deliver energy from the electric circuit to the vehicle, called electric vehicle support equipment (EVSE). The EVSE may at a minimum, be a specialized cordset that connects a household Level 1/120V socket to the vehicle; otherwise, the EVSE will include a cordset and a charging station (a wall or pedestal mounted box incorporating a charger and other equipment). Charging stations may include advanced features such as timers to delay charging until off-peak hours, communications equipment to allow the utility to regulate charging, or even electricity metering capabilities. Stakeholders are working on which features are best located on the EVSE or on the vehicle itself, and it is possible that redundant capabilities and features may be present in both the vehicle and EVSEs in the near future until these issues are worked out. EVSE and vehicle manufacturers are also working to ensure that current SAE-compliant "basic" EVSEs are charge-compatible with future grid-connected vehicles.

Some public charging stations will likely include **fee collection equipment** or will be networked with nearby fee-collection equipment already in use for parking fee collection. Under some local regulations, owners of charging stations cannot resell electricity;[CC] unless the utility itself owns the stations or can directly bill the vehicle owner, the station owner can only charge a flat or time-based fee to the vehicle driver. This may require credit/debit card readers, pay-to-park kiosks or standard parking meters (in a commercial parking lot, kiosks or meters could already be available, so no additional equipment may be needed), or radio-frequency ID cards linked to a subscription service. For the utility to directly bill the vehicle

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[AA] Current mini-e's and Tesla Roadsters presently have 11-19 kW on-board charger capability, though such high on-board power levels are not expected to be common in the majority of upcoming EV/PHEVs.

[BB] Some EVs will have an 840W charge setting to allow for a shared Level 1 circuit

[CC] One exception is provided by the California Public Utilities Commission; it concluded in July 2010 that companies that sell electric vehicle charging services to the public will not be regulated as public utilities.

owner, the charging station or vehicle must include a communication link to the utility that will identify the vehicle or owner.

An **electric circuit** located close to where the vehicle parks. A Level 1 circuit is standard household current, 120V AC, rated at 15 or 20 A (12 or 16 A usable). A Level 2 circuit is rated at 208 to 240V and up to 80 A and is similar to the type of circuit that powers electric stoves (up to 50 A) and dryers (usually 30 A). Generally, level 1 and 2 circuits used for electric vehicle recharging must be dedicated circuits,[DD] i.e., there cannot be other appliances on that circuit. For a Level 2 circuit, the homeowner or other user must install a charging station and will need a permit.

Optionally, separate **metering** (EUMD, end use measuring device) for the EV charger to allow time-of-day rates for EV recharging; otherwise, homeowners may choose to pay standard rates for EV charging or to have all household electricity on time-of-day rates, either option with a single meter.

Protection for the charging stations, including wheel stops, protective bollards, etc. Where vandalism is a concern, additional costs may be incurred for fencing or security equipment.

In addition to the costs of purchasing and installing charging equipment, charging station installation may include the costs of upgrading existing electrical panels and installing the electrical connection from the panel to the desired station location. These costs may be dramatically lowered if new construction incorporates the panel box and wiring required for charging stations, or even includes charging stations or outlets for charging stations as standard equipment.

In addition to Level 1 and 2 charging stations, “Level 3” commercial recharging stations may be installed in areas where 3-phase power is available; these can deliver 300V-600V, 3-phase 150-400 A DC power for rapid charging of EVs. These may be viewed as equivalent to gas station pumps due to a similar look.

The current costs of charging stations are highly variable depending on the level of service (Levels 1 through 3, and alternative power capabilities within these categories), location (individual residence, grouped residences, retail or business, parking lot or garage), level of sophistication of the station, and installation requirements, including electrical upgrading requirements. Estimated costs for charging stations are included in table below.

Table 4.2-2 Estimated Costs for Charging Stations[65,66,67,68,a]

Level	Location	Equipment	Installation

[DD] Some manufacturers are planning for lower-power level 1 charging which can be accomplished on a shared 120V circuit.

1	Single Residence	$30- $200 (charge cord only, included at no cost to consumer with EV/PHEV) when an accessible household plug (e.g., in a garage or adjacent to a driveway) with a ground fault interrupter is already available	$400-$1000+ may be necessary depending on difficulty of installing a new circuit at the desired location, but in most cases, owners with sufficient panel capacity would opt for a more capable 220 VAC Level 2 installation instead of a Level 1 dedicated circuit because the additional installation cost is only marginally higher
2	Residential, Apartment Complex, or Fleet Depot[b]	3.3 kW EVSE (each): $300-$4,000 6.6 kW EVSE (each): $400-$4,000	3.3- 6.6 kW installation cost: $400-$2,300 without wiring/service panel upgrade, or $2,000-$5,000 with panel upgrade
2	Public	$400-$3,800+ for each EVSE	$3,000- $7,000+ installation cost, varying significantly with distances from service entrance and number of EVSEs installed
3	Public	$8,000-$50,000	

[a] Detailed information on charger cost for each charging level and location and specific sources for cost estimates are available in Appendix G.

[b] Level 2 EVSE installation costs vary considerably for single-family residences, multi-family residences, and fleet depots, depending upon the need for wiring and service panel upgrades. The range depicted here reflects the anticipated variability of these costs. However, EPRI estimates that the typical residential Level 2 installation costs to be approximately $1,500. See Appendix G for additional information.

For the 2017-2025 period, there is a major potential for cost reduction in EVSEs if either or both PHEVs and EVs enter the market in substantial numbers – particularly if strong markets for these vehicles develop, as expected, in Europe and Asia and EVSEs are manufactured globally and compete for market share in this country. Although the reduction potential for installation costs would likely be somewhat smaller than for equipment costs, installation costs may also be reduced by incorporating EV requirements into building codes for new construction, and through standardization of procedures and better training and availability of installers. For purposes of the analysis presented in Chapter 6, the agencies' estimated costs for Level 1 and Level 2 in-home charging equipment for the 2017 to 2025 time frame is within the range of the values shown above and is detailed in Appendix B4.2.2.6.

4.2.4 Battery End-of-Life Value Assessment and Secondary Use Applications

At the end of an EV/PHEVs useful life, the battery will likely not be fully exhausted and could be used for a number of other tasks. Such a used battery would have a secondary use value and this expected value could be applied to the original purchase price of the vehicle (minus an appropriate discount rate) to lower the overall cost, making electric vehicles more affordable for the American public. These batteries could be used in utility peak load reduction and management, substation upgrade deferrals, and grid stabilization applications, as well as renewable energy installations to store solar and/or wind power.[69] Several electric utilities currently use large sodium-sulfer (NaS) batteries for these purposes and are exploring used EV/PHEV batteries as substitutes. These applications have specific requirements that could possibly be met by used automotive batteries.

This is a field being intensely studied at the present time and there is some uncertainty as to the extent of the market, as well as the value to the original vehicle purchaser. A summary of one such forthcoming study supported by DOE is in Appendix G.

4.2.5 Potential Impacts on the Electric Utility and Distribution Infrastructure

The overall distribution system capacity is expected to be adequate for EV charging. However, the effect of EV charging on specific circuits within the localized distribution system has not been fully evaluated and the impacts are not clearly understood; though, this issue is under study by EPRI, DOE, and several electric utilities.[70] Understanding the relationships between EV charging and the distribution system allows utilities to plan for additional stresses placed upon their systems as a result of EV charging.

Distribution system components which may be at risk due to the increased loading are substations, primary and laterals feeders, and distribution transformers. Distribution transformers are of primary concern. Distribution transformers may be impacted by several factors, including total EV penetration, EV clustering, time of charging, ambient operating conditions and thermal characteristics of the transformer, the prevalence of air conditioning, and the topography and age of the distribution system. These factors affect the cumulative thermal history of transformers, leading to their increased "thermal aging" and potential loss of transformer life. DOE and others are studying the effect of PHEV/EV charging on thermal aging of distribution transformer insulation.

Transformers are also impacted differently under Level 2 versus Level 1 charging. With more OEMs making public announcements to offer EVs, which are generally more likely to utilize Level 2 charging than PHEVs, there is further discussion of potential impacts to the infrastructure. Since Level 2 charging allows for charging power up to 14 times that of Level 1 charging, the distribution system impacts could be much more severe under Level 2 charging assumptions.

Load diversity[EE] becomes an issue further upstream in radial distribution systems. With diversified load profiles, peaks by individual loads are averaged out. The secondary transformer is the first distribution system component that will be exposed to the large current. Thus, it is expected that EV/PHEV charging will have the greatest impact on those components. The diversity of distribution system component vintages, sizing, and design practices varies greatly across the U.S. Older distribution systems, which were initially designed to support lower per-customer demand, are more likely to be affected by PHEV/EV charging than newer distribution systems, which were designed to support higher per-customer demand.

Potential distribution system impacts reported in the literature indicate that overall and, particularly, in newer residential developments (30 years and younger) and rural areas, distribution system capacity is expected to be adequate for EV charging. However, the potential for distribution system overloading exists with higher concentrations of charging vehicles in older residential neighborhoods, such as those in some coastal or mid-western metropolitan areas.[71] These areas may be of concern to utility infrastructure planners.

Time-of-use (TOU) rates[FF] may incentivize customers to delay charging to off-peak periods later at night. While TOU rates are likely to shift loads, they will not alleviate potential negative impacts on the distribution infrastructure. Smart load control technologies may be required in order to sequence charging or to perform load coordination strategies for charging vehicles in order to mitigate possible distribution transformer impacts.

The preceding discussion yields several important conclusions about the potential impacts on the electric utility and distribution infrastructure:

- The overall electrical distribution system capacity is expected to be adequate for EV/PHEV charging.
- There is some potential for localized impacts on distribution transformers, especially in older neighborhoods, depending on EV/PHEV charging load concentrations. However, the success of electric vehicles will not be limited by possible disruptions in the distribution system. Additional research is required to understand the magnitude and extent of the issue.
- Smart load control technologies that include sequencing and coordinating the charging of vehicles for Level 2 charging could help mitigate possible transformer impacts.

[EE] Load diversity refers to electric loads which come online at random times. Non-diversified loads come online at the same time. So, if EV owners come home at 6:00 PM and plug in to charge, the load is not diversified.

[FF] TOU pricing is a special electric rate feature under which the price per kilowatt-hour depends on the time of day; prices can be adjusted upward during periods of peak demand and downward during off-peak periods.

4.2.6 Voluntary Standards to Support PHEV & EV Infrastructure

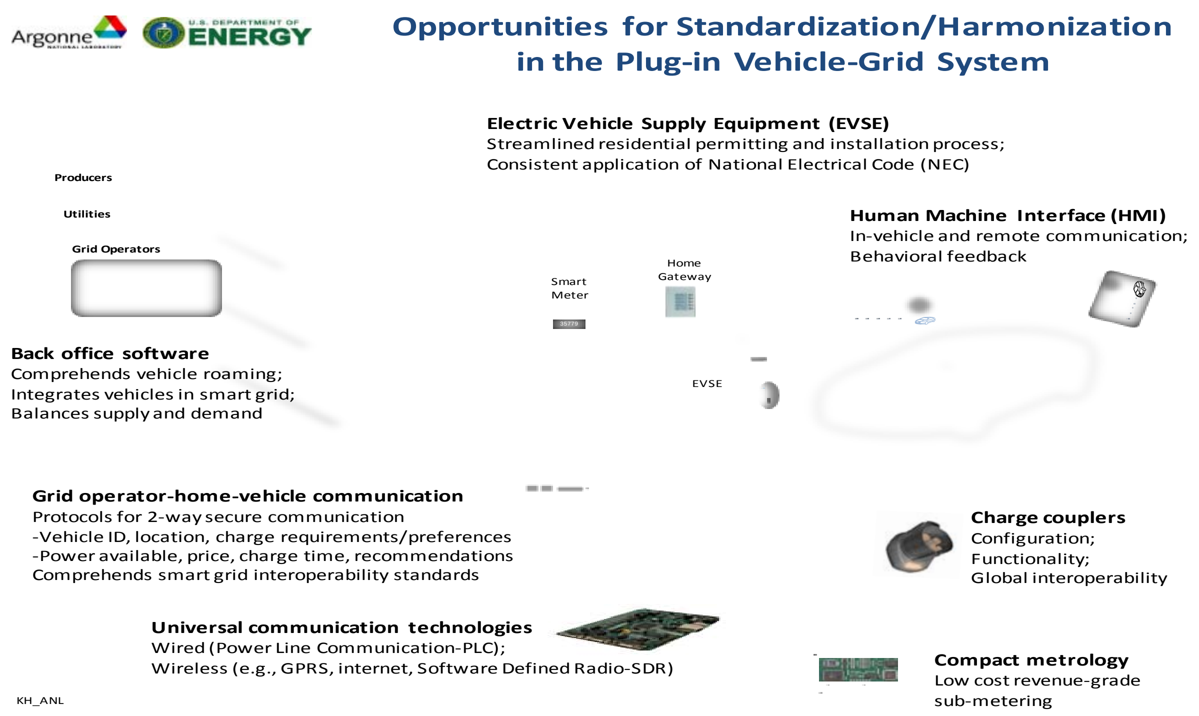
DOE has several ongoing activities to support the development of voluntary standards. These activities can be expected to accelerate under the May 21, 2010 Presidential Memorandum's request for DOE to work with stakeholders on the development of voluntary standards and coordinate its efforts with the Department of Transportation, NHTSA, and the EPA.[72] While these efforts on voluntary standardization are important in enhancing long-term success of EV/PHEVs, they are not a prerequisite for a successful near-term market launch.

On a conceptual level, electric-drive vehicles differ from conventional gasoline vehicles in the way they are repowered: conventional vehicles are refueled and electric vehicles are recharged. But, on a practical level, the means by which repowering happens is also very different. Where gasoline pumps and measurement standards are already well established, the equipment and measurement devices facilitating and governing electric-drive vehicle recharging are still being discussed. Coordination of the means by which EVs and PHEVs communicate with the grid—both in terms of hardware and software—offers the benefit of assuring that all electric-drive vehicles can plug in almost anywhere.

The primary link between the DOE vehicle technology activity and industry standards is the Society of Automotive Engineers (SAE). The most significant development to date has been the adoption of the voluntary standard SAE J1772, specifications for the electrical connector between EV/PHEVs and electric vehicle supply equipment (Levels 1 and 2 charging). DOE national laboratories have provided expertise, development and testing resources to support new SAE standards, as discussed further in the following sections.

4.2.6.1 Opportunities for Voluntary Standardization

There are numerous opportunities for standardization (or harmonization) in the plug-in vehicle-grid system, including hardware, software, communication and the human-machine interface (the device through which a driver interacts with the smart grid and/or charging device) – as exemplified in the following figure:



Opportunities for Standardization/Harmonization in the Plug-in Vehicle-Grid System

Electric Vehicle Supply Equipment (EVSE)
Streamlined residential permitting and installation process;
Consistent application of National Electrical Code (NEC)

Human Machine Interface (HMI)
In-vehicle and remote communication;
Behavioral feedback

Back office software
Comprehends vehicle roaming;
Integrates vehicles in smart grid;
Balances supply and demand

Grid operator-home-vehicle communication
Protocols for 2-way secure communication
-Vehicle ID, location, charge requirements/preferences
-Power available, price, charge time, recommendations
Comprehends smart grid interoperability standards

Charge couplers
Configuration;
Functionality;
Global interoperability

Universal communication technologies
Wired (Power Line Communication-PLC);
Wireless (e.g., GPRS, internet, Software Defined Radio-SDR)

Compact metrology
Low cost revenue-grade
sub-metering

Figure 4.2-1 Opportunities for Standardization/Harmonization in the Plug-in Vehicle-Grid System

Several opportunities for standardization/harmonization are identified in the preceding simplified concept of vehicle-grid interaction (and, others are possible). Starting from the vehicle and moving upstream to the utility, the first opportunity is the charge coupler—the physical connector and vehicle receptacle for hybrid and electric vehicle charging and the means by which the vehicle interacts with EVSE. Several additional opportunities are within the EVSE: first, the permitting process to facilitate the installation of EVSEs, to be coordinated at the local government level; second, the compact metrology, or small device the EVSE uses to measure energy consumption; and, third, the method of communication—both in terms of hardware (wired and wireless universal communication technologies) and software/protocols (grid operator-home-vehicle communication). At the utility, software can be standardized or harmonized to facilitate grid-wide smart management with targeted goals such as balancing supply and demand and sequencing vehicle charging.

4.2.6.2 Defining voluntary standards

“Voluntary” standards, i.e., those not required by regulation,[GG] address essentially all aspects of automobiles and are issued by several organizations around the world; for example the Society of Automotive Engineers (SAE) in the US, the International Organization for

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[GG] Although voluntary in some regions of the US, SAE J1772 is essentially a regulatory requirement in California and many other states that have adopted the CA ZEV Regulation because California requires vehicles to comply with J1772 in order to earn ZEV credit.

Standardization (ISO) or the International Electrotechnical Commission (IEC) in Europe and the Japan Automobile Research Institute (JARI) in Asia. The electrical content of automobiles adheres to standards developed by the Institute of Electrical and Electronics Engineers (IEEE) and, as plug-in vehicles and EVSE utilize the electric power grid, they are subject to standards by Underwriters Laboratories (UL) as well as the fire and building safety standards by the National Fire Protection Association (NFPA) including the National Electrical Code (NEC).

4.2.6.3 Standards for Electric Vehicle to Grid Interface

The Grid Interaction Technical Team (GITT) was initiated in 2009 to identify issues regarding vehicle electrification and related grid impacts, set functional requirements for the vehicle-grid interface and cooperate on key issues/projects to enable plug-in vehicles (PHEVs and EVs). The members include DOE (the Vehicle Technologies Program and the Office of Electricity Delivery and Energy Reliability), the domestic auto industry and selected electric utilities. Current DOE-funded projects under the auspices of the GITT focus on some of the immediate needs of the vehicle-grid interface, including:

- A draft national template to streamline the permitting and installation process of electric vehicle supply equipment
- The human-machine interface (HMI) for charger-grid communication standards validation
- Technology development to support universal vehicle-grid communication
- Standards for PHEV/EV Communications Protocol

4.2.6.4 SAE Standards Development

SAE is working with stakeholders to develop EV/PHEV and infrastructure-related standards. SAE J1772 is a standard for the “Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler,” and describes the physical, electrical, functional, and performance requirements for all grid-connected vehicles in North America. Work is also progressing towards the development of improved grid connectivity for electric vehicle charging infrastructure through lower cost, secure, universalized wired and wireless communications technologies.

SAE is working with organizations and consortia such as the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), utility companies, the Institute of Electrical and Electronics Engineers (IEEE), Electric Power Research Institute (EPRI), ZigBee Alliance, HomePlug Power Alliance, automotive OEMs and suppliers, and many others in the development of specifications and standards to address the requirements of the SmartGrid strategy. Several national laboratories directly support the committee activities, including Argonee National Lab, Idaho National Lab, National Renewable Energy Lab, Oak Ridge National Lab, and Pacific Northtwest National Lab.

A full list of applicable SAE standards—both completed and upcoming—is provided in Appendix G.

4.2.6.5 International Cooperation and Activities

Increasingly, vehicles are being developed to compete in a worldwide market. A manufacturer can realize significant cost savings by building a large number of standardized vehicles in several countries. International harmonization of EV/PHEV charging equipment and protocols can help speed the market penetration of these vehicles by more rapidly lowering the costs of these components.

International cooperation relies on the members and projects of the joint DOE-auto industry-utility Grid Interaction Tech Team (see previous section) as well as national laboratory personnel that directly support the SAE standards committees to interact to promote global vehicle-grid interoperability through outreach and programmatic support for harmonization of US, European and Asian codes & standards in selected international venues. Specific support is provided to the Administration's EU and China initiatives[HH] as well as the Departments of Commerce and State.[II] As mentioned in the preceding description of the SAE activities, there are U.S. Technical Advisory Groups (USTAGS) to the ISO activities, with all the groups listed on the SAE website.[JJ]

4.3 Hydrogen Infrastructure Overview

When run on hydrogen, fuel cell electric vehicles (FCEVs) produce zero tailpipe emissions making hydrogen an attractive alternative fuel. When produced from the reformation of natural gas (the method used for the vast majority of H2 currently produced) hydrogen reduces well-to-wheel (WTW) GHG (CO_2 equivalent) emissions by approximately 50 percent.[73] Unlike infrastructure for EVs and PHEVs, where the option of home charging exists, the successful rollout of FCEVs depends on the early and strategic placement of publicly accessible infrastructure to enable market penetration. This section of the report includes discussion on hydrogen infrastructure status today, costs and projections for technology improvement, rollout strategies, policies, and conclusions.

4.3.1 Status Today

4.3.1.1 Infrastructure Technologies

Hydrogen is produced through a variety of processes. Some are more suited for large scale centralized production; others are more often associated with on-site distributed production at traditional fueling stations. Most common technologies utilized today include:

[HH] e.g., Smart Grid-EV Working Group of the EU-US Energy Council, EU-US Transatlantic EV Workshop, US-China Vehicle and Battery Technology Workshop

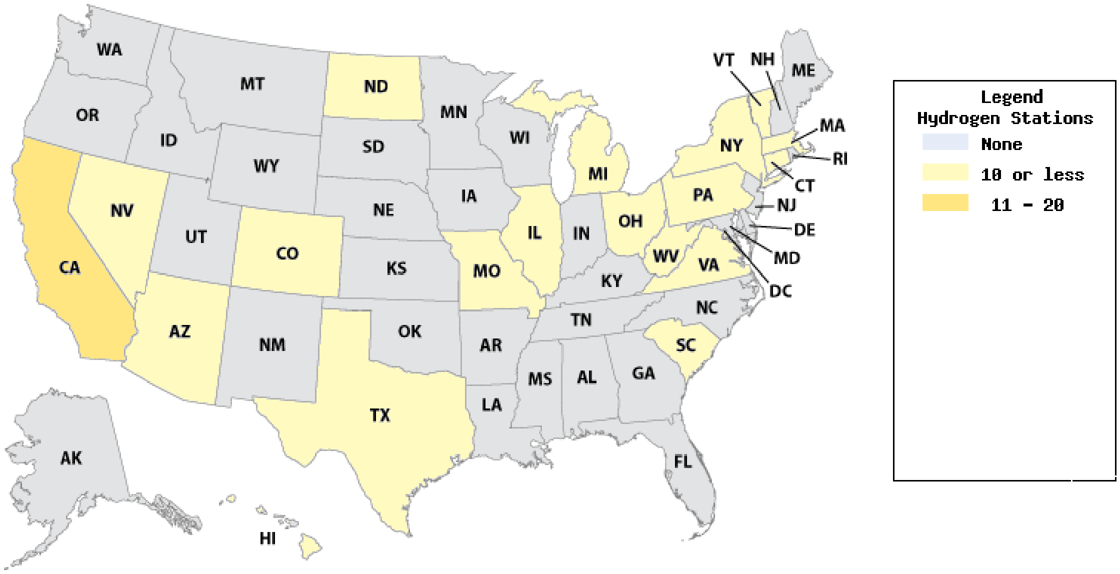
[II] e.g., EU 'green' trade mission, COP 15 and COP 16 UN Framework Conventions on Climate Change

[JJ] *See* http://www.sae.org/servlets/works/

- Steam methane reformation - The U.S produces over 9 million tons of hydrogen annually. Ninety Five percent of that amount is produced from natural gas by steam methane reformation (SMR) at large scale centralized plants. Most is used at petroleum refineries, for food processing and other industrial uses. Renewable hydrogen may also be reformed from biogas, landfill gas and ethanol for example. High daily throughput stations (100+ kg/day) with ample space can utilize onsite steam reforming on-site.
- Electrolysis - Electrolysis systems use electricity to split water into hydrogen and oxygen. The technology is compact, reliable, and has been used for decades in industrial, military and space applications. Today's typical station electrolyser produces 60 kg/day and requires approximately 55kW-hr of electricity to generate a kilogram of hydrogen. A clean, renewable electricity source (such as hydro, wind, photovoltaic or natural gas fired plant) can minimize upstream GHG emissions from electrolysis.
- Delivery - For those stations not producing hydrogen onsite, typically high pressure gaseous product can be delivered to the site in batches that can supply the station for a few days or even weeks, depending on station throughput. This method is easy to build but needs refilling regularly. Another common delivery method is trucked cryogenic liquid hydrogen, which is stored in much larger quantities at the station.
- Pipeline – There are over 300 miles of hydrogen pipeline in Texas, Louisiana and California serving industrial demand. The hydrogen is not fuel cell grade and is of relatively low pressure (350 – 1500 psi typically). With minimal clean-up and added storage, compression, and dispensing equipment, this option can be an economical source for hydrogen infrastructure placement, where pipelines exist.
- Co-generation - High temperature fuel cells for stationary or ancillary grid electricity production (hydrogen energy stations) can provide a fuel source for a hydrogen infrastructure. A jointly funded DOE/CARB/South Coast Air Quality Management District (SCAQMD) project at a waste water treatment plant near Los Angeles features a molten carbonate fuel cell run on treated anaerobic digester gas. The fuel cell produces electricity to run the plant, and tail gas from the anode will be further cleaned, compressed and dispensed at the on-site hydrogen station for FCEVs.[74]

4.3.1.2 Federal Demonstration Programs

The map below shows locations of hydrogen stations (includes lift trucks and transit bus stations) in the U.S.[75] Since 2004 the U.S. DOE Hydrogen Program has worked with multiple partners in several states including California, New York, Florida, Michigan and Washington D.C. to demonstrate FCEVs and infrastructure. The program worked in partnership with industry, academia, national laboratories, and Federal and international agencies to help overcome technical barriers through research and development of hydrogen production, delivery, and storage technologies, as well as to address safety concerns and develop model codes and standard. NREL has reported that over 130,000 kg of hydrogen has been produced or dispensed in 23 of the Nation's 56 stations.



4.3.1.3 California Demonstration Programs

Although there is much FCEV activity ongoing throughout the U.S. many OEMs are focusing their pre-commercial vehicle rollouts in California. The state's Zero Emission Vehicle (ZEV) regulation requires large volume automakers to produce a certain number of "pure" zero emission and "near zero" emission vehicles for sale in California as a percentage their overall sales.[76] To date, over 250 fuel cell vehicles have been deployed in the State fueling at over 26 limited access, private and public access fueling stations.

The SCAQMD which includes the greater Los Angeles area has been operating its "Five Cities" hydrogen stations for over five years now. Each fueling station supports OEM FCEVs and a fleet of five gas/electric hybrid vehicles that have been converted to run on hydrogen. The aim of the project is to stimulate demand for hydrogen fueling, accelerate the expansion of the region's hydrogen fueling network, and educate the public on hydrogen powered vehicles. City officials and staff have used the converted hybrids in everyday city fleet driving and showcased them to community groups, neighborhood associations and schools.

To support continued roll out of FCEVs in California, the state has committed to partnering with infrastructure providers to develop a network of stations in the greater Los Angeles area, Sacramento and in the San Francisco Bay Area. The following chart shows infrastructure and co-funding amounts for stations supporting OEM FCEV rollouts. Cost share in most cases varied between 50-70% of expected station costs.

Table 4.3-1 Public Access Stations Nearing Completion in California

Location & Station Proposer	State Funds (Millions)	Total Cost Estimated (Millions)	Capacity Kg H2/ day	Technology
Emeryville	$2.7	$5.56	60	Electrolyzer 100 % renewable
Oakland	$4.1	$ 5.96	180+	Liquid Delivery 33 % Biogas credits
San Francisco Airport	$1.7	$2.41	120	Liquid Delivery
Burbank	$300K/yr	Not Available	100	Gas deliver and On-site Steam Methane Reformation
Los Angeles - CSULA	$2.7	$4.4	60	Electrolyzer 100% renewable
Los Angeles - UCLA	$1.7	$4.32	140	On-site Steam Methane Reformation
Torrance	$0	Not Available	50	Pipe line supplied
Harbor City	$1.7	$2.47	100	High pressure delivered Hydrogen
Fountain Valley	$2.7	$8.19	100	High Temperature Fuel Cell; 100 % renewable from digester gas
Newport Beach	$1.7	$4.03	100	On-site Steam Methane Reformation

4.3.1.4 Station and Hydrogen Costs

The following chart shows actual and estimated ranges of costs to build 350/700 bar demonstration pre-commercial hydrogen stations in California. The figures include: site preparation, permits, engineering, capital equipment, utility connections, construction, renewables, and installation. It excludes operation and maintenance and real-estate. The third column figures are predicted cost ranges determined from an Institute of Transportation Studies (ITS) workshop held at the University of California, Davis. Appendix G shows information regarding the cost of hydrogen in the U.S. through 2050.

Table 4.3-2 Actual and Estimated Station Costs by Technology

Technology	Station capacity kg/day	CARB Cost $M 2008-11	ITS Est Cost $M 2012-17[77]
Tube trailer delivery	100	1	0.4-1.0
High pressure composite delivery	100	1.0-1.7	0.8-1.0
Liquid delivery	100+	1.7 - 2.7	1.1-1.4
Onsite electrolyzer(s)	60 - 130	2.0 - 4.0 (renewable)	1.4-2.0
Onsite SMR	100-140	2.5 - 4.0	1.4-2.0
Energy station/gasifier	100+	6.0 - 8.5 (renewable)	n/a

4.3.2 Prospects for Cost and Technology Improvement

Over the past several years, the *DOE Hydrogen* Program has tracked, set targets, researched and funded studies to better predict the costs to transition to different alternative fuels. The DOE 2009 target infrastructure performance metrics for hydrogen were set at $3/gasoline gallon equivalent (gge) with a target average hydrogen fueling rate of 1.0 kg/minute. NREL reported that average fueling rates have improved from 0.66 kg/min in 2006 to 0.77 kg/min in 2009, and early market hydrogen costs at an on-site natural gas reformation station ranged from $7.70 – $10.30, and onsite electrolysis ranged from $10.00 – $12.90 /gge.[78] In this NREL study, the number of refuelings by all OEMs with both Generation 1 and Generation 2 vehicles totaled 25,811.[79] However, independent of this project, industry panels concluded that at 500 replicate 1500 kg/day stations/year, distributed natural gas reformation could produce $2.75 – $3.50/kg and distributed electrolysis at $4.90 - $5.70/kg.[80] With the increased efficiency of FCEV relative to conventional vehicles, this makes hydrogen potentially competitive to conventional fuels such as gasoline.

4.3.3 Infrastructure Rollout Strategy

To help ensure that hydrogen infrastructure is in place to match planned vehicle rollouts, CARB and the California Energy Commission (CEC) conducted a confidential survey of OEMs. The following table shows the estimated number and timing of FCEV releases through the year 2017. The survey, conducted in late 2009, included an additional breakdown of regions and cities/clusters in both northern and southern California.

Table 4.3-3 California Hydrogen Fuel Cell Vehicle Rollout Estimates

Year/Period	2010	2011	2012	2013	2014	2015-2017
Cumulative Number of Vehicles CARB/CEC 2009 Survey	92	30	95	69	839	44,706

4.3.3.1 Station Location Strategy

Pre-commercial hydrogen infrastructure will roll out in phases consisting of “clusters.” A Hydrogen Cluster could be a city or group of cities, group of neighborhoods or unincorporated areas that are or will be targeted as a unit in which OEMs plan to place FCEVs. Clusters have already been developed in southern California. The Santa Monica/West Los Angeles area, the Torrance/Redondo Beach areas, the Hollywood area, and the Irvine/Newport Beach areas each have at least one station operating with more under construction to ensure increased convenience, sufficient redundancy, and increased capacity for future vehicle rollouts.[81]

Depending on availability and customer acceptance, as vehicle numbers increase, station number and capacity will increase within the Clusters. Bridging stations connecting the clusters and regions as well as destination (vacation cities for example) will be added to the infrastructure. Infrastructure will expand and "secondary Clusters" will develop as the FCEV market expands and the vehicles become more main stream.

4.3.3.2 Station Specifications

Pre-commercial hydrogen stations have made the transition from being "behind the fence," to a near full retail experience. Station performance specifications now include 3 – 5 minute back-to-back fills, both 350 and 700 bar dispensers, convenient 24/7 hours, with no attendant required and easy pay pumps. Extensive Codes and Standards have been developed to help ensure stations are designed and built to a consistently high standard, are safe and are compatible with all OEM vehicles. Appendix G provides a list of Codes and Standards that have been developed for hydrogen infrastructure.

4.3.4 Policies and Partnerships

Government policies and partnerships can assist in focusing work on the most important tasks needed for implementation of hydrogen infrastructure. Foremost in any alternative fuel vehicle rollout, timing and execution of alternative fuel infrastructure is difficult to achieve without help. A classic chicken and egg dilemma exists, more so with hydrogen than with most alternative fuels because of the newness of the fuel and the initial investment needed.

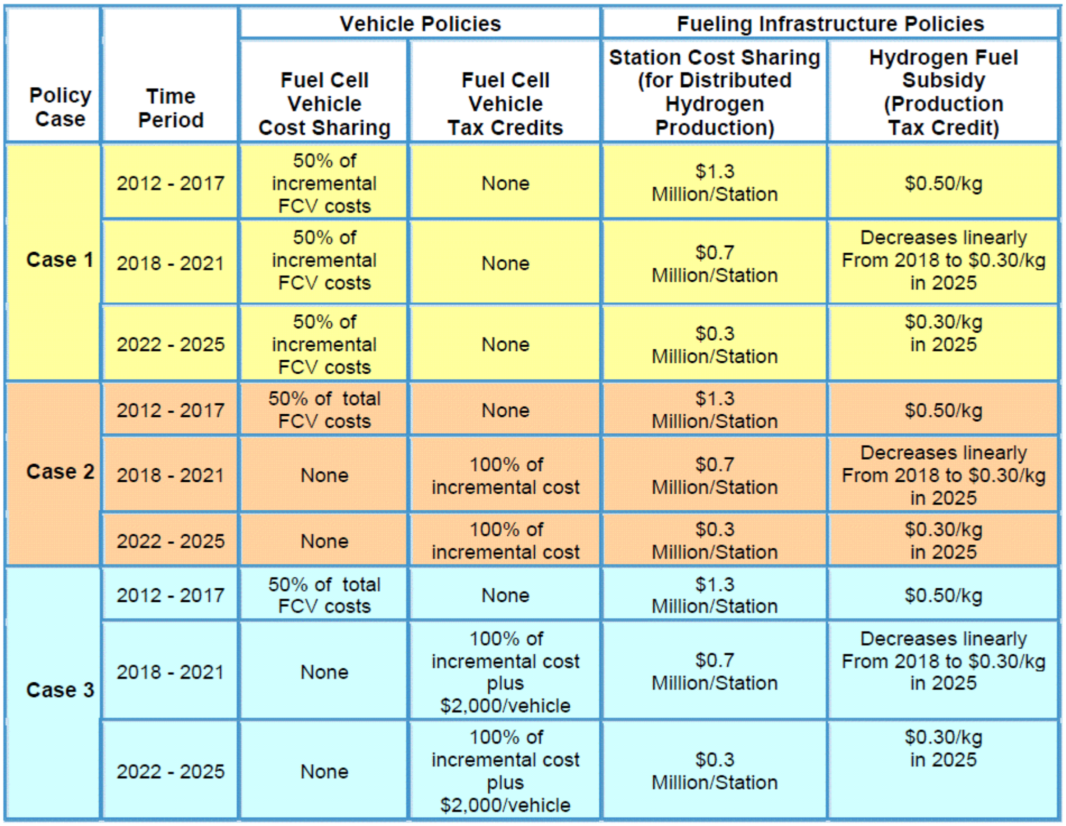
4.3.4.1 Partnerships

Partnerships such as the California Fuel Cell Partnership, made up of OEMs, energy companies, industrial suppliers, academia and government, have created important tools, communication pathways and served to build relationships between OEMs and fuel suppliers specific to hydrogen and fuel cell implementation efforts. Memoranda of Understanding (MOUs) like "H2 Mobility" in Germany for example are also being explored as a useful way to bridge the uncertainty regarding fueling needs and vehicle rollout plans. These MOUs between partners such as auto manufacturers, energy companies and local governments can formalize vehicle/infrastructure strategies and or goals surrounding vehicle volumes, timing, location and necessary fueling capacity. MOUs in Germany and Japan between major energy companies and OEMs will help define the business case for hydrogen stations and prepare for vehicle introductions.

4.3.4.2 Government Funding

Federal, State and local co-funding for both vehicle incentives and infrastructure costs will likely be necessary for some years as a way of sharing risk with early adopters of FCEVs. For example, in California, Assembly Bill 118 (2008) added a vehicle registration fee to motorists to generate a fund for alternative fuel investments to help reach energy, GHG and air quality goals. An annual investment plan is developed and serves as a guidance document for the allocation of funding. Funding from this program has been made available for many alternative fuels, including hydrogen infrastructure.[82]

Table 4.3-4 Scenarios of Government Support for Hydrogen Fuel Cell Vehicles and Infrastructure: Three Policy Cases*



Policy Case	Time Period	Vehicle Policies		Fueling Infrastructure Policies	
		Fuel Cell Vehicle Cost Sharing	Fuel Cell Vehicle Tax Credits	Station Cost Sharing (for Distributed Hydrogen Production)	Hydrogen Fuel Subsidy (Production Tax Credit)
Case 1	2012 - 2017	50% of incremental FCV costs	None	$1.3 Million/Station	$0.50/kg
	2018 - 2021	50% of incremental FCV costs	None	$0.7 Million/Station	Decreases linearly From 2018 to $0.30/kg in 2025
	2022 - 2025	50% of incremental FCV costs	None	$0.3 Million/Station	$0.30/kg in 2025
Case 2	2012 - 2017	50% of total FCV costs	None	$1.3 Million/Station	$0.50/kg
	2018 - 2021	None	100% of incremental cost	$0.7 Million/Station	Decreases linearly From 2018 to $0.30/kg in 2025
	2022 - 2025	None	100% of incremental cost	$0.3 Million/Station	$0.30/kg in 2025
Case 3	2012 - 2017	50% of total FCV costs	None	$1.3 Million/Station	$0.50/kg
	2018 - 2021	None	100% of incremental cost plus $2,000/vehicle	$0.7 Million/Station	Decreases linearly From 2018 to $0.30/kg in 2025
	2022 - 2025	None	100% of incremental cost plus $2,000/vehicle	$0.3 Million/Station	$0.30/kg in 2025

* This table is for illustrative purposes only and does not necessarily reflect a recommendation that specific policies should be adopted at this time.

4.3.4.3 Regulatory Incentives and Requirements

Short of the government support for development of new hydrogen stations to kick start the market sufficiently so that station volumes grow on their own, other policies or requirements may be necessary as shown in the three scenario table above.[83] California is exploring a variety of approaches including both regulatory incentives and possible requirements for installation of stations to ensure that enough stations are available to market FCEVs successfully.

California's Low Carbon Fuel Standard: Adopted in 2009, the Low Carbon Fuel Standard (LCFS) requires producers and importers of gasoline to ensure that the mix of fuel they sell into the California market meets, on average, a declining standard for GHG emissions. The standard is measured on a lifecycle basis in order to include all emissions from fuel consumption and production, including the "upstream" emissions that are major contributors to the global warming impact of transportation fuels. Because hydrogen has a very low well to wheel carbon content, some regulatory incentive exists for energy companies to provide hydrogen as part of their compliance strategy.

Clean Fuels Outlet: In the 1990s when it was thought that California's Low Emission Vehicle regulation would need alternative fuel vehicles to meet the strict fleet average tailpipe standards, CARB adopted the Clean Fuels Outlet regulation that would require the installation of an alternative fuel pump if a specified number of alternative fuel vehicles needing that fuel were marketed in California. This was California's approach to ensuring alternative fuel would be available when vehicles came to market. The thresholds that would trigger this program have not yet been reached. The program is currently being reviewed in the context of how it might be used to ensure sufficient hydrogen fueling stations.

4.4 Conclusions

The combined understanding of home recharging, electric vehicle charging system costs, and ongoing work to develop voluntary standards indicate that infrastructure to support electric-drive vehicles will be adequate to support EV/PHEV rollout in the near term. For areas where relative inexperience implies uncertainties—such as the need for and use of public infrastructure, and vehicle battery secondary uses—DOE activities have been designed and are underway to inform future decisions: Infrastructure deployment projects are underway and over the next 3-4 years will establish regional public charging networks and collect data on how and when consumers use them to clarify the future role of public charging in the U.S. In addition to confronting these technology challenges, DOE will continue to support a communication and information campaign at the local, national, and international levels. At the local level, DOE will continue to share information and best practice examples to ensure that cities and local planning organizations receive the best methods for facilitating vehicle electrification and the infrastructure to support it. At the national and international levels, DOE will continue to coordinate government activities to ensure that national and international voluntary standards for electric vehicles and support infrastructure work for U.S. auto manufacturers, utilities, and consumers.

Regarding hydrogen, the considerable learnings brought about by DOE and other programs, and the leadership, partnerships and funding commitment of California have enabled pre-commercial hydrogen infrastructure to be built today. OEMs are sharing FCEV rollout strategies with government leaders so public resources can be paired with private sector investment. A number of automobile manufacturers have stated publicly that initial, early commercial production of FCEVs could begin as early as 2015 if infrastructure is ready. A general understanding has been achieved regarding how to create hydrogen station networks using clusters in specific first markets. Government policies including regulations and incentives are being developed to support and help guide the progress and help ensure success.

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5 Incentives and Flexibilities

This Chapter includes three sections. Chapter 5.1 provides an overview of the regulatory flexibilities and incentives contained in the MYs 2012-2016 final rule for the National Program. Chapter 5.2 includes a discussion of the potential regulatory flexibilities and incentives for MYs 2017 and later which the agencies received input on during our meetings with stakeholders. Chapter 5.3 contains a summary of the non-regulatory incentives which the agencies received input on during our meetings with stakeholders. We note that some of the flexibilities discussed in this Chapter were used in our analysis of future scenarios in Chapter 6, though not all. As a result, when EPA and NHTSA undertake analysis for the upcoming federal rulemaking, we would not project additional per-vehicle cost reduction potential attributable to the flexibilities that have already been used to the current analysis. Chapter 6 contains a detailed discussion of the flexibilities we considered in the analytical assessment.

5.1 Overview of Existing Incentives and Flexibilities in the MYs 2012-2016 Program

EPA's and NHTSA's programs for MYs 2012 – 2016 provide compliance flexibilities to manufacturers, some indefinitely (such as those required by statute), and some that are designed, pursuant to agency discretion, to ease the transition during the early years of the National Program to increasingly stringent regulations. These flexibilities are intended to help provide sufficient lead time for most manufacturers to make necessary technological improvements and reduce the overall cost of the program, without compromising overall environmental and fuel economy objectives.

Under the CAFE program, Congress required through EPCA and EISA that NHTSA provide three specific types of compliance flexibilities – credits earned for over-compliance with a given standard, credits available due to production of alternative fuel vehicles, and the option of paying civil penalties in lieu of compliance.[KK] For the CAFE program, 49 U.S.C. 32903 allows manufacturers to earn credits (denominated in tenths of a mpg) if their fleet average fuel economy for either passenger cars or light trucks exceeds an applicable CAFE standard. Credits may be applied to compliance with a standard in any of the 3 consecutive model years immediately before the model year in which the credits were earned (referred to as "carry-back"), or in any of the 5 model years immediately after the credits were earned (referred to as "carry-forward"). Credits may also be transferred by a manufacturer from one of their fleets to another, or traded (sold) to other manufacturers. Credits may not, however, be used to comply with the domestic minimum passenger car standard, and transferred credits are subject to a statutory cap, preventing manufacturers from increasing a fleet CAFE level by more than 1-2 mpg with transferred credits, depending on the model year. For purposes of the MYs 2012-2016 GHG standards, EPA adopted similar averaging, banking, and trading

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[KK] We note that small volume manufacturers (*i.e.*, those that produce less than 10,000 vehicles for sale worldwide) may also petition NHTSA for an exemption from the generally-applicable CAFE standards and potentially obtain their own individual fuel economy standards under 49 U.S.C. 32902(d), but NHTSA does not consider this a generally-available compliance flexibility like the others listed above, given the production volume limit.

provisions allowing manufacturers to bank over-compliance credits, transfer the credits between their passenger car and light truck fleets, and trade them to other manufacturers. EPA, did not include the EISA cap on transfers – thus, for purposes of GHG compliance, manufacturers may transfer credits infinitely between their passenger car and light truck fleets.

EPCA has also long contained manufacturing incentives for alternative fuel automobiles. "Dedicated" (*i.e.*, "pure") alternative fuel vehicles and "dual-fueled" (*i.e.*, "flexible-fuel" or "flex-fuel") alternative fuel vehicles both receive special calculations to boost their fuel economy levels for compliance purposes under 49 U.S.C. 32905 and 32906. In EISA, Congress provided for a phase-out of the alt-fuel credit, so that while manufacturers can raise their CAFE levels up to 1.2 mpg using the alt-fuel credit through model year 2014, the amount of possible increase due to the credit decreases by 0.2 mpg each year until it phases out entirely after MY 2019. For purposes of the MYs 2012-2016 GHG standards, EPA will allow FFV credits in line with CAFE program limits, but only during the period from MYs 2012 to 2015. In MY 2016 and later, EPA will allow manufacturers to incorporate the emissions performance on alternative fuels by basing the FFV's compliance value on test values for both gasoline and the alternative fuel, weighted according to data provided by manufacturers demonstrating that the alternative fuel is actually being used by FFVs in-use.

The final compliance flexibility mandated by statute for the CAFE program, at 49 U.S.C. 32912, is the option of paying civil penalties in lieu of compliance with an applicable CAFE standard in a given model year. Some manufacturers face unique compliance challenges because they serve relatively small market segments that tend to value vehicle performance and utility much more highly than fuel economy. For these manufacturers, fuel-saving technologies (such as, *e.g.*, turbochargers), even when applied, are often used to increase performance or utility rather than to increase fuel economy. Some of these manufacturers have relied on this flexibility in past and recent model years, and for CAFE purposes, some manufacturers may continue to do so in the future. The CAA does not have a similar civil penalty flexibility – manufacturers who do not comply with applicable standards may not certify their vehicles for sale in the U.S.

For CAFE purposes, EPCA and EISA are fairly prescriptive with regard to what compliance flexibilities may be offered, but for GHG purposes, the CAA gives EPA broader authority to craft compliance flexibilities through regulation. The following paragraphs detail the flexibilities developed by EPA for the MYs 2012-2016 GHG program, in addition to the averaging, banking, and trading provisions and FFV credits noted above.

EPA Air Conditioning System Credits: Air conditioning (A/C) systems contribute to GHG emissions in two ways. First, hydrofluorocarbon (HFC) refrigerants, which are powerful GHGs, can leak from the A/C system (direct A/C emissions). Second, operation of the A/C system also places an additional load on the engine, which results in additional CO_2 tailpipe emissions (indirect A/C related emissions). EPA allows manufacturers to generate credits by reducing either or both types of GHG emissions related to A/C systems.

EPA Temporary Lead-time Allowance Alternative Standards (TLAAS): Manufacturers with limited product lines may be especially challenged in the early years of the National

Program, and need additional lead time. Manufacturers with narrow product offerings may not be able to take full advantage of averaging or other program flexibilities due to the limited scope of the types of vehicles they sell. For example, some smaller volume manufacturer fleets consist entirely of vehicles with very high baseline CO_2 emissions. Their vehicles are above the CO_2 emissions target for that vehicle footprint, but do not have other types of vehicles in their production mix with which to average. Often, these manufacturers pay fines under the CAFE program rather than meet the applicable CAFE standard. EPA believes that these technological circumstances call for more lead time in the form of a more gradual phase-in of standards. For these reasons, EPA included a temporary lead-time allowance for manufacturers that sell vehicles in the U.S. in MY 2009 and for which U.S. vehicle sales in that model year are below 400,000 vehicles. This allowance will be available only during the MY 2012-2015 phase-in years of the program. A manufacturer that satisfies the threshold criteria will be able to treat a limited number of vehicles as a separate averaging fleet, which will be subject to a less stringent GHG standard.[LL] Specifically, a standard of 25 percent above the vehicle's otherwise applicable footprint target level will apply to up to 100,000 vehicles total, spread over the four year period of MY 2012 through 2015. In addition, manufacturers with between 5,000 and 50,000 U.S. vehicle sales in MY 2009 will have an increased allotment of vehicles, a total of 250,000, compared to 100,000 vehicles (for other TLAAS-eligible manufacturers). In addition, the TLAAS program for these manufacturers would be extended by one year, through MY 2016, for a total of five years of eligibility. For the smallest volume manufacturers, those with below 5,000 U.S. vehicle sales, EPA did not set standards but instead deferred standards until a future rulemaking.

EPA Early Credits: EPA established opportunities for early credits in MYs 2009-2011 through over-compliance with a baseline standard. The baseline standard is set to be equivalent, on a national level, to the California standards. Credits can be generated by over-compliance with this baseline in one of two ways – over-compliance by the fleet of vehicles sold in California and the CAA section 177 states (*i.e.*, those states adopting the California program), or over-compliance with the fleet of vehicles sold in the 50 states. EPA is also providing for early credits based on over-compliance with CAFE, but only for vehicles sold in states outside of California and the CAA section 177 states. Under the early credit provisions, no early FFV credits are allowed, except those achieved by over-compliance with the California program based on California's provisions that manufacturers demonstrate actual use of the alternative fuel. EPA's early credits provisions are designed to ensure that there would be no double counting of early credits. Credits for over-compliance with CAFE standards during MYs 2009-2011 will still be available to be carried forward for manufacturers to use toward compliance with CAFE in future model years, just as before.

EPA Advanced Technology Incentive: EPA provides an additional temporary incentive to encourage the commercialization of advanced GHG/fuel economy control technologies--including electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell

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[LL] EPCA does not permit such an allowance. Consequently, manufacturers who may be able to take advantage of a lead-time allowance under the GHG standards would be required to comply with the applicable CAFE standard or be subject to penalties for non-compliance, unless they qualified for an exemption/alternative CAFE standard under 49 U.S.C. 32902(d).

vehicles (FCVs)--for model years 2012-2016. The advanced technology vehicle incentive program includes a zero gram/mile emissions compliance value for EVs and FCVs, and the electric portion of PHEVs, for up to the first 200,000 EV/PHEV/FCV vehicles produced by a given manufacturer during MY 2012-2016 (for a manufacturer that produces less than 25,000 EVs, PHEVs, and FCVs in MY 2012), or for up to the first 300,000 EV/PHEV/FCV vehicles produced during MY 2012-2016 (for a manufacturer that produces 25,000 or more EVs, PHEVs, and FCVs in MY 2012). For any production of EV/PHEV/FCV vehicles greater than this amount, the compliance value for the vehicle will be greater than zero gram/mile, set at a level that reflects the vehicle's net increase in upstream GHG emissions in comparison to the gasoline vehicle it replaces.[MM] The Final Rule notes: "EPA will reassess the issue of how to address EVs, PHEVs, and FCVs in rulemakings for model year 2017 and beyond, based on the status of advanced technology vehicle commercialization, the status of upstream GHG emissions control programs, and other relevant factors." [84]

EPA Off-cycle Credits: EPA is also providing an option for manufacturers to generate credits for employing new and innovative technologies that achieve GHG reductions that are not reflected on current test procedures. Examples of such potential "off-cycle" technologies might include solar panels on hybrids, adaptive cruise control, and active aerodynamics, among other technologies. This optional credit opportunity is currently available through the 2016 model year. Credits must be based on real additional reductions of CO_2 emissions and must be quantifiable and verifiable with a repeatable methodology.

5.2 Potential Credit Programs, Incentives, and Other Flexibilities for 2017 and Later

During the agencies' outreach with stakeholders, manufacturers provided early input that several of the flexibility provisions in place for MYs 2012-2016 should be retained for MY 2017 and later. Environmental groups also provided early input, as discussed below. As EPA and NHTSA develop the proposed rule for MY 2017 and beyond standards, the agencies will continue to consider the potential need for incentives and flexibilities in the 2017 and later program, including whether and how some of EPA's MYs 2012-2016 provisions could be applied to the new program, as well as whether any additional provisions would be appropriate to address lead-time issues. Changes to flexibilities provided under EPCA/EISA would require new legislation; NHTSA intends to develop any proposed standards within the context of its statutory framework.

Most manufacturers support EPA continuing 3-year credit carry-back to cover prior debits, 5-year credit carry-forward for use in future years, credit transfers between car and truck categories, and credit trading between manufacturers. One manufacturer noted support for unlimited credit carry-forward. These provisions, collectively known as Averaging, Banking, and Trading (ABT), have been an important part of many mobile source programs under CAA Title II, both for fuels programs as well as for engine and vehicle programs. EPA believes, and manufacturers have confirmed, that ABT is important because it can help to address many issues of technological feasibility and lead-time, as well as considerations of

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[MM] See 75 FR 25436-25437.

cost.[NN] EPA will strongly consider proposing to continue these provisions in the MY 2017 and later program, as these types of compliance flexibilities will remain important as standards become more stringent. As discussed above in Section 5.1, these provisions are required by EPCA and EISA for the CAFE program.

While not a flexibility in the same sense as other credit programs and incentives discussed in this chapter, several manufacturers supported the continued use of attribute-based standards using the vehicle's footprint for setting GHG standards, consistent with EISA's requirement that CAFE standards be attribute-based. A number of manufacturers also supported the use of separate passenger car and light-truck standards for the GHG standards, consistent with EISA's requirement that CAFE standards for cars and trucks be separate, though one manufacturer indicated a single combined passenger car and truck standard (though still attribute-based) should be considered.

Several smaller volume manufacturers have expressed continued concerns regarding lead-time, and support for additional flexibility to address the unique needs of small volume manufacturers such as the TLAAS program described above. In the MYs 2012-2016 Final Rule, EPA determined that smaller volume manufacturers needed additional lead time to meet the standards because their CO_2 baselines are significantly higher and their vehicle product lines are limited, reducing their ability to average across their fleets compared to larger manufacturers. The need for this type of flexibility is tied closely to the level of stringency of the standards to be proposed, and will be analyzed in that context.

EPA deferred small volume manufacturers (SVMs) with annual U.S. sales less than 5,000 vehicles from the MYs 2012-2016 standards. EPA plans to consider establishing standards for these very small volume manufacturers as part of the MYs 2017-2025 rulemaking. SVMs noted in discussions that SVMs only produce one or two vehicle types but must compete directly with brands that are part of large manufacturer groups that have far more resources available to them. There is often a time lag in the availability of technologies from suppliers between when the technology is supplied to large manufacturers and when it is available to small volume manufacturers. Also, incorporating new technologies into vehicle designs costs the same or more for small volume manufacturers, yet the costs are spread over significantly smaller volumes. Therefore, SVMs typically have longer model life cycles in order to recover their investments. SVMs further noted that despite constraints facing them, SVMs need to innovate in order to differentiate themselves in the market and often lead in incorporating technological innovations, particularly lightweight materials. Under the CAFE program, manufacturers who manufacture less than 10,000 passenger cars worldwide annually may petition for an exemption from generally-applicable CAFE standards, in which case NHTSA will determine what level of CAFE would be maximum feasible for that particular manufacturer if the agency determines that doing so is appropriate.[85]

[NN] NHTSA notes that it is statutorily prohibited from considering availability of credits (including the fuel economy credits for alternative fuel capability) in determining what levels of CAFE stringency would be maximum feasible for a given model year. 49 U.S.C. 32902(h).

Several manufacturers have also expressed support for the continuation of A/C system credits. EPA is strongly considering A/C credits for MYs 2017-2025. EPA has included A/C credits in the initial emissions modeling done to support this report, as described in Chapter 6 and Appendix D. EPA plans to further evaluate the methodology used to determine credits, including A/C-related test procedures.

Some manufacturers have also expressed support for the continuation of EPA's off-cycle credits program. The off-cycle credits for new and innovative technologies are currently available only through MY 2016. Manufacturers have noted that as long as the credits represent real-world off-cycle emissions reductions, the credits should be able to be generated beyond MY 2016. One manufacturer noted that company innovations do not end with MY 2016 and that technologies will always exist which do not show up on the test cycles. Also, credits give additional incentives for company investments in R&D and innovations. EPA understands this perspective and will evaluate the off-cycle credits provisions in the context of the MYs 2017-2025 program, including the potential need to update the technology eligibility criteria for determining whether a technology qualifies as new and innovative.

Some manufacturers encouraged EPA to continue to offer FFV credits. EPA finalized provisions in the MYs 2012-2016 Final Rule to treat MY 2016 and later FFVs similarly to conventional fueled vehicles, in that FFV emissions would be based on actual CO_2 results from emissions testing on the fuels on which it operates. In calculating the emissions performance of an FFV, manufacturers may base FFV emissions in part on vehicle emissions test results on the alternative fuel, if they can demonstrate that the alternative fuel is actually being used in the vehicles. Performance will otherwise be calculated assuming use only of conventional fuel. The manufacturer must establish the ratio of operation that is on the alternative fuel compared to the conventional fuel. The ratio will be used to weight the CO_2 emissions performance over the 2-cycle test on the two fuels. EPA will consider whether it is appropriate to retain this approach in the MYs 2017-2025 rulemaking. In addition, one manufacturer raised the concept of providing credits for CNG vehicles and vehicles operating on E-25 and other bio-fuels.

In the MYs 2012-2016 Final Rule, EPA established four pathways for manufacturers to earn early credits prior to MY 2012, and established baselines against which manufacturers can earn credits. For MY 2017 and later, we believe the credit carry-forward provisions are sufficient to provide manufacturers with credits for achieving reductions beyond those required by the MYs 2012-2016 standards. No additional baselines or other provisions would be needed if the credit carry-forward provisions remain in place.

For advanced technology vehicles, manufacturers support an advanced technology vehicle incentive in the form of a 0 g/mile compliance value for electric operation for MYs 2017 and later. Two manufacturers also expressed support for additional credits in the form of "bonus" credits or multipliers for advanced technology vehicles. EPA proposed a credit multiplier for MYs 2012-2016 advanced technology vehicles but did not finalize it for reasons described in the Final Rule.[86] Some environmental and public interest groups expressed concern that the 0 g/mi value does not adequately capture upstream emissions from the charging of electrified vehicles, and believe an upstream emissions factor should be included in the compliance calculation for electrified vehicles. For CAFE compliance purposes, the fuel economy of such vehicle models is determined consistent with petroleum equivalency factors (PEFs) issued by DOE.[87] Current EVs do not receive infinite fuel economy ratings that would be equivalent to a 0 g/mi CO_2 emission rate; for example, the MY 2008 Tesla Roadster received a fuel economy ratings of 248 mpg (equivalent to about 36 g/mi CO_2 based on gasoline). EPA understands that the treatment of upstream emissions for EVs, fuel cell vehicles, and the electric portion of PHEVs is a critical issue for the upcoming rulemaking, and this issue is further discussed in Chapter 7.

5.3 Input on Non-regulatory Incentives from Stakeholders

In addition to the regulatory incentives and flexibilities discussed in the previous section, the agencies recognize that there are many non-regulatory approaches that can promote the commercialization of low-GHG light-duty vehicle technologies. These approaches are outside the regulatory authority for NHTSA and EPA, but were raised in many of our stakeholder meetings (in particular the OEMs and the automotive supply firms) as potentially important drivers in the development and commercialization of advanced technology vehicles. This section will only identify and briefly discuss those non-regulatory strategies which were raised by stakeholders in our recent meetings. This is by no means a comprehensive list or discussion of the potential non-regulatory policies and incentives which could encourage low GHG/high fuel economy vehicles.

Federal research and development

The federal government performs automotive research and development (R and D) that is ultimately transferred to the private sector. Several of the OEMs identified this type of R and D support as an important the development of advanced vehicle technologies. The Department of Energy (DOE) is the federal lead on automotive R and D with extensive programs carried out at its national laboratories. DOE’s FY2010 budget for the Vehicles Technologies Program is $311 million, with major technology focuses on hybrid electric systems, advanced engines, lightweight materials, and fuels technologies. Other federal agencies have smaller programs, such as EPA which has a FY2010 budget of about $16 million. One major focus of EPA’s program has been hydraulic hybrids, which are currently being commercialized in heavy-duty vehicles. The Federal Transit Administration (FTA) of the Department of Transportation (DOT) has a number of ongoing research and development activities focusing on leading edge propulsion systems for buses designed to reduce operating costs and harmful emissions. These activities include studies and demonstrations on vehicles using plug-in hybrid electric, fuel cell, battery-dominant, and hydraulic hybrid technology.[88]

Federal financial assistance for private sector R and D and capital investment

Several of the OEMs and the automotive supply companies suggested that federal assistance for R and D programs, as well as for capital investment, can play an important role for the introduction of advanced technology vehicles. Historically, the federal government has periodically provided financial assistance for private sector R and D through favorable tax policies. More recently, the federal government has taken a much more proactive role in stimulating private sector investments in new technologies by providing grants and low-interest loans to automakers and suppliers for R and D and capital investment in breakthrough technologies with the potential to reduce fuel consumption and GHG emissions. For example, DOE has an Advanced Technology Vehicles Manufacturing Loan Program that has received appropriations of $7.5 billion for grants and loans to support the development of advanced technology vehicles and associated components in the United States.[89] The FTA has provided approximately $100 million and plans to award an additional $75 million in FY 2010 under the Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program.[90] Through this Program, public transit agencies partner and contract with private sector organizations, manufactures, system designers and integrators in acquiring and deploying new technologies and systems that reduce energy and greenhouse gases. Additionally, through the National Fuel Cell Bus Program (NFCBP), the FTA is leading a $50 million Federal effort with the support and leverage of an additional $50 million in local and private contributions for the innovative design and demonstration of fuel cell powered vehicles that have zero or near-zero emissions. The ultimate objective of the NFCBP is the commercialization of fuel cell buses. An additional $13.5 million has been appropriated under the Program in FY 2010.

Economic incentives for low-GHG vehicles

Some automakers told the agencies that the federal and state tax credits and grants played an important role in sparking the initial hybrid vehicle market, and could play an even more important role in promoting PHEVs and EVs in the future. Advanced technology vehicles often have higher up-front costs, due to more expensive components and/or lower production volumes, and any strategy that can reduce or offset the higher up-front cost to consumers can remove one of the most important barriers to greater consumer demand. The Energy Policy Act of 2005 established temporary federal income tax credits for buyers of new hybrid, diesel, dedicated alternative fuel, and fuel cell vehicles that meet certain requirements. For example, while available, consumers who purchased new hybrid vehicles received federal tax credits that ranged from a few hundred dollars to as much as approximately $3,000 for the Toyota Prius, the hybrid vehicle with the highest fuel economy. The federal hybrid vehicle tax credit has been phased out for many manufacturers who have exceeded the cumulative 60,000 production cap per manufacturer for hybrids and diesel vehicles. More recently, the American Recovery and Reinvestment Act of 2009 extended the tax credits to PHEVs and EVs, which are now eligible for a federal tax credit up to $7,500 per vehicle for the first 200,000 cumulative vehicle production per manufacturer.

Some states, such as California, have also adopted state grants for certain advanced technology vehicles. To date, both federal and state tax credits and grants for new vehicle purchases have been provided to consumers, but it is also possible for tax credits to be directed to manufacturers who sell advanced technology and/or low-GHG vehicles.

Another direct approach for reducing the up-front cost of advanced technology or low-GHG vehicles to consumers would be a state sales tax exemption for buyers of vehicles that meet certain requirements. Of course, without limitations such as cumulative production caps, federal tax credits and exemptions from state sales taxes could have important impacts on government revenues.

Non-economic incentives for owners of low-GHG vehicles

Some automakers have specifically indicated that high occupancy vehicle (HOV) access has been an important incentive for hybrid-electric vehicle owners, and could potentially be for EV and PHEV owners as well. By providing two important incentives—reduced travel time and improved trip time reliability—HOV lane access can be a big incentive in some urban areas. The Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU) of 2005 allows an exemption from the HOV occupancy requirement for vehicles certified as "low emission and energy-efficient." Some state and local governments have allowed drivers of certain advanced technology vehicles to use HOV lanes regardless of the number of vehicle occupants. Analyses have suggested that HOV access has been an effective incentive in promoting hybrid vehicle sales in certain urban areas.[OO]

Economic incentives for electric vehicle recharging systems/installation

One way to promote grid electricity use in EVs and PHEVs would be financial support for vehicle recharging infrastructure. The American Reinvestment and Recovery Act provides for a 50% tax credit on the installation of home charging equipment, up to a maximum cost of $2,000, and on installation of commercial equipment up to a maximum cost of $50,000. This tax credit expires at the end of 2010. Current home recharging systems cost on the order of $2000 or so. These costs are expected to drop as charging systems become more widespread and in higher volumes, as discussed further in Chapter 4. Public high-voltage quick charging systems cost much more. Federal grants and/or tax credits to reduce this cost would address another barrier to consumer demand. Many automakers have also raised the practical challenges involved in the permitting process for charging stations. Federal coordination to establish streamlined standards and codes for permitting processes could assist in EV and PHEV commercialization.[PP] Several of the OEMs and automotive suppliers suggested that these types of financial incentives for electric vehicle recharging systems can play an important role in encouraging the purchase of PHEVs and EVs.

Tax incentives or disincentives

There are a number of tax incentives and disincentives that could be considered as part of an overall strategy to promote low-GHG light-duty vehicle technology, such as higher gasoline taxes (which would improve the relative economics of other fuels), a gasoline price floor (which would preclude the risk of extremely low gasoline prices undercutting other vehicle fuels), and reduced or zero alternative fuel taxes (for example, electricity currently pays no excise/road tax, and there is uncertainty about whether this would be maintained if and when EVs and PHEVS gain greater market share). A few of the OEMs suggested that higher fuel taxes could be used to encourage the purchase of high fuel economy/low GHG vehicles.

[OO] See, for example, "Impact of High Occupancy Vehicle (HOV) Lane Incentives for Hybrid Vehicles in Virginia," David Diamond, LMI Research Institute, in Journal of Public Transportation, Vol. 11, No. 4, 2008, pages 39-58. Accessed at http://www.nctr.usf.edu/jpt/pdf/JPT11-4Diamond.pdf.

[PP] See discussion in Chapter 4.

Vehicle Labeling

Several stakeholders have emphasized the need for the federal government to educate consumers about the energy and environmental performance of vehicles in general and advanced technology vehicles in particular. On August 30, 2010, EPA and NHTSA jointly announced proposed changes to the current fuel economy label for MY 2012 and beyond that will provide new information (such as tailpipe CO_2 emissions) that will help consumers make more informed purchase decisions.[91] Among other changes, the joint proposal includes several potential new label designs for PHEVs and EVs.

Chapter 5 References

[84] 75 Fed. Reg. 25435, 25341 (May 7, 2010).

[85] 49 U.S.C. 32902(d).

[86] 75 Fed. Reg. 25434, (May 7, 2010).

[87] 65 Fed. Reg. 36986-36992 (June 12, 2000). *See also* 49 U.S.C. 32904(a).

[88] *See*, *e.g.*, http://www.fta.dot.gov/documents/HydrogenandFuelCellTransitBusEvaluations42781-1.pdf.

[89] http://www.atvmloan.energy.gov/

[90] *See* http://www.fta.dot.gov/planning/planning_environment_11424.html for more information on FTA's TIGGER Program.

[91] Revisions and Additions to Motor Vehicle Fuel Economy Label, Proposed Rule, http://www.epa.gov/fueleconomy/regulations.htm#sticker.

6 Analysis of Scenario Costs and Impacts

6.1 Context

The President's May 21 memorandum indicates that today's technical assessment should inform the rulemaking process, and that the subsequent (to the technical assessment) Notice of Intent (NOI) to Issue a Proposed Rule should describe, among other things, potential standards that could practicably be implemented for the 2017-2025 model years.

For today's technical assessment, the agencies conducted an initial fleet-level analysis of improvements in overall average GHG emissions and fuel economy levels. We have analyzed a range of potential stringencies for model years 2020 and 2025 (i.e., progressively lower GHG targets). We have also analyzed more than one illustrative technological pathway by which these GHG targets could be met. We considered these different technology pathways in order to address the difficulties in forecasting a single pathway and a single cost estimate for the penetration of different advanced technologies into the light-duty vehicle fleet at this time. We also believe this approach reflects the diversity in strategies we heard from the OEMs during the stakeholder outreach meetings, who at this time indicated they are each pursuing a range of technologies which they may use in the 2017-2025 time frame. The agencies believe that the analyses presented in this technical assessment permit a reasonable initial and approximate evaluation of the relative potential costs and effects of the aggregate stringency levels evaluated in this report.

This analyses began with methods and information developed and applied in support of the recently-promulgated GHG standards for the 2012-2016 model years, and also reflect updates to the forecast of the future light vehicle fleet, as well as updates to the range and characteristics of anticipated GHG and fuel-saving technologies (as discussed in Chapter 3).

However, we note, as discussed further below, that several of the simplifications employed here would not be used for purposes of a full Federal rulemaking analysis. This includes the requirements for both EPA and NHTSA to promulgate standards which meet each agency's statutory requirements. The agencies have therefore provided a number of caveats to today's analysis, discussed at greater length below.

6.2 Analytic Approach

This report presents modeling results that provide the technical basis for the analysis provided by EPA, NHTSA, and CARB in this chapter. The modeling was performed by EPA using the OMEGA model, which EPA utilized in the MYs 2012-2016 light-duty vehicle rulemaking. The key inputs for the analysis (e.g., the technology costs and effectiveness) are a result of the joint technical assessment of EPA, CARB, and NHTSA, as described in Chapter 3 of this report.

OMEGA is EPA's vehicle greenhouse gas cost and compliance model, and it can be used to simulate how manufacturers might respond to a specified vehicle CO_2 emission standard. Broadly, the model starts with a description of the future vehicle fleet, including different vehicle platforms,[QQ] sales, base CO_2 emissions, attributes such as vehicle mass and the extent to which CO2 reducing/fuel saving technologies are already utilized.

For the purpose of this analysis, over 60 vehicle platforms were used to capture the anticipated important differences in vehicle and powertrain design and utility between now and model year 2025. The model is then provided with a list of technologies which are applicable to various types of vehicles, along with their cost and effectiveness and the percentage of vehicle sales which can receive each technology during the time frame of interest. The model combines this information with economic parameters, such as fuel prices and a discount rate, to project how technologies could be added to vehicles in order to meet various levels of GHG control. The result is a description of which technologies could be added to each vehicle platform, along with the resulting cost, in order to meet a specified GHG performance level.[RR] We note that for purposes of this Technical Assessment Report, NHTSA did not perform modeling using the CAFE model, also referred to as the Volpe model[SS], to help analyze potential fuel economy standards as NHTSA has in recent CAFE rulemakings. The Volpe model simulates how manufacturers might respond to potential fuel economy standards on a yearly basis and supports analysis of fuel economy improving technologies, economic effects, environmental effects and safety effects. For today's technical assessment, the agencies decided to use the OMEGA model. In upcoming joint rulemaking, NHTSA and EPA plan to make use of the CAFE and OMEGA models, respectively, for purposes of examining potential future CAFE standards and GHG emissions standards.

As discussed above, for this technical assessment, the vehicle fleet was analyzed as one single industry wide fleet, irrespective of individual manufacturer differences. The size and composition of the fleet is otherwise equivalent to our projection of the entire fleet through model year 2025.[92] Treating the entire fleet as a single fleet assumes, for example, averaging GHG performance across all vehicle platforms is possible irrespective of who the individual manufacturer is for a particular vehicle platform. This can be thought of as analyzing the fleet as if there was a single large manufacturer, instead of multiple individual manufacturers. Alternatively, it is equivalent to an assessment that assumes there are no statutory limits on the ability to transfer credits between passenger car and light truck fleets (which is the case under the CAA, but not under EISA), there are no market limits on the ability to trade them between manufacturers, and that all manufacturers fully utilize such flexibilities and experience no transaction costs in doing so.

[QQ] Vehicle platforms represent aggregations of similar vehicle models built by a manufacturer – for example, the Dodge Caliber, Jeep Compass and Jeep Patriot are built from a single platform, and include a mix of passenger cars and light trucks.

[RR] A description of OMEGA's specific methodologies and algorithms, as well as a copy of the peer review documentation, is on the EPA website at http://www.epa.gov/oms/climate/models.htm.

[SS] DOT's CAFE Compliance and Effects Modeling System (commonly referred to as "the Volpe model") is available at http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/CAFE+Compliance+and+Effects+Modeling+System:+The+Volpe+Model, which also provides model documentation, source code, inputs and outputs from NHTSA's MY 2012-2016 rulemaking analysis, and links to prior versions and analyses.

This approach allows evaluation of multiple scenarios in the context of a long-term technology-driven assessment. It focuses the analysis on the technology itself, independent of the individual manufacturer, and produces a result that indicates how the fleet could hypothetically achieve greater GHG reductions and increased fuel economy in the most efficient manner. This approach also allows the assessment for this report to be performed without consideration of the particular shapes of the passenger car and light truck attribute-based curves, which are required by statute for CAFE purposes and will define the future federal standards. The unlimited averaging that is modeled may reach the same result irrespective of any specific attribute curves, and as long as the curves are calibrated to the flat standard that is modeled here (without prejudging the outcome of those curves, which will be carefully evaluated as part of the federal rulemaking process), the same fleet average may be required.

We note that while the single fleet analysis approach simplifies some aspects of the analysis and does offer some advantages, there are also important limitations which will be addressed during the formal rulemaking process. Some of these limitations are statutory – the requirements for CAFE under EPCA and EISA are more prescriptive than for GHG standards under the CAA. Some of these limitations are more informational in nature – for example, a simplified analysis leaves the agencies unable to consider certain information about the potential effects of standards that the public (and particularly, the regulated manufacturers) are accustomed to seeing in NHTSA and EPA analyses. The agencies recognize and emphasize again that today's analysis, while reasonable at this early stage in developing a National Program for post-MY2016 standards, is a first step, and that much more work will need to be completed for the upcoming NPRM, including full modeling by both EPA and NHTSA that will address each of the limitations, as discussed further below. As with the MYs 2012-2016 final rule, the agencies' analyses for the NPRM will examine attribute-based standards under which each manufacturer is subject to its own individual passenger car and light truck CAFE and CO_2 requirements, where the standard for each manufacturer is based on the production-weighted average of its passenger car and light truck targets, with the targets established in the attribute-based curves. In the upcoming rulemaking both EPA and NHTSA will also consider more than the overall industry-wide perspective provided in this Report, and intend to analyze potential future CAFE and GHG standards in a manner similar to that done for the MYs 2012-2016 rulemaking. For further information on the kinds of comprehensive analyses performed for the MYs 2012-2016 rulemaking, *see* 75 Fed. Reg. 25324 (May 7, 2010).

EPCA as amended by EISA requires separate attribute-based CAFE standards for passenger cars and light trucks, for each model year, that are the maximum feasible standards for that fleet of vehicles in that model year.[TT] Today's analysis combines the passenger car and light truck fleets, considers flat standards, and considers only a single model year out of the nine model years that will be covered by the rulemaking.

[TT] 49 U.S.C. 32902.

EPCA as amended by EISA allows manufacturers to pay fines in lieu of compliance[UU] and subject to certain limitations allows manufacturers to earn, trade, and transfer credits (and also earn credits for production of alternative-fueled vehicles in addition to simple over-compliance with applicable standards),[VV] but does not allow the availability of credits to be considered in determining what standards would be maximum feasible.[WW] Today's analysis combines the passenger cars and light trucks of all manufacturers into a single fleet, which is equivalent to assuming fully efficient trading and transfer of credits but is not allowed under EPCA, and does not include the additional credit that manufacturers would get under EPCA and EISA for alternative-fueled vehicles.

In determining what passenger car and light truck standards would be maximum feasible in each model year, EPCA as amended by EISA requires NHTSA to consider and balance four statutory factors: technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy. While the tables of information presented below concerning technology cost, effectiveness, and lead-time, fuel savings and GHG emissions avoided, and other things, would help to inform NHTSA's consideration of many of the statutory factors, this information alone may not be sufficient for purposes of a full rulemaking analysis. Other pieces of information have historically been used to decide what standards would be maximum feasible for each fleet for each model year, as discussed below.

By modeling a single fleet rather than separate fleets for different manufacturers, we show the most cost-effective hypothetical path for the industry, as a whole, to any specific overall average fuel economy level or GHG emission level. Differential impacts on individual manufacturers, based on the different standards applicable to them given the production-weighted average of their specific passenger car and light truck targets (with the targets established in attribute-based curves), are thus not reflected in the current analysis. In addition, in representing the market as a single fleet produced by a single manufacturer, today's analysis exhausts available technologies only when, given input assumptions regarding technology applicability and phase-in potential, no further technology can be applied to any vehicle model. In contrast, in past rulemakings when the fleet is represented in terms of discrete manufacturers' separate passenger car and light truck fleets, some manufacturers have been estimated to exhaust available technologies in some model years at stringencies well below those that would cause the aggregated manufacturer of a combined fleet to do so. This occurs because manufacturers produce different mixes of vehicles, with different levels of baseline technology utilization.

This is information that has historically been relevant to NHTSA's determinations of whether standards are economically practicable.[XX] Understanding and recognizing the

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[UU] 49 U.S.C. 32912.

[VV] 49 U.S.C. 32903, 32905, 32906.

[WW] 49 U.S.C. 32902(h).

[XX] For example, in its recent analysis of its final MY 2016 CAFE standards, NHTSA estimated that required CAFE levels for passenger cars would average 37.8 mpg, but would range from 34.2 mpg (for Jaguar) to 41.1 mpg (for Porsche). Additionally, that same analysis estimated that passenger car cost increases (relative to differential impact of standards on manufacturers is one of the issues with which NHTSA has grappled in determining maximum feasible standards. While the agency should not key its standards to the least capable manufacturer, the agency should be aware of the impacts in making its decision, since economic practicability is determined in part by the effects of the standards on vehicle manufacturers. The results presented in this report represent what the three agencies expect a hypothetical comprehensive-line vehicle manufacturer could achieve, given the assumptions made here regarding the composition of the fleet and the availability, cost, and effectiveness of various technologies. Note that the results presented here assume trading between auto firms, which has not occurred in the past and may not occur in the future. Among actual full-line vehicle manufacturers, we expect that a manufacturer-specific assessment based on footprint-attribute standard curves will result in costs which are higher and lower for the actual full-line manufacturers than a fleet-wide average due to the differences among their product offerings. With respect to smaller volume manufacturers and very low volume manufacturers (many of whom only produce high-performance luxury vehicles), the agencies would expect that, in general, the level of technology they would require and the costs they would incur would be higher than presented today, all other things being equal. Thus, in future analysis done for the joint federal rulemaking NHTSA and EPA would expect individual companies' projected costs will be higher or lower than the costs shown here, depending on their particular fleet mixes. The results of this more detailed analysis which will look at individual manufacturers could potentially change NHTSA's evaluation of what CAFE standards are maximum feasible.

In addition, today's analysis includes estimates of cost increases associated with the application of additional fuel-saving technology, as well as estimates of the corresponding reductions in fuel consumption and CO_2 emissions, but does not include estimates of the corresponding social benefits. In the rulemaking the agencies will consider a much broader ranges of impacts of the standards.[YY] Estimates of social benefits both reflect and inform NHTSA's consideration of the four statutory factors, and are often a subject of great interest among commenters to CAFE and GHG rules.

Finally, today's analysis does not include an evaluation of potential safety effects of new standards. NHTSA has historically considered safety effects along with the four statutory factors in determining appropriate levels of CAFE stringency, a practice recognized approvingly in case law over several decades. EPA also considered the potential safety effects of the 2012-2016 GHG standards in that recent rulemaking. Although today's analysis

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compliance with the MY 2011 standard) would average $907 in MY 2016, but would range from $126 for Toyota to $1,884 for Ford. NHTSA also found that, without using credits, instances of technology exhaustion among a number of manufacturers would increase rapidly as stringencies increase faster than 4% annually. The aggregated approach of today's analysis would have shown almost no technology exhaustion among the regulatory alternatives considered by NHTSA in the MY 2012-2016 final rule. *See, e.g.,* 75 Fed. Reg. at 25600 (May 7, 2010).

[YY] For example, NHTSA's and EPA's analysis supporting the MYs 2012-2016 final rule include estimates of social benefits associated with fuel costs (setting aside taxes), economic impacts of petroleum dependence, the social cost of carbon dioxide emissions (and criteria pollutant emissions), social costs (*e.g.*, additional highway congestion) and benefits (the value of additional travel) of additional travel demand induced by fuel economy increases, and other factors.

considers significantly greater levels of mass reduction than considered for the MYs 2012-2016 final rule, it does not yield estimates of the corresponding safety implications. As discussed in Chapter 3, NHTSA, EPA, and DOE have undertaken a number of important, new safety-focused analyses to inform the future joint Federal rulemaking. NHTSA and EPA will include a detailed assessment of safety impacts at that time.

Section 202(a) of the Clean Air Act, in contrast, provides broad discretion regarding how EPA can consider relevant factors in establishing GHG emissions standards for light-duty vehicles. For example, in setting GHG standards, section 202(a) of the CAA allows for the consideration of the availability of transferred or traded credits earned for over-compliance, the availability of credits for the use of advanced technologies and for A/C, and other credit-generation mechanisms. This broader discretion to reflect anticipated manufacturer behavior in response to available compliance flexibilities could allow standards established under the CAA to be more stringent than could be established under EPCA as amended by EISA, because the CAA allowed analysis would be able to show that more stringent standards could be feasible when those flexibilities are taken into account. However, as noted in several other locations in this report, there is significant additional information and analysis which EPA (and NHTSA) believe are necessary in order to support the future federal rulemaking, and EPA intends to develop a detailed analysis similar to that performed for the MY2012-2016 standard setting rulemaking, and to consider many of the same kinds of factors as it did in that rulemaking.

We emphasize again, however, that the upcoming rulemaking to develop the next phase of the National Program will be based on a full analysis that is consistent with both the statutory framework that provided under EPCA as amended by EISA, and the flexibilities that can be considered under the CAA, just as the detailed analysis for the MYs 2012-2016 was conducted. With these explanations and caveats, NHTSA and EPA believe today’s analysis provides a useful means of comparing the scenarios discussed below.

6.3 Development of Technology Pathways

The analysis for this Technical Assessment Report considers two model years – 2020 and 2025; four “technology pathways” – “A,” “B,” “C” and “D;” and four potential rates of increase in fleetwide average stringency – 3%/year, 4%/year, 5%/year, and 6%/year. This section of Chapter 6 discusses each of these elements, 6.4 describes other key inputs employed in the analysis, 6.5 presents the results of the analysis., and in 6.6 we present a sensitivity assessment related to battery cost estimates.

6.3.1 Model Years Considered

The analysis for this Technical Assessment Report considered two model years, 2020 and 2025. Vehicles are typically redesigned every 5 years on average, and tend to receive a more modest “refresh” between major redesigns. By assessing potential scenarios at a five-year increment, we base our assessment on an assumption of the efficient use of capital investments, engineering, financing, and other resources.[ZZ] This approach predicts that manufacturers therefore have the opportunity to redesign vehicles by 2020, and again by 2025.

6.3.2 Scenario Stringencies Assessed

For each model year and each technology pathway (described below) we analyzed four potential GHG targets representing a 3, 4, 5 and 6% decrease in GHG levels -- that is, starting with a 250 gram/mile overall average requirement in MY 2016, the g/mile CO_2 scenario fleet-wide target was lowered at the rates of 3% per year, 4% per year, 5% per year, and 6% per year.[AAA] The 3, 4, 5, and 6% annual stringency increases were chosen for evaluation because they represent a reasonably broad range of targets for this initial assessment and because the rates of increase are consistent with CARB's letter of commitment in response to the President's memorandum. The assessment for each scenario is characterized using four broad metrics: per-vehicle cost increase, vehicle technology mix, net reduction in GHG emissions, and net reduction in fuel consumption. [BBB]

The scenario stringencies are shown below in terms of the specific grams/mile CO2 values analyzed for MY 2020 and 2025, and like the 250 g/mile standard, include the potential usage of air conditioning emissions reductions (Table 6.3-1). Air conditioning emissions reduction in the 2025 time frame was estimated at 15 grams compared to a 2008 baseline system for all four technology paths.[CCC,93] The increase in estimated air conditioning reductions relative to those projected in the MYs 2012-2016 timeframe is largely due to an anticipated increase in the use of alternative refrigerants.[DDD] Note that EPA has not made any determination at this time whether reductions due to improvements in air conditioning should be treated as a credit or a requirement during the 2017-2025 timeframe.

[ZZ] The MYs 2012-2016 final rule discusses the 5-year vehicle redesign practice in much more detail; *see* 75 FR at 25445 and 25573.

[AAA] For this assessment these future targets were modeled as a flat, or universal, standard, rather than as attribute-based standards. Since the difference between attribute-based and flat standards is that flat standards apply the same requirement to every manufacturer in the fleet, while attribute-based standards allow different requirements depending on the vehicles that each manufacturer produces for sale, modeling the entire new vehicle fleet as if it were a single automotive firm causes flat standards and attribute-based standards to produce the same average required stringencies. For the upcoming joint federal rulemaking, NHTSA and EPA will propose attribute-based standards.

[BBB] Additional impacts from fuel economy/CO_2 standards such as co-pollutants, the social cost of carbon, or energy security premiums could be quantified. While this text does not discuss these topics, as discussed above, they are extensively discussed in the recent 2012-2016 final rule and will be discussed in the upcoming joint federal rulemaking.

[CCC] While the air conditioning reductions were modeled in this analysis, their relative cost-effectiveness suggests that manufacturers will use them to meet any standard. As the MYs 2012-2016 final rule allowed for a similar crediting program, all costs and benefits from the A/C system control are present in the reference case (MY 2016) as well. A more complete discussion of the potential reductions in leakage from air conditioning systems is presented in Appendix D to the Technical Assessment Report.

[DDD] In this analysis, EPA anticipates that prior to the MY 2020 timeframe, low GWP refrigerants will be approved under the Significant New Alternatives Policy Final Rule (1994). The use of low GWP refrigerants in this analysis does not indicate a decision on behalf of EPA.

Table 6.3-1: Modeled GHG Targets

Scenario Title	CO2 Target (g/mile) in MY 2020 (MPG)	CO2 Target (g/mile) in MY 2025 (MPG)
3% per year	221 (40)	190 (47)
4% per year	212 (42)	173 (51)
5% per year	204 (44)	158 (56)
6% per year	195 (46)	143 (62)

Note: The targets evaluated were CO2 targets which could be meet through reductions in CO2 as well as through air conditioning system hydroflurocarbon reductions converted to a CO2 equivalent value. MPGe is the equivalent MPG value if all of the CO2 reductions came from fuel economy improvement technologies. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Thus, the 3% to 6% range evaluated in this assessment for MY 2025 would span a range of real world fuel economy values of approximately 37 to 50 mpg, which correspond to the regulatory test procedure values of 47 and 62 mpg, respectively.

The reference case GHG emissions scenario assumes no further improvements in CO2 emissions from the 2016 final rule standards, which are projected to produce a fleet wide average of approximately 250 grams CO_2 per mile. This projected fleet wide average is assumed to remain in place indefinitely. We also assume that the fleet mix, including market segmentation, is unchanged between scenarios, though it does change over time from 2016 to 2025 as discussed in Appendix A. Additionally, we did not explicitly model any crediting schemes in this analysis, other than the air conditioning emission reductions which are a fundamental component of EPA's MYs 2012-2016 program, and the allowance of unlimited car-truck credit transfer and inter-manufacturer trading which result from combining individual manufacturers into a single industry-wide fleet.

6.3.3 Technology Pathways Considered

As discussed in the introduction to this Chapter, the use of distinct "technology pathways" illustrate that there are multiple mixes of advanced technologies which can achieve the range of GHG targets we analyzed. The approach of considering four technology pathways for this assessment was chosen for several reasons. First, in our stakeholder meetings with the auto manufactures, the companies described a range of technical strategies they were pursuing for potential implementation in the 2017-2025 time frame. For example, some firms are pursuing an HEV focused strategy and others a mass reduction and next generation gasoline/diesel engine focused strategy. Using multiple technology pathways allows the agencies to evaluate how different technical approaches could be used to meet progressively more stringent scenarios.

Second, this approach helps to generally capture the uncertainties we see with forecasting the potential penetration of and costs of different advanced technologies into the light-duty vehicle fleet ten to fifteen years into the future at this time. As discussed in Chapter 3, there is significant on-going technology development work occurring at the auto companies and in the broader automotive supply base on a large range of advanced technologies. The three agencies also have on-going technology cost, safety, and effectiveness work which has not been completed. Therefore we believed it is appropriate for this initial technology assessment to consider more than one technology pathway.

What are the four technology pathways?

- Pathway A is intended to portray a technology path focused on HEVs, with less reliance on advanced gasoline vehicles and mass reduction, relative to Pathways B and C.
- Pathway C represents an approach where the industry focuses most on advanced gasoline vehicles and mass reduction, and to a lesser extent on HEVs.
- Pathway B represents an approach where advanced gasoline vehicles and mass reduction are utilized at a more moderate level, higher than in Pathway A but less than Pathway C.
- Pathway D represents an approach focused on the use of PHEV, EV and HEV technology, and less reliance on advanced gasoline vehicles, mass reduction.

For MY 2025, as will be seen in the following section which presents the results of the assessment, as the CO2 stringency scenario increases progressively from 3% per year to 6% per year, the extent of electrification of the fleet (the combined penetration of HEVs, PHEVs, and EVs) increases for each of the three pathways. However, the degree of electrification is highest for Pathways A and D, and the least for Pathway C. This occurs because under pathway C, there is a higher degree of mass reduction and a higher penetration of advanced gasoline, which means that the penetration of HEV/PHEV/EVs needed to achieve the CO2 stringency is lower, as compared to Pathways A, B and D. This impact is seen clearly for the 4%, 5%, and 6% per year stringency scenarios. However, for the 3% per year scenario the distinction between Pathways B and C are very small, because the level of stringency is low enough that it requires only a modest level of mass reduction and advanced gasoline vehicle technology and the degree of electrification needed to meet the CO2 target (190 g/mile CO2 in MY 2025) for Pathways B and C is minimal. Pathway D has the highest level of EVs, and also high levels of HEVs, in particular when compared to Pathways B and C.

For MY 2020, in contrast, there is little distinction between the technology projected for the technology pathways A, B, and C for the 3%, 4%, and 5% per year scenarios, because the overall level of stringency for each of these scenarios in MY 2020 is modest, and the overall difference between the MY2020 emission target for 3%, 4%, and 5% per year is small compared to in MY 2025. For example, the 3% and 4% per year targets in MY 2025 are 17 g/mile CO_2 apart, but in MY 2020, the 4% per year target is only 9 g/mile more stringent than the 3% per year scenario (See Table 6.3-1 above). The combination of the less stringent targets in MY 2020 and the smaller delta between the emission targets results in only small differences between Pathways A, B, and C for the 3%, 4%, and 5% per year targets for MY2020. Only with the most stringent scenario analyzed for MY 2020, the 6% per year scenario, is there a significant difference in the technology penetrations between Pathways A, B and C for MY 2020. Note that due to time constraints we were not able to assess MY2020 for Pathway D.

All four of these pathways include significant amounts of mass reduction, relative to 2008 model year vehicles, ranging from 15 to 30% in 2025. The ability of the industry to reduce mass at the higher end of this range is an open technical issue which the agencies are carefully evaluating and will continue to as we move forward. In addition, as discussed in the joint 2012-2016 NHTSA and EPA final rule, the effects of vehicle mass reduction on safety should be analyzed from a societal fatality perspective, which could affect the maximum levels used for the future joint federal rulemaking. Although those effects have not been included in this Report, the two agencies will consider them for the future joint federal rulemaking. As discussed in Chapter 3, NHTSA, EPA, and DOE have a number of on-going projects in this area which will inform the future joint federal rulemaking.

The agencies note that these pathways, of course, are meant to represent ways that manufacturers *could* respond to eventual standards, and do not represent ways that they *must* respond to those standards. EPA's GHG standards and NHTSA's CAFE standards are performance-based and not technology mandating – manufacturers have wide discretion to apply the technologies that they choose in meeting the standards.

How are the different technology pathways implemented in the analysis?

In order to analyze four distinct technology pathways, we developed maximum technology penetration rates which we could implement within the OMEGA model. These maximum technology penetration rates are discussed in Chapter 3. These penetration rates were informed by the range of technology approaches we heard from different auto companies, and represent the three agencies' initial assessment of potential technology feasibility and lead time considerations for model year 2025.

A large number of technologies were considered by the agencies and are used in this analysis (see Chapter 3 for a detailed discussion of all the technologies considered). For the purposes of evaluating the four technical pathways, we assessed the impact of approaches which placed a different emphasis on broad technology classes. The broad technology classes evaluated for purposes of this analysis are defined below. For a more detailed discussion of any individual technology, please see Chapter 3 of this report:

- Conventional Spark Ignition (SI) - This technology category includes all technologies that are not contained in other categories such as gasoline direct injection engines, cylinder deactivation, six and eight speed automatic and dual clutch transmissions, and start-stop micro-hybrid technology.

- Advanced SI - This technology includes gasoline spark ignition engines which are currently under development by OEMs and suppliers and are not anticipated to be widely used in the 2012- 2016 time frame. For purposes of this analysis, based on the agencies expert judgment to define these advanced SI engines, we modeled a direct injection gasoline engine with cooled exhaust gas recirculation, and with a larger degree of engine downsizing and higher level of turbocharging as compared to the turbo-downsized engines included in our analysis for the MYs 2012-2016 final rule. This technology is discussed in detail in chapter 3, and is similar to the technologies that many OEMs indicated were underdevelopment and which they anticipate will be introduced into the market in the 2017-2025 time frame.

- Hybrid – While the agencies recognize there are many types of full-hybrids either in production or under development, for the purposes of this analysis we have specifically modeled two types of hybrids, P-2 and 2-Mode type hybrids.

- Plug-in Hybrid (PHEV) - This technology includes PHEV's with a range of 20 and 40 miles and is discussed in Chapter 3. As discussed in Appendix B, we project that PHEV technology is not available to some vehicle types, such as large pickup. While it is possible to electrify such vehicles, there are tradeoffs in terms of cost, electric range, and utility that would reduce the appeal of the vehicle to a narrower market.

- Electric Vehicle (EV) - This technology includes vehicles with actual on-road ranges of 75, 100, and 150 miles. The actual on-road range was calculated using a projected 30% gap between two-cycle and on-road range. These vehicles are powered solely by electricity and are not powered by any liquid fuels. As with PHEVs, and as discussed in Appendix B, we assumes that EV technology is not available to some vehicle types, such as large pickup. While it is possible to electrify such vehicles, there are tradeoffs in terms of cost, range, and utility that would reduce the appeal of the vehicle to a narrower market. These trade-offs are expected to reduce the market for other vehicle types as well, and for this analysis we have considered this in the development of the maximum technology penetration rates we use for the three pathways as discussed in Chapter 3. Note that for this assessment, we modeled EVs and did not consider fuel cell vehicles (FCVs). An assessment could be done considering FCVs in addition to EVs. However, such an assessment would need to carefully consider the availability of the necessary infrastructure to support FCV penetration.

- Mass Reduction - This technology includes material substitution, smart design, and mass reduction compounding. The actual amount of reduction from the 2008 baseline was determined based on CBI provided by vehicle manufacturers, assessments provided by material suppliers, and existing studies in the literature, including the 2010 report from Lotus Engineering. As discussed above as well as in Chapter 1 and Chapter 3, NHTSA and EPA intend to conduct a thorough assessment of the levels of mass reduction that could be achieved which is both technologically feasible and which can be implemented in a safe manner for the joint federal NPRM.

Chapter 6.4 discusses additional key inputs used in our technical assessment, and Chapter 6.5 presents the results of the assessment.

6.4 Other Key Inputs to the Analysis

In addition to the technology effectiveness and cost estimates detailed in Chapter 3, and the development of the four technology pathways discussed above, key inputs to today's analysis are summarized below, and are discussed in more detail in Appendix E.

Vehicle Sales – The vehicle sales projection is based upon output from the National Energy Modeling System (NEMS) which is maintained by the Department of Energy's Energy Information Administration. As in the MYs 2012-2016 Final Rule, the car and truck split was drawn from NEMS, while market segmentation was drawn from CSM Worldwide's forecasting tool. Total market size is estimated in 2025 at 17.0 million vehicles (58% cars). Cars, in the context of NEMS, are defined using the pre-MY 2011 CAFE definition. For this analysis the DOT Volpe Center produced a custom run of NEMS. This run generated the same overall vehicle sales as the Reference Case for the Energy Information Administration's Annual Energy Outlook (AEO) 2010,[94] but a different sales split between cars and light trucks. A detailed discussion on this topic is presented in Appendix A.

On-road Fuel Economy Shortfall – The "on-road gap" is the difference between the fuel economy experienced and the CO_2 emissions emitted in actual driving, as opposed to the higher fuel economy and lower emission level experienced on the specified emissions tests (the FTP and the HFET). The gap includes the real-world effects of wind, road grade, air conditioning usage, and a variety of other factors. As in the MYs 2012-2016 final rule, we assume a 20% gap from certification results, similar to today's vehicles for internal combustion engines, as determined in EPA's 2006 fuel economy labeling rulemaking.[95] Based on engineering judgment, the 2006 labeling rule analysis, and Confidential Business Information, we estimated a larger, 30% gap from test results for power consumed by electric motors in PHEVs and EVs in-use compared to the emissions test procedure.

Fuel Prices – The gasoline and electricity prices used in today's analysis are drawn from the Reference Case Scenario AEO 2010.[96] The gasoline fuel prices were $3.49 in 2025 including all taxes.[EEE] Electricity prices are projected at approximately $0.11 in 2025 and gradually increase beyond that point. Beyond 2035, fuel prices were extrapolated, and the details are discussed in Appendix E.

Vehicle Miles Traveled Assumptions, Survival rates– VMT schedules and survival rates are available in Appendix E. Expected lifetime VMT is approximately 207,000 miles for cars in the 2025 time frame and approximately 246,000 miles for trucks in the 2025 time frame. While long term trends for VMT growth are uncertain, these schedules reflect the same projection methodology used in the MYs 2012-2016 final rule.[97] As in the 2012-2016 final rule, these values derive from assumptions made in AEO 2010.

VMT Rebound - Chapter Four of the Joint Technical Support Document to the recent MYs 2012-2016 final rule surveys previous studies, summarizes recent work on the rebound effect, and explains the basis for the 10 percent rebound effect EPA and NHTSA are using in the current technical analysis.[98] The use of a 10 percent rebound effect in this analysis reflects an assumption that the rebound effect applicable to the MYs 2012-2016 vehicles will remain applicable throughout future time periods.[FFF] The agencies plan to conduct new analysis of the expected rebound effect in this time frame in a future rulemaking.

Upstream Emissions – The upstream emission factors for gasoline is the same as that used in the MYs 2012-2016 final rule (2,478 g CO_2eq / gallon).[99] For the present report, we rely

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[EEE] Note fuel taxes are included when models select technology options and when conducting payback analysis. However fuel taxes are not used for calculating social benefits.

[FFF] It should be noted, however, that CARB, when adopting its initial GHG standards for MYs 2009-2016, relied on a study that found that a rebound effect on the order of 3 percent was appropriate.

upon the electricity emission factors produced by the EPA Office of Atmospheric Programs for an analysis of the American Clean Energy and Security Act of 2009 (H.R. 2454).[100] This scenario assumes no new power sector regulations, but does assume construction of new plants to replace older retired plants. In 2025, it is assumed that electricity generation at the plant is equivalent to 558 g CO_2 eq/kwh. This value should be adjusted upwards for feedstock gathering, transmission losses, and losses while charging the vehicle. After adjustment, the 2025 electricity emission factor is approximately 703 g CO_2 eq for each kW-hour consumed from the battery pack.

Global Warming Potentials –The global warming potentials (GWP) used in this analysis are consistent with the MYs 2012-2016 final rule and with the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). These GWP values are 1430 for HFC, 298 for NO_2, and 25 for CH_4. [101] At this time, the 1996 IPCC Second Assessment Report (SAR) global warming potential values have been agreed upon as the official U.S. framework for addressing climate change and are used in the official U.S. greenhouse gas inventory submission to the United Nations climate change framework, which is consistent with the use of the SAR global warming potential values in current international agreements. There are slight differences between SAR and AR4 values, most notably a 10% increase in the value used for HFC.

6.5 Results of Analysis

This section presents the results from our modeling assessment of future stringency scenarios using the four technology pathways described in Chapter 6.3. The inputs are discussed in Chapter 3 of this technical report, and a detailed description of the analytic methodology is provided in Appendix F. In addition, all of the modeling input and output files used for the assessment are available on the web.[GGG]

This section presents the assessment results for model year 2020 and 2025. First, we present results at a “fleet-wide” level, that is at an aggregated level for the new model year fleet in 2025, for the four technology pathways we analyzed. The four technology pathways are discussed in detail in Chapter 6.3. Second, we present results at a car-fleet and truck-fleet level, in order to show the range of costs and impacts at a more detailed level. This is followed by the fleet-wide level results for the MY2020 assessment.

The following tables show summaries of per-vehicle increases in costs, as well as fleet wide reductions in fuel consumption and GHG emission reductions. The costs, fuel savings, and GHG emission reductions are calculated against the reference fleet of MY 2025 vehicles complying with the MY 2016 standards. The listed reductions in GHG emissions and fuel consumption are cumulative over the lifetime of the selected model years, and are the delta between the GHG emissions and fuel consumption under the MY 2016 reference case and the selected emission control/fuel economy scenario.

[GGG] The input files, modeling tool, and output files used for this Technical Assessment Report are available at http://www.epa.gov/oms/climate/models.htm

In the assessment of potential future ranges of stringency presented in this report, we based our compliance analysis on the tailpipe emissions from all vehicles – thus EVs were evaluated at a 0 gram/mile CO2 level and PHEVs were evaluated as 0 gram/mile for the electric drive portion of the vehicles operation. For the purposes of the GHG impacts, we have included the resultant increase in upstream CO2 from the use of PHEVs and EVs in our overall calculation of the net CO_2 reductions for each of the scenarios evaluated. As a result, a single stringency scenario may have a range of CO_2e impacts depending on the electrification of the fleet.

Based on our initial assessment in this report, we see that the conventional vehicle technologies are typically more cost effective than any of the other technology options, followed by advanced spark-ignition (SI) engines, hybrids, electric vehicles, and PHEVs (see Table 6.5-2 for example).[HHH] Mass reduction, which is generally highly cost effective, is often among the first technologies chosen. In our modeling assessment, vehicle technologies are applied in a ranked manner that values cost-effective reductions in fuel consumption and CO_2 emissions.

The cost of the MY 2025 scenarios for the entire new vehicle fleet ranges from $773 (3%, Path C) to $3,455 (6%, Path A) per vehicle, as shown in Table 6.5-1. Technology pathway C, which relies upon advanced gasoline technology and greater mass reduction as compared to Pathway A and B, demonstrates the lowest costs. Pathway A and B show a greater electrification of the fleet and somewhat higher costs.

The GHG reduction over the lifetime of the MY 2025 vehicles ranges from 343 million metric tons (MMT) CO_2e avoided in the 3% scenario to between 531MMT and 593 MMT CO_2e in the 6% scenario. The range in CO_2 emission reduction is due to differing degrees of fleet electrification under the technology pathways. MY 2025 vehicles, over the course of their lifetimes, will reduce between 0.7 billion barrels of gasoline consumption under the 3% scenario to 1.3 billion barrels under the 6% scenario. For reference, the NHTSA & EPA National Program in MY 2016 is projected to reduce 0.6 billion barrels of fuel and 325 MMT CO2e over the lifetime of MY 2016 vehicles.

Table 6.5-1: Assessment Projections for Model Year 2025 Vehicles by Technology Path

	New Fleet Target			**Per-Vehicle Cost increase ($)**		
Scenario	CO2	MPGe*	Path A	Path B	Path C	Path D
3%/year	190	46.8	$930	$850	$770	$1,050
4%/year	173	51.4	$1,700	$1,500	$1,400	$1,900
5%/year	158	56.2	$2,500	$2,300	$2,100	$2,600
6%/year	143	62.1	$3,500	$3,200	$2,800	$3,400

[HHH] We did not assign an explicit monetary value to driving range, and as a consequence, the model typically chose shorter range electric vehicles (EV75) over longer range electric vehicles (EV150), as each produced the same statutory CO_2 reduction. The agencies will consider this issue in the context of a future rulemaking.

	Lifetime CO2e Reduction (MMT)				**Lifetime Gasoline Reduction (Billion Barrels)**			
Scenario	Path A	Path B	Path C	Path D	Path A	Path B	Path C	Path D
3%/year	340	340	340	340	0.7	0.7	0.7	0.7
4%/year	440	440	440	405	0.9	0.9	0.9	0.9
5%/year	520	520	530	440	1.1	1.1	1.1	1.1
6%/year	530	550	590	470	1.3	1.3	1.3	1.3

Note – these costs, CO2 reductions, and fuel savings are relative to the 2016 EPA GHG standards. Per-vehicle cost represented the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.
* MPGe is the MPG equivalent to the CO2 target if all CO2 reductions occur from fuel economy improvement technologies. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Thus, the 3% to 6% range evaluated in this assessment would span a range of real world fuel economy values of approximately 37 to 50 mpg, which correspond to the regulatory test procedure values of 47 and 62 mpg, respectively. For the technical assessment, we have estimated a reduction of 15 g/mile CO2 equivalent from air conditioning system improvements, which would not actually translate into MPG improvements.

The penetration of HEVs, EVs, and PHEV in MY 2025 varies considerably depending on the technology pathway and scenario, as can be seen in Table 6.5-2. As discussed in Chapter 6.3, Technology Pathway A places greater focus on HEV technology and less emphasis on mass reduction and advanced gasoline engine technology. Thus, in the 3%/year scenario, Path A results in 11% HEV penetration, and the most stringent 6% scenario increases HEV penetration to 68% for Path A, all with approximately a 15% reduction in mass for the new vehicle fleet.

Pathway C places greater emphasis on mass reduction and advanced gasoline vehicle technology, and therefore the penetration of HEVs ranges from 3% up to 44% of the new vehicle fleet. The penetration of gasoline and diesel vehicles for each of the stringency scenarios is highest for Pathway C, and the degree of mass reduction is also the highest among the four pathways, ranging from 18% to 26%.

Pathway B shows a technology approach in between Paths A and C, with advanced gasoline technology and mass reductions higher than for Path A but lower than Path C, and HEV penetrations lower than Path A but higher than Path C. This trend is not as strong for the 3% per year stringency scenario because the level of stringency does not require enough advanced technology to show much of a difference between Pathways B and C.

Pathway D places a greater emphasis on PHEV and EVs than the other three technology paths. As a consequence, there are lower penetrations of advanced gasoline engines and of mass reduction, but more electric vehicles than in the other three pathways.

Table 6.5-2: Assessment Projections for Model Year 2025 Vehicles
New Fleet Technology Penetration Estimates

Scenario	Technology	New Vehicle Fleet Technology Penetration

		Gasoline & diesel vehicles	HEV	PHEV	BEV	Net Mass Reduction[III]
3%/year	Path A	89%	11%	0%	0%	15%
	Path B	97%	3%	0%	0%	18%
	Path C	97%	3%	0%	0%	18%
	Path D	75%	25%	0%	0%	15%
4%/year	Path A	65%	34%	0%	0%	15%
	Path B	82%	18%	0%	0%	20%
	Path C	97%	3%	0%	0%	25%
	Path D	55%	41%	0%	4%	15%
5%/year	Path A	35%	65%	0%	1%	15%
	Path B	56%	43%	0%	1%	20%
	Path C	74%	25%	0%	0%	25%
	Path D	41%	49%	0%	10%	15%
6%/year	Path A	23%	68%	2%	7%	14%
	Path B	44%	47%	2%	7%	19%
	Path C	53%	44%	0%	4%	26%
	Path D	29%	55%	2%	14%	14%

Table 6.5-3 present estimates of payback period and net lifetime savings. Payback period is the number of years it takes for the higher initial cost of the vehicle to be off-set by the vehicle’s fuel savings. As discussed in Chapter 6.4, we used AEO 2010 reference case for fuel prices, including fuel taxes, and we discounted the fuel savings using a 3 percent discount rate. The net lifetime savings is the total lifetime fuel savings for the vehicle discounted at 3 percent minus the initial vehicle cost increase. As can be seen in Table 6.5-3, all MY 2025 scenarios, regardless of technology pathway, have a positive net lifetime fuel savings between approximately $4,900 and $7,400, and for MY 2025 all of the scenarios and technology pathways pay back in 4.2 years or less.

[III] Please note that we show net mass reduction relative to model year 2008 vehicles. In the case of PHEVs and EVs, the batteries increase the weight of the vehicle. This battery weight increase is combined with the mass reduction technology to calculate net mass reduction for those vehicles.

Table 6.5-3: Estimated Consumer Payback and Lifetime Savings For Model Year 2025 Vehicles (3% Discount Rate)

	Payback (years)				**Net Lifetime Savings ($s)**			
Scenario	Path A	Path B	Path C	Path D	Path A	Path B	Path C	Path D
3%/year	1.6	1.5	1.4	1.9	$5,032	$5,084	$5,174	$4,882
4%/year	2.5	2.2	1.9	2.9	$5,862	$6,041	$6,198	$5,329
5%/year	3.1	2.8	2.5	3.6	$6,450	$6,705	$6,959	$5,532
6%/year	4.1	3.7	3.1	4.2	$6,162	$6,564	$7,379	$5,705

Note – these estimates are relative to vehicle which comply with the 2016 EPA GHG standards

The following discussion presents information regarding the assessment projections of technology application and per-vehicle cost increases at the car-fleet and truck-fleet level for MY 2025. We categorized passenger cars and light trucks using the same category definitions as contained in the 2012-2016 National Program final rule. The results are presented sequentially by technology pathway (i.e., Pathway A, Pathway B, Pathway C, and Pathway D). The costs and CO_2 emission levels discussed in this section reflect the same parameters as the previous fleet level summaries (Section 6.5.1.1). The cost increases are relative to the same vehicles under the MY 2016 standard, and the CO_2e and MPGe levels include improvements to the vehicle air conditioning system, but exclude outlet electricity.

Car and Truck Fleet Information for Technology Path A for MY 2025

Table 6.5-4 presents vehicle segment level results for Technology Pathway A showing the CO2e target level by segment, the MPG-equivalent level by segment, and the average per-vehicle cost increase by segment for the four scenario stringency levels. Table 6.5-5 presents the corresponding vehicle segment level technology penetration rates and mass reductions for model year 2025 under the Technology Pathway A. The results show that as would be expected, the smaller size vehicles (e.g., the subcompact/compact segment and the midsize car segment), which start off at a lower average CO2 level, also generally have the lowest CO2 levels under the four stringency scenarios.

As can be seen in Table 6.5-5, mass reduction is very cost effective across all vehicle categories, and under all stringency scenarios is at or near the maximum 15% we allowed under Pathway A. The penetration of HEV technology is significantly higher in the truck-fleet for the 3% and 4% per year scenarios, and more evenly distributed between the car and truck fleets for the 5% and 6% per year scenarios. EVs first penetrate the new vehicle fleet in the 5% per year stringency scenario at a low level, and for the 6% per year scenario EVs represent 10% of all passenger cars, and only 2% of all light-duty trucks. PHEV technology is generally selected last in our assessment, and does not enter the new fleet until the assessment of the 6% per year category.

Table 6.5-4: Technology Path A, Assessment Projections for Model Year 2025: CO2, MPG, and Per-Vehicle Costs for Car and Truck Fleets

Scenario	Vehicle Segment	CO2e Level (g/mile)*	MPGe Level*	Per-Vehicle Cost Increase ($)
3%/year	All Cars	174	51.2	$659
	All Trucks	225	39.5	$1,485
	Fleet	**190**	**46.7**	**$927**
4%/year	All Cars	162	54.9	$1,184
	All Trucks	197	45.0	$2,792
	Fleet	**173**	**51.3**	**$1,705**
5%/year	All Cars	141	62.9	$2,231
	All Trucks	192	46.4	$3,106
	Fleet	**158**	**56.4**	**$2,515**
6%/year	All Cars	117	75.9	$3,629
	All Trucks	198	45.0	$3,095
	Fleet	**143**	**62.0**	**$3,455**

*note, the CO2e value includes 15 grams/mile of CO2-equivalent reduction from air conditioning related GHGs (CO2 and HFC reductions), and the MPGe level is equivalent MPG value if all CO2 reductions come from fuel economy improvements. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Per-vehicle cost represented the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.

Table 6.5-5: Technology Path A, Assessment Projections for Model Year 2025: New Fleet Technology Penetration for Car and Truck Fleets

Scenario	Vehicle Type	Net Mass Reduction (%)	Net Mass Reduction (lbs)	HEV (%)	PHEV (%)	EV (%)	Adv. SI (%)
3%/year	All Cars	15%	491	6%	0%	0%	23%
	All Trucks	15%	673	24%	0%	0%	49%
	Fleet	**15%**	**550**	**11%**	**0%**	**0%**	**31%**
4%/year	All Cars	15%	491	20%	0%	0%	46%
	All Trucks	15%	673	65%	0%	0%	18%
	Fleet	**15%**	**550**	**34%**	**0%**	**0%**	**37%**
5%/year	All Cars	15%	491	60%	0%	1%	27%
	All Trucks	15%	673	74%	0%	0%	14%
	Fleet	**15%**	**550**	**65%**	**0%**	**1%**	**23%**
6%/year	All Cars	14%	467	71%	3%	10%	15%
	All Trucks	15%	665	61%	1%	2%	35%
	Fleet	**14%**	**529**	**68%**	**2%**	**7%**	**22%**

Car and Truck Fleet Information for Technology Path B for MY 2025

Table 6.5-6 presents vehicle segment level results for Technology Pathway B showing the CO2e target level by car-truck fleet, the MPG-equivalent level by car-truck fleet, and the average per-vehicle cost increase by car-truck fleet for the four scenario stringency levels. Table 6.5-7 presents the corresponding car-truck fleet technology penetration rates and mass reductions for model year 2025 under the Technology Pathway B.

As can be seen in Table 6.5-7, mass reduction is very cost effective across all vehicle categories, and under all stringency scenarios is at or near the maximum 20% we modeled under Pathway B. The penetration of HEV technology is generally more focused in the truck-fleet, and increases overall as the level of stringency increases. In general, when compared to Pathway A, the penetration of HEVs in Pathway B is lower.

EVs first penetrate the new vehicle fleet in the 5% per year stringency scenario, though at a low rate of 1% for the fleet. This increases to approximately 7% of the fleet under the 6% per year scenario, with most of these concentrated in the passenger car vehicles. PHEV vehicles are only seen in the 6% per year scenario, and represent 2% of the vehicle fleet for Pathway B.

Table 6.5-6: Technology Path B Assessment Projections for Model Year 2025: CO2, MPG, and Per-Vehicle Costs for Car and Truck Fleets

Scenario	Vehicle Type	CO_2e Level (g/mile)	MPGe Level	Per-Vehicle Cost Increase ($)
3%	All Cars	170	52.4	$753
	All Trucks	233	38.2	$1,047
	Fleet	**190**	**46.7**	**$849**
4%	All Cars	160	55.7	$1,070
	All Trucks	202	44.1	$2,465
	Fleet	**173**	**51.3**	**$1,522**
5%	All Cars	146	61.0	$1,748
	All Trucks	183	48.6	$3,335
	Fleet	**158**	**56.3**	**$2,263**
6%	All Cars	130	68.5	$2,698
	All Trucks	171	52.0	$4,327
	Fleet	**143**	**62.1**	**$3,227**

*note, the CO2e value includes 15 grams/mile of CO2-equivalent reduction from air conditioning related GHGs (CO2 and HFC reductions), and the MPGe level is equivalent MPG value if all CO2 reductions come from fuel economy improvements. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Per-vehicle cost represented the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.

Table 6.5-7: Technology Path B, Assessment Projections for Model Year 2025: New Fleet Technology Penetration for Car and Truck Fleets

Scenario	Vehicle Type	Net Mass Reduction (%)	Net Mass Reduction (lbs)	HEV (%)	PHEV (%)	EV (%)	Adv. SI (%)
3%/year	All Cars	17%	572	4%	0%	0%	46%
	All Trucks	19%	848	2%	0%	0%	66%
	Fleet	**18%**	**658**	**3%**	**0%**	**0%**	**52%**
4%/year	All Cars	20%	655	5%	0%	0%	72%
	All Trucks	20%	897	45%	0%	0%	45%
	Fleet	**20%**	**733**	**18%**	**0%**	**0%**	**63%**
5%/year	All Cars	20%	654	30%	0%	1%	62%
	All Trucks	20%	897	72%	0%	0%	21%
	Fleet	**20%**	**733**	**43%**	**0%**	**1%**	**49%**
6%/year	All Cars	19%	630	27%	2%	9%	60%
	All Trucks	20%	887	88%	1%	2%	9%
	Fleet	**19%**	**712**	**47%**	**2%**	**7%**	**44%**

Car and Truck Fleet Information for Technology Path C for MY 2025

Table 6.5-8 presents car-fleet and truck-fleet level results for Technology Pathway C, specifically the CO2e target levels, the MPG-equivalent target levels, and the average per-vehicle cost increase for the four scenario stringency levels. Table 6.5-9 presents the corresponding car-fleet and truck-fleet technology penetration rates and mass reductions for model year 2025 under the Technology Pathway C. The results show that as with Pathways A and B, the car fleet, which start off at a lower average CO2 level, also has a lower CO2 levels under the four stringency scenarios as compared to the truck fleet. The per-vehicle cost increase difference between the car-fleet and truck-fleet is on the order of $300 to $350 for the 3% and 4% per year scenarios, but increases to approximately $2,000 for the 5% per year scenario and $1,600 for the 6% per year scenario.

As can be seen in Table 6.5-9, mass reduction is very cost effective across both the car and truck fleets, and is on the order of 18% for the 3% per year scenario, and between 25 and 27% for the high stringency scenarios. The penetration of HEV technology is similar between the car and truck fleets for the 3% and 4% scenarios, but in the 5% and 6% per year scenarios is more weighted towards the truck-fleet. Technology Path C has the overall highest use of the advanced gasoline technologies, and as can be seen the mix between the car fleet and the truck fleet is very dependent upon the level of stringency, with higher levels under the 3% , 5% and 6% per year scenario in the car-fleet, but similar levels between cars and trucks in the 4% per year scenario.

EVs penetrate the new vehicle fleet only in the 6% per year stringency scenario for Pathway C, and overall are concentrated in the passenger cars fleet, representing 5% of all passenger cars, and only 1% of all light-duty trucks. PHEV technology is not required in this assessment under Technology Pathway C.

Table 6.5-8: Technology Path C Assessment Projections for Model Year 2025: CO2, MPG, and Per-Vehicle Costs for Car and Truck Fleets

Scenario	Vehicle Type	CO_2e Level (g/mile)	MPGe Level	Per-Vehicle Cost Increase ($)
3%	All Cars	169	52.6	$674
	All Trucks	233	38.1	$980
	Fleet	**190**	**46.8**	**$773**
4%	All Cars	154	57.9	$1,255
	All Trucks	213	41.8	$1,604
	Fleet	**173**	**51.4**	**$1,368**
5%	All Cars	148	60.1	$1,420
	All Trucks	178	49.9	$3,412
	Fleet	**158**	**56.3**	**$2,066**
6%	All Cars	130	68.3	$2,316
	All Trucks	170	52.4	$3,909
	Fleet	**143**	**62.2**	**$2,833**

*note, the CO2e value includes 15 grams/mile of CO2-equivalent reduction from air conditioning related GHGs (CO2 and HFC reductions), and the MPGe level is equivalent MPG value if all CO2 reductions come from fuel economy improvements. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Per-vehicle cost represented the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.

Table 6.5-9: Technology Path C Assessment Projections for Model Year 2025: New Fleet Technology Penetration for Car and Truck Fleets

Scenario	Vehicle Type	Net Mass Reduction (%)	Net Mass Reduction (lbs)	HEV (%)	PHEV (%)	EV (%)	Adv. SI (%)
3%/year	All Cars	17%	569	4%	0%	0%	32%
	All Trucks	19%	839	2%	0%	0%	76%
	Fleet	**18%**	**653**	**3%**	**0%**	**0%**	**46%**
4%/year	All Cars	25%	809	4%	0%	0%	96%
	All Trucks	25%	1,122	2%	0%	0%	98%
	Fleet	**25%**	**909**	**3%**	**0%**	**0%**	**97%**
5%/year	All Cars	25%	818	8%	0%	0%	91%
	All Trucks	25%	1,143	60%	0%	0%	39%
	Fleet	**25%**	**922**	**25%**	**0%**	**0%**	**74%**
6%/year	All Cars	27%	868	31%	0%	5%	65%
	All Trucks	26%	1,180	71%	0%	1%	28%
	Fleet	**26%**	**970**	**44%**	**0%**	**4%**	**53%**

Car and Truck Fleet Information for Technology Path D for MY 2025

Table 6.5-10 presents car-fleet and truck-fleet level results for Technology Pathway D, specifically the CO2e target levels, the MPG-equivalent target levels, and the average per-vehicle cost increase for the four scenario stringency levels. Table 6.5-10 presents the corresponding car-fleet and truck-fleet technology penetration rates and mass reductions for model year 2025 under the Technology Pathway D. The results show that as with the three other pathways, the car fleet, which starts off at a lower average CO2 level, also has a lower CO2 levels under the four stringency scenarios as compared to the truck fleet. The per-vehicle cost increase difference between the car-fleet and truck-fleet is on the order of $500 to $1,000 depending on the stringency of the scenario, with the exception of the 3% per year scenario, where there is little cost difference between the car fleet and truck fleet.

As can be seen in Table 6.5-10, mass reduction is very cost effective across both the car and truck fleets, though the level of mass reduction is no higher than the 15% we considered for this Pathway. The penetration of HEV technology is similar between the car and truck fleets in the 6% scenario, but in the 3%, 4%, and 5% scenarios are weighted more heavily towards the car fleet. Advanced gasoline engines were not allowed in this scenario, as we were trying to assess a hypothetical industry approach in which no advancements in gasoline powertrain systems are pursued beyond MY2016, and all of the industry resources are concentrated on HEV, PHEV, and EV technology.

Relative to the other Technology Pathways, Technology Pathway D features a higher penetration of EVs and HEVs. The relatively high penetration of HEVs in the 3% scenario is due to the complete lack of advanced gasoline engines (that is, no improvement in gasoline engines and transmissions beyond what will be used in MY 2015). More stringent scenarios require relatively higher penetrations of EVs and HEVs. The penetration of PHEV technology remains relatively low, appearing only in the 6% scenario.

Table 6.5-10: Technology Path D Assessment Projections for Model Year 2025: CO2, MPG, and Per-Vehicle Costs for Car and Truck Fleets

Scenario	Vehicle Type	CO_2e Level (g/mile)	MPGe Level	Per-Vehicle Cost Increase ($)
3%	All Cars	166	53.4	$1,026
	All Trucks	238	37.4	$1,096
	Fleet	**190**	**46.9**	**$1,049**
4%	All Cars	143	62.2	$2,215
	All Trucks	235	37.8	$1,203
	Fleet	**173**	**51.4**	**$1,887**
5%	All Cars	127	69.8	$2,940
	All Trucks	222	40.0	$1,917
	Fleet	**158**	**56.2**	**$2,608**
6%	All Cars	115	77.4	$3,555
	All Trucks	201	44.2	$3,061
	Fleet	**143**	**62.3**	**$3,395**

*note, the CO2e value includes 15 grams/mile of CO2-equivalent reduction from air conditioning related GHGs (CO2 and HFC reductions), and the MPGe level is equivalent MPG value if all CO2 reductions come from fuel economy improvements. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Per-vehicle cost represented the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.

Table 6.5-11: Technology Path D Assessment Projections for Model Year 2025: New Fleet Technology Penetration for Car and Truck Fleets

Scenario	Vehicle Type	Net Mass Reduction (%)	Net Mass Reduction (lbs)	HEV (%)	PHEV (%)	EV (%)	Adv. SI (%)
3%/year	All Cars	15%	491	30%	0%	1%	0%
	All Trucks	15%	673	14%	0%	0%	0%
	Fleet	**15%**	**550**	**25%**	**0%**	**0%**	**0%**
4%/year	All Cars	15%	489	54%	0%	6%	0%
	All Trucks	15%	673	13%	0%	1%	0%
	Fleet	**15%**	**549**	**41%**	**0%**	**4%**	**0%**
5%/year	All Cars	15%	482	59%	0%	13%	0%
	All Trucks	15%	669	29%	0%	3%	0%
	Fleet	**15%**	**542**	**49%**	**0%**	**10%**	**0%**
6%/year	All Cars	14%	467	55%	2%	19%	0%
	All Trucks	15%	657	57%	2%	4%	0%
	Fleet	**14%**	**528**	**55%**	**2%**	**14%**	**0%**

MY 2020 Results

We present here the fleet-wide results for our MY2020 assessment. The cost of the MY 2020 scenarios for the entire new vehicle fleet ranges from $289 (3%) to $1,057 (6%, Path A) per vehicle, as shown in Table 6.5-12. Technology pathway C, which relies upon advanced gasoline technology and greater mass reduction as compared to Pathway A and B, demonstrates the lowest costs. Pathways A and B show greater penetration of HEVs and somewhat higher costs.

The GHG reduction over the lifetime of the MY 2020 vehicles ranges from 172 million metric tons (MMT) CO_2e avoided in the 3% scenario to between 306 MMT CO_2e in the 6% scenario. MY 2020 vehicles, over the course of their lifetimes, will reduce between 0.4 billion barrels of gasoline consumption under the 3% scenario to 0.6 billion barrels under the 6% scenario. For reference, the NHTSA & EPA National Program in MY 2016 is projected to reduce 0.6 billion barrels of fuel and 325 MMT CO2e over the lifetime of MY 2016 vehicles.

Table 6.5-12: Assessment Projections for Model Year 2020 Vehicles by Technology Path

	New Fleet Target		**Per-Vehicle Cost increase ($)**			**Lifetime CO2e Reduction (MMT)**			**Lifetime Gasoline Reduction (Billion Barrels)**		
Scenario	CO2	MPGe*	Path A	Path B	Path C	Path A	Path B	Path C	Path A	Path B	Path C
3%/year	221	40.2	$289	$289	$289	172	172	172	0.4	0.4	0.4
4%/year	212	41.9	$399	$399	$399	215	215	215	0.5	0.5	0.5
5%/year	204	43.6	$577	$583	$565	262	262	262	0.5	0.5	0.5
6%/year	195	45.5	$1,057	$1,035	$865	306	306	306	0.6	0.6	0.6

Note – these costs, CO2 reductions, and fuel savings are relative to the 2016 EPA GHG standards. Per-vehicle cost represented the estimated cost to the consumer, including the direct manufacturing costs for the new technologies, indirect costs for the auto manufacturer (e.g., product development, warranty) as well as auto manufacturer profit, and indirect costs at the dealership - see Chapter 3.2.5 for detail on our estimation of indirect costs.

* MPGe is the MPG equivalent to the CO2 target if all CO2 reductions occur from fuel economy improvement technologies. Real-world CO2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower. Thus, the 3% to 6% range evaluated in this assessment would span a range of real world fuel economy values of approximately 32 to 36 mpg, which correspond to the regulatory test procedure values of 40.2 and 45.5 mpg, respectively. For the technical assessment, we have estimated a reduction of 15 g/mile CO2 equivalent from air conditioning system improvements, which would not actually translate into MPG improvements

The penetration of HEVs, EVs, and PHEV in MY 2020 varies little depending on the technology pathway and scenario, as can be seen in Table 6.5-13.

Pathway C places greater emphasis on mass reduction and advanced gasoline vehicle technology. Therefore, the degree of mass reduction is also the highest among the four pathways, ranging from 11% to 18%.

Pathway B shows a technology approach in between Paths A and C, with advanced gasoline technology and mass reductions higher than for Path A but lower than Path C, and HEV penetrations lower than Path A but higher than Path C. This trend is not as strong in the

MY 2020 results because the level of stringency does not require enough advanced technology to show much of a difference between Pathways B and C under most stringencies.

Table 6.5-13: Assessment Projections for Model Year 2020 Vehicles New Fleet Technology Penetration Estimates

Scenario	Technology Path	New Vehicle Fleet Technology Penetration Gasoline & diesel vehicles	HEV	PHEV	BEV	Net Mass Reduction[JJJ]
3%/year	Path A	97%	3%	0%	0%	11%
	Path B	97%	3%	0%	0%	11%
	Path C	97%	3%	0%	0%	11%
4%/year	Path A	97%	3%	0%	0%	14%
	Path B	97%	3%	0%	0%	14%
	Path C	97%	3%	0%	0%	14%
5%/year	Path A	97%	3%	0%	0%	15%
	Path B	97%	3%	0%	0%	15%
	Path C	97%	3%	0%	0%	15%
6%/year	Path A	85%	15%	0%	0%	15%
	Path B	87%	13%	0%	0%	15%
	Path C	97%	3%	0%	0%	18%

Table 6.5-14 present estimates of payback period and net lifetime savings for MY 2020 vehicles. Payback period is the number of years it takes the cost increase of the vehicle to be off-set by the vehicle's fuel savings. As discussed in Chapter 6.4, we used AEO 2010 reference case for fuel prices, including fuel taxes, and we discounted the fuel savings using a 3 percent discount rate. The net lifetime savings is the total lifetime fuel savings for the vehicle discounted at 3 percent minus the initial vehicle cost increase. As can be seen in Table 6.5-14, all MY 2020 scenarios, regardless of technology pathway, have a positive net lifetime fuel savings between approximately $2,600 and $4,300, and for MY 2020 all of the scenarios and technology pathways pay back in 2.2 years or less.

Table 6.5-14: Estimated Consumer Payback and Lifetime Savings For Model Year 2020 Vehicles (3% Discount Rate)

	Payback (years)			**Net Lifetime Savings ($s)**		
Scenario	Path A	Path B	Path C	Path A	Path B	Path C
3%/year	1.0	1.0	1.0	$2,632	$2,632	$2,632
4%/year	1.1	1.1	1.1	$3,249	$3,249	$3,249
5%/year	1.4	1.4	1.3	$3,854	$3,792	$3,823
6%/year	2.2	2.2	1.8	$4,082	$4,105	$4,281

Note – these estimates are relative to vehicles which comply with the 2016 EPA GHG standards

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[JJJ] Please note that we show net mass reduction relative to model year 2008 vehicles. In the case of PHEVs and EVs, the batteries increase the weight of the vehicle. This battery weight increase is combined with the mass reduction technology to calculate net mass reduction for those vehicles.

6.6 PHEV and EV Battery Cost Sensitivity Assessment

The agencies judged that there is uncertainty in the cost for EV and PHEV large-format lithium-ion batteries in the 2025 time frame. As discussed in Chapter 3, the development of these batteries for automotive applications is occurring at a very rapid rate and the market is far from mature, thus our ability to accurately predict the costs for these technologies for the 2025 time frame is difficult. The cost of the battery pack is the single largest incremental cost difference between a gasoline vehicle and either a PHEV or an EV. Depending upon the vehicle range (and thus the size of the battery) and the time frame (e.g., today or the 2025 time frame), the battery pack cost can represent on the order of 60 to 80% or more of the incremental cost of a PHEV/EV. Given the uncertainty in the costs of lithium-ion batteries in the 2025 time frame, and the significant portion of the PHEV and EV incremental costs the battery represents, the agencies believe it is appropriate to include a sensitivity analysis on battery pack costs.

As discussed in Chapter 3, the agencies used a battery costing model developed by Argonne National Laboratory (ANL) which provides unique battery pack cost estimates for EV and PHEVs based on various variables such as production volume, battery cell chemistry material, battery capacity and power, useable fraction of the state-of-charge range, etc. There are also many economic projections used in the ANL model, such as cost of capital equipment, plant area, labor cost, etc. Based on 500,000 units per year production volume, and using an assumption there will be incremental improvements in battery cycle life such that the battery performance is maintained for the useful life of the vehicle, EPA derived a battery pack cost projection for 2025 EVs of approximately $160/kW-h for EV75, $150/kW-h for EV100, $140/kW-h for EV150, and of 2025 PHEVs of $180/kW-h for 40-mile PHEVs and $250/kW-h for 20-mile PHEVs assuming the use of $LiMn_2O_4$-spinel/graphite cell chemistry. We note that this cost is lower than the cost estimates projections obtained from our meetings with the OEMs, where the majority of the estimates were in the $300 to $400/kW-h range for 2020 and $250 to $300/kW-h range for 2025.

Because of uncertainty in future battery costs, the agencies conducted a sensitivity assessment on the battery costs for 2025 by increasing all of the PHEV and EV battery-pack costs by $100/kW-hr. We also examined the potential impact of lower battery costs by reducing all of the PHEV and EV battery-pack costs by $50/kW-hr. The $100/kW-hr higher cost is comparable to commodity pricing for high-volume $LiCoO_2$ cells for consumer applications. The $50/kW-hr lower cost assumes a breakthrough in battery design that would approximately triple cell energy density.

We selected the 5% per year and 6% per year targets under technology Pathway B for 2025 as the scenario on which to assess the potential impact of these changes in Li-ion battery costs. The results show that for the higher battery cost estimates, the projected 2025 Pathway B costs for the 5% per year targets would increase by $36 per vehicle and for the 6% per year targets would increase by $397 per vehicle. For the lower battery cost estimates, the projected 2025 Pathway B costs for the 5% per year targets would decrease by $18 per vehicle and for the 6% per year targets would decrease by $199 per vehicle. This impact on the fleet-wide average cost assessment is relatively modest because PHEVs and EVs represent on the order of 1% of the new vehicles under the Pathway B 5% per year scenario, and 9% under the

Pathway B 6% per year scenario. However, the impact on actual PHEVs and EVs can be large. For example, for a midsize EV passenger car with a real-world range of 100 miles (an EV100), the sensitivity analysis done by adding $100/kW-hr to the battery pack costs increased the cost of the midsize car EV100 on the order of $5,700, and the impact of lowering the EV100 battery pack costs by $50/kW-hr reduced the costs of the midsize car EV100 by $2,800.

Chapter 6 References

[92] Documented in Appendix A to this report.

[93] See Appendix D to this report.

[94] Energy Information Administration, Annual Energy Outlook 2010, Reference Case (May 2010 2009), Table 12. Available at http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html

[95] EPA. 2006, Final Technical Support Document. Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates. EPA-HQ-OAR-2009-0472-0281

[96] Energy Information Administration, Annual Energy Outlook 2010, Reference Case (May 2010 2009), Table 12. Available at http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html

[97] EPA. Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. Joint Technical Support Document. Chapter 4. EPA-420-R-10-901 http://www.epa.gov/otaq/climate/regulations/420r10901.pdf. Additional details on the projections used here can be found in Appendix E of this report.

[98] Sorrell, S. and J. Dimitropoulos, 2007. "UKERC Review of Evidence for the Rebound Effect, Technical Report 2: Econometric Studies", UKERC/WP/TPA/2007/010, UK Energy Research Centre, London, October and Greening, L.A., D.L. Greene and C. Difiglio, 2000. "Energy Efficiency and Consumption – The Rebound Effect – A Survey", Energy Policy, vol. 28, pp. 389-401.

[99] EPA. Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule Regulatory Impact Analysis Chapter 5.

[100] EPA. Analysis of H.R. 2454 in the 111th Congress. http://www.epa.gov/climatechange/economics/economicanalyses.html

[101] EPA. Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. Joint Technical Support Document. Chapter 4. EPA-420-R-10-901. http://www.epa.gov/otaq/climate/regulations/420r10901.pdf. Original data found in Intergovernmental Panel on Climate Change. Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing. September 2007. http://www.ipcc.ch/pdf/assessmentreport/ar4/wg1/ar4-wg1-chapter2.pdf. Docket ID: EPA-HQ-OAR-2009-0472-0117

7 Other Key Factors

7.1 Potential Impacts on the Economy and Employment

The primary impacts of the use of advanced vehicle technologies on the economy are the net benefits that they produce. Positive net benefits result in improvements in economic welfare in the aggregate. Measures of net benefits, though, are not necessarily correlated with the effects of technologies on employment or on the auto manufacturing base in the U.S. This report does not provide a quantitative assessment of these effects. Instead, this section discusses the potential impacts of advanced technologies on the auto industry in general and employment in the auto sector.

7.1.1 Impacts on Auto Manufacturers, Suppliers, and Auto Industry Employment

The automotive market is becoming increasingly global. The U.S. auto companies produce and sell automobiles around the world, and foreign auto companies produce and sell in the U.S. As a result, the industry has become increasingly competitive. Staying at the cutting edge of automotive technology while maintaining profitability and consumer acceptance has become increasingly important for the sustainability of auto companies.

Trends in the world automotive market suggest that investments in improved fuel economy and advanced technology vehicles are a necessary component for maintaining competitiveness in coming years. For instance, most companies are expanding hybrid-electric vehicle production to stay competitive while meeting more stringent fuel economy and emissions regulations. Fuel economy requirements in other developed countries are generally higher, and greenhouse gas (GHG) emissions standards tighter, than in the U.S. As automakers seek greater commonality across the vehicles they produce for the domestic and foreign markets, improving fuel economy and reducing GHGs in U.S. vehicles should have spillovers to foreign production, and vice versa, thus yielding the ability to amortize investment in research and production over a broader product and geographic spectrum.

Auto companies are already conducting major research and investment activities in advanced technologies and improvements to conventional technologies to improve fuel economy and reduce GHG emissions. In addition, as discussed in Chapter 2, in recent meetings with auto firms, all expressed plans to increase significantly their offerings and sales of advanced technology vehicles in coming years. Successful research and investment activities can contribute to long-term gains in many directions. Companies that develop new technologies not only get the advantages of using them, but also the opportunity to license those technologies to other companies. Those technologies may have spinoffs into other sectors. For instance, research into new battery technologies may lead to improvements in other battery-intensive uses, such as storage of wind or solar energy when the quantity of electricity demanded is lower than the amount produced.

The effects of the use of advanced technologies on U.S. auto sector employment depend on how the standards affect several factors: the number of vehicles produced (discussed below), the labor intensity of vehicle production, and any changes in market shares between domestically produced and imported vehicles and auto parts.

Productivity in the auto industry has been increasing over time, as automakers have improved process efficiency and enhanced vehicle quality.[102] Improved productivity has the great benefit of providing better vehicles at lower prices to consumers; it also means fewer worker-hours needed per dollar of vehicle value. Higher productivity leads to more efficient vehicle manufacturing, which could result in less expensive and/or improved quality vehicles. Either outcome would likely give consumers greater purchasing power, and thus lead to higher vehicle sales. Even though higher productivity implies that worker-hours per vehicle may go down, increased vehicle sales may lead overall employment in the auto industry to increase, as it did in the 1990s (a time of both high productivity increases and employment increases). At this time it is not possible to predict the effect of production involving advanced vehicle technologies on labor needs. It is possible that the smaller-volume production likely in the early years for advanced technology vehicles may be more labor-intensive than mass production, if scale economies of production are not exhausted.

Another variable affecting auto sector employment is where production takes place. The location of production will depend on how domestic production costs, especially for advanced technologies, compare to foreign production costs, and on the cost of transporting vehicles and parts between the U.S. and other countries. Investments in advanced technology production facilities, such as battery manufacturing and vehicle electrification projects, supported by the Recovery Act (for example) reduce the need for importing these parts from overseas.[103] These investments by the Department of Energy have created immediate jobs in building this capacity, and they also help ensure that these components can be produced in the U.S. Tax breaks and other manufacturing incentives provided by a number of local and state governments for advanced vehicle technologies, such as in Michigan, have also contributed incentives for domestic production.

7.1.2 Impacts on Vehicle Sales

The effect of advanced technologies on vehicle sales depends on the attractiveness to consumers of the new technologies and improved fuel economy relative to the increased vehicle price. In the light-duty greenhouse gas/fuel economy rule covering 2012-2016, the very large fuel savings were estimated to recover the up-front technology costs in under three years. If consumers considered at least three years' worth of fuel savings when purchasing a vehicle, then that rule was predicted to increase vehicle sales.[104] The use of advanced technologies can be expected, as in that rule, to improve fuel economy and increase vehicle costs. Chapter 6 of this report shows that more stringent standards will provide fuel savings that exceed vehicle cost increases in four years or less. The weights that consumers put on these two factors will affect total vehicle sales.[105]

7.1.3 Summary

With increased globalization of auto markets, increased competitiveness in the industry, and higher fuel economy/lower GHG standards becoming the norm around the world, auto companies have already begun to invest in new technologies that will meet future standards. These new technologies will increase the purchase prices of new vehicles, at the same time that they reduce their fuel costs; the net effect on auto sales depends on how consumers trade off those attributes. The net effect on employment will be affected not only by the effects of the proposed standards on auto sales, but also on the effects on productivity and location of production. These investments will help the U.S. auto sector to stay on the cutting edge of auto technology.

For the forthcoming notice of proposed rulemaking for 2017-2025 GHG and CAFE standards, EPA and NHTSA will further investigate the impacts of the proposed standards on the auto industry, and employment. Further analysis requires information on the effects of the proposed standards on vehicle sales, on expected expenditures in the auto sector, and on any predictions of changes in location of manufacturing due to the specific standards in the forthcoming proposal.

7.2 Upstream GHG Emissions

In the assessment of potential future ranges of stringency presented in Chapter 6 of this report, we based our analysis on the tailpipe emissions from all vehicles – thus EVs were evaluated at a 0 gram/mile CO2 level and PHEVs were evaluated as 0 gram/mile for the electric drive portion of the vehicles operation. For the purposes of the GHG impacts presented in Chapter 6, we have included the resultant increase in upstream CO2 from the use of PHEVs and EVs in our overall calculation of the net CO2 reductions for each of the scenarios evaluated. As discussed in Chapter 6, the upstream CO2 emission factors from powerplants is based on a future business as usual case,

The issue of upstream emissions will be considered in the MY 2017-2025 light-duty vehicle joint federal rulemaking. EPA has not considered upstream fuel-related emissions issues in the past with respect to the non-GHG emissions standards for motor vehicles.

As discussed in Chapter 2, many stakeholders have expressed opinions on this topic, with most automakers supporting the tailpipe only or zero grams per mile approach and environmental groups typically supporting a net upstream GHG emissions accounting.

EPA will be fully evaluating this issue for the MY 2017-2025 light-duty vehicle GHG emissions proposal based on the status of commercialization of EVs, PHEVs, and FCVs, the potential of these technologies to provide long-term GHG emissions savings, the status of and outlook for upstream GHG control programs, and other relevant factors.

Chapter 7 References

[102] Baily, Martin N., et al., "Increasing Global Competition and Labor Productivity: Lessons from the US Automotive Industry," McKinsey Global Institute, November 2005, http://www.mckinsey.com/mgi/publications/us_autoindustry/index.asp , accessed 8/17/10.

[103] "Recovery Act Awards for Electric Drive Vehicle Battery and Component Manufacturing Initiative" and "Recovery Act Awards for Transportation Electrification," http://www1.eere.energy.gov/recovery/pdfs/battery_awardee_list.pdf

[104] This result led to questions why private market interactions between auto producers and consumers had not led to incorporation of these technologies into vehicles in the absence of the rule. This issue was discussed in the Preamble for that rule, Federal Register 75(88) (Friday, May 7, 2010), in Section III.H.1, pp. 25510-25513, and IV.G.6, pp. 25651-25657.

[105] Though a number of studies have included examination of the role of fuel economy in consumers' purchases, the results appear to be highly varied. See Greene, David L., "How Consumers Value Fuel Economy: A Literature Review," Report EPA-420-R-10-008, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, March 2010. EPA-HQ-OAR-2009-0472-11465.

A1 Appendix A: The Baseline and Reference Vehicle Fleet

The passenger cars and light trucks sold currently in the United States, and those which are anticipated to be sold in the MYs 2017-2025 time frame, are highly varied and satisfy a wide range of consumer needs. From two-seater miniature cars to 11-seater passenger vans to large extended cab pickup trucks, American consumers have a great number of vehicle options to accommodate their utility needs and preferences. Recent volatility in oil prices and the state of the economy have demonstrated that consumer demand and choice of vehicles within this wide range can be sensitive to these factors. Although it is impossible for anyone or any organization to precisely predict the future, a characterization and quantification of the future fleet are required to assess the impacts of rules which would affect that future fleet. In order to do this, the various leading publicly-available sources are examined, and a series of models are relied upon that help us to project the composition of a reference fleet. This appendix gives a high level over view of the process to accomplish this and a simple analysis of the fleet's characteristics, drawing extensively from the joint final TSD for the MYs 2012-2016 final rule.

A1.1 Why do the agencies establish a baseline and reference vehicle fleet?

In order to calculate the impacts of potential future EPA and NHTSA standards, it is necessary to estimate the composition of the future vehicle fleet absent those CAFE/GHG standards in order to conduct comparisons. EPA in consultation with NHTSA has developed a comparison fleet in two parts. The first step was to develop a baseline fleet based on model year 2008 data. EPA and NHTSA create a baseline fleet in order to track the volumes and types of fuel economy-improving and CO_2-reducing technologies which are already present in today's fleet. Creating a baseline fleet helps to keep, to some extent, the agencies' models from adding technologies to vehicles that already have these technologies, which would result in "double counting" of technologies' costs and benefits. The second step was to project the baseline fleet sales into MYs 2017-2025. This is called the reference fleet, and it represents the fleet that would exist in MYs 2017-2025 absent any change from current regulations. The third step was to add technologies to that MY 2008 fleet such that each manufacturer's average car and truck CO_2 levels are in compliance with their MY 2016 CAFE standards. This final "reference fleet" is the light duty fleet estimated to exist in MYs 2017-2025 without new CAFE/GHG standards. All of the agencies' estimates of emission reductions/fuel economy improvements, costs, and societal impacts for purposes of this Technical Assessment Report are developed in relation to this reference fleet for MY 2016. This Appendix describes the first two steps of the development of the baseline and reference fleets. The third step of technology addition is developed separately by each agency as the outputs of the OMEGA and Volpe models; for purposes of this Technical Assessment Report, as discussed above, only the OMEGA model was employed for the main analysis, although both models will be run for the forthcoming federal rulemaking. The overall process for developing baseline and reference fleets for the agencies' modeling is described in the MYs 2012-2016 final rule in section II of the preamble and in each agency's respective RIA.

A1.2 The 2008 baseline vehicle fleet

A1.2.1 Why did the agencies choose 2008 as the baseline model year?

A baseline vehicle fleet was developed by EPA in consultation with NHTSA for the 2012-2016 final rule. The baseline for the 2012-2016 final rule is comprised of model year 2008 individual vehicle attribute data volumes along with projected volumes out to 2016. Model year 2008 vehicle data was again chosen to be the basis of the baseline fleet, but for different reasons than the final rule. Model year 2008 is now the most recent model year for which the industry had normal sales. Model year 2009 data was available, but the agencies believe that the model year was disrupted by the economic downturn and the bankruptcies of both General Motors and Chrysler. There was a significant reduction in the number of vehicles sold by both companies and the industry as a whole. These abnormalities made the agencies conclude that 2009 data was unsuitable for projecting the future fleet. Therefore, the agencies chose to use model year 2008 as the baseline since it was the latest representative transparent data set available.

A1.2.1.1 On what data is the baseline vehicle fleet based?

As part of the CAFE program, EPA measures vehicle CO_2 emissions and converts them to mpg and generates and maintains the federal fuel economy database. Most of the information about the 2008 vehicle fleet was gathered from EPA's emission certification and fuel economy database**,** most of which is available to the public**.** The data obtained from this source included vehicle production volume, fuel economy, carbon dioxide emissions, fuel type, number of engine cylinders, displacement, valves per cylinder, engine cycle, transmission type, drive, hybrid type, and aspiration. However, EPA's certification database does not include a detailed description of the types of fuel economy-improving/CO_2-reducing technologies considered in this final rule, because this level of information is not necessary for emission certification or fuel economy testing. Thus, EPA augmented this description with publicly-available data which includes more complete technology descriptions from Ward's Automotive Group.[1,A] In a few instances when required vehicle information was not available from these two sources (such as vehicle footprint), this information was obtained from publicly-accessible internet sites such as Motortrend.com, Edmunds.com and other sources to a lesser extent (such as articles about specific vehicles revealed from internet search engine research.[2,B]

For details on how the 2008 baseline fleet was constructed for the 2012-2016 final rule, please see the Chapter 1 of the Joint Technical Support Document for that rule.

[A] Note that WardsAuto.com is a fee-based service, but all information is public to subscribers.

[B] Motortrend.com and Edmunds.com are free, no-fee internet sites.

A1.3 The MY 2017-2025 Reference Fleet

The reference fleet aims to reflect the current market conditions and expectations about conditions of the vehicle fleet during the model years to which the agencies' rules apply. Fundamentally, constructing this fleet involved projecting the MY 2008 baseline fleet into the 2017-2025 model years. It also included the assumption that none of the models had changes during this period, in terms of both the technology present in the vehicles themselves, and the vehicles present in the fleet. Projecting what the fleet will look like in the future is a process that is inherently uncertain. NHTSA and EPA therefore relied on many sources of reputable information to make these projections.

A1.3.1 On what data is the reference vehicle fleet based?

EPA and NHTSA have based the projection of total car and light truck sales on recent projections made by the Energy Information Administration (EIA). EIA publishes a projection of national energy use annually called the Annual Energy Outlook (AEO).[3] EIA published its Annual Energy Outlook for 2010 in May 2010. Similar to the analyses supporting the MYs 2012-2016 rulemaking, the agencies have used the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) to estimate the future relative market shares of passenger cars and light trucks. However, the version of NEMS supporting EIA's Annual Energy Outlook 2010 (AEO2010) contains a "dummy variable" that forces the passenger car market share to increase after 2007, to facilitate projected compliance with EISA's requirement that the overall fleet achieve 35 mpg by 2020 (the car and truck volumes based on this analysis are shown in Table A1.3-1. Because we use our market projection as a baseline relative to which we measure the effects of new standards, and we attempt to estimate the industry's ability to comply with new standards without changing product mix, the AEO2010 projected shift in passenger car market share as a result of legislatively required fuel economy improvements creates a circular logic. Therefore, for the current analysis, a new projection of passenger car and light truck sales shares was developed by running scenarios from the AEO2010 reference case that first deactivate the above-mentioned dummy variable and holds post-2017 CAFE standards constant at MY 2016 levels. Incorporating these changes reduced the projected passenger car share of the light vehicle market by an average of about 5% during 2017-2025. This case is referred to as the Unforced Reference Case, and the values are shown below in Table A1.3-2.

Table A1.3-1 AEO Original Reference Case Values

Model Year	Cars	Trucks	Total Vehicles
2017	9,329,656	6,855,287	16,184,943
2018	9,375,428	6,595,148	15,970,576
2019	9,640,245	6,482,139	16,122,384
2020	10,105,479	6,436,088	16,541,566
2021	10,156,471	6,303,343	16,459,813
2022	10,178,345	6,166,611	16,344,956
2023	10,293,661	6,118,791	16,412,452
2024	10,516,662	6,166,036	16,682,698

2025	10,761,857	6,204,297	16,966,155

Table A1.3-2 AEO Unforced Reference Case Values

Model Year	Cars	Trucks	Total Vehicles
2017	8,783,816	7,401,127	16,184,943
2018	8,728,990	7,241,586	15,970,576
2019	8,899,836	7,222,548	16,122,384
2020	9,230,279	7,311,287	16,541,566
2021	9,265,881	7,193,932	16,459,813
2022	9,282,884	7,062,072	16,344,956
2023	9,382,100	7,030,352	16,412,452
2024	9,588,366	7,094,332	16,682,698
2025	9,817,211	7,148,944	16,966,155

Using the unforced reference case, EIA projects that total light-duty vehicle sales gradually recover from their currently depressed levels by roughly 2013. In 2017, car and light truck sales are projected to be 8.8 and 7.4 million units, respectively. While the total level of sales of 16.1 million units is similar to pre-2008 levels, the fraction of car sales is projected to be higher than that existing in the 2000-2007 timeframe. Note that EIA's definition of cars and trucks follows that used by NHTSA prior to the MY 2011 CAFE final rule. The MY 2011 CAFE final rule reclassified a number of 2-wheel drive sport utility vehicles from the truck fleet to the car fleet. EIA's sales projections of cars and trucks for the 2017-2025 model years under both the old NHTSA truck definition are shown above in Table A1.3-1 and Table A1.3-2.

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have also been changing and are expected to continue to change in the future. Manufacturers are continuing to introduce more crossover models which offer much of the utility of SUVs but use more car-like designs and unibody structures. In order to reflect these changes in fleet makeup, EPA and NHTSA used a custom long range forecast purchased from CSM Worldwide (CSM). CSM Worldwide (CSM) [4] is a well-known industry analyst, that provided the forecast used for the 2012-2016 final rule. NHTSA and EPA decided to use the forecast from CSM for several reasons. One, CSM agreed to allow us to publish their high level data, on which the forecast is based, in the public domain. Two, it covered all the timeframe of greatest relevance to this analysis (2017-2025 model years). Three, it provided projections of vehicle sales both by manufacturer and by market segment. Four, it utilized market segments similar to those used in the EPA emission certification program and fuel economy guide. As discussed further below, the CSM forecast is combined with other data obtained by NHTSA and EPA.

A1.3.2 How do the agencies develop the reference vehicle fleet?

The process of producing the 2017-2025 reference fleet involved combining the baseline fleet with the projection data described above. This was a complex multistep procedure, which is described in detail in the Joint Technical Support Document from the 2012-2016 final rule with an abbreviated discussion in this section.

A1.3.2.1 How was the 2008 baseline data merged with the CSM data?

Merging the 2008 baseline data with the 2017-2025 CSM data required a thorough mapping of certification vehicles to CSM vehicles by individual make and model. One challenge the agencies faced when determining a reference case fleet was that the sales data projected by CSM had different market segmentation than the data contained in EPA's internal database. In order to create a common segmentation between the two databases, side-by-side comparison of the specific vehicle models in both datasets was performed, and an additional "CSM segment" modifier in the spreadsheet was created, thus mapping the two datasets. The reference fleet sales based on the "CSM segmentation" was then projected.

In the combined EPA certification and CSM database, all of the 2008 vehicle models were assumed to continue out to 2025, though their volumes changed in proportion to CSM projections. Also, any new models expected to be introduced within the 2011-2025 timeframe are not included in the data. These volumes are reassigned to the existing models. All MY 2017-2025 vehicles are mapped to the existing vehicles by a process of mapping to manufacturer market share and overall segment distribution.

A1.3.2.2 How were the CSM forecasts normalized to the AEO forecasts?

The projected CSM forecasts for relative sales of cars and trucks by manufacturer and by market segment were normalized (set equal) to the total sales estimates of the AEO 2010 reference case. NHTSA and EPA used projected car and truck volumes for this period from AEO 2010. However, the AEO projects sales only at the car and truck level, not at the manufacturer and model-specific level, which are needed for the analysis. The CSM data provided year-by-year percentages of cars and trucks sold by each manufacturer as well as the percentages of each vehicle segment. Using these percentages normalized to the AEO-projected volumes then provided the manufacturer-specific market share and model-specific sales for model years 2017-2025 (it is worth clarifying that the agencies are not using the model-specific sales volumes from CSM, only the volumes by manufacturer and segment). This process is described in greater detail in Chapter 1 of the Joint Technical Support Document for the 2012-2016 final rule.

A1.3.3 What are the sales volumes and characteristics of the reference fleet?

Table A1.3-3 and Table A1.3-6 below contain the sales volumes that result from the process above for MY 2008 and 2017-2020. Table A1.3-4 and Table A1.3-5 below contain the sales volumes that result from the process above for MY 2021-2025.

Table A1.3-3 Vehicle Segment Volumes[a]

Reference Class Segment	Actual and Projected Sales Volume				
	2008	2017	2018	2019	2020
LargeAuto	557,693	381,148	361,437	361,164	406,604
MidSizeAuto	3,097,859	3,472,360	3,456,168	3,501,241	3,603,571
CompactAuto	1,976,424	2,452,469	2,432,700	2,500,944	2,598,610
SubCmpctAuto	1,364,434	2,530,789	2,529,308	2,588,403	2,674,638
All Cars	6,971,256	8,783,816	8,728,990	8,899,836	9,230,279
LargePickup	1,581,880	1,521,906	1,452,047	1,404,242	1,413,451
SmallPickup	177,497	156,992	158,850	163,210	148,911
LargeSUV	2,783,949	3,210,047	3,168,335	3,226,391	3,266,435
MidSizeSUV	1,263,360	1,365,334	1,316,762	1,286,724	1,311,146
SmallSUV	285,355	148,962	150,791	157,027	165,874
MiniVan	642,055	758,207	743,808	727,994	728,384
CargoVan	110,858	186,730	200,370	205,042	223,940
All Trucks	6,870,108	7,401,127	7,241,586	7,222,548	7,311,287

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table A1.3-4 Vehicle Segment Volumes[a]

Reference Class Segment	Actual and Projected Sales Volume				
	2021	2022	2023	2024	2025
LargeAuto	384,191	353,301	352,705	345,006	356,435
MidSizeAuto	3,604,960	3,635,168	3,732,222	3,781,545	3,835,289
CompactAuto	2,629,933	2,645,629	2,651,598	2,756,463	2,847,781
SubCmpctAuto	2,704,376	2,708,913	2,708,098	2,770,523	2,843,941
All Cars	9,265,881	9,282,884	9,382,100	9,588,366	11,461,493
LargePickup	1,352,502	1,302,512	1,251,253	1,226,935	1,215,296
SmallPickup	148,400	142,033	145,507	149,188	149,308
LargeSUV	3,274,899	3,245,920	3,281,687	3,353,515	3,395,154
MidSizeSUV	1,266,485	1,238,672	1,219,552	1,247,145	1,258,695
SmallSUV	165,290	163,744	163,691	167,086	169,425
MiniVan	720,675	713,307	712,312	695,336	700,287
CargoVan	208,102	195,757	193,828	189,957	194,544
All Trucks	7,193,932	7,062,072	7,030,352	7,094,332	5,504,662

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table A1.3-5 2011+ NHTSA Car and Truck Definition Based Volumes

Vehicle Type	Actual and Projected Sales Volume				
	2008	2017	2018	2019	2020
Trucks	5,620,847	5,846,663	5,703,588	5,667,948	5,714,586

Cars	8,220,517	10,338,280	10,266,989	10,454,435	10,826,981
Cars and Trucks	13,841,364	16,184,943	15,970,576	16,122,384	16,541,566

Table A1.3-6 2011+ NHTSA Car and Truck Definition Based Volumes

Vehicle Type	Actual and Projected Sales Volume				
	2021	2022	2023	2024	2025
Trucks	5,618,286	5,505,720	5,468,789	5,475,941	5,504,662
Cars	10,841,528	10,839,236	10,943,663	11,206,758	11,461,493
Cars and Trucks	16,459,813	16,344,956	16,412,452	16,682,698	16,966,155

Table A1.3-7 also shows how the change in fleet make-up may affect the footprint distributions over time. The resulting data indicate that footprint will not change significantly between 2008 and 2025. There will be an increase in the number of cars sold (as compared to trucks), which will cause the average footprints for cars and trucks combined to be slightly smaller (about 2%). This is the result of AEO projecting an increased number of cars, and CSM predicting that most of that increase will be in the subcompact segment.

Table A1.3-7 Production Foot Print Mean

Model Year	Foot Print Mean Cars	Foot Print Mean for Trucks	Foot Print Mean for Cars & Trucks Combined
2008	45.45	54.12	48.97
2017	44.94	53.93	48.19
2018	44.93	53.85	48.12
2019	44.92	53.76	48.03
2020	44.95	53.89	48.04
2021	44.93	53.81	47.96
2022	44.91	53.78	47.90
2023	44.93	53.66	47.84
2024	44.92	53.51	47.74
2025	44.92	53.47	47.69

Table A1.3-8 and Table A1.3-9 below show the changes in engine cylinders over the model years. The current assumptions show that engines will be downsized over the model years to which these rules apply. The biggest projected shift occurs between MY 2008 and 2013. This shift is a projected consequence of the expected changes in class and segment mix as predicted by AEO and CSM, and does not represent engine downsizing attributable to the rules.

Table A1.3-8 Truck Percentages of 4, 6, 8 Cylinder Engines by Model Year

Model Year	Percentage of 4 Cylinders	Percentage of 6 Cylinders	Percentage of 8 Cylinders
2008	10.33%	56.40%	33.27%
2017	10.94%	63.67%	25.39%
2018	10.65%	64.51%	24.84%
2019	10.42%	65.47%	24.12%
2020	10.29%	65.57%	24.14%
2021	10.28%	66.33%	23.39%
2022	10.26%	66.74%	23.00%
2023	10.26%	67.73%	22.01%
2024	10.47%	68.09%	21.44%
2025	10.52%	68.22%	21.26%

Table A1.3-9 Car Percentages of 4, 6, 8 Cylinder Engines by Model Year

Model Year	Percentage of 4 Cylinders	Percentage of 6 Cylinders	Percentage of 8 Cylinders
2008	56.99%	37.80%	5.20%
2017	60.63%	34.55%	4.82%
2018	60.70%	34.47%	4.83%
2019	60.72%	34.43%	4.85%
2020	60.39%	34.74%	4.87%
2021	60.75%	34.47%	4.78%
2022	61.19%	34.16%	4.65%
2023	61.05%	34.32%	4.63%
2024	61.12%	34.19%	4.68%
2025	61.20%	34.11%	4.69%

A1.3.4 How does manufacturer product plan data factor into the baseline?

In the spring and fall of 2009, many manufacturers submitted product plans in response to NHTSA's request. NHTSA and EPA both have access to these plans, and both agencies have reviewed them in detail. A small amount of product plan data was used in the development of the baseline. The specific pieces of data are:

- Wheelbase
- Track Width Front
- Track Width Rear
- Curb Weight
- GVWR (Gross Vehicle Weight Rating)

The track widths, wheelbase, curb weight, and GVWR for vehicles could have been looked up on the internet (159 were), but were taken from the product plans when available for convenience. To ensure accuracy, a sample from each product plan was used as a check against the numbers available from Motortrend.com. These numbers will be published in the baseline file since they can be easily looked up on the internet.

Appendix A References

All references can be found in Docket **EPA-HQ-OAR-2009-0472.**

[1] WardsAuto.com: Used as a source for engine specifications.

[2] Motortrend.com and Edmunds.com: Used as a source for foot print and vehicle weight data.

[3] Energy Information Administration's 2009 Annual Energy Outlook.

[4] CSM World Wide, CSM World Wide is a paid service provider.

Appendix B: Package Cost and Effectiveness

B1 Explanation of Technology Packages

As discussed briefly at the end of Chapter 3, EPA believes that manufacturers are likely to bundle technologies into –packages” to capture synergistic aspects and reflect progressively larger CO2 reductions with additions or changes to any given package. In addition, manufacturers typically apply new technologies in packages during model redesigns—which occur once roughly every five years—rather than adding new technologies one at a time on an annual or biennial basis. This way, manufacturers can more efficiently make use of their redesign resources and more effectively plan for changes necessary to meet future standards.

Therefore, the approach taken by EPA for purposes of this Technical Assessment Report is to group technologies into packages of increasing cost and effectiveness. While developing its analysis for the 2012-2016 rulemaking, EPA employed 19 different vehicle types for modeling the entire fleet. For the current assessment, we have used the same 19 vehicle types, with the exception that vehicle type 15 was replaced with a different baseline engine to provide us with a more appropriate set of technologies and packages for large cars with baseline V8 overhead valve engines. Each of these 19 vehicle types is mapped into one of six classes of vehicles: Subcompact, Small car, Large car, Minivan, Small truck, and Large truck. Note that, for the current assessment, EPA has created a new vehicle class called –Subcompact” which allows for greater differentiation of costs for this growing class of vehicles (such as the Honda Fit, the Toyota Yaris, and the new Ford Fiesta). Note also that these 19 vehicle types span the range of vehicle footprints—smaller footprints for smaller vehicles and larger footprints for larger vehicles—which served as the basis for the 2012-2016 GHG standards. The resultant 19 vehicle types, their baseline engines and their descriptions are shown in Table B1-1.

Table B1-1: List of 19 Vehicle Types used to Model the Light-duty Fleet

Vehicle Type #	Base Engine	Base Trans	Vehicle Class	Description
1	1.5L 4V DOHC I4	4sp AT	Subcompact	Subcompact car I4
2	2.4L 4V DOHC I4	4sp AT	Small car	Compact car I4
3	2.4L 4V DOHC I4	4sp AT	Small car	Midsize car/Small MPV I4
4	3.0L 4V DOHC V6	4sp AT	Minivan	Compact car/Small MPV V6
5	3.3L 4V DOHC V6	4sp AT	Large car	Midsize/Large car V6
6	4.5L 4V DOHC V8	4sp AT	Large car	Midsize car/Large car V8
7	2.6L 4V DOHC I4 (I5)	4sp AT	Minivan	Midsize MPV/Small truck I4
8	3.7L 2V SOHC V6	4sp AT	Small truck	Midsize MPV/Small truck V6
9	4.0L 2V SOHC V6	4sp AT	Minivan	Large MPV V6
10	4.7L 2V SOHC V8	4sp AT	Minivan	Large MPV V8
11	4.2L 2V SOHC V6	4sp AT	Large truck	Large truck/van V6
12	3.8L 2V OHV V6	4sp AT	Large truck	Large truck/MPV V6
13	5.7L 2V OHV V8	4sp AT	Large truck	Large truck/van V8
14	5.4L 3V SOHC V8	4sp AT	Large truck	Large truck/van V8
15	5.7L 2V OHV V8	4sp AT	Large car	Large car V8
16	3.5L 4V DOHC V6	4sp AT	Minivan	Large MPV V6
17	4.6L 4V DOHC V8	4sp AT	Minivan	Large MPV V8

18	4.0L 4V DOHC V6	4sp AT	Large truck	Large truck/van V6
19	5.6L 4V DOHC V8	4sp AT	Large truck	Large truck/van V8

To prepare inputs for the OMEGA model, EPA builds a –master-set” of technology packages. The master-set of packages for each vehicle type are meant to reflect the most likely technology packages manufacturers would consider when determining their plans for complying with future standards (as well as technology pathways described in Chapter 3 and 6). In other words, they are meant to reflect the most cost effective groups of technologies—those that provide the best trade-off of costs versus fuel consumption improvements. This is done by grouping reasonable technologies in all possible permutations and ranking those groupings based on the Technology Application Ranking Factor (TARF).[A] Grouping –reasonable technologies” simply means grouping those technologies that are complementary (*e.g.*, turbocharging plus downsizing) and not grouping technologies that are not complementary (*e.g.*, dual cam phasing and coupled cam phasing).

To generate the master-set of packages for each of the vehicle types, EPA has built packages in a step-wise fashion looking first at conventional gasoline technologies, then advanced gasoline technologies and then hybrid and other electrified vehicle technologies. This was done by presuming that auto makers would first concentrate efforts on conventional gasoline engine and transmission technologies paired with varying levels of mass reduction to improve fuel consumption. This is essentially the impact that the 2012-2016 rule will have as that rule did not rely heavily on advanced gasoline technologies or hybridization/electrification of the fleet. The initial levels of mass reduction considered were up to 15%.[B] Different pathways matched more intensive mass reductions with more advanced technologies.

Once the conventional gasoline engine and transmission technologies have been fully considered, we expect that auto makers would apply more complex (and costly) technologies such as advanced gasoline engines (turbocharged and cooled EGR technology for example) and further mass reduction (beyond 15%) in both the conventional and advanced gasoline packages.

From there, auto makers would most likely move to hybridization using one of two types of hybridization –P2 or 2-mode—depending on the vehicle type.[C] These hybrids could

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[A] The Technology Application Ranking Factor (TARF) is the factor used by the OMEGA model to rank packages and determine which are the most cost effective to apply. The TARF is calculated as the net incremental cost (or savings) of a package per kilogram of CO_2 reduced by the package relative to the previous package. The net incremental cost is calculated as the incremental cost of the technology package less the incremental discounted fuel savings of the package over 5 years. The incremental CO_2 reduction is calculated as the incremental CO_2/mile emission level of the package relative to the prior package multiplied by the lifetime miles travelled. More detail on the TARF can be found in the OMEGA model supporting documentation (see EPA-420-B-09-035).

[B] Importantly, the mass reduction associated for each of the 19 vehicle types was based on the vehicle-type sales weighted average curb weight.

[C] For the current assessment, we have considered P2 hybrids and 2-mode hybrids and have not considered power-split or other hybrid technologies. The 2-mode hybrid has been considered because it provides for hybridization of a vehicle while also maintaining acceptable towing capability. The P2 hybrid has been chosen employ either conventional or advanced gasoline engines and would be paired with varying levels of mass reduction ranging from 15% up to 30%.

Lastly, for some vehicle types, we anticipate that auto makers would move to more advanced electrification in the form of both range extended electric vehicles (REEV)[D] and full electric vehicles (EV). These also would be paired with varying levels of mass reduction from 15% up to 30%. In general the packages are generated in order of increasing complexity or cost.

Focusing first on the conventional gasoline packages, the first step in creating these packages was to consider the 8 primary categories of conventional gasoline engine technologies. These are:

- Our ―anytime technologies" (ATT) which consist of low friction lubes, engine friction reduction, aggressive shift logic (automatic transmission only), early torque converter lock-up (automatic transmission only), and low rolling resistance tires.
- Variable valve timing (VVT) consisting of coupled cam phasing (CCP, for OHV and SOHC engines) and dual cam phasing (DCP, for DOHC engines)
- Variable valve lift (VVL) consisting of discrete variable valve lift (DVVL, for DOHC engines)
- Cylinder deactivation (Deac, considered for OHV and SOHC V8 engines)
- Gasoline direct injection (GDI)
- Turbocharging and downsizing (TDS, which always includes a conversion to GDI)
- Stop-start
- Mass reduction consisting, in this step, of 3%, 5%, 10% and 15%.

In this first step, we also considered the 3 primary transmission technologies. These are:

- 6 speed automatic transmission (6sp AT)
- 6 speed dual clutch transmission with wet clutch (6sp wet-DCT)
- 6 speed dual clutch transmission with dry clutch (6sp dry-DCT)

In considering the transmissions, we had to first determine how each transmission could reasonably be applied. DCTs, especially dry-DCTs, cannot be applied to every vehicle type due to low end torque demands at launch. In addition, wet-DCTs are more efficient than 6sp ATs, and dry-DCTs are more efficient still. Further, each transmission has lower costs, respectively. Therefore, moving from 6sp AT to wet-DCT to dry-DCT as quickly as possible is preferable. Throughout this assessment, each of these transmissions were allowed on each

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because we believe that, in the timeframe of the current assessment, the P2 hybrid will provide the most cost effective approach to improving fuel consumption in vehicles that have no and/or comparatively low towing demands.

[D] We are using the term REEV synonymously with PHEV (plug-in hybrid electric vehicle) for the purposes of this analysis.

vehicle type giving consideration to the expected towing demands and curb weights as shown in Table B1-2 For example, vehicle type 5 is equipped with a 4 speed automatic transmission in the baseline. In a package consisting of a 3% to 20% mass reduction, we believe this vehicle type could convert to a wet-DCT because the lighter weight results in reduced low end torque demands thus making the wet-DCT feasible. Upon reaching 25% mass reduction, the vehicle type could employ a dry-DCT because the even lighter weight results in further reduction in low end torque demands. We note that we have estimated that all vehicle types will employ DCTs rather than 6 speed automatic transmissions, because we believe that the wet-DCT is capable of meeting the towing demands of the light-duty fleet while providing better efficiency and lower costs than the 6 speed automatic transmission, and it is thus reasonable to assume that all manufacturers will choose to employ wet-DCTs rather than 6 speed automatics.

Table B1-2: Application of Transmission Technologies in Building Packages

Vehicle Type #	Vehicle Class	Base Engine	Mass Reduction							
			0%	3%	5%	10%	15%	20%	25%	30%
1	Subcompact	I4	4spAT	6sp dry-DCT						
2	Small car	I4	4spAT	6sp dry-DCT						
3	Small car	I4	4spAT	6sp dry-DCT						
4	Minivan	V6	4spAT	6sp wet-DCT				6sp dry-DCT		
5	Large car	V6	4spAT	6sp wet-DCT					6sp dry-DCT	
6	Large car	V8	4spAT	6sp wet-DCT						
7	Minivan	I4	4spAT	6sp dry-DCT						
8	Small truck	V6	4spAT	6sp wet-DCT						
9	Minivan	V6	4spAT	6sp wet-DCT						
10	Minivan	V8	4spAT	6sp wet-DCT						
11	Large truck	V6	4spAT	6sp wet-DCT						
12	Large truck	V6	4spAT	6sp wet-DCT						
13	Large truck	V8	4spAT	6sp wet-DCT						
14	Large truck	V8	4spAT	6sp wet-DCT						
15	Large car	V8	4spAT	6sp wet-DCT						
16	Minivan	V6	4spAT	6sp wet-DCT						
17	Minivan	V8	4spAT	6sp wet-DCT						
18	Large truck	V6	4spAT	6sp wet-DCT						
19	Large truck	V8	4spAT	6sp wet-DCT						

We start by first building a ―preliminary-set” of conventional gasoline packages for each vehicle type consisting of combinations of each of these 8 primary engine technologies. The initial packages represent what we expect a manufacturer will most likely implement on all vehicles, including low rolling resistance tires, changes to accommodate low friction lubricants, engine friction reduction, aggressive shift logic, early torque converter lock-up and improved electrical accessories. Subsequent packages include more sophisticated gasoline engine and transmission technologies such as turbo/downsizing, GDI, increasing mass reduction and dual-clutch transmissions. This preliminary-set of conventional gasoline packages was ranked by its TARF for each vehicle type. The TARF ranking process eliminated some packages in favor of more cost effective packages. The packages that remained after the TARF ranking process were then included in the master-set of packages for each vehicle type.

Once the preliminary-set of conventional gasoline packages had been pared down and moved into the master-set of packages, the most effective (*i.e.*, not the most cost effective, but simply the most effective) of the conventional gasoline packages was paired with increasing levels of mass reduction up to 30%. Also, the advanced gasoline packages come in—note that all advanced gasoline packages are turbo/downsized GDI engines equipped with cooled EGR, dual cam phasing and discrete variable valve lift. We have built one advanced gasoline package without stop-start technology and one with. Each of these is then paired with increasing levels of mass reduction up to 30%. Even though these advanced technologies are paired with increased mass reduction, the model is able to isolate the effect of these individually in order to examine the separate technology pathways described in Chapter 3 and 6 of the TAR. The master-set of packages now consists of the most cost effective conventional gasoline packages with mass reductions ranging from 0% to 15%, the most effective conventional gasoline package with increasing levels of mass reduction up to 30%, and advanced gasoline packages (both with stop-start and without) with mass reduction levels ranging from 15% to 30%.

The next packages after the conventional and advanced gasoline packages are the HEVs. As noted, we have considered P2 and 2-mode HEVs for this assessment as discussed in section B4[E]. The agencies assumed that, for some of the vehicles types ranging in size up to and including ―Large Car", ―Minivan" and ―Small Truck", towing capacity could be reduced to approximately 1,500 pounds[F] on HEV models and that these vehicles would use a P2 HEV configuration. As described in Chapter 3, in some cases this reflects a loss in towing utility as compared to the baseline vehicle. For such vehicle types, consumers requiring greater towing capacity would select a non-HEV powertrain. The agencies assumed that the HEV versions of most of the larger vehicle types would require the same towing capacity as the baseline vehicle and a 2-mode HEV powertrain was selected for these vehicle types. The breakdown of HEV application is shown in Table B1-3.

Table B1-3: Types of Hybridization Considered in this Assessment

Vehicle Type #	Vehicle Class	Base Engine	HEV Type
1	Subcompact	I4	P2
2	Small car	I4	P2
3	Small car	I4	P2
4	Minivan	V6	P2

[E] P2 hybrids are defined and described in Chapter 3 (sction 3.2.3)

5	Large car	V6	P2
6	Large car	V8	P2
7	Minivan	I4	P2
8	Small truck	V6	P2
9	Minivan	V6	2-mode
10	Minivan	V8	2-mode
11	Large truck	V6	2-mode
12	Large truck	V6	P2
13	Large truck	V8	2-mode
14	Large truck	V8	2-mode
15	Large car	V8	P2
16	Minivan	V6	P2
17	Minivan	V8	2-mode
18	Large truck	V6	P2
19	Large truck	V8	2-mode

As done with conventional gasoline packages, we began with a preliminary-set of HEV packages that paired the HEV powertrain with increasing levels of engine technologies. For example, the preliminary-set of HEV packages would pair the HEV powertrain first with a very basic gasoline engine (*e.g.,* anytime technologies (ATT) and variable valve timing (VVT), such as dual cam phasing (DCP)), then a slightly more sophisticated gasoline engine (*e.g.,* ATT, DCP, GDI), then a more sophisticated gasoline engine (*e.g.,* ATT, DCP, GDI, turbo/downsize), then an advanced gasoline engine (*e.g.,* ATT, DCP, variable valve lift, GDI, turbo/downsize, cooled EGR), etc. We then ranked the preliminary-set of HEV packages according to TARF to generate the most cost effective set of HEV packages for each vehicle type that would then be included in the master-set of packages.

In general, the result of the TARF ranking of the preliminary-set of packages resulted in a master-set of packages that included three versions of HEV for each vehicle type. The first version employs a simple conventional gasoline engine such as one equipped with anytime technologies and valve timing control. The second employs a downsized/turbocharged gasoline engine and gasoline direct injection. The third employs an advanced gasoline engine with turbo/downsizing, direct injection and cooled EGR. Each of these versions of HEV was then paired with mass reduction levels ranging from 15% to 30%.

The last step was to build the REEVs and EVs for vehicle types 1 through 8 and 15. The other vehicle types were not considered for electrification beyond HEVs for purposes of the current analysis, either because of their expected towing demands or because of their high vehicle weight which would make the electrification of the vehicle prohibitively expensive. We have developed 2 primary types of REEV packages and 3 primary types of EV packages all of which are included in the master-set of packages. The REEVs consist of packages with battery packs capable of 20 miles of all electric operation (REEV20) and packages with battery packs capable of 40 miles of all electric operation (REEV40). For EVs, we have built packages capable of 75, 100 and 150 miles of all electric operation, EV75, EV100 and EV150, respectively. These ranges were selected to represent an increasing selection of ranges (and costs) that consumers will require and that we believe will be available in the

2020 timeframe. For each of these packages, we have estimated specific battery-pack costs for systems placed in vehicles with 15% and 20% mass reduction to the ―glider” (*i.e.,* the vehicle less any powertrain elements). We have then paired each REEV with 15%, 20%, 25% and 30% mass reduction and each EV with 15% and 20% mass reduction. Note that the REEVs with 25% and 30% mass reduction are not assumed to be constructed with the smaller battery packs and electric motors that would be possible with the 30%-lighter vehicle. This may make our estimates of cost effectiveness for REEVs with these higher mass reductions conservative since, while the higher mass reduction means lower fuel consumption and CO_2 emissions, those benefits are balanced against the higher costs of further mass reduction without accounting for the lower cost of a smaller battery pack and motor. The end result is a master-set of over 40 packages for those vehicle types with REEVs and EVs and as many as 30 packages for those vehicle types without REEVs and EVs. Because of the large number of total packages, Table B1-4 shows only the resultant master-set of packages for vehicle type 5, a large car with a V6 DOHC engine in the baseline. Note that a complete master-set of packages for each vehicle type along with their costs and effectiveness estimates is contained in a memorandum to the docket for this report.[1] Importantly, for each level of mass reduction, there is some level of expected engine downsizing made possible due to the lower vehicle weight. The analysis does not account for any cost credit for downsizing that consists only of minor displacement changes (*i.e.,* less than 20%)—only because we have not yet developed estimated costs or savings of doing so—even though the engine itself would contain somewhat less material. However, when a downsize occurs that consists of cylinders being removed (in the case of V8 to V6 and V6 to I4 downsizing) or a large displacement change (in the case of an I4 to smaller I4), we do consider the cost implications of the downsizing because we have tear-down data upon which to base our cost estimates.

Table B1-4: Technology Packages used in OMEGA for Vehicle Type 5, Large Car V6

Tech Pkg #	Mass Rdxn	Package Technologies	Transmission	Description
500	0%	3.3L 4V DOHC V6	4sp AT	Baseline Package
501	3%	4V DOHC I4+ATT+DCP+GDI+TDS	6sp DCT-wet	ATT=Anytime techs
502	5%	4V DOHC I4+ATT+DCP+GDI+TDS	6sp DCT-wet	DCP=dual cam phasing
503	15%	4V DOHC I4+ATT+DCP+GDI+TDS	6sp DCT-wet	GDI=gasoline direct injection, TDS=turbo/downsize
504	15%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS	6sp DCT-wet	DVVL=discrete variable valve lift
505	15%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-wet	SS=stop-start
506	15%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-wet	EGR=cooled EGR
507	15%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-wet	
508	20%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-wet	
509	25%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-dry	
510	30%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-dry	
511	20%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-wet	
512	25%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-dry	
513	30%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-dry	
514	20%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-wet	
515	25%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-dry	
516	30%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-dry	
517	15%	4V DOHC I4+ATT+DCP+DS+HEV	6sp DCT-wet	HEV=P2 for this vehicle type
518	20%	4V DOHC I4+ATT+DCP+DS+HEV	6sp DCT-wet	
519	25%	4V DOHC I4+ATT+DCP+DS+HEV	6sp DCT-dry	

520	30%	4V DOHC I4+ATT+DCP+DS+HEV	6sp DCT-dry	
521	15%	4V DOHC I4+ATT+DCP+GDI+TDS+HEV	6sp DCT-wet	
522	20%	4V DOHC I4+ATT+DCP+GDI+TDS+HEV	6sp DCT-wet	
523	25%	4V DOHC I4+ATT+DCP+GDI+TDS+HEV	6sp DCT-dry	
524	30%	4V DOHC I4+ATT+DCP+GDI+TDS+HEV	6sp DCT-dry	
525	15%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-wet	
526	20%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-wet	
527	25%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-dry	
528	30%	4V DOHC I4+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-dry	
529	15%	4V DOHC I4+ATT+GDI+DS+REEV20	6sp DCT-wet	
530	20%	4V DOHC I4+ATT+GDI+DS+REEV20	6sp DCT-wet	
531	30%	4V DOHC I4+ATT+GDI+DS+REEV20	6sp DCT-dry	
532	15%	4V DOHC I4+ATT+GDI+DS+REEV40	6sp DCT-wet	
533	20%	4V DOHC I4+ATT+GDI+DS+REEV40	6sp DCT-wet	
534	30%	4V DOHC I4+ATT+GDI+DS+REEV40	6sp DCT-dry	
535	15%	EV75 (27kWh, 75 miles onroad @ 314 Wh/mi)	N/A	
536	20%	EV75 (27kWh, 75 miles onroad @ 304 Wh/mi)	N/A	
537	15%	EV100 (39kWh, 100 miles onroad @ 323 Wh/mi)	N/A	
538	20%	EV100 (39kWh, 100 miles onroad @ 314 Wh/mi)	N/A	
539	15%	EV150 (63kWh, 150 miles onroad @ 346 Wh/mi)	N/A	
540	20%	EV150 (63kWh, 150 miles onroad @ 337 Wh/mi)	N/A	

To reiterate, some preliminary packages considered during the package creation process were determined to not be cost-effective when ranked with other packages for the given vehicle type. For example, the packages shown in Table B1-4 move immediately from the baseline package to a rather complex turbo/downsized package in package number 501. This does not mean that we did not consider packages consisting only of, for example, DCP or DCP+GDI when generating our preliminary-set of packages. Rather, it means that those packages simply were not as cost effective in this analysis, based on their Technology Application Ranking Factor (TARF), as was the package shown as #501. For that reason, the intermediate packages that were part of the preliminary-set of packages have simply been eliminated from consideration and have not been included in the master-set of packages since OMEGA will never pick them given the levels of potential standards considered in this Technical Assessment Report.

Once the master-set of packages is complete, they are all ranked once again based on TARF to generate the ―ranked-set” of packages for each of the technology paths discussed in Section 3.3 of the main report. While the master-set of packages is considered unchanging (at least in the context of this current analysis), the ranked-set of packages is different for each technology pathway because each pathway has different levels of, for example, mass reduction caps. For a technology pathway with a mass reduction cap of 15%, those packages with mass reductions greater than 15% would be eliminated from consideration and would not be included in the ranked-set of packages. Likewise, those packages having mass reductions greater than 20% would be eliminated in a technology pathway having a mass reduction cap of 20%. The package ranking also changes for each given year since technology costs and, hence, package costs change year-to-year. As a result, a ranked-set of packages in 2020 may or may not include the same packages as a ranked-set of packages in 2025 even if using the same mass reduction cap, and they may or may not be ranked in the same order.

B2 Engine Technologies

B2.1 Updated Tear-down Costs from FEV

As noted in Chapter 3, the agencies have reconsidered many of the costs used in the 2012-2016 joint final rule where those costs were based on tear-down studies conducted by FEV under contract to EPA. We have reconsidered these costs because, in the 2012-2016 light-duty final rule, the agencies relied on the FEV tear-down study findings in part for estimating the cost of several technologies. However, for some of the technologies, NHTSA and EPA modified FEV's actual estimated costs. This was done because FEV based their costs on the assumption that these technologies would be mature when produced in large volumes (450,000 units or more). The agencies believed that there was some uncertainty regarding each manufacturer's near-term ability to employ the technology at the volumes assumed in the FEV analysis with fully learned costs. There was also the potential for near term (earlier than 2016) supplier-level costs to be higher than those considered in the FEV analysis because existing equipment and facilities need to be converted to the production of new technologies and may lead to stranded capital if done too rapidly.[G] However, the agencies consider the FEV results to be valid for the 2017-2025 timeframe because the limitations considered in the 2012-2016 light-duty rule should no longer exist and sales volumes of 450,000 units are likely by then due to, at least in part, the new GHG and fuel economy requirements.

We reiterate that the agencies believe that the best method to derive technology cost estimates is to conduct studies involving tear-down and analysis of actual vehicle components. A tear-down analysis involves breaking down a technology into its fundamental parts and manufacturing processes by completely disassembling vehicles and vehicle subsystems and precisely determining what would be required for its production. More details about tear-down studies can be found in the studies supporting the 2012-2016 light-duty final rule as well as the FEV and Munro Associates report for EPA.[2] This tear-down method of costing technologies is often used by manufacturers to benchmark their products against competitive products. Historically, vehicle and vehicle component tear-down has not been done in large scale by researchers and regulators due to the expense required for such studies.

To date, such tear-down studies have been completed on the five technologies listed below. These completed tear-down studies provide a thorough evaluation of the component or system cost relative to their baseline (or replaced) technologies. A more detailed description of these technologies can be found in the Technical Support Document prepared for the 2012-2016 light-duty final rule.[3] For these technologies, the agencies have relied on the tear-down data available and scaling methodologies used in EPA's ongoing study with FEV.

[G] Stranded Capital is defined as manufacturing equipment and facilities that cannot be used in the production of a new technology.

1. Stoichiometric gasoline direct injection and turbocharging with engine downsizing (TDS) for a large DOHC (dual overhead cam) 4 cylinder engine to a smaller DOHC 4 cylinder engine.
2. Stoichiometric gasoline direct injection and turbo charging with engine downsizing for a SOHC (single overhead cam) 3 valve/cylinder V8 engine to a SOHC V6 engine.
3. Stoichiometric gasoline direct injection and turbo charging with engine downsizing for a DOHC V6 engine to a DOHC 4 cylinder engine.
4. 6-speed automatic transmission replacing a 5-speed automatic transmission.
5. 6-speed wet dual clutch transmission (DCT) replacing a 6-speed automatic transmission.

FEV's costing methodology for these studies has been published and has been peer reviewed.[4] Using this tear down costing methodology, FEV has developed costs for each of the above technologies. In addition, using the studies listed above, FEV and EPA were able to extrapolate the engine downsizing costs for the following scenarios to estimate costs presented in the 2012-2016 rule:

1. Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6.
2. Downsizing a DOHC V8 to a DOHC V6.
3. Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.
4. Downsizing a DOHC 4 cylinder engine to a DOHC 3 cylinder engine.

The costs used in the 2012-2016 rule and the updated costs used in this assessment are shown in Table B2.1-1.

Table B2.1-1: Comparison of Stoichiometric Gasoline Direct Injection, Turbo/Downsizing and Transmission Costs, Inclusive of Markups, used in the 2012-2016 Rulemaking versus this Assessment

	2012-2016 rulemaking; applicable to the 2012MY (2007 dollars)	2012-2016 rulemaking; applicable to the 2016MY (2007 dollars)	Assessment Report; applicable to the 2017MY (2008 dollars)	Assessment Report; applicable to the 2025MY (2008 dollars)
Stoichiometric GDI (I3/I4)[a]	$236	$209	$213	$181
Stoichiometric GDI (V6) [a]	$341	$301	$370	$299
Stoichiometric GDI (V8) [a]	$390	$346	$446	$360
Turbo/Downsize I4 DOHC to I3 DOHC[b]	$395	$349	$287	$245
Turbo/Downsize I4 DOHC to smaller I4 DOHC[b]	$441	$391	$365	$311
Turbo/Downsize V6 DOHC to I4 DOHC[b]	$168	$149	-$27	-$3
Turbo/Downsize V6 SOHC to I4 DOHC[b]	$365	$323	$110	$107
Turbo/Downsize V6 OHV to I4 DOHC[b]	$872	$771	$754	$628
Turbo/Downsize V8 DOHC to V6 DOHC[b]	$669	$592	$491	$428
Turbo/Downsize V8 SOHC	$923	$816	$649	$555

2V/cyl to V6 DOHC				
Turbo/Downsize V8 SOHC 3V/cyl to V6 DOHC[b]	$832	$736	$590	$507
Turbo/Downsize V8 OHV to V6 DOHC[b]	$1,242	$1,099	$1,101	$920
6 speed automatic transmission (from a 4 speed automatic transmission) [a]	$112	$99	-$13	-$10
6 speed dual wet-clutch transmission (from a 4 speed automatic transmission) [a]	$104	$92	-$134	-$108
6 speed dual dry-clutch transmission (from a 4 speed automatic transmission) [a]	$53	$47	-$190	-$153

[a] Low complexity ICMs applied: 2012MY=1.11; 2016MY=1.11; 2017MY=1.17; 2025MY=1.13. The 2012MY and 2016MY ICMs differ from the 2017MY ICM—all considered near term—due to factors described in Section 3.2.5 of the main report. The 2025MY ICM is a long term ICM.

[b] Medium complexity ICMs applied: 2012MY=1.25; 2016MY=1.25; 2017MY=1.31; 2025MY=1.19. The 2012MY and 2016MY ICMs differ from the 2017MY ICM—all considered near term—due to factors described in Section 3.2.5 of the main report. The 2025MY ICM is a long term ICM.

B2.2 Advanced Gasoline Cost and Effectiveness

B2.2.1 Turbocharged/downsized Engines with Gasoline Direct Injection

In the 2012-2016 final rule, the agencies estimated the combined effectiveness of turbocharging, engine downsizing and GDI in reducing GHG emission to be 7%. Recent data supports GHG effectiveness in the range of 12 to 30% depending on the extent of engine downsizing for a given engine torque requirement.[5,6,7] Taking into consideration the availability of more recent published data and confidential business information, the Agencies estimate the effectiveness of a Turbocharged GDI with single-stage turbocharging, dual cam-phasing and with downsizing consistent with a BMEP level of approximately 22-24 bar to be 15%.

B2.2.2 Cooled EGR

A new technology considered for this assessment was cooled EGR with turbocharging. This technology was described briefly in the 2012-2016 GHG and CAFE final rule but the technology was not used in the cost and effectiveness analysis. Cooled EGR can prevent combustion knock and thus allows for an increase in engine compression ratio and/or more aggressive engine downsizing when combined with turbocharging and gasoline direct injection while maintaining torque output and vehicle performance. Cooled EGR with aggressive engine downsizing (approximately 24-bar BMEP), single-stage turbocharging, dual cam phasing and discrete variable valve lift has been estimated by Ricardo to reduce CO2 emissions over both the UDDS and highway fuel economy test by 23%.[8] The incremental effectiveness of cooled EGR relative to a downsized, turbocharged GDI engines without EGR has been estimated to reduce BSFC by various sources to be approximately 5 to 13%.[5,9,10,11] Based on the cited publically available data and confidential business information, the Agencies estimate the incremental effectiveness of cooled EGR with single-stage variable geometry turbocharging and with downsizing consistent with approximately 24-bar BMEP to be 6% relative to turbocharging, downsizing and GDI without cooled EGR as described in section B2.2.1; and 20% relative to a baseline 2008 PFI engine. We expect to update the effectiveness values of this technology for the NPRM based on vehicle simulation modeling currently being conducted under an EPA contract with Ricardo.

The costs for the technology here build upon the costs presented in the 2012-2016 rule which showed costs of $75 for an EGR cooler, $20 for an EGR valve and $20 for associated piping for a total direct manufacturing cost of $115 (2007 dollars). We have updated each of those costs to 2008 dollars with the results being $77, $20 and $20, for a total of $117. To provide sufficient transient engine control, we have assumed that a dual-loop EGR system will be used with both high and low pressure EGR loops. We have doubled EGR component costs to $235 to reflect components in both EGR loops and have added a $5 venturi to provide for EGR flow from the low pressure exhaust system to the high pressure intake system, thus giving a total of $240 for the cooled EGR portion of the system. Because the system is expected to employ higher levels of boost over a broader range of flow conditions than the conventional gasoline turbocharged system, we have also included a 1.5x factor to the turbocharger costs to cover the incremental cost increase of a variable geometry turbocharger. In other words, the turbocharger system cost is 1.5x greater on engines with cooled EGR than on downsized, turbocharged engines without cooled EGR. This was estimated based on engineering judgment with input from suppliers. Therefore, to the $240 value, we have added $620 for I-configuration engines (1.5x the single turbocharger cost of $413 equals $620) and $1,043 (1.5x the twin turbocharger cost of $695 equals $1,043) for V-configuration engines (one turbocharger per cylinder bank, which is conservative as it is possible that not all V-configuration engines will use twin turbochargers). The results being $859 ($240+$620) for I-configuration engines and $1,283 ($240+$1,043) for V-configuration engines (direct manufacturing costs, 2008 dollars, 2012MY). All of the costs stated thus far represent direct manufacturing costs in 2008 dollars and are applicable to the 2012 model year. We consider time based learning to be applicable to this advanced gasoline technology. The resultant direct manufacturing cost and marked up costs are shown in Table B2.2-1 Importantly, these costs shown here do not represent package costs since they do not include the anytime technologies,[H] DCP, DVVL, GDI, or downsizing related costs or other technologies that might be included in an advanced gasoline package (such as stop-start or hybridization).

Table B2.2-1: Cooled EGR System Costs (2008 dollars)

	Direct Mfg Costs			Costs with ICM		
Year	2012	2020	2025	2012	2020	2025
I-configuration engines	$859	$701	$634	$1,125	$878	$754
V-configuration engines	$1,283	$1,048	$947	$1,681	$1,304	$1,127

[H] Anytime technologies are simpler technologies that can be added outside the normal redesign cycle, thus they can be implemented anytime. An example is low rolling resistance tires.

ICM applied				1.31	1.31	1.19

B3 Transmission Technologies

B3.1 6, 7, and 8 speed Automatic Transmissions

As discussed in the 2012-2016 rule, manufacturers can choose to replace 4- and 5-speed transmission with 6-, 7-, or 8-speed automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional planetary gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers need to develop strategies for smooth shifts. Some manufacturers are replacing 4- and 5-speed automatics with 6-speed automatics, and 7- and 8-speed automatics have also entered production, albeit in lower-volume applications in luxury and performance oriented cars.

As discussed in the 2012-2016 rule, confidential manufacturer data projected that 6-speed transmissions could incrementally reduce fuel consumption by 0 to 5 percent from a baseline 4-speed automatic transmission, while an 8-speed transmission could incrementally reduce fuel consumption by up to 6 percent from a baseline 4-speed automatic transmission. GM has publicly claimed a fuel economy improvement of up to 4 percent for its new 6-speed automatic transmissions.[12] The 2008 EPA Staff Technical Report found a 4.5 to 6.5 percent fuel consumption improvement for a 6-speed over a 4-speed automatic transmission.[13] Based on this information, the agencies estimated that the conversion to a 6-,7- and 8-speed transmission from a 4 or 5-speed automatic transmission with IATC would have an incremental fuel consumption benefit of 1.4 percent to 3.4 percent, for all vehicle classes. From a baseline 4 or 5 speed transmission without IATC, the incremental fuel consumption benefit would be approximately 3 to 6 percent, which is consistent with the EPA Staff Report estimate.

The agencies reviewed these effectiveness estimates and concluded that they remain accurate. The GHG model estimates the packaged effectiveness of 4.5 to 6.5 percent.

The cost associated with 6 speed automatic transmissions has been updated for this assessment relative to the estimates presented in the 2012-2016 rule. These updated costs are presented above in Table B2.1-1 Dual Clutch Transmissions / Automated Manual Transmissions.

An Automated Manual Transmission (AMT) is mechanically similar to a conventional manual transmission, but shifting and launch functions are automatically controlled by the electronics. There are two basic types of AMTs, single-clutch and dual-clutch (DCT). A single-clutch AMT is essentially a manual transmission with automated clutch and shifting. Because of shift quality issues with single-clutch designs, DCTs will likely be far more common in the U.S. and are the basis of the estimates that follow. A DCT uses separate clutches (and separate gear shafts) for the even-numbered gears and odd-numbered gears. In this way, the next expected gear is pre-selected, which allows for faster and smoother shifting.

For example, if the vehicle is accelerating in third gear, the shaft with gears one, three and five has gear three engaged and is transmitting power. The shaft with gears two, four, and six is idle, but has gear four engaged. When a shift is required, the controller disengages the odd-gear clutch while simultaneously engaging the even-gear clutch, thus making a smooth shift. If, on the other hand, the driver slows down instead of continuing to accelerate, the transmission will have to change to second gear on the idling shaft to anticipate a downshift. This shift can be made quickly on the idling shaft since there is no torque being transferred on it.

In addition to single-clutch and dual-clutch AMTs, there are also wet clutch and dry clutch designs which are used for different types of vehicle applications. Wet clutch AMTs offer a higher torque capacity that comes from the use of a hydraulic system that cools the clutches. Wet clutch systems are less efficient than the dry clutch systems due to the losses associated with hydraulic pumping. Additionally, wet AMTs have a higher cost due to the additional hydraulic hardware required.

Overall, DCTs likely offer the greatest potential for effectiveness improvements among the various transmission options presented in this report because they offer the inherently lower losses of a manual transmission with the efficiency and shift quality advantages of electronic controls. The lower losses stem from the elimination of the conventional lock-up torque converter, and a greatly reduced need for high pressure hydraulic circuits to hold clutches or bands to maintain gear ratios in automatic transmissions. However, the lack of a torque converter will affect how the vehicle launches from rest, so a DCT will most likely be paired with an engine that offers sufficient torque at low engine speeds to allow for adequate launch performance.

Referring to the 2012-2016 rule, these transmissions offer an effectiveness of 9.5 to 14.5 percent over a 4-speed automatic transmission. The agencies conclude that 8 to 13 percent effectiveness is still appropriate for this rule. The costs associated with 6 speed dual clutch transmissions have been updated for this assessment relative to the estimates presented in the 2012-2016 rule. These updated costs are presented above in Table B2.1-1. EPA had hoped to include in this assessment FEV-generated tear-down cost estimates for an 8 speed dual clutch transmission. Unfortunately, that work was not complete in time, but it is expected to be used in the upcoming federal NPRM.

B4 Vehicle Technologies

B4.1 Aerodynamic Improvement Cost and Effectiveness

This can be achieved via two approaches, either reducing the drag coefficients or reducing vehicle frontal area. To reduce drag coefficients, skirts, air dams, underbody covers, and more aerodynamic side view mirrors can be applied, or the vehicle ride height can be lowered. In addition to the standard aerodynamic treatments, the agencies have included a second level of aerodynamic technologies (Aero 2) which could include active grille shutters, rear visors, and larger under body panels. The GHG and fuel economy effectiveness of 2% is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule, and is based on a 10% assumed reduction in aerodynamic drag coefficient . This second level of aerodynamic technologies was not considered in the 2012-2016 light-duty rule and, as such, the estimated costs are new and are presented in Table B4.1-1 along with the first level (Aero 1) as used in the 2012-2016 rule. Effectiveness for Aero 2 is based on an additional 10% reduction in aerodynamic drag coefficient from the 2008 baseline and provides another 2% reduction in GHG. Note that we apply time based learning to aerodynamic improvements.

Table B4.1-1: Costs Associated with Aerodynamic Improvements (2008 dollars)

Direct Manufacturing Costs (applicable to the 2015MY)				
Technology	Quantity	$/unit	$/vehicle Low	$/vehicle High
Aero 1 (incremental to base vehicle)				
Air dam	1	$15-20	$15	$20
Tire spats	4	$2.50		$10
Under body panels	1	$15-20	$15	$20
Total (Average=$40)			$30	$50
Aero 2 (incremental to base vehicle)				
Under body panels	3, 4	$10-20	$30	$80
Active grill shutters	1	$25-40	$25	$40
Rear visors – hood, liftgate, tailgate	1	$15-20	$15	$20
Low profile roof rack – stowable cross bows	1	$30		$30
Total (Average=$120)			$70	$170
Marked up costs				
Technology	Year→	2015	2020	2025
Aero 1 (ICM: Near term=1.17; Long term=1.13)		$47	$40	$36
Aero 2 (ICM: Near term=1.31; Long term=1.19)		$157	$128	$115

B4.2 Electrified Vehicles Costing – HEV, PHEV, and EV Vehicles

While the overall methodology for costing electrified vehicles has not changed from the 2012~2016 rule the scaling and cost basis for both batteries and electric motors has been modified. Specifically, cost information developed by Oak Ridge National Laboratory (ORNL) on electric motors has been applied, as well as battery costing information from Argonne National Laboratory (ANL). Refer to the Technical Support Document (TSD)[14] for the 2012-2016 rule for a full description of the electrified vehicle costing methodology.

B4.2.1 Changes to the 2017-2025 Electrified Vehicle Costing

Unless otherwise noted, the cost basis and scaling for electrified vehicles in the 2017-2025 analysis is identical to that used in the 2012-2016 rule. There are, however, several changes to the cost basis due to various factors. The first was agreement within the agencies that the mass of electrified vehicles would continue to be reduced while energy densities of batteries are expected to increase. These trends made the current battery and motor sizing strategies inappropriate for this analysis. In addition, recent data from ANL, which has been corroborated with battery manufacturer data, indicates that battery costs will be dependent on not only the annual production volume, but also the ratio of the power to energy. The agencies, once again, determined that the application of a fixed $/kW-hr value was not appropriate going forward. One of the caveats in applying the ANL cost model was that it was highly dependent of production volumes, volumes at which batteries will on be produced until approximately MY 2025. As such, the electrified vehicle costing model was to apply time based learning to the non-battery costs, as those are based on the 2012 -2016 rule, and treat the ANL battery costs as 2025 values. With regard to motor costs, the agencies leveraged a cost study performed by ORNL on the Toyota Prius[15] motor costs and applied the ORNL results directly. Further detail for each of these considerations is provided below.

B4.2.1.1 P2 Hybrid Electric Vehicles

A P2 hybrid is a vehicle with an electric drive motor coupled to the engine crankshaft via a clutch. The engine and the drive motor are mechanically independent of each other, allowing the engine or motor to power the vehicle separately or combined. This is similar to the Honda HEV architecture with the exception of the added clutch between the flywheel or flexplate and the electric motor, additional battery capacity, and increased electric motor power. Examples P2 hybrids include the 2011 Hyundai Sonata Hybrid, 2010 Hyundai Elantra LPI HEV (Korean market only), the 2011 Infinity G35 Hybrid and the 2011 Volkswagen Touareg Hybrid. The agencies believe that the P2 is an example of a ―strong" hybrid technology that is typical of what we will see in the timeframe of this rule. The agencies could have equally chosen the power-split architecture as the representative HEV architecture. These two HEV's have comparable average GHG effectiveness values (combined city and highway fuel economy), though the P2 systems may have lower cost due to reduced number of parts and complexity.

The Agencies estimated the effectiveness of the P2 hybrid system to be 30% within our analysis. The effectiveness when combined with a DCT transmission is approximately 37%. The effectiveness used for vehicle packages with the P2 hybrid configuration within this analysis reflects a conservative estimate of system performance. Vehicle simulation modeling of technology packages using the P-2 hybrid configuration is currently underway under contract with Ricardo Engineering. The agencies plan to update the effectiveness of hybrid electric vehicle packages using the new Ricardo vehicle simulation modeling runs prior to the NPRM.

Hybrid effectiveness was also applied differently across vehicle classes within this analysis when compared to the 2012-2016 rule. Previously, the Agencies assumed less engine downsizing and reduced effectiveness with increasing vehicle size to preserve some light-towing capability for large cars, CUVs, minivans and small light trucks. For this analysis, P2 hybrid packages were only applied to vehicles with reduced towing capability (SAE Class I or less) and the relative effectiveness due to engine downsizing with the P2 hybrid package was applied equally across all vehicle categories capable of receiving the P2 hybrid package in the Omega model.

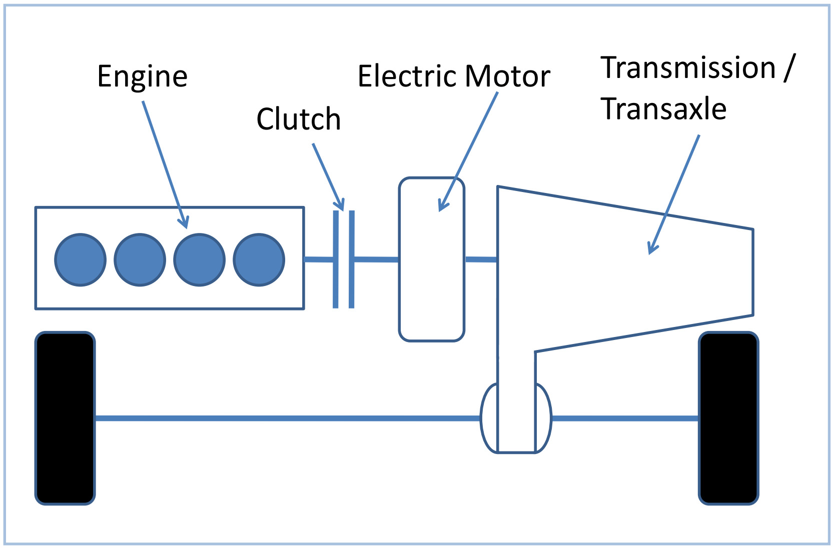


Figure B4.2-1: Functional schematic of P2 hybrid electric vehicle powertrain configuration (not to scale).

B4.2.1.2 Battery and Motor Sizing

Baseline vehicle effective power-to-weight ratio[I] was used to approximate equivalent performance for EVs, PHEVs and P2 hybrids. Electric motors were sized based on maintaining this ratio for EV, PHEV and hybrid[J] vehicles. In addition, some level of mass reduction is expected to be realized for these types of vehicles, so the motor sizing was dependent on the final, mass reduced, vehicle. Motor size for PHEVs assumed full vehicle performance could be achieved on electric motor drive only. The Agencies scaled P2 hybrid motors to represent 20% of the vehicle's (combined) effective power, as supported by manufacturer's confidential information.

The battery packs were sized to provide 75, 100 or 150 mile on-road[K] ranges in the case of EVs and 20 or 40 mile on-road ranges in the case of PHEVs. Battery sizing for EVs and PHEVs was based on a vehicle energy demand estimate (derived from EPA's lumped parameter model) used to determine each vehicle's electric energy consumption, in Wh/mile, for future EV, PHEV and hybrid packages (which considers road load and weight reductions).

[I] To compare with conventional ICE-powered vehicles, we use ―effective" vehicle power -defined here as the peak combined power of the vehicle's engine and electric motor. In the case of P2 hybrids it is assumed that the peak rated power values are additive, although this is not necessarily true for other architectures (such as power-split hybrids, where the engine and motor power peaks do not occur at the same operating speed)

[J] Vehicle weight reduction when applied to EVs and PHEVs was applied to the glider only (curb-weight less electric drive components). Weight reduction was applied to the entire vehicle in the case of HEVs.

[K] EVs and PHEVs are assumed to experience an onroad range shortfall of 30%, whereas HEVs are assumed to see a shortfall of 25%. In terms of energy consumption (and thus battery size), this represents an increase of 43% and 33% for EVs/PHEVs and HEVs, respectively.

Additionally, battery usable state-of-charge (SOC) windows[L] were assumed at 80% for future EVs, 70% for future PHEVs and 50% for future HEVs.

B4.2.1.3 Battery Cost

Battery costs were determined using a model developed by Argonne National Laboratory (ANL) which provides unique battery pack cost estimates for each of the three major types of electrified vehicles. Within the model, battery pack costs are estimated based on a bill of materials determined by battery pack design criteria. The costs include materials, manufacturing processes, cost of capital equipment, plant area and labor for each manufacturing step. A basic description of the ANL Li-ion battery cost model and initial modeling results for PHEV applications were published within a peer-reviewed technical paper presented at EVS-24[16]. ANL has extended modeling inputs and pack design criteria within the cost model to include analysis of manufacturing costs for EV and HEV battery packs in addition to the original work on PHEV battery costs.[17] A thorough peer-review of the ANL Li-ion battery cost model and its inputs and results is pending. The agencies expect to continue to work with DOE and ANL (as well as manufacturers) to obtain the most up to date information for the upcoming NPRM.

Within the ANL battery cost model, a bill of materials for a battery pack is determined based on specific design criteria. The design criteria include a vehicle application's power and energy storage capacity requirements, the battery's cathode and anode chemistry, and the number of cells per module and modules per battery pack. The model assumes use of a laminated multi-layer prismatic cell and battery modules consisting of double-seamed rigid containers (Figure B4.2-2). The model also assumes that the battery modules are air-cooled. The model takes into consideration the cost of capital equipment, plant area and labor for each step in the manufacturing process for battery packs and places relevant limits on electrode coating thicknesses and other processes limited by existing and near-term manufacturing processes. Figure B4.2-3 shows a basic schematic of the plant layout and production steps assumed within the model The ANL model also takes into consideration annual pack production volume and economies of scale for high-volume production.

[L] On-road range is defined as the percentage of a battery pack's useful operating range. For durability and safety reasons, electric vehicle batteries are not discharged completely, nor are they typically operated at fully charged levels. Because of this limitation, . Thus the nominal battery size required always larger than that which is used, and is calculated as the actual required capacity divided by the SOC window.

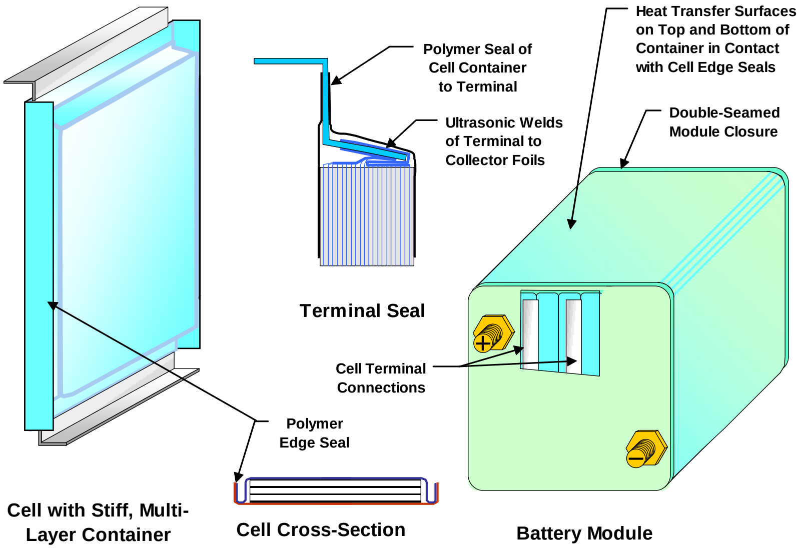


Figure B4.2-2: Prismatic Cell and Module Design for High Power-to Energy HEV Battery Packs (provided courtesy of Argonne National Laboratory).

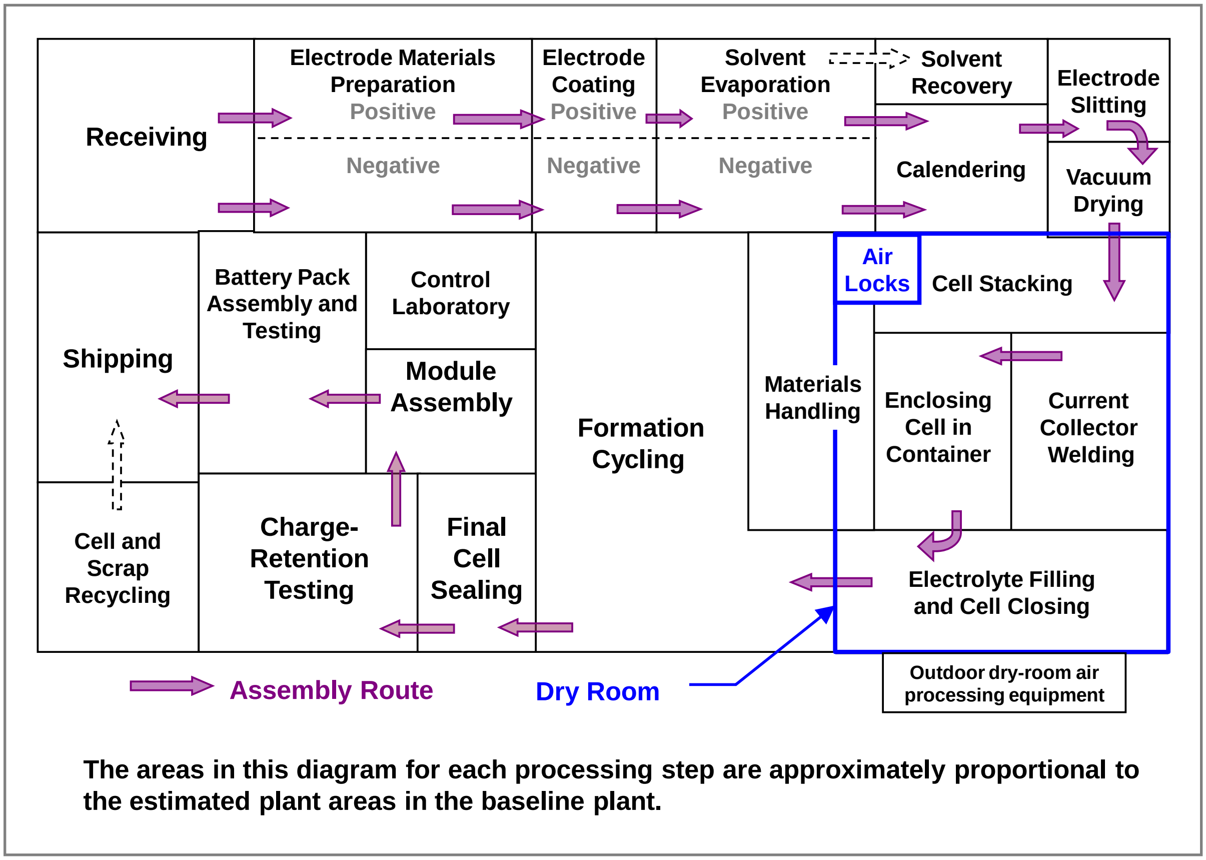


Figure B4.2-3: Lithium-ion Battery Pack Manufacturing Plant Schematic Diagram (provided courtesy of Argonne National Laboratory).

The cost outputs from the ANL model used by the Agencies to determine 2025 HEV, PHEV and EV battery costs assume 500,000 pack/year production volume. We also assumed the use of a common cathode and anode chemistry, LiMn2O4-spinel for the cathode and graphite for the anode. While it is expected that other Li-ion battery chemistries will likely be available in the 2017-2025 timeframe, the specific chemistry used for the cost analysis was chosen to be consistent with publicly available information on current and near term HEV, PHEV and EV product offerings from Hyundai, GM and Nissan.[18,19,20,21] The battery designs used in the model also assumed full power delivery at 80% of the open circuit voltage. For EVs, battery power was assumed to be sufficient to provide peak motor power for an application with 15% added to account for HVAC and other non-motor electric loads. For HEVs and PHEVs, battery power was assumed to be sufficient to provide peak motor power for an application. The ANL battery cost model results for is compared to the costs used in the 2012-2016 final rule and to cost estimates compiled by EPA from OEM battery suppliers and auto OEMs in Figure B4.2-4.

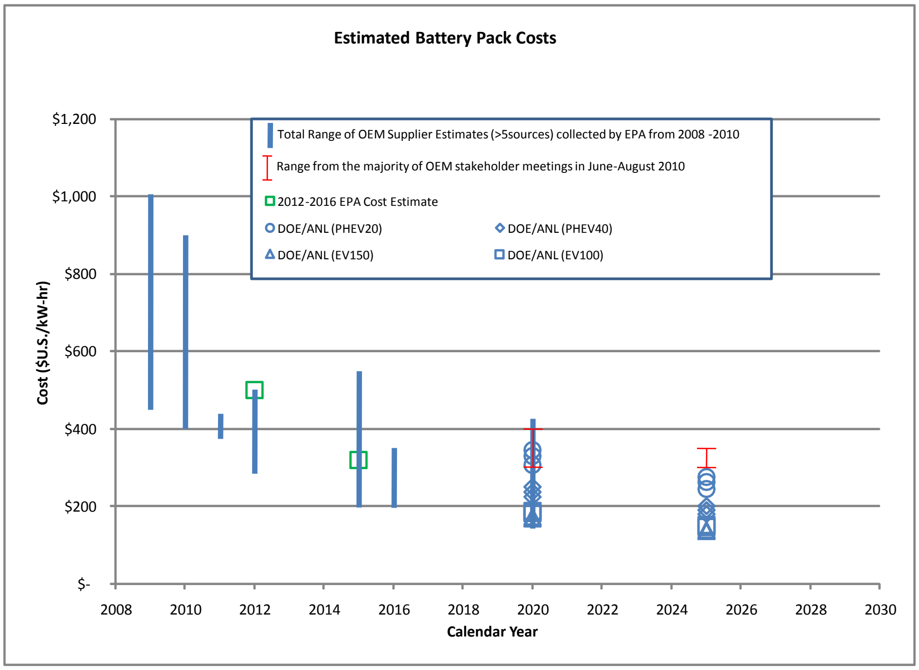


Figure B4.2-4: Comparison of direct manufacturing costs per unit of energy storage ($/kW-hr) between the estimates used by EPA in the 2012-2016 GHG final rule, the ANL battery cost model results for PHEV20, PHEV40, EV100 and EV150 packages and OEM battery suppliers (2008 dollars, markups not included). Multiple points shown for the ANL cost model results for PHEV 20, PHEV40, EV100 and EV150 reflect the range of energy-specific costs for EPA's subcompact through large-car package categories (see Table B4.2-1 for details). A range of OEM estimated battery costs is also shown for comparison (red bars) which may or may not reflect additional cost markups.

A PHEV and EV battery cost sensitivity analysis is included in Chapter 6, section 6.5 of the Technical Assessment. The analysis includes PHEV and EV battery pack costs approximately $100/kW-hr higher and $50/kW-hr lower than the costs estimates from the ANL battery cost model. The $100/kW-hr higher cost is comparable to commodity pricing for high-volume LiCoO2 cells for consumer applications. The $50/kW-hr lower cost assumes a breakthrough in battery design that would approximately triple cell energy density.

B4.2.1.4 Motor Costing

The agencies agreed that based on a review of the technical literature the cost-vs-power relationship should not be a constant $15/kW across motor sizes. A linear relationship was chosen based on 2007 Camry/Prius motor and generator costs (based on ORNL/EEA-estimated costs) and treated as near-term (2012-2016) results. The motor sizing, determined as described above was then applied to the linear cost model developed by ORNL:

- y (motor cost in USD) = 8.28 * (motor size in kW) + 181.43

The final value is then learned down from 2012 to 2025 by applying time based learning.

B4.2.1.5 Learning Applied to Battery and Non-Battery Costs

As described above, the battery costs developed using the ANL model were considered the 2025 model year costs expressed in 2008 dollars. In contrast, the remaining parts of the hybrid or electrified vehicle system, termed the non-battery costs, were considered the 2012 model year costs expressed in 2008 dollars. While the non-battery systems are considered rather mature technologies for which time based learning is appropriate, the Li-ion battery system is a new technology for which volume based learning is more appropriate. In fact, the agencies believe it is likely that battery technology will undergo several levels of volume based learning between 2012 and 2025 given the newness of the technology and the rapid pace of development. For this reason, we have generated a unique learning curve for the battery system technology that attempts to estimate costs back in time from the 2025 estimates discussed above. This allows us to estimate costs in the 2020 timeframe for OMEGA as well as estimate those costs in each year between today and 2025. The learning curve we have generated is shown in Figure B4.2-5. This learning curve consists of 5 full volume based learning steps each of which results in costs being reduced 20% relative to the prior step. These learning steps are shown occurring every two years beginning in 2012 until 2020 at which time a 5 year gap is imposed until 2025 when the ANL costs are reached and the learning curve factor equals 1. Beyond 2025, time based learning is applied at 3% cost reductions per year. The smooth line shows a logarithmic curve fit applied to the learning curve as EPA's cost model would apply learning.

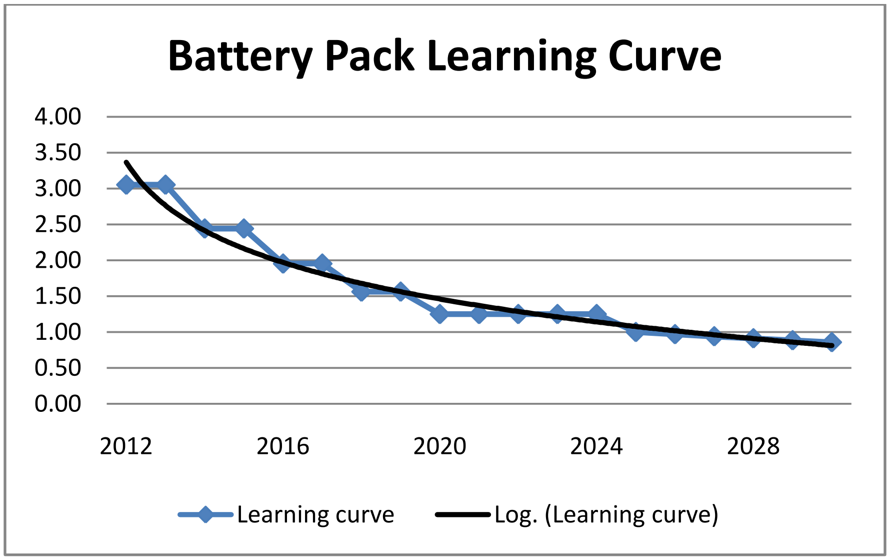


Figure B4.2-5: Battery Pack Learning Curve

Using this learning curve, we can estimate the battery pack direct manufacturing costs for each year and for each type of battery pack. These details are shown in Table B4.2-1 which shows, in the upper portion of the table, the estimated direct manufacturing costs for each type of battery pack considered (for a large car in this example) and in the lower portion the $/kWh estimated in each year based on the learning curve shown in Figure B4.2-5.

Table B4.2-1: Direct Manufacturing Costs for Battery Packs and Associated $/kWh for Each, Costs for a Large Car (2008 dollars, markups not included)

Cost Element	2012	2015	2018	2019	2020	2021	2022	2023	2024	2025
Battery Pack Costs										
P2 battery pack	$1,956	$1,565	$1,002	$1,002	$801	$801	$801	$801	$801	$641
REEV20 battery pack	$7,120	$5,696	$3,645	$3,645	$2,916	$2,916	$2,916	$2,916	$2,916	$2,333
REEV40 battery pack	$10,461	$8,368	$5,356	$5,356	$4,285	$4,285	$4,285	$4,285	$4,285	$3,428
EV75 battery pack	$14,276	$11,421	$7,309	$7,309	$5,847	$5,847	$5,847	$5,847	$5,847	$4,678
EV100 battery pack	$18,170	$14,536	$9,303	$9,303	$7,443	$7,443	$7,443	$7,443	$7,443	$5,954
EV150 battery pack	$26,869	$21,495	$13,757	$13,757	$11,005	$11,005	$11,005	$11,005	$11,005	$8,804
Cost per Kilowatt-hour										
$/kWh (P2)	$2,964	$2,371	$1,518	$1,518	$1,214	$1,214	$1,214	$1,214	$1,214	$971
$/kWh (REEV20)	$809	$647	$414	$414	$331	$331	$331	$331	$331	$265
$/kWh (REEV40)	$581	$465	$298	$298	$238	$238	$238	$238	$238	$190
$/kWh (EV75)	$501	$401	$256	$256	$205	$205	$205	$205	$205	$164
$/kWh (EV100)	$464	$371	$237	$237	$190	$190	$190	$190	$190	$152
$/kWh (EV150)	$426	$341	$218	$218	$174	$174	$174	$174	$174	$140

B4.2.1.6 In-home Charger Costs

We have also estimated cost associated with in-home chargers and installation of in-home chargers. Charger costs are covered in more detail in Section 4.2.3 of the main report. Here we summarize the actual costs used for developing EV and REEV package costs. We have estimated the cost of a level 1 charge cord at $30 (2008 dollars) based on typical costs of similar electrical equipment sold to consumers today and that for a level 2 charger at $200 (2008 dollars). Labor associated with installing either of these chargers is estimated at $1,000 (2008 dollars). Further, we have estimated that all REEV20 vehicles (REEVs with a 20 mile range) would be charged via a level 1 charger and that all EVs, regardless of range, would be charged via a level 2 charger. For the REEV40 vehicles (REEVs with a 40 mile range), we have estimated that: 25% of subcompacts would be charged with a level 1 charger with the remainder charged via a level 2 charger; 10% of small cars would be charged with a level 1 charger with the remainder charged via a level 2 charger; and all remaining REEV 40 vehicles would be charged via a level 2 charger. All costs presented here are considered valid for the 2025 model year. We have applied the learning curve presented above in Section B4.2.1.5 to the charger costs. We have also applied our High 2 ICMs to these costs (1.70 through the 2021MY and 1.45 thereafter). Installation costs, being labor costs, have no learning impacts or ICM applied. The resultant costs for 2017, 2020 and 2025 are shown in Table B4.2-2. These costs are included in our package costs for all REEV and EV packages.

Table B4.2-2: In-home Charger Related Costs for REEVs and EVs (2008 dollars)

Technology	Vehicle Class	2017	2020	2025
REEV20-Charger	Subcompact Small car Large car Minivan Small truck	$100	$64	$44
REEV40-Charger	Subcompact	$523	$335	$228
	Small car	$608	$389	$265
	Large car Minivan Small truck	$664	$425	$290
EV-Charger	Subcompact Small car Large car Minivan Small truck	$664	$425	$290
Labor	Subcompact Small car Large car Minivan Small truck	$1,000	$1,000	$1,000

B4.3 Mass Reduction Cost Model

Application of mass reduction technologies for 2017-2025 vehicles has been discussed at length in meetings with vehicle manufacturers in preparation for this Technical Assessment Report. One of the challenges the manufacturers identified with respect to mass reduction was the feasibility of substituting some lower density materials for higher density materials. These issues included material availability, forming, joining, painting, corrosion, reparability, and impact performance. The agencies agree that these issues need further study in order to determine the feasibility of certain types of mass reduction and the appropriateness of assuming their applicability in the MYs 2017-2025 timeframe for purposes of the upcoming federal rulemaking.

To begin to address these issues, the collaborative NHTSA, EPA, and DOE team described in Chapter 3 has focused on several tasks including a peer review of the Lotus Engineering report[22] regarding holistic vehicle mass reduction opportunities, a 2nd phase of analysis by Lotus Engineering to assess the functional performance and safety of phase 1 designs and to modify designs as appropriate through computer aided engineering (CAE), and two projects being conducted by DOE regarding, one regarding mass reduction feasibility and the other consisting of an actual vehicle build (Multi Material Vehicle – MMV[M]). NHTSA and EPA may also consider jointly funding a study to evaluate potentially feasible amounts of mass reduction and their accompanying cost for MY 2017-2025 separately from the study contracted to Lotus engineering by CARB. Computer Aided Engineering (CAE) tools would be used to analyze the structure of the vehicle. The proposed design should meet at least the same functional objectives as the baseline vehicle. If funded, this study would be designed to be finished in time for incorporation in the final rule analysis.

For the 2012-2016 final rule, NHTSA and EPA relied on a 2015 cost of $1.32 (2007$) per pound of mass reduction, and the limit of mass reduction (penetration cap) was set to 10% based on our feasibility analysis.[23] This cost was estimated by calculating an average of the costs estimated in three studies: 2002 NAS report (normalized estimated cost $1.50/lb)[24], Sierra Research (normalized estimated cost $1.01/lb for 10% mass reduction with compounding)[25], and MIT (normalized estimated cost $1.36/lb for 14% mass reduction without mass compounding).[26] The $1.32 per pound cost would be $1.35 per pound in 2008 dollars. With a year of time-based learning at 3% per year the cost would be $1.31 (2008$) per pound in 2016 and with 4 years of time-based learning at 2% per year would be $1.20 (2008$) per pound in 2020.

However, in the 2017-2025 timeframe, many of the OEMs indicated in meetings with the agencies over the summer that they will be capable of higher levels of mass reduction than 10 percent per vehicle. The OEMs also generally stated that there is some initial amount of mass reduction which can be accomplished with zero or very little cost (much lower than that estimated in the 2012-2016 rule of $1.32/lb), but emphasized that higher percentages of mass reduction may result in higher costs and that these costs are likely to increase non-linearly with increasing mass reduction levels. In response to this stakeholder feedback and based on our own preliminary analysis of the potential for vehicle mass reduction in the 2020 and 2025 timeframe, the agencies have begun updating our mass reduction cost model to reflect this progressively increasing level of cost. A simple non-linear cost model is introduced below that has been employed for purposes of this Technical Assessment Report, but EPA and NHTSA intend to rely on additional studies for the upcoming federal rulemaking that are expected to be complete before the NPRM and final rule. The collaborative team has taken several actions to inform the cost model, including meeting with vehicle manufacturers, DOE's update of their 2007 study on feasibility and cost, and EPA funding a 3rd party cost assessment of the Lotus Report.

The agencies developed the non-linear cost model for mass reduction for purposes of this Technical Assessment Report by averaging the 2012-2016 linear cost for mass reduction in 2025 with the cost estimate for the High Development Case in the Lotus Engineering study, and then drawing a parabolic curve between $0 for 0 percent mass reduction and that average dollar value at 32 percent mass reduction. While the agencies recognize that there have been a number of vehicle mass reductions studies conducted in the literature in the past 10 years[27]

[M] DOE Notice of Intent to Issue Funding Opportunity Announcement N.:DE-FOA-000239. http://www.netl.doe.gov/business/solicitations/NOTICE%20OF%20INTENT.pdf

[28] [29] [30] [31], a complete literature review is beyond the scope of the report, and thus the agencies believe that the mass reduction feasibility and cost study conducted by Lotus Engineering in 2010 is the most comprehensive vehicle mass reduction study conducted to date.

Lotus Engineering purchased a 2009 Toyota Venza (a crossover SUV, or CUV) and tore the vehicle down, analyzing every subsystem of the vehicle. The study split the mass reduction into two phases: “low” and ―high” development, to represent different potential levels of mass reduction. For the low development case, the majority of the body in white (BIW) weight reduction was accomplished by converting mild steel to high strength steel. In addition, all vehicle components and subsystems were compared to the best-in-class vehicle mass leaders and substituted (and scaled) to the Venza, which allowed significantly more weight reduction and the use of mass decompounding. This approach provided an extremely cost effective manner of reducing weight and cost compared to other studies in the literature that attempted to evaluate reducing similar amounts of mass. In the high development case, Lotus considered much more material substitution in the BIW, from steel to aluminum, magnesium, plastic and other materials, and relied extensively on completely novel (and smart) design of all possible components to reduce mass in all vehicle systems. Table B4.3-1 summarizes the cost results from this study:

Table B4.3-1: Costs for Mass Reduction Based on the Lotus Engineering Study*

		Low Development (19% mass reduction)		High Development (32% mass reduction)	
Cost per vehicle	Lower bound	-$400	-$1600	$600	-$600
	Upper bound		$800		$1800
Cost per pound	Lower bound	-$0.55	-$2.20	$0.50	-$0.50
	Upper bound		$1.10		$1.49

* Estimates assume a total variable (or piece) cost of the Toyota Venza to be $20,000

The agencies note that some limitations exist for the Lotus study. First, Lotus analyzed these considerable levels of mass reduction based on a single vehicle. The agencies acknowledge that most of the improvements described in the report can be applied across all vehicles to varying degrees, but due to the expense and time of the study, it is impractical for our current purposes to conduct similar studies across many different vehicles. Second, Lotus’ cost estimates were based on manufacturer (OEM) piece costs due to the initial scope of the study, and only partially included the manufacturer tooling and assembly plant costs. As mentioned earlier, follow-up studies are being planned to improve these cost estimates. Third, the designs created by Lotus for the low and high development cases have not been shown to meet FMVSS safety regulations and voluntary NCAP and IIHS guidelines, or to achieve vehicle functional performance similar to the baseline vehicle. Each of these issues is being addressed in the Phase 2 Lotus study, but was not addressed in time for this Technical Assessment Report.

The Lotus study also shows that it is possible to take up to 19% of the mass out of the vehicle at no cost (cost savings in fact) by using less costly piece costs for many components based on their benchmarking analysis. The agencies agree that it may be possible to remove mass at a cost savings on many vehicles – there are a number of other studies that have similar conclusions. However, the agencies are concerned about assigning a negative cost value at the higher ranges of what some of the manufacturers shared was the maximum feasible (approximately 20% mass reduction) within the 2017-2025 timeframe. Therefore, the agencies are pursuing further cost studies to confirm all of the costs (including manufacturing and tooling) before using the Lotus results directly. The agencies do acknowledge that the Lotus study included a high degree of uncertainty in the cost estimates, and that some degree of mass reduction may be possible at a cost savings.

The agencies note that most manufacturers stated in stakeholder meetings over the summer that they anticipate that future safety and emission regulatory requirements will require increases in vehicle mass and, in addition, they intend to implement voluntary safety improvements that will increase vehicle mass. Net mass reduction for the 2017-2025 timeframe will thus actually be the mass reduction achieved through methods similar to those identified in studies discussed above, but offset by mass increases for safety and emission regulations and voluntary safety improvements. Manufacturers also frequently stated that they already have incorporated varying levels of mass reduction in current production vehicles. The agencies have not considered these baseline factors explicitly in estimating the cost for mass reduction that is being used for this assessment.

Thus, to model how mass reduction costs could increase at a non-linear rate for purposes of this Technical Assessment Report, the agencies have relied on a parabolic shape for the cost curve – where the cost per pound increases as the square of the percentage mass reduction. To determine the magnitude of the curvature, the parabola was calibrated to go through a designated ―high value" at 32% mass reduction. To determine this high value, the agencies averaged the $1.20/lb (2008$ in the 2020MY) value developed using the 2012-2016 rule methodology, with the Lotus high development cost figure of $0.50/lb at 32% mass reduction (as described above). This averaging represents two factors. First, that the agencies believe that the cost used in the 2012-2016 rule appropriately captures the longer timeframe and improved design optimization methods that are likely to lower costs in the 2017-2025 timeframe; but on the other hand, that the agencies believe that a constant value, independent of the complexities involved with greater levels of mass reduction, is not realistic. And second, as described above, the agencies believe that the Lotus costs on their own are too low, due to the missing manufacturing and tooling costs. The averaging of the two costs offsets the missing Lotus costs. A variety of non-linear curves could have been employed, however, the 2nd order polynomial defines the simplest model, which seemed reasonable for the current analysis. The curve has the shape shown in Figure B4.3-1.

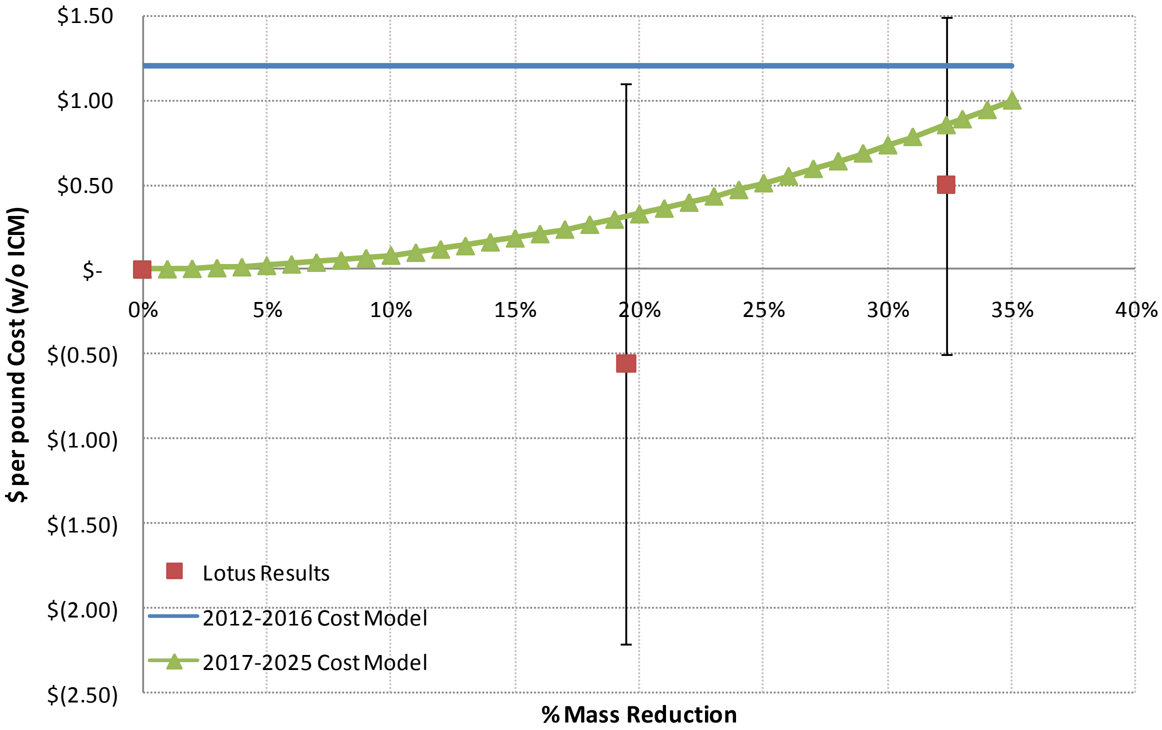


Figure B4.3-1: Mass Reduction Cost Model in Dollars per Pound in Model Year 2020 Compared to the Lotus Results and 2012-2016 Final Rule Cost.

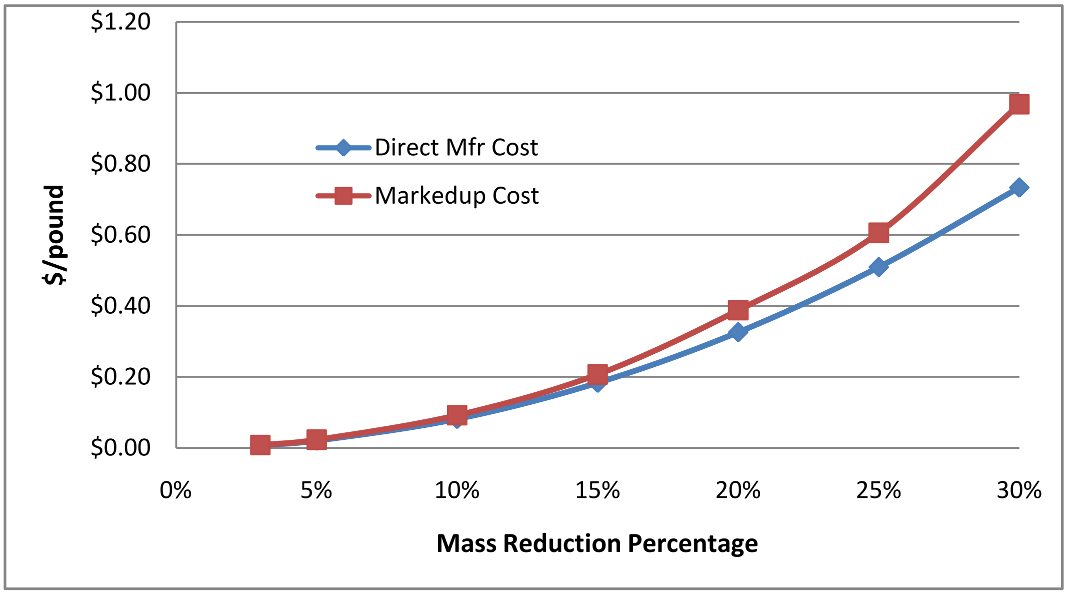
Accounting for the indirect cost markup (ICM) on the mass reduction cost model, the agencies believe that it is appropriate to assign higher markups for the higher levels of mass reduction due to their increased complexity and lead time required. Descriptions of these different levels of ICM are in Chapter 3. Table B4.3-2 shows this increasing ICM with mass reduction levels.

Table B4.3-2: Indirect Cost Markup Factors for Increasing Levels of Mass Reduction

Mass Reduction	Complexity	ICM Near Term	ICM Long Term
3%	Low	1.17	1.13
5%	Low	1.17	1.13
10%	Low	1.17	1.13
15%	Low	1.17	1.13
20%	Medium	1.31	1.19
25%	Medium	1.31	1.19
30%	High 1	1.51	1.32

Accounting for the ICMs, the model with and without markups is shown in Figure B4.3-2.

Figure B4.3-2: Mass Reduction Cost Model in 2008 Dollars per Pound in Model Year 2020 With and Without Indirect Cost Markups



As mentioned earlier, the agencies continue to explore avenues of increasing the fidelity of the mass reduction cost model, and believe that there are studies that are currently or anticipated being conducted which will improve the fidelity of the points used to calibrate this model and which may be employed for the upcoming federal rulemaking.

B5 Fuel Cell Vehicle Technology Cost, Effectiveness and Lead-time Assessment

B5.1 Technology Summary

The state of fuel cell vehicle (FCV) technology has seen significant progress towards the U.S. Department of Energy (DOE) 2015 performance targets over the last few years. Fuel cell stack durability has more than doubled since 2006 and high volume production system cost has been reduced by over 80% since 2002 (additional details are provided below). Progress is still required in the areas of fuel cell costs, durability, and on-board hydrogen storage. However, the technology has matured sufficiently for commercialization, and production launch is feasible in the 2015-2017 time-frame. First generation vehicles will likely require financial incentives to initiate the market (as is currently planned for battery technologies).

B5.2 Fuel Cell Costs

Based on the most recent fuel cell system cost analysis by Directed Technologies, Inc (DTI[32]), contracted by DOE, today's fuel cell technology when produced at high volumes would have a cost of $51/kW (system net power). Additionally, projected 2015 technology at high volume production would cost $39/kW. For a 100kW system in a large car (vehicle type 5), this would equate to $3,945 (not including hydrogen storage). The analysis for this report bundled the fuel cell system costs with the electric drive component costs consistent with how the EV and PHEV technology packages were developed. For FCVs, this analysis assumed a system sized for the large car platform (vehicle type 5), and included the HEV battery pack and hydrogen storage costs in addition to the system noted above.

The system costs noted above are the fully-learned, high volume production costs from DTI. However, these production volumes are not assumed to be achieved by 2025 for this analysis. FCV production levels of ~85,000 per year in the U.S. were assumed, representing approximately 0.5% of the U.S. LDV market in 2025. This is discussed further in Section B4.3.4. At these lower production levels, the incremental fuel cell system direct manufacturing cost is closer to +$4,800.

As part of this analysis, fuel cell vehicle production costs were developed by relying on the 2015 technology costs from DTI along with the non-fuel cell electric drive component costs from the EPA OMEGA model. Figure B5.2-1 below shows the simulated production costs for a 100kW fuel cell system (average system size for larger vehicle platforms in this analysis). Note this is not the full FCV production cost which would include the full electric drive bill of material. Also not shown is the retail price markup (ICM); FCVs are assumed to have the same ICM as the EV and PHEV vehicle types, using the high complexity ICM values noted earlier in Appendix B.

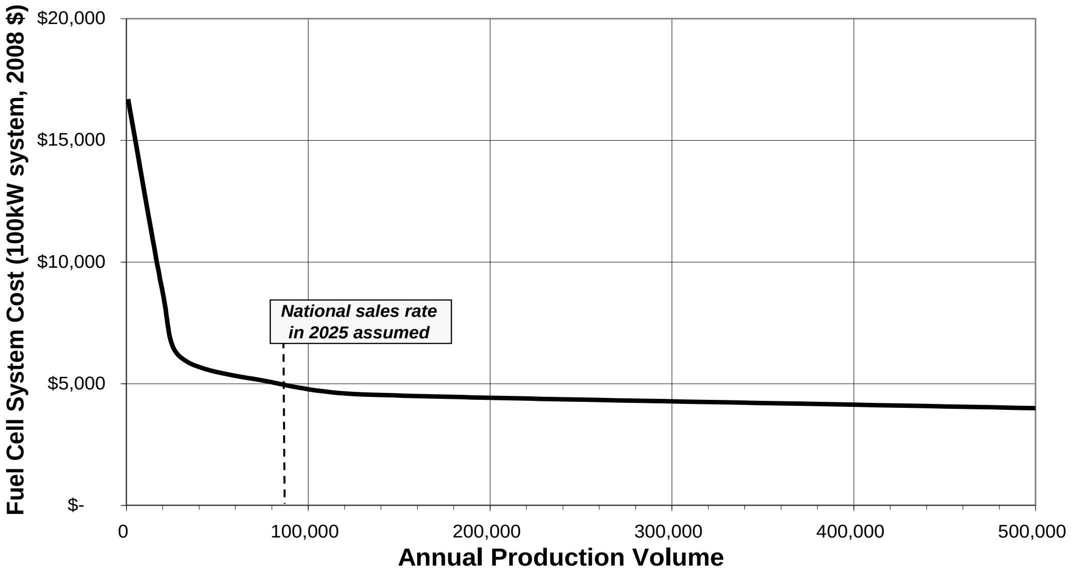


Figure B5.2-1: FC Production Cost Curve for a 100kW system (not including H2 storage)

(Sources: DTI (cost curve), extrapolation to 100kW)

Figure B5.2-2 shows the summary breakdown of vehicle costs at the high volume production level. The fuel cell system cost at this level is based on the DTI $39/kW high volume data point. Compared to the 2010 DTI system estimate, this 2015 production cost assumes system improvements, including the elimination of external humidification components, elimination of an air expander, and slightly higher membrane operating temperatures that allow the reductions in the radiator and cooling loop size. For fuel cell stack costs, DTI assumes platinum loadings of 0.15 mg/cm^2. In addition to the fuel cell system, the battery pack modeled was the lithium-ion battery assumed for HEVs in Table B4.2-1. Balance of EV drive components include drive motors, controllers, DC/DC converters, electric AC and heating, and a few other components. Finally, as noted above, the hydrogen storage system cost was assumed to be $10/kWh, notably higher than the DOE 2015 target given the lower production volumes.

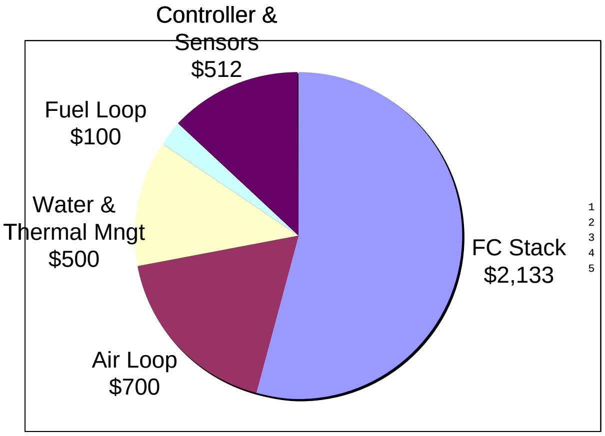


Figure B5.2-2: Detailed fuel cell system costs at high volume production

(Source: DTI, CARB)

Table B5.2-1 shows the resulting direct manufacturing costs for the 2020 and 2025 model years, highlighting the higher costs compared to the fully learned production levels at the far right of Figure B5.2-1.

Table B5.2-1: Fuel cell direct manufacturing costs at assumed production volumes

	2020MY	**2025MY**
U.S. FCV Sales	20,000	85,000
Fuel cell system cost (100 kW)	$ 5,900	$ 4,800
Hydrogen storage cost (4 kg @ $10/kWh)	$1,320	$1,320

Finally, as a reference, DOE's analysis of various hydrogen storage systems was reviewed. The production costs for various on-board hydrogen storage technology alternatives were analyzed by TIAX under contract to DOE[33]. This analysis assumed high pressure gaseous storage remained the technology choice in 2025, although the cryo-compressed alternative is receiving increased attention by major OEMs. The current DOE 2010 target is $4/kWh and the 2015 target is $2/kWh, although DOE is planning to revise these targets soon. For the 2025 FCV simulated in this analysis, a storage cost of $10/kWh was assumed given production levels will not reach the fully mature point.

B5.3 Performance Status

Automakers are nearing DOE 2015 performance targets and continue to push the technology toward commercial readiness, as documented in the DOE 2009 Report to Congress[34]. A few of the key accomplishments are listed below and further information can be found at DOE's Hydrogen Program Accomplishments webpage[35].

- Significantly reduced the cost of automotive fuel cells (from $275/kW in 2002 to $51/kW in 2010 (DTI), based on projections of high-volume manufacturing costs)
- Doubled the durability of fuel cell systems in vehicles operating under real-world conditions (data in 2006 showed 950-hour durability—today, this number is 2500 hours, equivalent to approximately 75,000 miles of driving)
- Reduced the cost of producing hydrogen from both renewable resources and natural gas (hydrogen can now be produced by distributed reforming of natural gas at a projected high-volume cost of $3.00/gallon gasoline equivalent; this does not take into account FCV efficiency gains over an ICE which would improve these operating costs further)
- Independently validated a real-world driving range of 450 miles for an FCV from one of the major OEMs.

The table below summarizes the cost, durability, and efficiency targets along with the status of today's technology as assessed by DOE's Technology Validation Program.[36]

Table B5.3-1: Current Status and U.S. DOE Targets for Automotive Fuel Cells

	2009 (Current Status)	2010 (Cost Update)	2010 Target	2015 Target
System Efficiency	53-59%		60%	60%
System Cost	$61 /kW	$51 /kW [37]	$45 /kW	$30 /kW
Fuel Cell System Durability	2,500 hours (~75,000 mi)		2,000 hours (~60,000 mi)	5,000 hours (~150,000 mi)
Vehicle Range	254 miles [38]		250 miles	300 miles
H2 Storage Costs		$20 /kWh [39]	$4 /kWh	$2 /kWh

Fuel cell system volume and weight have been largely reduced and are expected to achieve the targets, allowing for marketable vehicle integration. For example, the Honda FCX

Clarity's fuel cell stack is 1/5 the weight and 1/4 the volume compared to the previous FCV model[40]. The weight and volume progress are a result of improvements in fuel cell materials (stamped metal flow plates, aromatic membrane structure, reductions in catalyst loading) and fuel cell simplification (part-count reduction, improved manufacturing). A detailed summary of the performance of the Generation 2 FCVs being evaluated in the DOE Technology Validation Program can be found in the NREL presentation to the 2010 DOE Merit Review[41].

FCVs have achieved the DOE 2015 efficiency targets already, which translates into large energy and greenhouse gas reductions compared to conventional vehicles. Although the full well-to-wheel (WTW) GHG reductions depend on the fuel source, hydrogen produced from natural gas and used in an FCV results in WTW GHG reductions of 50% compared to a projected internal combustion engine vehicle, and 20% compared to a projected hybrid vehicle[42]. Given that the vehicle powertrain is a zero emission technology, all emissions are generated from the fuel production and delivery stages.

B5.4 Hydrogen Storage

As noted above, the majority of FCV technology requirements necessary for a marketable vehicle have been addressed through continued R&D and demonstration. This includes rapid start-up, cold-start operation, stack power density, balance-of-plant (BOP) operation, and efficiency. On-board hydrogen storage is one of the remaining challenges that will require further development. This will not prevent the commercial launch of FCVs, however, as adequate storage systems are available for use in early commercial vehicles. The storage technology chosen by the majority of OEMs for existing FCVs is high pressure (700 bar or 10,000 psi) gaseous storage. Although volumetric density, cost, and station dispensing complexity (a need for pre-cooling) are not ideal, the technology is ready today.

Technologies under consideration by OEMs and energy companies for next generation vehicles include intermediate pressure gaseous storage (between 350 and 700 bar where pre-cooling won't be required) and cryo-compressed hydrogen storage. The latter has the promise of higher volumetric density, lower cost, and substantially reduced fuel boil-off (in engine-off mode) compared to liquid storage[43].

Additional FCV and hydrogen storage information can be found from the following DOE resources.

- 2010 U.S. DOE Merit Review Proceedings, June 2010.
  http://www.hydrogen.energy.gov/annual_review10_proceedings.html
- 2009 U.S. DOE Hydrogen Program Annual Progress Report, November 2009.

  http://www.hydrogen.energy.gov/annual_progress09.html

B5.5 Commercialization Status

Production announcements have been made by at least three major OEMs for a 2015 launch. Production volumes will depend in part on the hydrogen infrastructure rollout in strategic locations where early customers are expected. In the U.S., this is likely to be in

Southern California and New York where infrastructure is emerging. Based on two independent confidential surveys of OEMs and their FCV plans (conducted by the CaFCP[44] and CARB/CEC), up to 50,000 FCVs could be deployed in California by 2018 (cumulative on-road).

Hydrogen infrastructure continues to be a large challenge for FCVs in preparation for vehicle commercialization in 2015. Addressing this challenge requires stakeholder coordination and sustained commitments from both the public and private sectors. However, this activity is progressing in California, with actions coordinated by the CaFCP, CARB and CEC. The state is providing large cost-share incentives for hydrogen stations (led by CEC), and strategic planning is relying on concepts outlined in the CaFCP's 2009 Action Plan[45] and 2010 Progress and Next Steps, as well as the UC Davis Roadmap.[46]

For the purposes of identifying production costs in this analysis, annual production volumes were estimated. Broadly based on California's Zero Emission Vehicle Regulation as well as hydrogen infrastructure advancements in California and a few other states, it was assumed FCVs would comprise 0.5% of the U.S. LDV market in 2025. With a total assumed LDV market of 16.5 million vehicles, this equates to annual sales volumes of 85,000 nationally. Although these levels are lower than previous FCV scenarios by the DOE (ORNL[47]) and the National Academies (NAS[48]), they represent full commercial scale production volumes and should result in the needed FCV cost reductions such that market share could grow significantly beyond 2025.

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Appendix C - Reserved

D1 Appendix D: Air Conditioning

D1.1 Overview

Over 95% of the new cars and light trucks in the United States are equipped with mobile air conditioning (MAC or A/C) systems. In the 1970s and 1980s, A/C systems were an optional (luxury) feature, but these systems are now standard on almost all new vehicle models. The A/C system is a unique and distinct technology on the automobile. It is different from the other technologies described in Chapter 3 of the joint Technical Support Document (TSD) to the recent MY 2012-2016 Final Rule in several ways. First, most of the technologies described in the joint TSD directly affect the efficiency of the engine, transmission, and vehicle systems. As such, these systems are almost always active while the vehicle is moving down the road or being tested on a dynamometer for the fuel economy and emissions test drive cycles. A/C on the other hand, is a parasitic load on the engine that only burdens the engine when the vehicle occupants demand it. Since it is not tested as a normal part of the fuel economy and emissions test drive cycles for compliance purposes, it is referred to as an “off-cycle” effect. There are many other off-cycle loads that can be switched on by the occupant that affect the engine; these include lights, wipers, stereo systems, electrical defroster/defogger, heated seats, power windows, etc. However, these electrical loads individually amount to a very small effect on the engine (although together they can be significant). The A/C system (by itself) adds a significantly higher load on the engine as described later in this chapter. Secondly, present A/C systems are capable of leaking a powerful greenhouse gas (GHG) directly into the air - even when the vehicle is not in operation. No other vehicle system has associated GHG leakage. Because of these factors, a distinct approach to control of MAC systems is justified, and a separate technical discussion is also warranted.

D1.2 Leakage

D1.2.1 Overview

This section describes a preliminary analysis of leakage emission reductions in the 2025 timeframe. It is expected that this analysis will be reevaluated during the rulemaking process. The technological basis for the expected leakage reductions is discussed in detail in the EPA’s model year (MY) 2012-2016 Light Duty Greenhouse Gas Final Rule (2016 FRM) RIA Chapter 2, and is summarized here.

Mobile air conditioner (MAC) systems leak a powerful greenhouse gas directly into the air - even when the vehicle is not in operation. Because MAC emissions are not measured during certification testing for the GHG program, the 2016 final rule offered a compliance credit to encourage manufacturers to reduce the leakage from MAC systems. The analysis discussed herein serves as an update to that analysis. As in the 2016 FRM, a 2008 vehicle is considered an unimproved system, and is the basis of the discussion shown here.

The hydrofluorocarbon (HFC) refrigerant compound used in most model year 2008 vehicles is R134a (also known as 1,1,1,2-Tetrafluoroethane, or HFC-134a). Based on the higher global warming potential (GWP) of HFC-134a, a small leakage of this refrigerant has a greater global warming impact than a similar amount of emissions of some other mobile source GHGs. R134a has a global warming potential of 1430,[A] which means that 1 gram of R134a has a warming potential equivalent to 1,430 grams of CO_2 (which has a GWP of 1).[1]

The high pressure of an MAC system increases its propensity for leaks. In order for the A/C system to take advantage of the refrigerant's thermodynamic properties and to exchange heat properly, the system must be kept at high pressures even when not in operation. Typical static pressures can range from 50-80 psi depending on the temperature, and during operation, these pressures can get to several hundred psi. At these pressures leakage can occur through a variety of mechanisms. The refrigerant can leak slowly through seals, gaskets, and even small failures in the containment of the refrigerant. The rate of leakage may also increase over the course of normal wear and tear on the system. Leakage may also increase more quickly through rapid component deterioration such as during vehicle accidents, maintenance or end-of-life vehicle scrappage (especially when refrigerant capture and recycling programs are less efficient). Small amounts of leakage can also occur continuously even in extremely "leak-tight" systems by permeating through hose membranes. This last mechanism is not dissimilar to fuel permeation through porous fuel lines. Manufacturers may be able to reduce these leakage emissions through the implementation of technologies such as leak-tight, non-porous, durable components. The global warming impact of leakage emissions also can be addressed by using alternative refrigerants with lower global warming potential.

As MACs leak even when not being driven, it is most appropriate to determine their leakage based on a g/year or g/lifetime. However, for purposes of an estimation of reductions, it is possible to divide lifetime leakage losses by lifetime vehicle miles traveled (VMT) in order to determine the appropriate average g/mile leakage rate.

D1.2.2 Description of Vintaging Model Inputs and Data Sources

New data concerning HFC leakage has become available since the 2016 final rule analysis was completed. Most significantly, based on new data from the EPA Office of Atmospheric Programs (OAP), EPA has decreased the average charge size and leakage assumed in its analysis as compared to the 2016 final rule analysis. The inputs used to derive the HFC reductions are drawn from the OAP Vintaging model and are shown below in Table D1.2-1. These values are discussed in the following paragraphs, and are drawn from internal EPA documentation of the Vintaging model.

Table D1.2-1: Inputs for HFC Potential Reduction Calculation from Vintaging Model

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[A] The global warming potentials (GWP) used in this analysis are consistent with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the IPCC Second Assessment Report (SAR) global warming potential values have been agreed upon as the official U.S. framework for addressing climate change. The IPCC SAR GWP values are used in the official U.S. greenhouse gas inventory submission to the United Nations climate change framework.

	Car	Truck
2008 MY Vehicle MAC Charge (g HFC)	550	780
Lifetime of a MAC system (years)	12	12
Fraction of Vehicles w/AC	99%	99%
Recurring Annual Loss Rate (Service+Leaks)	18%	18%
End of Life Loss	43%	43%

D1.2.2.1 Charge Size

The Vintaging model contains weighted average refrigerant charge sizes based on motor vehicle sales data and charge size data, by make, model, and year. 2008 Sales data is from *Ward's US Light Vehicle Sales: 2005 through 2008 Calendar Years*.[2] Charge size data is from the Mobile Air Conditioning Society (MACS) Worldwide's *A/C & Cooling System Specifications: 1996-2007*.[3] No assumptions are made regarding continued reductions in charge size beyond 2008.

D1.2.2.2 AC System Lifetime

The Vintaging Model assumes that all light duty passenger vehicle AC systems (in the U.S.) last exactly 12 years. This is in agreement with the IPCC report IPCC/TEAP 2005 *Safeguarding the Ozone Layer and the Global Climate System – Issues Related to Hydrofluorocarbons and Perfluorocarbons,* which indicates lifetimes (worldwide) of 9 to 12 years.

D1.2.2.3 Fraction of Vehicles with AC

Not all vehicles are sold with AC; Ward's vehicle sales data are adjusted based on the percentage of vehicles with AC, which increases over time before reaching a maximum of 99% in 2002 (light trucks) and 2003 (cars). The Vintaging Model assumes that 1% of vehicles continue to be sold without air conditioning beyond 2003.

D1.2.2.4 Emission Rates

The Vintaging Model assumes that losses occur from three events: leak, service, and disposal. Although vehicle ACs are serviced during discrete events and not usually every year, emissions from those events are averaged over the lifetime of the AC system. Leak and service emissions are considered "annual losses" and are applied every year; disposal is considered an "end of life loss" and is applied only once for each vintage of vehicles. Emission rates in the Vintaging model do improve over time, with the 2008 vehicle emission rates attributable to vehicles manufactured from 1998 to present.

Of note, the Vintaging model assumes that charge loss is replaced every year; ie, a vehicle with a charge of 100 grams would lose a constant rate of 18 grams/year. While other emissions, such as fugitive emissions at a production facility, leaks from cylinders in storage, etc., are not explicitly modeled, such emissions are accounted for within the annual loss rate.

D1.2.3 Calculation of the Lifetime HFC loss per vehicle

Several modifications were made to the Vintaging model outputs for the analysis of the potential HFC reductions. Most importantly, the charge size of the average car was increased as a result of the reclassification of a number of two wheel drive SUVs below 6,000 pounds as cars starting in MY 2011, as discussed in Appendix A. It was assumed that 20% of the new cars were classic trucks. As a result, the charge sizes were weighted together, with a weighting of 80% car and 20% truck in order to calculate the car charge under the revised MY 2011 and later definition. The charge size of trucks was not adjusted. We also assume that only vehicles which have AC systems are eligible for the AC credit, increasing the 99% value to 100%

Using this data, the total average lifetime losses from an AC system can be calculated using Equation D1.2-1:

$$\text{Total Lifetime HFC Emissions} = (\text{Average Charge Size}) * (\text{Average Annual Loss}) * (\text{Average Lifetime}) + (\text{End of Life Loss})$$

Equation D1.2-1: Calculation of Total Lifetime HFC Loss

Applying this equation results in an average per-vehicle HFC loss of approximately 2.59 charges (18% loss of initial charge * 12 years + 43% loss at end of life.). This results in total lifetime losses of 1,543 g for cars and 2,020 grams for trucks.

D1.2.4 Calculation of the HFC Credit Maximum

The maximum HFC credit is set so that the reduction in HFC emissions can be replaced by an equivalent amount of tailpipe CO_2 emissions. As CO_2 emissions are regulated on a gram/mile basis, the HFC emissions must be converted into an equivalent metric using Equation D1.2-2. Based on the MY 2012-2016 final rule, the total lifetime VMT of cars and trucks is estimated at 195,264 and 225,865 respectively. These values are consistent with the MY 2012-2016 final rule, consistent with the early years of the time frame, and are slightly lower than the MY 2025 VMT estimated in this technical report.

$$\text{CO2eq g / mile} = (\text{Total lifetime HFC emissions}) / (\text{Total Lifetime VMT}) * (\text{GWP})$$

Equation D1.2-2: Conversion of Lifetime HFC Emissions into CO2eq emissions

Finally, because a known 20% shortfall (the “on-road” gap) exists between certification test CO_2 emissions and actual on-road emissions, the CO_2 equivalent emissions calculated above were multiplied by 0.8 in order to appropriately offset the reduction in real emissions.

The maximum possible credit, calculated through this methodology, is shown below. Assuming that alternative refrigerant with a GWP of zero is used, the maximum potential credit would be based on removing the full lifetime emissions. As discussed in the 2016 final rule, if conventional HFC 134a were used in an AC system, the maximum potential leakage reduction is 50% of the annual emission leakage. No improvements would be expected to end of life emissions, so the total possible credit is approximately 45% of the maximum credit with alternative refrigerant.

Table D1.2-2: Maximum Credit (g/mile CO_2 eq)

	Car	Truck	Fleet (MY 2025)
Maximum Credit (Alternative Refrigerant w/ 0 GWP)	9.2	10.4	9.6
Maximum Credit (HFC 134a)	3.8	4.3	3.9

As the charges for the cars and light trucks differ, the mix of cars and trucks is significant to this analysis. MY 2025 is projected to have 67.5% cars and 2 wheel drive SUVs below 6,000 lbs.

D1.2.5 System Leakage Standards

In the timeframe considered in this Technical Assessment Report, EPA is considering a number of options to reduce A/C leakage emissions, including the setting of a refrigerant leakage standard for mobile A/C systems. The purpose of a leakage standard, as opposed to credits, is to assure that high-quality, low-leakage components are used in each air conditioning system design. EPA is considering a percent leakage per year standard curve, which is scaled to the refrigerant capacity of the system (i.e. small-capacity systems would have a larger allowable leakage standard than those with larger capacity). Since refrigerant leakage past the compressor shaft seal is the dominant source of leakage in belt-driven air conditioning systems, a single “percent refrigerant leakage per year” standard may not fairly addresses the range of system refrigerant capacities likely to be used in passenger cars, light duty trucks, and other vehicles. Since systems with less refrigerant may have a larger percentage of their annual leakage from the compressor shaft seal than systems with more refrigerant capacity, their relative percent refrigerant leakage per year could be higher, and a more extensive application of leakage reducing technologies could be needed to meet a standard.

Manufacturers can choose to reduce A/C leakage emissions in two ways. First, they can utilize leak-tight components. Second, manufacturers can largely eliminate the global warming impact of leakage emissions by adopting systems that use an alternative, low-GWP refrigerant. EPA believes that reducing A/C system leakage is both highly cost-effective and technologically feasible. The availability of low leakage components is being driven by the air conditioning program in the light duty GHG rule which apply to 2012 model year and later vehicles. The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program has demonstrated that new-vehicle leakage emissions can be reduced by 50% by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system. All of these technologies are already in commercial use and exist on some of today’s systems.

In the MY 2012-2016 rule, EPA required that manufacturers demonstrate improvements in their A/C system designs and components through a design-based method. Thismethod for calculating A/C Leakage is based closely on an industry-consensus leakage scoring method, described below. This leakage scoring method is correlated to experimentally-measured leakage rates from a number of vehicles using the different available A/C components. Under this approach, manufacturers would choose from a menu of A/C equipment and components used in their vehicles in order to establish leakage scores, which would characterize their A/C system leakage performance and calculate the percent leakage per year as this score divided by the system refrigerant capacity.

Consistent with the Light Duty Vehicle Greenhouse Gas Emissions rulemaking, EPA is considering that a manufacturer would compare the components of its A/C system with a set of leakage-reduction technologies and actions that is based closely on that being developed through IMAC and the Society of Automotive Engineers (as SAE Surface Vehicle Standard J2727, August 2008 version). See generally 75 FR at 25426. The J2727 approach was developed from laboratory testing of a variety of A/C related components, and EPA believes that the J2727 leakage scoring system generally represents a reasonable correlation with average real-world leakage in new vehicles. Like the IMAC approach, our proposed approach would associate each component with a specific leakage rate in grams per year identical to the values in J2727 and then sum together the component leakage values to develop the total A/C system leakage. However, in this "percent system leakage per year" approach, the total A/C leakage score and is then divided the value by the total refrigerant system capacity to develop a percent leakage per year.

EPA believes that the design-based approach would result in estimates of likely leakage emissions reductions that would be comparable to those that would eventually result from performance-based testing (e.g. SAE J2763), and may consider allowing performance test results in lieu of design-based results, if a manufacturer can demonstrate that 100% of their vehicles systems are leak tested before they leave the assembly plant. At the same time, comments are encouraged on all developments that may lead to a robust, practical, performance-based test for measuring A/C refrigerant leakage emissions.

D1.3 Air conditioning Efficiency

D1.3.1 Overview

EPA estimates that the CO_2 emissions from A/C related load on the engine of a vehicle with an unimproved air conditioning system accounts for about 3.9% of total greenhouse gas emissions from passenger vehicles in the United States. This is equivalent to CO_2 emissions of approximately 14.3 g/mi per vehicle. A complete discussion of this estimate is available in Chapter 2 of the EPA RIA to the MY 2012-2016 final rule.

In brief, most of the excess load on the engine comes from the compressor, which pumps the refrigerant around the system loop. Significant additional load on the engine may also come from electrical or hydraulic fan units used for heat exchange across the condenser and radiator. EPA believes that the controls which manufacturers would use to achieve improved A/C efficiency would focus primarily, but not exclusively, on the compressor, electric motor controls, and system controls which reduce load on the A/C system (e.g. reduced „reheat' of the cooled air and increased use of recirculated cabin air).

The program EPA finalized in the MY 2012-2016 final rule encourages the reduction of A/C CO_2 emissions from cars and trucks by up to 40% from 2008 baseline levels through a credit system. A 40% reduction would be equivalent to a reduction of 5.7 grams of CO_2 emissions per mile.

D1.3.2 A/C Efficiency Credits

Similar to the 2012-to-2016 Light-Duty GHG Rule, a design-based approach to credits is being considered, although the number and type of items listed in the technology "menu" – as well as the amount of credit assigned to each item - may change as new methods of testing them in the vehicle develop. The design-based approach used in the GHG Rule was used because it was not possible to accurately assess their effectiveness of these technologies using the A/C Idle Test.

D1.3.3 A/C Efficiency Test

A new test to measure the impact of the A/C system operation on emissions is being evaluated with input from USCAR, CARB, and the European Union. The primary goal in developing this new test is to create a test cycle and test conditions which reflect environmental and driving experience found in typical customer usage (rather than the extreme, high ambient temperature condition of the SC03 or the idle-only condition of the A/C Idle Test). A secondary goal of this new test is to create a cycle which captures the effectiveness of advanced A/C technologies, and can demonstrate a fuel savings compared to a baseline technology. This new test may include a solar soak condition (to measure the effectiveness of solar load reducing technologies such as solar glass and cabin ventilation), a transient drive cycle (to measure the dynamic performance of the system during cabin cool-down), and steady-state cycles (to measure the effectiveness of the system under stabilized cabin temperature conditions).

If this new test cycle is able to accurately assess the efficiency of the A/C system and its components, it could be used to determine the level of credits available. But if the effectiveness of certain technologies cannot be measured on the new test, a design menu approach may be utilized.

Appendix D References

[1] IPCC. Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing. September 2007.

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[3] Mobile Air Conditioning Society (MACS) Worldwide. *A/C & Cooling System Specifications: 1996-2007*.

E1 Appendix E: Key Inputs to the Analysis

This section discusses the key inputs to the analysis which were jointly developed by the agencies for today's Technical Assessment Report. These economic inputs incorporate a range of forecast information, economic estimates, and input parameters. This section describes the sources that the agencies relied upon for this information, the rationale underlying each assumption, and the agencies' estimates of specific parameter values. These common values were then used as inputs to the analyses presented in this Technical Assessment Report.

Please note that there are additional economic and environmental impacts which were not considered in this assessment. A partial list includes: co-pollutant impacts, health impacts, the social cost of carbon emissions, and energy security. The exclusion of these impacts from this Technical Assessment Report does not suggest that these impacts should be disregarded. As in the MY 2012-2016 final rule, NHTSA and EPA will carefully consider other impacts of emission and fuel economy standards during the development of the upcoming Notice of Proposed Rulemaking (NPRM).

Many of the inputs used in this technical assessment are carried forward from the analyses conducted for the MY 2012-2016 final rule. As part of developing the upcoming NPRM, EPA and NHTSA will consider updating these inputs.

E1.1 Vehicle Sales

As discussed in Chapter 6, the vehicle sales projection is based upon output from the National Energy Modeling System (NEMS) which is maintained by the Energy Information Administration (EIA). As in the MY 2012-2016 final rule, the car and truck split was drawn from NEMS, while market segmentation was drawn from CSM's forecasting tool. Total market size is estimated in 2020 at 16.5 million vehicles (55.8 % cars) and in 2025 at 17.0 million vehicles (57.9% cars). Cars, in the context of NEMS, are defined using the pre-MY 2011 CAFE definition, as discussed above in Appendix A.

For this analysis the DOT Volpe center produced a custom run of NEMS. This run generated the same overall vehicle sales as the reference case for AEOEIA Annual Energy Outlook 2010, but a different sales split between cars and light trucks. A detailed discussion on this topic is presented in Appendix A.

E1.2 On-road Fuel Economy Shortfall

Fuel economy levels achieved by vehicles in on-road driving fall significantly short of their levels measured by EPA under the laboratory test conditions used under the CAFE program to establish its published fuel economy ratings. In analyzing the impacts from passenger car and light truck GHG and fuel efficiency standards, the agencies adjust the test fuel economy performance of each passenger car and light truck model downward from its rated value to reflect the expected size of this on-road fuel economy differential.

The agencies note that in December 2006, EPA adopted changes to its regulations on fuel economy labeling, which were intended to bring vehicles' rated fuel economy levels closer to their actual on-road fuel economy levels.[1] Comparisons of on-road and CAFE fuel economy levels developed by EPA as part of that final rule indicate that actual on-road fuel economy for light-duty vehicles averages approximately 20 percent lower than published fuel economy levels.[2] While there is great heterogeneity among the population of drivers, as discussed in the referenced material, 20 percent represents the average for modeling a fleet. For example, if the overall EPA fuel economy rating of a light truck is 20 mpg, the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be 16 mpg (20*.80). EPA and NHTSA both applied this 20% differential in calculating the fuel savings of the MY 2012 – 2016 joint final rule.

In this technical assessment report, the agencies assume that the overall energy shortfall for the electric drivetrain is 30%. Specifically, this refers to a larger shortfall relative to laboratory conditions while operating on electricity rather than liquid fuel. The 30% value is derived from engineering judgment based on several data points. Foremost among these, during the stakeholder meetings conducted prior to this technical assessment, confidential business information (CBI) was supplied by several manufacturers which indicated that electrically powered vehicles had greater variability in their on-road energy consumption than vehicles powered by internal combustion engines. Further, data from the 2006 analysis of the "five cycle" label potentially supported a larger on-road shortfall for vehicles with hybrid-electric drivetrains.[3] Finally, heavy accessory load, extreme temperatures, and aggressive driving have deleterious impacts of unknown magnitudes on battery performance. As a counterpoint, CBI provided by several other manufacturers suggested that the on-road/laboratory differential attributable to electric operation should approach that of liquid fuel operation in the future. Consequently, 30% was judged a reasonable estimate for the current analysis.

E1.3 Fuel Prices

Federal government agencies generally use EIA's projections in their assessments of future energy-related policies. The retail fuel price forecasts presented in AEO 2010 span the period from 2007 through 2035. Measured in constant 2008 dollars, the AEO 2010 Reference Case forecast of retail gasoline prices during calendar year 2020 is \$3.34 per gallon, rising gradually to \$3.91 by the year 2035 (these values include federal, state and local taxes). However, valuing fuel savings over the maximum lifetimes of passenger cars and light trucks used in this analysis requires fuel price forecasts that extend through 2060, approximately the last year during which a significant number of MY 2025 vehicles will remain in service.[A] To obtain fuel price forecasts for the years 2036 through 2060, the agency assumes that retail fuel prices will continue to increase after 2035 at the average annual rate (0.7%) projected for 2008-2035 in the AEO 2010 Reference Case. This assumption results in a projected retail price of gasoline that reaches \$4.34 in 2050.

[A] The agency defines the maximum lifetime of vehicles as the highest age at which more than 2 percent of those originally produced during a model year remain in service. In the case of light-duty trucks, for example, this age has typically been 36 years for recent model years.

The value of fuel savings resulting from improved fuel economy and GHG emissions to buyers of light-duty vehicles is determined by the retail price of fuel, which includes federal, state, and any local taxes imposed on fuel sales. Total taxes on gasoline, including federal, state, and local levies averaged $0.42 per gallon during 2008, while those levied on diesel averaged $0.50. Because fuel taxes represent transfers of resources from fuel buyers to government agencies, however, rather than real resources that are consumed in the process of supplying or using fuel, their value must be deducted from retail fuel prices to determine the value of fuel savings resulting from more stringent fuel efficiency and GHG standards to the U.S. economy as a whole.[4] When calculating the costs to any individual driver, the taxes are included as part of the realized fuel savings.[B]

E1.4 Vehicle Lifetimes and Survival Rates

The agencies' analysis of fuel savings and related benefits for this Technical Assessment Report begins by estimating the resulting changes in fuel use over the entire lifetimes of cars and light trucks. The change in total fuel consumption by vehicles produced during each of these model years is calculated as the difference in their lifetime fuel use under the reference and alternative assumptions.

The first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number of those vehicles expected to remain in service during each future calendar year after they are produced and sold.[C] This number is calculated by multiplying the number of vehicles originally produced during a model year by the proportion expected to remain in service at the age they will have reached during each subsequent calendar year, often referred to as a "survival rate."

The agencies used survival rate estimates from a NHTSA study[5] in calculating fuel savings and other impacts from the analyzed scenarios. The proportions of passenger cars and light trucks expected to remain in service at each age up to their maximum lifetimes are shown in Table E1.4-1.[D] Note that that these survival rates were calculated against the pre-MY 2011 definitions of cars and light trucks, because the NHTSA study has not been updated

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[B] For society, the fuel taxes represent a transfer payment. By contrast, an individual realizes savings from not paying the additional money.

[C] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 1 during calendar year 2001, and to reach their maximum age of 26 years during calendar year 2025. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 26 years, while light trucks have a maximum lifetime of 36 years. *See* Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf (last accessed August 25, 2010).

[D] The maximum age of cars and light trucks was defined as the age when the number remaining in service has declined to approximately two percent of those originally produced. Based on an examination of recent registration data for previous model years, typical maximum ages appear to be 26 years for passenger cars and 36 years for light trucks.

since 2006. Because the agencies are unaware of a better data source, these values were used unchanged. No improvements in survival rates were explicitly projected into the future.

The survival and annual mileage estimates reported in this section's tables reflect the convention that vehicles are defined to be of age 1 during the calendar year that coincides with their model year Thus for example, model year 2012 vehicles will be considered to be of age 1 during calendar year 2012. This convention is used in order to account for the fact that vehicles produced during a model year typically are first offered for sale in June through September of the preceding calendar year (for example, sales of a model year typically begin in June through September of the previous calendar year, depending on manufacturer). Thus virtually all of the vehicles produced during a model year will be in use for some or all of the calendar year coinciding with their model year, and they are considered to be of age 1 during that year.[E]

[E] As an illustration, virtually the entire production of model year 2012 cars and light trucks will have been sold by the end of calendar year 2012, so those vehicles are defined to be of age 1 during calendar year 2012. Model year 2012 vehicles are subsequently defined to be of age 2 during calendar year 2013, age 3 during calendar year 2014, and so on. One complication arises because registration data are typically collected for July 1 of each calendar year, so not all vehicles produced during a model year will appear in registration data until the calendar year when they have reached age 2 (and sometimes age 3) under this convention.

Table E1.4-1 Survival Rates

VEHICLE AGE	ESTIMATED SURVIVAL FRACTION CARS	ESTIMATED SURVIVAL FRACTION LIGHT TRUCKS
1	0.9950	0.9950
2	0.9900	0.9741
3	0.9831	0.9603
4	0.9731	0.9420
5	0.9593	0.9190
6	0.9413	0.8913
7	0.9188	0.8590
8	0.8918	0.8226
9	0.8604	0.7827
10	0.8252	0.7401
11	0.7866	0.6956
12	0.7170	0.6501
13	0.6125	0.6042
14	0.5094	0.5517
15	0.4142	0.5009
16	0.3308	0.4522
17	0.2604	0.4062
18	0.2028	0.3633
19	0.1565	0.3236
20	0.1200	0.2873
21	0.0916	0.2542
22	0.0696	0.2244
23	0.0527	0.1975
24	0.0399	0.1735
25	0.0301	0.1522
26	0.0227	0.1332
27	0	0.1165
28	0	0.1017
29	0	0.0887
30	0	0.0773
31	0	0.0673
32	0	0.0586
33	0	0.0509
34	0	0.0443
35	0	0.0385
36	0	0.0334

E1.5 VMT

A critical element in estimating lifetime fuel use by the cars or light trucks produced during a future model year is to calculate the total number of miles that they will be driven during each year of their expected lifetimes. To estimate total miles driven, the number of cars and light trucks projected to remain in use during each future calendar year is multiplied by the average number of miles a surviving car or light truck is expected to be driven at each age. Estimates of average annual miles driven by MY 2001 cars and light trucks at each age were developed by NHTSA from the Federal Highway Administration's 2001 National Household Transportation Survey (Table E1.5-1). These estimates represent the typical number of miles driven by a surviving light duty vehicle. To determine the miles driven by the average vehicle of a given vintage at a given age, one would multiply the mileage accumulation by the corresponding survival rate.

Table E1.5-1 MY 2001 Mileage Schedules based on NHTS Data

VEHICLE AGE	ESTIMATED VEHICLE MILES TRAVELED CARS	ESTIMATED VEHICLE MILES TRAVELED LIGHT TRUCKS
1	14,231	16,085
2	13,961	15,782
3	13,669	15,442
4	13,357	15,069
5	13,028	14,667
6	12,683	14,239
7	12,325	13,790
8	11,956	13,323
9	11,578	12,844
10	11,193	12,356
11	10,804	11,863
12	10,413	11,369
13	10,022	10,879
14	9,633	10,396
15	9,249	9,924
16	8,871	9,468
17	8,502	9,032
18	8,144	8,619
19	7,799	8,234
20	7,469	7,881
21	7,157	7,565
22	6,866	7,288
23	6,596	7,055
24	6,350	6,871
25	6,131	6,739
26	5,940	6,663
27	0	6,648
28	0	6,648
29	0	6,648
30	0	6,648
31	0	6,648
32	0	6,648
33	0	6,648
34	0	6,648
35	0	6,648
36	0	6,648

E1.5.1 Adjusting vehicle use for future fuel prices

The estimates of average annual miles driven by passenger cars and light trucks reported in Table E1.5-1 reflect the historically low gasoline prices that prevailed at the time the 2001 NHTS was conducted. Under the assumption that people tend to drive more as the cost of driving decreases, the higher fuel prices in more recent projections leads to lower mileage schedules. For this report, the agencies updated the analysis with the forecasts of future gasoline prices reported in the AEO 2010 reference case. This adjustment accounts for the difference between the average retail price per gallon of fuel forecast during each calendar year over the expected lifetimes of future model year passenger cars and light trucks, and the average price that prevailed when the NHTS was conducted in 2001. The elasticity of annual vehicle use with respect to fuel cost per mile corresponding to the 10 percent fuel economy rebound effect used in this analysis (*i.e.*, an elasticity of -0.10) was used in conjunction with the difference between each future year's fuel prices and those prevailing in 2001 to adjust the estimates of vehicle use derived from the NHTS to reflect the effect of higher future fuel prices. This procedure was applied to the NHTS derived mileage figures to adjust annual mileage by age during each calendar year of the expected lifetimes of future model year cars and light trucks.

E1.5.2 Ensuring consistency with growth in total vehicle use

The estimates of annual miles driven by passenger cars and light trucks at each age were also adjusted to reflect projected future growth in average vehicle use. Increases in the average number of miles cars and trucks are driven each year have been an important source of historical growth in *total* car and light truck use, and are expected to represent an important source of future growth in total light-duty vehicle travel as well. As an illustration of the importance of growth in average vehicle use, the total number of miles driven by passenger cars increased 35 percent from 1985 through 2005, equivalent to a compound annual growth rate of 1.5 percent.[6] During that time, however, the total number of passenger cars registered for in the U.S. grew by only about 0.3 percent annually.[F] Thus growth in the average number of miles automobiles are driven each year accounted for the remaining 1.2 percent (= 1.5 percent - 0.3 percent) annual growth in total automobile use.[G] Further, the AEO 2010 Reference Case forecasts of total car and light truck use and of the number of cars and light trucks in use suggest that their average annual use will continue to increase gradually from 2010 through 2035.

In order to develop reasonable estimates of future growth in average car and light truck use, the agencies calculated the rate of growth in the mileage schedules necessary for

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[F] A slight increase in the fraction of new passenger cars remaining in service beyond age 10 has accounted for a small share of growth in the U.S. automobile fleet. The fraction of new automobiles remaining in service to various ages was computed from R.L. Polk vehicle registration data for 1977 through 2005 by the agency's Center for Statistical Analysis.

[G] *See supra* note k below.

total car and light truck travel to increase at the rate forecast in the AEO 2010 Reference Case. The growth rate in average annual car and light truck use produced by this calculation is approximately 1.15 percent per year.[H] This rate was applied to the mileage figures reported in Table E1.5-1 to estimate annual mileage by age during each calendar year of the expected lifetimes of cars and light trucks during all model years.

Separate adjustments for projected fuel prices and growth in vehicle use were made for each calendar year. Because the effects of both fuel prices and cumulative growth in average vehicle use vary by year, these adjustments result in different VMT schedules for each future year. While the adjustment for future fuel prices generally reduces average mileage at each age from the 2001 values, the adjustment for expected future growth in average vehicle use increases it. The net impact is growth over time.

E1.5.3 Final VMT equation

Below, we show the equations used to determine the VMT schedules used in this analysis. This particular form of the equation uses a negative form of the rebound rate.

Where:
V = CY 2001 VMT from NHTSA analysis of NHTS data
SGR = Secular Growth Rate
YS = Years since 2001
RR= Rebound rate
FCPM = Fuel Cost per mile

Where:
EC= Electrical consumption per mile
EP = Electricity Price
GC = Gasoline Consumption per mile
GP = Gasoline Price

[H] It was not possible to estimate separate growth rates in average annual use for cars and light trucks, because of the significant reclassification of light truck models as passenger cars discussed previously.

Table E1.5-2 MY 2020 and 2025 Reference Mileage Schedules[I]

	MY 2020		MY 2025	
VEHICLE AGE	ESTIMATED VMT CARS	ESTIMATED VMT LIGHT TRUCKS	ESTIMATED VMT CARS	ESTIMATED VMT LIGHT TRUCKS
1	16,882	19,017	17,749	19,991
2	16,334	18,398	17,152	19,315
3	16,235	18,281	17,071	19,219
4	16,143	18,160	16,976	19,094
5	16,048	18,024	16,879	18,954
6	15,750	17,643	16,586	18,578
7	15,356	17,145	16,175	18,056
8	15,040	16,728	15,846	17,623
9	14,044	15,538	14,774	16,342
10	13,707	15,092	14,427	15,883
11	13,243	14,504	13,921	15,244
12	12,824	13,968	13,492	14,693
13	12,439	13,472	13,101	14,188
14	11,991	12,912	12,634	13,603
15	11,518	12,333	12,142	12,999
16	11,054	11,773	11,664	12,422
17	10,607	11,245	11,193	11,866
18	10,169	10,741	10,731	11,334
19	9,743	10,266	10,281	10,833
20	9,337	9,833	9,854	10,376
21	8,949	9,438	9,444	9,960
22	8,588	9,098	9,064	9,601
23	8,252	8,809	8,709	9,296
24	7,943	8,576	8,382	9,050
25	7,671	8,415	8,096	8,880
26	7,436	8,324	7,847	8,784
27	0	8,307	0	8,766
28	0	8,313	0	8,773
29	0	8,317	0	8,777
30	0	8,315	0	8,775
31	0	8,318	0	8,779
32	0	8,323	0	8,784
33	0	8,324	0	8,785
34	0	8,328	0	8,789
35	0	8,335	0	8,797
36	0	8,335	0	8,797

[I] VMT schedules differing by approximately 0.2% over the course of a vehicle lifetime were used in the estimation of costs and impacts. The VMT schedules used in cost estimation are shown here.

E1.5.4 Comparison to the VMT schedules in the MY 2012-2016 Final Rulemaking

The VMT schedules used in the MY 2012-2016 final rulemaking and this assessment report are compared below.

Table E1.5-3 Summary of Reference Expected Lifetime VMT

	2001 NHTS in NHTSA Report	MY 2012-2016 Final Rule	MY 2020	MY 2025
Car	152,137	195,264	197,578	207,922
Trucks	179,954	225,865	231,856	244,026

E1.6 VMT Rebound

The VMT rebound effect refers to the fraction of fuel savings expected to result from an increase in vehicle fuel economy that is offset by additional vehicle use. The increase in vehicle use that stems from improved fuel economy occurs because vehicle owners respond to the resulting reduction in vehicle fuel consumption and operating costs by driving more.

The magnitude of the rebound effect is one of the determinants of the actual fuel savings that are likely to result from adopting stricter fuel economy or emissions standards, and thus is an important parameter affecting the evaluation of potential standards for future model years. It can be measured directly by estimating the elasticity of vehicle use with respect to fuel economy itself, or indirectly by the elasticity of vehicle use with respect to fuel cost per mile driven.[J] When expressed as a positive percentage, either of these parameters gives the fraction of fuel savings that would otherwise result from adopting stricter standards, but is offset by the increase in fuel consumption that results when vehicles with increased fuel economy are driven more.

The fuel economy rebound effect for light-duty vehicles has been the subject of a large number of studies since the early 1980s. Although they have reported a wide range of estimates of its exact magnitude, these studies generally conclude that a significant rebound effect occurs when vehicle fuel efficiency improves.[K] The most common approach to

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[J] FuelFuel cost per mile is equal to the price of fuel in dollars per unit divided by fuel economy in miles per unitunit, so this figure declines when a vehicle's fuel economy increases.

[K] Some studies estimate that the long-run rebound effect is significantly larger than the immediate response to increased fuel efficiency. Although their estimates of the adjustment period required for the rebound effect to estimating its magnitude has been to analyze household survey data on vehicle use, fuel consumption, fuel prices (often obtained from external sources), and other determinants of household travel demand to isolate the response of vehicle use to higher fuel economy. Other studies have relied on econometric analysis of annual U.S. data on vehicle use, fuel economy, fuel prices, and other variables to identify the response of total or average vehicle use to changes in fleet-wide average fuel economy and its effect of fuel cost per mile driven. Two recent studies analyzed yearly variation in vehicle ownership and use, fuel prices, and fuel economy among individual states over an extended time period in order to measure the response of vehicle use to changing fuel economy.[L]

Chapter Four of the Joint Technical Support Document to the recent MYs 2012-2016 final rule surveys these previous studies, summarizes recent work on the rebound effect, and explains the basis for the 10 percent rebound effect EPA and NHTSA are using in the current technical analysis.[7] The use of a 10 percent rebound effect in this analysis reflects an assumption that the rebound effect applicable to the MYs 2012-2016 vehicles will remain applicable throughout future time periods. The agencies plan to conduct new analysis of the expected rebound effect in this time frame in a future rulemaking.

E1.7 Estimating Emissions and Fuel Savings

A vehicle emission standard would reduce GHG emissions emitted directly from vehicles due to reduced fuel use and decreased leakage from air conditioning systems. In addition to these "downstream" emissions, reducing CO_2 emissions translates directly to reductions in the emissions associated with the processes involved in getting petroleum to the pump, including the extraction and transportation of crude oil, and the production and distribution of finished gasoline (termed "upstream" emissions). The agencies quantified these impacts using the inputs discussed in this section.

Table E1.7-1 Processes Considered

PROCESS	UPSTREAM / DOWNSTREAM
Crude Oil Extraction	Upstream
Crude Oil Transport	Upstream
Oil Refining	Upstream
Fuel Transport and Distribution	Upstream
Fuel Tailpipe Emissions	Downstream
Air Conditioning System Leakage	Downstream

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reach its long-run magnitude vary, this long-run effect is most appropriate for evaluating the fuel savings and emissions reductions resulting from stricter standards that would apply to future model years.

[L] In effect, these studies treat U.S. states as a data "panel" by applying appropriate estimation procedures to data consisting of each year's average values of these variables for the separate states.

1.7.1 Estimating reductions in GHG emissions from vehicle use (downstream)

For the analysis documented in today's Technical Assessment, the agencies used the OMEGA model to directly calculate CO_2 emissions based on g/mile rates. These CO_2 emissions were converted to gallons of fuel under the assumption that approximately the entire carbon content of liquid fuel is converted to CO_2 emissions during the combustion process. The weighted average CO_2 content of gasoline is estimated to be 8,887 grams per gallon, while that of diesel fuel is estimated to be approximately 10,200 grams per gallon. For details, please see EPA's RIA and NHTSA's RIA from the recent MY 2012-2016 Final Rule.

EPA estimated the increases in emissions of methane (CH_4) and nitrous oxide (N_2O) due to increased vehicle use ("rebound driving") by multiplying the increase in total miles driven by cars and light trucks of each model year and age by emission rates per vehicle-mile for these GHGs. These emission rates, which differ between cars and light trucks as well as between gasoline and diesel vehicles, were estimated by EPA using its Motor Vehicle Emission Simulator (MOVES 2010) model. The MOVES model assumes that the per-mile rates at which cars and light trucks emit these GHGs are determined by the efficiency of fuel combustion during engine operation and chemical reactions that occur during catalytic after-treatment of engine exhaust, and are thus independent of vehicles' fuel consumption rates. Thus MOVES emission factors for these GHGs are assumed to be unaffected by changes in energy consumption. TheCH_4 and N_2O emission factors are the same as those used in the MY 2012-2016 Final Rule. The full derivation of these factors is available in Chapter 4 of the related Joint Technical Support Document.

The emission factors used for HFC leakage emissions are discussed in Appendix D to this report.

E1.8 Upstream Emissions

In this analysis, we calculated upstream emission impacts for the greenhouse gases CH_4, N_2O, and CO_2 from both gasoline and electricity production. The upstream gasoline emission factor, expressed in the form of gram/gallon produced, is taken directly from the analysis supporting the MYs 2012-2016 final rule. EPA derived the upstream gasoline emission factor from the Department of Energy's GREET model, which provides separate estimates of air pollutant emissions that occur in four phases of fuel production and distribution: crude oil extraction, crude oil transportation and storage, fuel refining, and fuel distribution and storage. EPA modified the GREET model to change certain assumptions about emissions during crude petroleum extraction and transportation, as well as to update its emission rates to reflect adopted and pending EPA emission standards. The agency converted these emission rates from the mass per fuel energy content basis on which GREET reports them to mass per gallon of fuel supplied using the estimates of fuel energy content reported by GREET. Full details of this analysis are described in the MYs 2012-2016 rulemaking docket memo "Calculation of Upstream Emissions for the GHG Vehicle Rule." The upstream gasoline emission factor does not change over time.

Table E1.8-1 Gasoline Upstream Emission Factors

POLLUTANT	GASOLINE (g/gallon)
CO_2	2,161
CH_4	12.25
N_2O	0.03
CO_2eq	2477

In the MY 2012-2016 Final Rule analysis, we noted that there are many issues involved with projecting the electricity upstream GHG emissions. Relevant issues associated with future EV and PHEV use include, but are not limited to, average versus marginal power generation, daytime versus nighttime vehicle charging, geographical differences, and changes in future electricity feedstocks.

For the present report, we rely upon the reference case projections produced by the EPA Office of Atmospheric Programs for an analysis of the American Clean Energy and Security Act of 2009 (H.R. 2454).[8] This scenario assumes no new power sector regulations, but does assume construction of new plants to replace older retired plants. This results in a slight decrease (~10% compared to 2005) in the emission rate per kWh electricity produced, as newer plants tend to emit less than the plants which they have replaced. The H.R 2454 base case analysis indicates that 4,395 MWh of net generation will be produced in 2025, with 2462 million metric tons of CO_2 emissions resulting. This results in an emission factor of 555 grams CO_2 per kWh. Based on eGrid2005[9], we estimate that approximately 0.01 grams of CH_4 and 0.01 grams of N_2O are emitted per kilowatt hour. We assume that electricity emission factors do not change after 2025.

The upstream emission factor for electricity was adjusted upwards by six percent in order to properly capture the feedstock gathering that occurs upstream of the powerplant. [M] Feedstock gathering includes the gathering, transporting, and preparing fuel for electricity generation. This adjustment factor is consistent with those discussed in the MY 2012-2016 Final Rule.[10]

It is important to carefully outline the frame of reference for electricity emission factors. For calculations of GHG emissions from electricity generation, the total energy consumed from the battery is divided by 0.9 to account for charging losses, and by 0.93 to account for losses during transmission. The upstream emission factor is applied to total electricity production, rather than simply power consumed at the wheel. [NO]

[M] The factor of 1.06 to account for GHG emissions associated with feedstock extraction, transportation, and processing is based on Argonne National Laboratory's The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.8c.0, available at http://www.transportation.anl.gov/modeling_simulation/GREET/). EPA Docket EPA-HQ-OAR-2009-0472.

[N] By contrast, consumer electricity costs would not include the power lost during transmission. While consumers indirectly pay for this lost power through higher rates, this power does not appear on their electric meter.

POLLUTANT	CY 2025 ELECTRICITY (g/kWh)
CO_2	555
CH_4	0.01
N_2O	0.01
CO_2eq	558
CO2eq adjusted for feedstock gathering	591

E1.9 Global Warming Potentials

Increases in emissions of non-CO_2 GHGs are converted to equivalent increases in CO_2 emissions using estimates of the Global Warming Potential (GWP) of hydrofluorocarbon 134a (HFC134a), methane and nitrous oxide. These GWPs are one way of accounting for the higher radiative forcing capacity and differing lifetimes of methane and nitrous oxide when they are released into the earth's atmosphere, measured relative to that of CO_2. Because these gases differ in atmospheric lifetimes, their relative damages are not constant over time. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Methane contributes to health and ecosystem effects arising from increases in tropospheric ozone, while damages from methane emissions are not offset by the positive effect of CO2 fertilization. Noting these caveats, the CO_2 equivalents of increases in emissions of these gases are then added to the increases in emissions of CO_2 to summarize the effect of the total increase in CO_2-equivalent GHG emissions from vehicle use.

As in the final rule, the GWP values from the Intergovernmental Panel on Climate Change Annual Report 4 are used. These are 1430 for HFC134a, 298 for N_2O, and 25 for CH_4. [11,P]

[O] By contrast, consumer electricity costs would not include the power lost during transmission. While consumers indirectly pay for this lost power through higher rates, this power does not appear on their electric meter.

[P] The global warming potentials (GWP) used in this rule are consistent with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). Due to international agreement, the IPCC Second Assessment Report (SAR) GWP values are used in the official U.S. greenhouse gas inventory submission to the climate change framework.

Appendix E References

1 EPA, Fuel Economy Labeling of Motor Vehicles: Revisions To Improve Calculation of Fuel Economy Estimates; Final Rule, 40 CFR Parts 86 and 600, Federal Register, December 27, 2006, pp. 77872-77969, http://www.epa.gov/fedrgstr/EPA-AIR/2006/December/Day-27/a9749.pdf.

2 EPA, *Final Technical Support Document: Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates*, Office of Transportation and Air Quality EPA420-R-06-017 December 2006, Chapter II, http://www.epa.gov/fueleconomy/420r06017.pdf.

[3] EPA, Fuel Economy Labeling of Motor Vehicles: Revisions To Improve Calculation of Fuel Economy Estimates; Final Rule, 40 CFR Parts 86 and 600, Federal Register, December 27, 2006, pp. 77872-77969, http://www.epa.gov/fedrgstr/EPA-AIR/2006/December/Day-27/a9749.pdf.

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5 Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2006/809952.pdf (last accessed Feb. 15, 2010).

6 FHWA, Highway Statistics, Summary to 1995, Table vm201at http://www.fhwa.dot.gov/ohim/summary95/vm201a.xlw , and annual editions 1996-2005, Table VM-1 at http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm (last accessed Feb. 15, 2010).

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9 U.S. EPA. 2009. eGrid2007 dataset. http://www.epa.gov/cleanenergy/energyresources/

egrid/index.html. Accessed February 3, 2010. The Emissions & Generation Resource Integrated Database (eGRID) is a comprehensive inventory of environmental attributes of electric power systems. The preeminent source of air emissions data for the electric power sector, eGRID is based on available plant-specific data for all U.S. electricity generating plants that provide power to the electric grid and report data to the U.S. government.

10 MY 2012-2016 Final Rule, Section III.2.C

11 EPA. Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. Joint Technical Support Document. Chapter 4. EPA-420-R-10-901 http://www.epa.gov/otaq/climate/regulations/420r10901.pdf. Original data found in Intergovernmental Panel on Climate Change. Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing. September 2007. http://www.ipcc.ch/pdf/assessmentreport/ar4/wg1/ar4-wg1-chapter2.pdf. Docket ID: EPA-HQ-OAR-2009-0472-0117

F1 Appendix F: EPA Documentation of OMEGA model Analysis

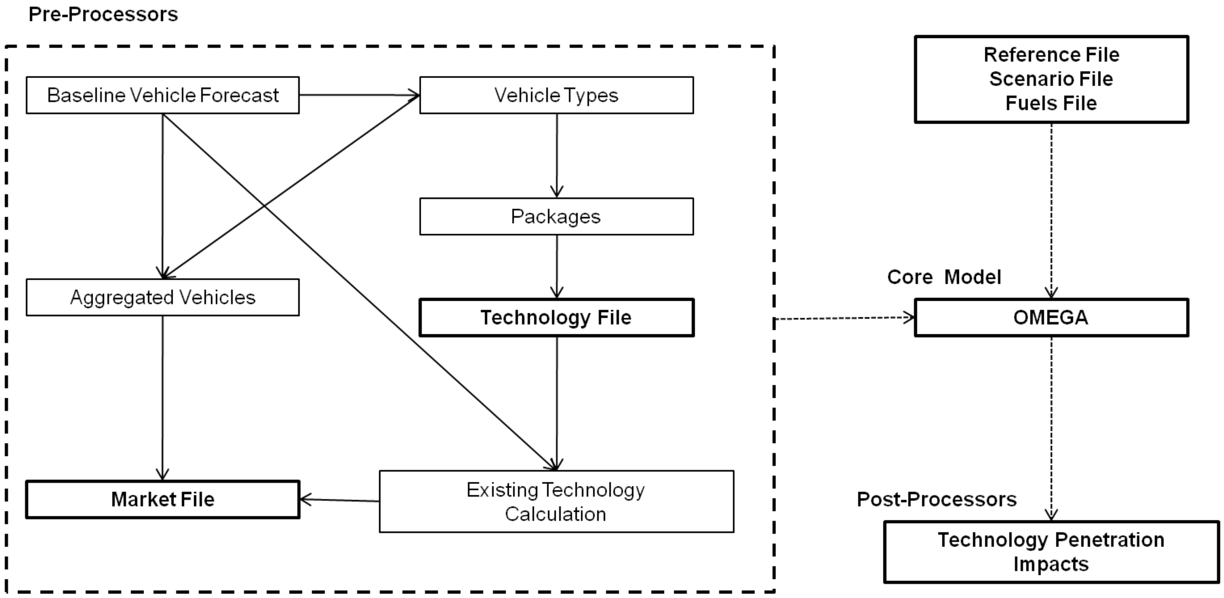
F1.1 Overview of OMEGA

This Appendix provides the methodology underlying the technical assessment of the future vehicle scenarios presented in Chapter 6. As in the analysis of the MY 2012-2016 rulemaking, evaluating the feasibility of these scenarios included identifying potentially available technologies and assessing their effectiveness, cost, and impact on relevant aspects of vehicle performance and utility. The wide number of technologies which are available and likely to be used in combination required a method to account for their combined cost and effectiveness. As described in Chapter 6, this included developing three distinct technology pathways which emphasized one or the other of the more advanced technologies, such as hybrids, advanced gasoline engine, plug-ins and battery EVs.

Applying these technologies efficiently to the wide range of vehicles produced by various manufacturers is a challenging task. In order to assist in this task, EPA has developed a computerized model called the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). Broadly, the model starts with a description of the future vehicle fleet, including manufacturer, sales, base CO_2 emissions, footprint and the extent to which emission control technologies are already employed. For the purpose of this Technical Assessment Report analysis, 63 generic vehicle platforms—were used to capture important differences in engine design, vehicle design and vehicle utility. The model is then provided with a list of technologies which are applicable to various types of vehicles, along with their cost and effectiveness and the maximum percentage of vehicle sales which can receive each technology. This list varies slightly depending on whether model year 2020 or 2025 standards are being evaluated and on the specific technology pathway being evaluated. The model combines this information with economic parameters, such as fuel prices and a discount rate, to project how manufacturers could apply available technology in order to meet specified levels of emission control. For this Technical Assessment Report, as all vehicle sales have been combined into a single manufacturer, the model indicates how the industry when complying as a single manufacturer might use technology to reduce GHG emissions. The resulting output is a description of which technologies are added to each vehicle platform, along with the accompanying cost.

OMEGA includes several components, including a number of pre-processors that assist users in preparing a baseline vehicle forecast,[1] creating and ranking technology packages,[2] and calculating the degree to which technology is present on baseline vehicles. The OMEGA core model assembles this information and produces estimates of increases in vehicle cost and CO_2 reduction. Based on the OMEGA core model output, the technology penetration of the new vehicle mix and the scenario impacts (fuel savings, emission impacts, and other monetized benefits) are calculated by post-processors. The pre- and post- processors are Microsoft Excel spreadsheets and visual basic programs, while the OMEGA core model is an executable program written in the C# language. The files used in this analysis, as well as the current version of OMEGA, are available in the TAR docket.

Figure F1.1-1: Information Flow in the OMEGA Model



A detailed description of the OMEGA model, as well as the general modeling methodology is provided in the MY 2012-2016 rule preamble Section III.D. Consequently, the interested reader may find additional depth there,[3] or in the OMEGA user guide on the EPA website.[4] The remainder of this appendix assumes a basic knowledge of OMEGA's operation, and focuses on the particular data sources and methodologies used in the scenario analysis described in Chapter 6.

F1.2 Summary of Inputs

The inputs underlying the OMEGA analysis have significant impacts on the results, and are described in detail elsewhere in this Assessment Report, as follows. The fleet projection used for this analysis is described in Appendix A. The vehicle technology packages are described in Chapter 3 and Appendix B. The inputs relating to air conditioning controls are outlined in Appendix D. The other economic and environmental outputs are described in Appendix E. The detailed description of analytic scenarios, including the standards modeled and the reasoning behind a single fleet analysis, is available in Chapter 6. Generally, the table of contents to this technical assessment is a useful guide to additional detail.

F1.3 Configuration of the Scenario File

The scenario file in OMEGA contains a directory of data input files, a group of economic parameters, and a set of CO_2 g/mile targets. For the Technical Assessment Report analysis, OMEGA was configured so that each technical pathway/model year combination was a single scenario file containing six runs. Four runs corresponding to each of the four emission control scenarios (*i.e.*, 3% per year, 4% per year, etc.) were included. Also included were a diagnostic run requiring maximum application of technology, as well the reference case scenario of MY 2016 GHG standards from the recent MY 2012-2016 final rule. As a result, six scenario files were created (2 MYs x 3 technical pathways), and each scenario file contained parameters for six OMEGA runs.

The emission control scenarios were each configured with a flat standard corresponding to the appropriate stringency. No limits were placed on credit transfers between the car and truck fleets. As in the MY 2012-2016 final rule analysis, EPA accounted for the emission reductions and technology costs due to air conditioning controls outside of the OMEGA model. In the MY 2025 timeframe, air conditioning remains a highly cost-effective technology to control GHG emissions, and consequently, EPA projects that the entire market will convert to low leakage, high efficiency systems. In the time frame of MY 2020 and later, these emission reductions were assigned a statutory value of 20.6 grams in the reference scenario[5] and 15.3 grams in the control scenarios.[6] An example of the adjustments is shown in Table F1.3-1. The MY 2016 footprint curves and the flat standards were each adjusted by the maximum potential AC credits to produce the credit adjusted targets. The agencies note, as discussed in Chapter 6 above, that the upcoming federal rulemaking analysis will consider fuel economy and emission control scenarios defined in terms of attribute-based standards, but we believe the scenarios considered here are meaningful for purposes of this assessment.

Table F1.3-1: Adjustment of Standards for Air Conditioning Credits

Scenario	Sales-Weighted MY 2025 Target	Projected AC Credits[1]	Sales-Weighted MY 2025 Credit Adjusted Target
Reference	248.1	20.6	268.7
3%	190.1	15.3	205.4
4%	173.1	15.3	188.4
5%	157.6	15.3	173.9
6%	143.2	15.3	158.5

A further adjustment was made with respect to the credit adjusted targets listed above. The scenarios described in this document are defined by a sales weighted average of car and truck CO_2 emissions. When credit transfer is allowed between cars and trucks, OMEGA weights the CO_2 average by both sales and vehicle miles traveled (VMT).[A] Light trucks generally are driven more than cars, so the sales and VMT weighted CO2 emission average tends to be slightly lower than the sales-weighted average. To account for this difference, the diagnostic run was used to produce VMT and sales weighted targets that corresponded to the sales weighted targets listed above. These calibrated targets can be seen in the scenario files available in the TAR docket.

We also updated the VMT ratios used in car/truck credit transfer to the appropriate MY lifetime values discussed in Appendix E.

F1.4 Configuration of the Technology File

The technology input file defines the technology packages which the model can add to the vehicle fleet. A separate technology file was developed for each of the six technology pathway/model year combinations considered in this Technical Assessment Report. While the individual technology costs were the same between technology pathways, they differed between MY 2020 and MY 2025 due to the learning effects discussed in the Appendix 3 and the MY 2012-2016 Final Rule Section II.E. Due to the different limits on maximum penetrations of several key technologies (discussed in Chapter 6), each of the technology pathways also required a separate technology file and model run. The change in those maximum penetration rates also slightly affected the set of most cost effective technology packages selected for inclusion in the OMEGA model runs. The processes to build and rank technology packages for the technology file are described in the Chapter 3 and Appendix B of this report. This section describes the configuration of the OMEGA Technology input file which occurs after the ranked packages are developed.

F1.4.1 Multiple Fuel Tracking

OMEGA 1.0.2, which was used during the MY 2012-2016 rule analysis, tracked CO_2 emissions at the vehicle platform level. For the present analysis, an upgrade was made to the OMEGA model to track CO_2 emissions by fuel within each vehicle platform. As a result, a vehicle platform can be composed of sub-vehicles, each with its own fuel, CO_2 emission rate and electricity consumption rate. To facilitate this tracking, every technology is encoded with its operating fuel, as well as the fuel of the vehicles to which it applies. In combination with technology specific caps,[B] this allows a vehicle platform to be split so that subsequent technologies can be applied to the specific subsets of the vehicle (Table F1.4-1). Thus, for example, a certain fraction of a vehicle's sales can be equipped with a diesel engine. Subsequent diesel-based technologies can then be applied more simply and directly to this

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[A] This practice is consistent with EPA's MY 2012-2016 regulations allowing VMT weighted credit transfer between car and truck fleets.

[B] ―Cap" is a shorthand term for the maximum penetration rates for certain technologies which define the various technology paths.

subset of sales. The model keeps track of the sales and CO_2 emission rates of both the gasoline and diesel versions of the vehicle.

In the example below, Technology Package 3 is applied to the gasoline fuel vehicle created by the application of Technology Package 1. Technology Package 4 is applied to the diesel fuel vehicle created by the application of Technology Package 2.

Table F1.4-1: Example of Multiple Fuel Technology File

Tech Package	Name	Cap[1]	Fuel of the Technology	Fuel to which the Technology Applies
1	GDI Gasoline Engine	100%	Gasoline	Gasoline
2	Diesel Engine	15%	Diesel	Gasoline
3	Gasoline Hybrid	100%	Gasoline	Gasoline
4	Improved Diesel	100%	Diesel	Diesel

[1] Please note that OMEGA technology caps are relative to the population on that fuel, so a 100% cap on technology package four indicates that it applies to 100% of the 15% of vehicles which were converted to diesel in step

In the current TAR analysis, this model feature simplified the ability to apply several types of electric vehicle and plug-in electric vehicle technology packages to the same baseline vehicle. In addition, we found it useful when applying certain advanced gasoline technology packages which had caps of less than 100%. For example, most of the technology paths limit the use of advanced (e.g., EGR-boosted) gasoline engine technologies to less than 100%. In most cases, further technology packages can be applied to both the vehicles which received this advanced gasoline technology and those that did not. By effectively treating ―advanced gasoline engines" as including a change in fuels, we were able to simplify the addition of subsequent technologies to both the subset of vehicle sales with this technology and that without it. This could have been accomplished without taking advantage of the OMEGA model's new fuel tracking capability, but the estimation of the cost and effectiveness of the subsequent technology packages would have had to consider the fact that they were being applied to a subset of the vehicle's sales which did not have the average attributes of that vehicle at that stage of technology addition.

For example, if EGR boost technology is added to 50% of the sales of those vehicles operating on gasoline, it may be possible to hybridize both the vehicles with and without the EGR boost technology, with differing costs and effectiveness. It is possible to determine the overall impact of hybridizing the non-EGR vehicles first and then the EGR-boosted vehicles and developing the appropriate OMEGA model inputs which accomplish both of these steps of technology addition. However, since we were not using all of the fuel types currently tracked in the OMEGA model (e.g. E10), it was easier to separate the EGR-boosted vehicles from those without this technology by changing the former vehicles' fuel to ―E10". We simply made the fuel properties of E10 exactly the same as those for gasoline. Then for example, the incremental effect of hybridizing the non-EGR boosted vehicles could be used directly in the model without the need to sales weight this impact by including the fact that the emissions of the non-EGR vehicles were not changing.

To further illustrate this issue, consider the case of Vehicle A, a gasoline vehicle with CO_2 emissions of 300 g/mile. In this example scenario, diesel packages are limited to 50% of the fleet because of concerns relative to production capacity.[C] In this case, two sequential diesel packages should be applied to the same 50% subset of the vehicle (Table F1.4-2). As can be seen in this table, OMEGA 1.3 now more accurately attributes the reductions to the appropriate subset within the vehicle platform.

Table F1.4-2: Tracking CO_2

Step	Package Fuel	Maximum Penetration Limit	Reduction	OMEGA 1.0.2 Applied to average vehicle.	OMEGA 1.3 Applied to a specific fuel within a platform.		
				CO_2 Avg	**CO_2 Avg**	**CO_2 Gas**	**CO_2 Diesel**
				300	300	300	N/A
1	Diesel	50%	10%	285	285	300	270
2	Diesel	50%/100%	10%	270.75	271.5	300	243

[1] The maximum penetration limit in the second step applies to 50% of the total vehicles (OMEGA 1.0.2) or 100% of the diesel vehicles (OMEGA 1.3)

In the analysis presented in this report, we encode limited technologies to different fuels so that the appropriate reductions are taken. As an example, plug-in hybrids are coded to diesel fuel. The fuels input file was modified so that the appropriate gasoline fuel properties are attributed to –diesel” fuel.

F1.4.2 Tracking of Electricity

OMEGA 1.3 also tracks electrical consumption in kWh per mile. Each technology package is now associated with an –electricity conversion percentage” which refers to the increase in the energy consumed by the electric drivetrain relative to reduction in the consumption of energy from liquid fuel. Electricity is a highly refined form of energy which can be used quite efficiently to create kinetic energy. Thus, electric motors are much more efficient than liquid fuel engines. Consequently, the electric consumption percentage input in in the Technology File for plug-in vehicles is generally well below than 100%. It may be possible that this percentage could exceed 100% under certain circumstances, for example when one type of plug-in vehicle is being converted into another plug-in vehicle and electricity consumption per mile is increasing due to larger and heavier batteries, etc. However, that was not the case for any of the technologies evaluated in this analysis.

[C] Please note, this is just an example, and has no implications relative to actual maximum penetration rates for diesel vehicles.

F1.5 Configuration of the Market File

F1.5.1 Creating the Generic Vehicles

As discussed in Section F1.4 above, vehicle manufacturers typically develop many different models by basing them on a smaller number of vehicle platforms. The platform typically consists of a common set of vehicle architecture and structural components. This allows for efficient use of design and manufacturing resources. In the MY 2012-2016 Final Rule, EPA created over 200 vehicle platforms which were used to capture the important differences in vehicle and engine design and utility of future vehicle sales of roughly 16 million units in the 2016 timeframe. For the current analysis, we are not differentiating between manufacturers, and consequently require fewer vehicle platforms for the analysis. The approximately sixty vehicle platforms are a result of mapping the 1130 vehicle fleet into the 19 engine based vehicle types (Table F1.5-1) and the 10 body size and structure based utility classes (Table F1.5-2). As not all vehicle types match to all utility types, the number of generic vehicles is less than the multiplicative maximum of the two tables.

Table F1.5-1 : Vehicle Types in the TAR Analysis

Vehicle Type #	Name	Cam	Engine
1	Subcompact Car	DOHC	I4
2	Compact Car I4	DOHC	I4
3	Midsize Car/Small MPV (unibody)	DOHC	I4
4	Compact Car/Small MPV (unibody)	DOHC	V6
5	Midsize/Large Car	DOHC	V6
6	Midsize Car/Large Car	DOHC	V8
7	Mid-sized MPV (unibody)/Small Truck	DOHC	I4
8	Midsize MPV (unibody)/Small Truck	SOHC	V6
9	Large MPV (unibody)	SOHC	V8
10	Large MPV (unibody)	SOHC	V8
11	Large Truck (+ Van)	SOHC	V6
12	Large Truck + Large MPV	OHV	V6
13	Large Truck (+ Van)	OHV	V8
14	Large Truck (+Van)	SOHC3V	V8
15	Large Car	OHV	V8
16	Large MPV (unibody)	DOHC	V6
17	Large MPV (unibody)	DOHC	V8
18	Large Truck (+ Van)	DOHC	V6
19	Large Truck (+ Van)	DOHC	V8

Table F1.5-2 : Vehicle Types in the Technical Assessment Analysis

Utility Class #	Utility Class	Vehicle Use [1]	Footprint Criteria	Structure Criteria
1	Subcompact Auto	Car	Footprint <43	--
2	Compact Auto	Car	43<=Footprint<46	--
3	Mid Size Auto	Car	46<=Footprint<53	--

4	Large Auto	Car	56<=Footprint	--
5	Small SUV	SUV	43<=Footprint<46	--
6	Large SUV	SUV	46<=Footprint	--
7	Small Pickup	Pickup	Footprint < 50	--
8	Large Pickup	Pickup	50<=Footprint	--
9	Cargo Van	Van	--	Ladder Frame
10	Minivan	Van	--	Unibody

1. Vehicle use type is based upon analysis of EPA certification data.

F1.5.2 Accounting for Technology already on the Vehicles

The market data input file utilized by OMEGA, which characterizes the vehicle fleet, is designed to account for the fact that the 2008 model year vehicles which comprise our baseline fleet may already be equipped with one or more of the technologies available in general to reduce CO2 emissions. As described in Appendix B, EPA decided to apply technologies in packages, as opposed to one at a time. However, 2008 vehicles were equipped with a wide range of technology combinations, many of which cut across the packages. Thus, EPA developed a method to account for the presence of the combinations of applied technologies in terms of their proportion of the EPA packages described in Chapter 3. This analysis can be broken down into four steps

The first step in the updated process is to breakdown the available GHG control technologies into five groups: 1) engine-related, 2) transmission-related, 3) hybridization, 4) weight reduction and 5) other. Within each group we gave each individual technology a ranking which generally followed the degree of complexity, cost and effectiveness of the technologies within each group. More specifically, the ranking is based on the premise that a technology on a 2008 baseline vehicle with a lower ranking would be replaced by one with a higher ranking which was contained in one of the technology packages which we included in our OMEGA modeling. The corollary of this premise is that a technology on a 2008 baseline vehicle with a higher ranking would be not be replaced by one with an equal or lower ranking which was contained in one of the technology packages which we chose to include in our OMEGA modeling. This ranking scheme can be seen in the TEB/CEB calculation macro, available in the docket.

In the second step of the process, we used these rankings to estimate the complete list of technologies which would be present on each baseline vehicle after the application of each technology package. We then used the EPA lumped parameter model to estimate the total percentage CO2 emission reduction associated with the technology present on the baseline vehicle (termed package 0), as well as the total percentage reduction after application of each package. This process was repeated to determine the total cost of all of the technology present on the baseline vehicle and after the application of each applicable technology package.

The third step in this process is to determine the degree of each technology package's incremental effectiveness and incremental cost is affected by the technology already present on the baseline vehicle. The degree to which a technology package's incremental effectiveness is reduced by technology already present on the baseline vehicle is termed the technology effectiveness basis, or TEB, in the OMEGA model. The value of each vehicle's TEB for each applicable technology package is determined as follows:

$$TEB_i = \frac{1-\left(\frac{TotalEffect_{v,i-1}}{1-TotalEffect_{v,i}}\right)\times\left(\frac{1-TotalEffect_{p,i}}{1-TotalEffect_{p,i-1}}\right)}{\left(1-\frac{1-TotalEffect_{p,i}}{1-TotalEffect_{p,i-1}}\right)}$$

Where

$TotalEffect_{v,i}$ = Total effectiveness of all of the technologies present on the baseline vehicle after application of technology package i

$TotalEffect_{v,i-1}$ = Total effectiveness of all of the technologies present on the baseline vehicle after application of technology package i-1

$TotalEffect_{p,i}$ = Total effectiveness of all of the technologies included in technology package i

$TotalEffect_{p,i-1}$ = Total effectiveness of all of the technologies included in technology package i-1

Equation 1.5-1 – TEB calculation

The degree to which a technology package's incremental cost is reduced by technology already present on the baseline vehicle is termed the cost effectiveness basis, or CEB, in the OMEGA model. The value of each vehicle's CEB for each applicable technology package is determined as follows:

$$CEB_i = 1 - (TotalCost_{v,i} - TotalCost_{v,i-1}) / (TotalCost_{p,i} - TotalCost_{p,i-1})$$

Where

$TotalCost_v$ = total cost of all of the technology present on the vehicle after addition of package i or i-1 to baseline vehicle v

$TotalCost_p$ = total cost of all of the technology included in package i or i-1

i = the technology package being evaluated

i-1 = the previous technology package

Equation 1.5-2 – CEB calculation

The values of CEB and TEB are capped at 1.0 or less, since a vehicle cannot have more than the entire package already present on it. In other words, the addition of a technology package cannot increase emissions nor reduce costs. (A value of 1.0 causes the OMEGA model to not change either the cost or CO2 emissions of a vehicle when that technology package is added.) The value of a specific TEB or CEB can be negative, however. This implies that the incremental effectiveness or the incremental cost of adding a package can be greater than that when adding the packages in sequence to a vehicle with no baseline technology.

An example of this is a baseline vehicle with a 6 speed manual transmission. All of our technology package effectiveness and cost estimates are estimated for specified baseline vehicles, all of which have 4 speed automatic transmissions. Our technology packages improve this transmission, sometimes to a 6 speed automatic transmission and then a dual clutch transmission and sometimes directly to a dual clutch transmission. Subsequent packages may then strongly hybridize the vehicle. If a baseline vehicle has a 6 speed manual transmission, this transmission is unaffected by the technology packages which include either a 6 speed automatic transmission or a dual clutch transmission, since the manual transmission is both cheaper and/or more efficient than these other transmissions. However, when the vehicle is hybridized, this manual transmission is replaced. The incremental cost of changing this vehicle to a power-split hybrid design, for example, is greater than that for a vehicle with a dual clutch transmission, since the credit for removing the manual transmission is less than that for the dual clutch transmission. The negative CEB causes the OMEGA model to apply a cost for this power-split package which is slightly higher than that for the typical baseline vehicle.

The fourth step is to combine the fractions of the cost and effectiveness of each technology package already present on the individual 2008 vehicles models for each vehicle type. For cost, percentages of each package already present are combined using a simple sales-weighting procedure, since the cost of each package is the same for each vehicle in a vehicle type. For effectiveness, the individual percentages are combined by weighting them by both sales and base CO_2 emission level. This appropriately weights vehicle models with either higher sales or CO_2 emissions within a vehicle type. Once again, this process prevents the model from adding technology which is already present on vehicles, and thus ensures that the model does not double count technology effectiveness and cost associated with complying with the reference standards or the CO_2 control scenarios.

For this analysis, we automated the process through a visual basic macro that both operates the lumped parameter model and calculates the TEBs and CEBs. This macro-enabled excel file is available in the docket.

F1.6 Post-processing OMEGA

F1.6.1 A/C Credits

As noted above, A/C credits were simply subtracted off the OMEGA results for both the reference and control cases. A/C system costs were added into both cases. As a result, the delta between reference and control cases, both in terms of costs and environmental impact, did not change.

F1.6.2 Calculating Technology Penetrations

Technology penetrations were calculated using the new ―techpacksales" output file of the OMEGA model. This output provides, for each of the approximately 60 vehicle platforms, the distribution of sales among the tech packs. In a post-processing step, this distribution is applied back to the 1130 individual vehicles of the disaggregate baseline fleet projection so that we have the tech pack distribution of each vehicle. As discussed in the description of TEB/CEB calculations, we have already produced a file which contains the specific technologies on each vehicles with every possible technology package. By applying the technology pack distributions from the 60 vehicle platforms back against the 1130 vehicles in dissagregated fleet, we are able to determine the specific technologies on each vehicle in each scenario and tech pathway. As an example, this file would show what technologies are actually on a Ford F150 with technology package 1, 2, 3 etc. This file is combined with OMEGA's technology pack distribution output to determine the penetration of each tracked technology.

F1.6.3 Impacts Calculations

Liquid fuel consumption, electricity consumption and emission impacts were calculated in a modified version of the post-processor spreadsheet that was used in the MY 2012-2016 final rule. This spreadsheet, available in the downloadable material accompanying this technical assessment report, is the repository for the inputs discussed in Appendix E. The impacts calculations sequentially calculate light duty vehicle stock, VMT, and impacts for each MY and CY from 2010 through 2050. Outputs are available on either calendar year or model year basis. For this Technical Assessment Report, the VMT algorithm was integrated into the benefits calculations, electricity calculations were added, and the inputs and outputs were restructured. Provided the same inputs, the current benefits spreadsheet would still provide the same outputs as the version used in the MY 2012-2016 Final Rule.

A detailed discussion of the benefits calculations algorithms is available in the MY 2012-2016 Final Rule RIA chapter 5 and in the OMEGA users guide.

We note that the current analysis did not rely upon many of the outputs of the OMEGA benefits post-processor. These outputs, such as co-pollutant impacts, monetized emission impacts, the benefits of additional travel time, and damages due to noise, accidents, and congestion, may not produce accurate results in the context of the numerous input changes, and should not be used.

Appendix F References

[1] Appendix A

[2] Appendix B

[3] http://www.epa.gov/oms/climate/regulations.htm

[4] http://www.epa.gov/oms/climate/models.htm

[5] EPA. LD GHG MY 2012-2016 Rule, RIA Chapter 2 and 5.

[6] Appendix D to this report.

G1 Appendix G: Infrastructure

Appendix G contains a compilation of additional information to support Chapter 4, Infrastructure Assessment. Appendix G contains additional information covering the following topic areas:

- DOE-funded grants for electric drive demonstration and evaluation programs
- Estimates of costs of charging equipment
- Battery end of life value
- Voluntary standards
- Hydrogen Infrastructure

G1.1 American Recovery and Reinvestment Act: Transportation Electrification Initiative

Through the American Recovery and Reinvestment Act of 2009 (ARRA), DOE has awarded cost-shared grants to companies under the Transportation Electrification Initiative to establish development, demonstration, evaluation, and education projects to accelerate the market introduction and penetration of advanced electric drive vehicles. The component projects of the Transportation Electrification Initiative and other DOE electric-drive vehicle infrastructure activities are discussed below.

ECOtality North America

ECOtality North America has been awarded a cost-shared grant of nearly $115 million to support ―The EV Project,” to deploy electric-drive vehicles and charging infrastructure in sixteen major U.S. cities beginning in 2010. Upon full deployment of vehicles and infrastructure under this project in 2011, approximately 8,500 electric drive vehicles and 14,850 Level 2 charging stations will be in service, providing a rich set of data regarding the operational and charging behavior of electric drive vehicle owners in a variety of markets.

The ECOtality project will install grid-connected vehicle infrastructure in Phoenix, AZ; Tucson, AZ; San Diego, CA; Los Angeles, CA; Portland, OR; Eugene, OR; Salem, OR; Corvallis, OR; Seattle, WA; Dallas, TX; Fort Worth, TX; Houston, TX; Nashville, TN; Knoxville, TN; Chattanooga, TN; and Washington, DC. Residential Level 2 charging stations will be provided at no cost to purchasers of the Nissan LEAF EV and the Chevrolet Volt Extended Range Electric Vehicle (EREV) who subscribe to the program. Additionally, Level 3 DC ―fast” chargers will be installed along routes connecting neighboring cities – such as Nashville/Knoxville/Chattanooga, Phoenix/Tucson, and Seattle/Portland/Eugene – establishing a network of electric vehicle corridors between electric transportation hubs. More information about The EV Project is available at http://www.theevproject.com.

Coulomb Technologies

Coulomb Technologies has been awarded a cost-shared grant of $15 million to support its ―ChargePoint America" project, to deploy electric-drive vehicles and charging infrastructure in nine major metropolitan areas beginning in 2010. The project will result in the deployment of approximately 5,000 Level 2 charging stations at residential and commercial locations in Bellevue/Redmond, WA; Sacramento, CA; San Jose/San Francisco Bay, CA; Los Angeles, CA; Austin, TX; Detroit, MI; New York, NY; Washington, DC; and Orlando, FL. Residential chargers will be provided to purchasers of the Chevrolet Volt EREV – in some cases, at no cost – and will also be deployed in conjunction with electric drive vehicles from Ford and Smart USA. More information about ChargePoint America is available at http://www.chargepointamerica.com.

Navistar

Navistar was awarded a cost-shared grant of over $39 million to develop and demonstrate a fleet of all-electric medium-duty delivery trucks, which the company has named the eStar. These vehicles will be manufactured in Wakarusa, IN, and deployed through various fleet partners nationwide. In total, 950 Class 2c-3 electric trucks will be deployed in conjunction with 950 Level 2 charging stations, at locations specified by the respective fleet owners. Data collected from these vehicles and charging stations will provide valuable information regarding the performance and suitability of medium-duty electric vehicles and the infrastructure required to support them. More information about eStar trucks is available at http://www.estar-ev.com.

General Motors

General Motors was awarded a cost-shared grant of over $30 million to develop and deploy a fleet of Chevrolet Volt EREVs, and to gather data on vehicle performance and infrastructure requirements. A fleet of 125 Chevy Volts will be deployed in combination with over 650 Level 2 charging stations, through electric utility partners in several diverse geographic locations throughout the U.S. The project will include the installation, demonstration, and testing of charging infrastructure in residential, commercial, and public locations. Additionally, a comprehensive set of data will be collected from the vehicles and charging stations from December 2010 through 2012, and will contribute to a more complete understanding of typical vehicle usage and operational needs, supporting the next generation of vehicle designs and infrastructure planning. The project will also include an analysis of fast charging requirements and the development and demonstration of smart charging capabilities using General Motors' OnStar telematics service.

Smith Electric Vehicles

Smith Electric Vehicles has been awarded a $32 million cost-shared grant to develop and demonstrate a fleet of all-electric medium-duty trucks. Approximately 500 vehicles will be built in Kansas City, MO, and deployed with 500 Level 2 charging stations through fleet partners representing a range of commercial and public-sector markets in diverse geographic and climatic areas by the end of 2011. In addition, the project will include the collection of real-world performance data using an automatic GPS-based telemetry system. The Smith Electric Vehicles project, combined with the Navistar project, will provide valuable insight into the applicability of electric-drive powertrains in medium-duty trucks in a variety of vocations. More information about Smith Electric Vehicles is available at http://www.smithelectric.com.

South Coast Air Quality Management District

SCAQMD was awarded a cost-shared grant of over $45 million to develop, demonstrate, and evaluate a fleet of medium-duty plug-in hybrid electric trucks and shuttle buses. A total of 378 vehicles will be demonstrated nationwide, in combination with 378 Level 2 charging stations. The majority of the vehicles will be bucket trucks based on the Ford F-550 chassis, deployed through electric utility partners, while the shuttle buses, based on the Ford E-450, will be deployed via shuttle bus fleet operators. Data collected from the fleet will be analyzed in order to quantify the attributes of PHEV technologies for Class 4/5 vehicles in terms of emissions, greenhouse gas reductions, and fossil fuel displacement. An additional goal of the project is to develop production ready smart charging capability for commercial applications. More information about the current status of this program is available at http://www.aqmd.gov/hb/2010/july/100710a.htm.

Chrysler Group LLC

Chrysler has been awarded a $48 million cost-shared grant to develop and demonstrate 153 plug-in hybrid electric Dodge Ram pickup trucks combined with Level 2 charging infrastructure. The trucks and charging stations will be deployed through partner fleets in diverse geographies and climates, spanning from North Dakota to Arizona, and from Hawaii to Massachusetts. Full deployment of the vehicles will be achieved in early 2011, followed by data collection and vehicle monitoring activities through 2013 in order to prove real-world product viability and to quantify the benefits to consumers and to the nation. As part of this project Chrysler, with support from its project partners, will develop and demonstrate bi-directional charging capability.

Education Grants

Through the *Transportation Electrification Initiative*, ten grants totaling nearly $40 million were awarded to educational institutions to establish programs to train engineers, technicians, and emergency first responders, as well as to inform the general public, in preparation for the transition to vehicles with advanced electric drive technologies. At the university level, graduate and undergraduate engineering degree programs will be created to educate students in technologies related to electric drive vehicles and charging infrastructure. Several community colleges received grants to establish technical training courses and certificate programs to train service personnel and automotive technicians to properly service and maintain vehicles with electric drive powertrains. Similarly, electric vehicle safety training programs will be created to train emergency personnel in proper safety protocols related to electric vehicles and infrastructure, which will differ from current vehicles and infrastructure with which first responders are already familiar. Furthermore, consumer outreach and K-12 educational materials will be created to familiarize the general public with electric-drive vehicle capabilities and infrastructure utilization. All of these activities will take place through projects supported by *Transportation Electrification* grants awarded to the

University of Michigan, J. Sargeant Reynolds Community College, West Virginia University/National Alternative Fuels Training Consortium, Michigan Technological University, Missouri University of Science and Technology, Wayne State University, Colorado State University, Purdue University, City College of San Francisco, and the National Fire Protection Association.

G1.2 Charger Cost Estimates

The following list of charger cost estimates details the sources and the respective estimates pulled from each that were used in constructing the charger cost estimate Table 4.2-2, ―Estimated Costs for Charging Stations". Here, the estimates are listed by source along with assumptions and context that are relevant to the cost estimate.

Level 1

1. Residential (Morrow, Karner and Francfort, 2008)[1]
    a. Charge cord + circuit installation, 20A $878
2. Public networked (May and Mattila, 2009)[2]
    a. 12A stations (Coulomb Technologies) $2500 each + $1000 for ―gateway" station
3. Public (May and Mattila, 2009)[3]
    a. 20 amp/4 vehicle (Shorepower Technologies/SynkroMotive) $2500-$2900
4. Apartment complex, not networked (5 stations) (Morrow, Karner and Francfort, 2008)[4]
    a. 5 charge cords $1250
    b. 5 20 amp circuits $2221
    c. Installed $4165

Level 2, Residential or Fleet Depot

1. Residential, no service panel upgrade (ETEC, 2009)[5]
    a. 40 amp EVSE $780
    b. Installed $2272
2. Residential (Morrow, Karner and Francfort, 2008)[6]
    a. EVSE 32 amp $650
    b. Charge cord $200
    c. 40 amp circuit $1080
    d. Installed $2146
3. Residential, no upgrade (May and Mattila, 2009)[7]
    a. 9-25 amp EVSE, output 3.3 kW (Brusa/Metric Mind) $3870 - $6353
4. Residential (Electrification Coalition, 2009)[8]
    a. No upgrade $500-$1500
    b. With upgrade, ―up to $2500")
5. Commercial Fleet (10 stations) (ETEC, 2009)[9]
    a. Distribution panel $650
    b. EVSE 40 amp $780 * 10
    c. EVSE Pedestal $450 * 10
    d. Installed $31,375

   e. $3138/station

6. Apartment complex, not networked (5 stations) (Morrow, Karner and Francfort, 2008)[10]
   a. 5 EVSEs $3250
   b. 5 charge cords $1000
   c. 5 circuits $2611 including labor costs for circuits and EVSEs
   d. Installed $7597 for 5 stations
   e. $1520/station

Level 2, Public

7. Public (2 chargers) (ETEC, 2009)[11]
   a. Distribution sub-panel $250
   b. EVSE 40 amp $780 * 2
   c. EVSE Pedestal $450 * 2
   d. Installed $12,875
   e. $6438/station
8. Public networked (May and Mattila, 2009)[12]
   a. 32 amp stations (Coulomb Technologies) $3500 each + $1000 for —gateway” station
   b. 120 amp stations, charges 4 vehicles (EV-Charge America) $1200-$1500
   c. 16.8 kW smart station (GoSmart Technologies) $2200-$3800
   d. Above apparently are hardware only
9. Public stations (May and Mattila, 2009)[13]
   a. Pre-assembled unit, $1400-$1800/single 24-30 amp, $2800/60 amp double (eTec)
10. Public (Electrification Coalition, 2009)[14]: up to $5,000

Level 3, Public Quick Charge

1. Public Level 3 (2 stations) (ETEC, 2009)[15]
   a. Distribution sub-panel $650
   b. Fast charger (30 kW) $25,000 * 2
   c. Point of sale system $2500
   d. Installed $64,158
2. Unspecified (Electrification Coalition, 2009)[16] $25,000-$50,000
3. Nissan 50 kW Quick EV Charger, CHAdeMO standard, manufacturer‘s suggested retail price, not including installation $17,500 – 20,600[A,17]
4. Confidential submission, EVSE in high volume, direct manufacturing cost, not including installation $8,000[B]

The range in the costs for quick-charge EVSEs reflects a difference between current, relatively low volume public quick-charge EVSEs and a future EVSE incorporating multiple

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[A] Lower cost is base unit, higher cost reflects options for hot or cold climate operation.

[B] Confidential information provided to EPA, ARB and NHTSA, August 2010. Manufacturing cost and general description of architecture cleared for release by the original source on September 10, 2010.

chargers of the same type used for on-vehicle charging in order to share economies of scale between EVSEs and components sourced in much higher volume for automobile production. This would be expected to provide a significant cost reduction for some of the most expensive components within public quick-charge EVSEs.

G1.3 Battery End-of-Life Value Potential

Chapter 4.2.4 discusses issues surrounding the assessment of a secondary use value for EV/PHEV batteries. Work is underway to study this issue, including the extent of the market for secondary use batteries and the potential value to the original vehicle purchaser. This section summarizes one such study supported by DOE.

Accelerated development and market penetration of PHEVs and EVs is presently restricted by the high cost of lithium-ion (Li-Ion) batteries. In fact, it has been estimated that a ~50% reduction in battery costs is necessary to equalize the current economics of owning PHEVs and conventionally fueled vehicles.[18]

One way to address this problem is to recover a fraction of the battery cost via reuse in other applications after it is retired from service within the vehicle, where it may still have sufficient performance to meet the requirements of other energy storage applications. By extracting additional services and revenue from the battery in a post-vehicle application, the total lifetime value of the battery is increased.

There are several current and emerging applications where the secondary use of PHEV and EV batteries may be beneficial. For example, the use of renewable solar and wind technologies to produce electricity is growing, and their increased market penetration requires energy storage to mitigate the intermittency of wind and solar energy. New trends in utility peak load reduction, energy efficiency, and load management also need energy storage. Smart grid, grid stabilization, low-energy buildings, and utility reliability require energy storage as well. It is reasonable to suggest that some utility applications are capable of supporting 2010‘s new battery prices.[19] [20] [21] Assuming that battery prices fall faster than the value of these utility applications (not improbable, given the anticipated decline in battery prices and that the increased presence of renewable generation should drive utility application values higher), the same will be true in the 2017-2025 time frame.

Thus, substantial markets for used automotive batteries may exist, and given that the allowable battery costs for these applications will exceed new battery prices, battery salvage values must be determined relative to competing products rather than application values. Assuming that a primary competitor is new automotive Li-Ion batteries, salvage values can be computed based upon anticipated future Li-Ion prices. Additionally, the salvage value must be greater than the ―competing" application of leaving the battery in the aging vehicle and accepting its reduced range capability or selling it to someone with reduced range requirements. Under these assumptions, it is reasonable to assume that the future salvage value of a used PHEV/EV battery will be proportional to the cost of an equally capable new battery, taking into consideration the health of the used battery, the cost of collecting, refurbishing, and certifying the used battery, and a ‗used‘ product discount factor. Given efforts to ramp up automotive battery production between 2010 and 2015, it is reasonable to assume that such batteries will be a relatively mature product and that the majority of the benefits owed to economies of scale will be achieved by 2017, leading to the following:

- Battery life will be improved such that 10 years of in-vehicle life is common and significant health remains in the battery post automotive retirement
- Battery price reduction across the battery life will be relatively small
- Batteries will be treated as a commodity, thus used product discounts will be fairly low
- Recognizing the value of secondary use and leveraging advances in battery health monitoring, automotive batteries will be designed to minimize reconditioning costs

Based on the preceding conditions, one study estimates that net present salvage values for EV/PHEV batteries sold in the 2017-2025 time frame are approximately 20% of their initial purchase price.[22]

G1.4 List of Voluntary Standards

This list of voluntary standards illustrates the complexity and interrelationships due to the addition of communication to the interface between the vehicle and each major element of the consumer-vehicle-grid system. These efforts are to enhance long-term success; however, they are not a prerequisite for a successful near-term market launch. It is worth noting that the SAE J1772 standard is complete, which is a significant development; many others are still under development.

SAE – The following existing standards were identified in the Phase 1 NIST *Framework and Roadmap for Smart Grid Interoperability Standards*[C] as standards that can be used now to support Smart Grid development:

- SAE J1772 Electrical Connector between PEV[D]/EV and EVSE
    - SAE J1772™ Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
- SAE J2293 Communications between PEVs and EVSE for DC Energy [Part 1, Part 2]
    - SAE J2293/1 Energy Transfer System for Electric Vehicles: Functional Requirements and System Architectures

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[C] *Available at* http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf (last accessed August 26, 2010).

[D] –PEV” (plug-in electric vehicle) is SAE‘s language of choice for what is called a PHEV elsewhere in this document.

  - SAE J2293/1 Energy Transfer System for Electric Vehicles: Communication Requirements and Network Architecture

- SAE J2836/1-3 Use Cases for PEV Interactions (in development) [Part 1, Part 2, Part 3]
  - J2836/1 Use Cases for Communication between Plug-in Vehicles and the Utility Grid
  - J2836/2 Use Cases for Communication between Plug-in Vehicles and the Supply Equipment (EVSE)
  - J2836/3 Use Cases for Communication between Plug-in Vehicles and the Utility Grid for Reverse Power Flow
  - J2836/4 Use Cases for Diagnostic Communication for Plug-in Vehicles
  - J2836/5 Use Cases for Communication between Plug-in Vehicles and their customers.
- SAE J2847/1-3 Communications for PEV Interactions (in development) [Part 1, Part 2, Part 3]
  - J2847/1 Communication between Plug-in Vehicles and the Utility Grid
  - J2847/2 Communication between Plug-in Vehicles and the Supply Equipment (EVSE)
  - J2847/3 Communication between Plug-in Vehicles and the Utility Grid for Reverse Power Flow
  - J2847/4 Diagnostic Communication for Plug-in Vehicles
  - J2847/5 Communication between Plug-in Vehicles and their customers
- J2894 Power Quality Requirements for Plug-in Vehicle Chargers – Part 1: Requirements
- J2894/2 Power Quality Requirements for Plug-in Vehicle Chargers – Part 2: Test Methods
- J2931/1 Power Line Carrier Communications for Plug-in Electric Vehicles

IEEE – Standards Coordinating Committee 21 (SCC21) sponsors the development of 1547 interconnection standards and the P2030 smart grid interoperability standards project.

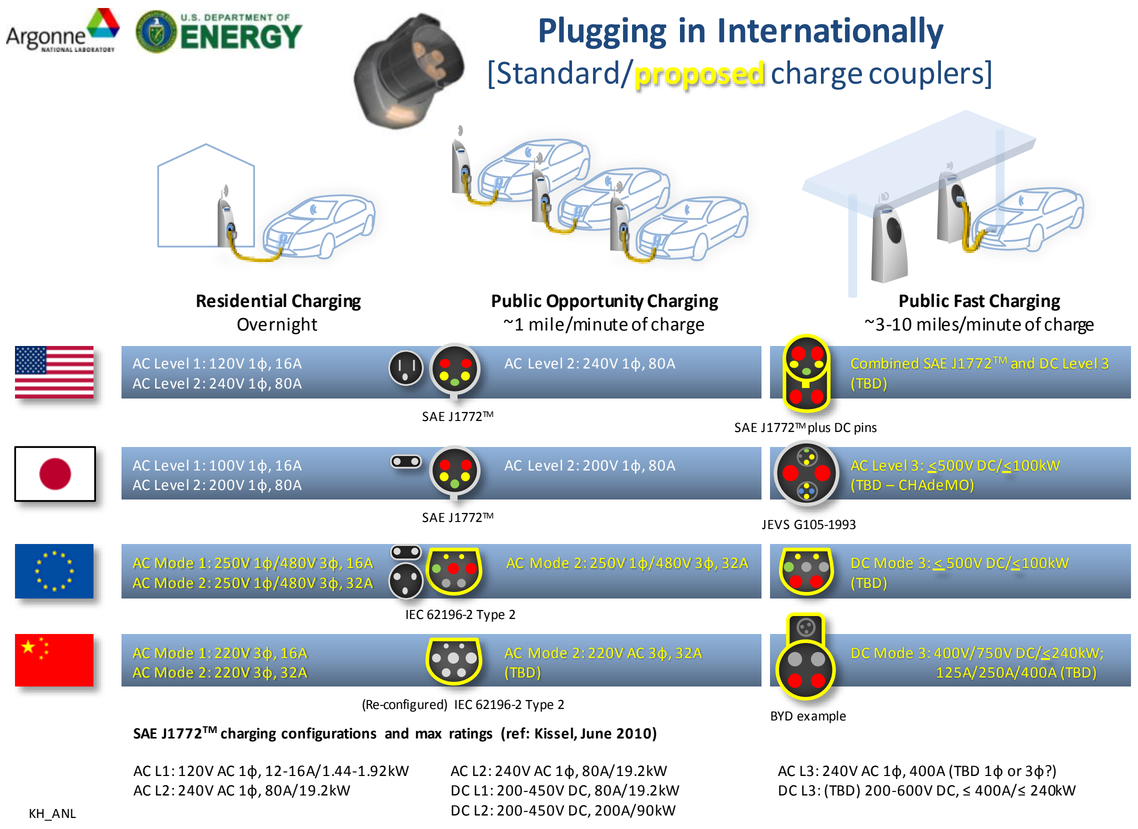
- IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems

- IEEE P2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology and Information Technology Operation with the Electric Power System (EPS) and End-Use Applications and Loads

UL – Underwriters Laboratories plays a critical role in the certification of hardware to be used in charging. UL offers certification for the many aspects of the EVSE, including the charge equipment (Levels 1-3), plugs, receptacles, cord sets and personal protection equipment. Of particular interest are specifications with respect to grounding/isolation.

NFPA - NEC, part 625, specifically addresses the installation of charging equipment. It is updated every 3 years; currently NEC-2008 applies and inputs/petitions for the next version (NEC-2011) are closed. The draft national template project relies heavily on the NEC as it is the primary reference for permitting and installation in local municipalities.

International - SAE and JARI agree on Level 2 charging standards (both countries use single-phase current); though, high-power Level 3 DC coupler standards for public charging differ substantially from those proposed in the U.S. (and Europe so far). The JARI Level 3 standards are promoted by CHAdeMO, an association formed in Japan to promote global adoption of JARI EV infrastructure standards, and are used on the TEPCO charge equipment that will be deployed by the ARRA-funded vehicle demonstration program (along with the Nissan Leaf EV); a U.S. Level 3 standard has yet to be developed. Though proposed charge coupler standards are constantly being refined, the following chart was recently developed to explain the differences at this time.



Plugging in Internationally

[Standard/proposed charge couplers]

	Residential Charging Overnight	Public Opportunity Charging ~1 mile/minute of charge	Public Fast Charging ~3-10 miles/minute of charge
	AC Level 1: 120V 1ϕ, 16A AC Level 2: 240V 1ϕ, 80A	AC Level 2: 240V 1ϕ, 80A SAE J1772™	Combined SAE J1772™ and DC Level 3 (TBD) SAE J1772™ plus DC pins
	AC Level 1: 100V 1ϕ, 16A AC Level 2: 200V 1ϕ, 80A	AC Level 2: 200V 1ϕ, 80A SAE J1772™	AC Level 3: ≤500V DC/≤100kW (TBD – CHAdeMO) JEVS G105-1993
	AC Mode 1: 250V 1ϕ/480V 3ϕ, 16A AC Mode 2: 250V 1ϕ/480V 3ϕ, 32A	AC Mode 2: 250V 1ϕ/480V 3ϕ, 32A IEC 62196-2 Type 2	DC Mode 3: ≤ 500V DC/≤100kW (TBD)
	AC Mode 1: 220V 3ϕ, 16A AC Mode 2: 220V 3ϕ, 32A	AC Mode 2: 220V AC 3ϕ, 32A (TBD) (Re-configured) IEC 62196-2 Type 2	DC Mode 3: 400V/750V DC/≤240kW; 125A/250A/400A (TBD) BYD example

SAE J1772™ charging configurations and max ratings (ref: Kissel, June 2010)

AC L1: 120V AC 1ϕ, 12-16A/1.44-1.92kW	AC L2: 240V AC 1ϕ, 80A/19.2kW	AC L3: 240V AC 1ϕ, 400A (TBD 1ϕ or 3ϕ?)
AC L2: 240V AC 1ϕ, 80A/19.2kW	DC L1: 200-450V DC, 80A/19.2kW	DC L3: (TBD) 200-600V DC, ≤ 400A/≤ 240kW
	DC L2: 200-450V DC, 200A/90kW	

KH_ANL

Figure G1.4-1: International Charge Couple Comparison[E]

G1.5 Hydrogen Infrastructure

Section 4.3 in Chapter 4, Infrastructure Assessment, contains an overview of hydrogen refueling technology and availability. This section provides additional details about hydrogen infrastructure including costs, standards, and codes for hydrogen infrastructure installation.

G1.5.1 Cost of Hydrogen

This section summarizes slides taken from a presentation by Professor Joan Ogden of the *Institute of Transportation Studies University of California, Davis.* [23]

The slides indicate projected cost of hydrogen in various U.S. cities from 2014 to 2030, U.S. average delivered hydrogen cost through 2050 and hydrogen transition timing and costs.

[E] Level 2 is up to 80 amp, but typically 16-32 amp

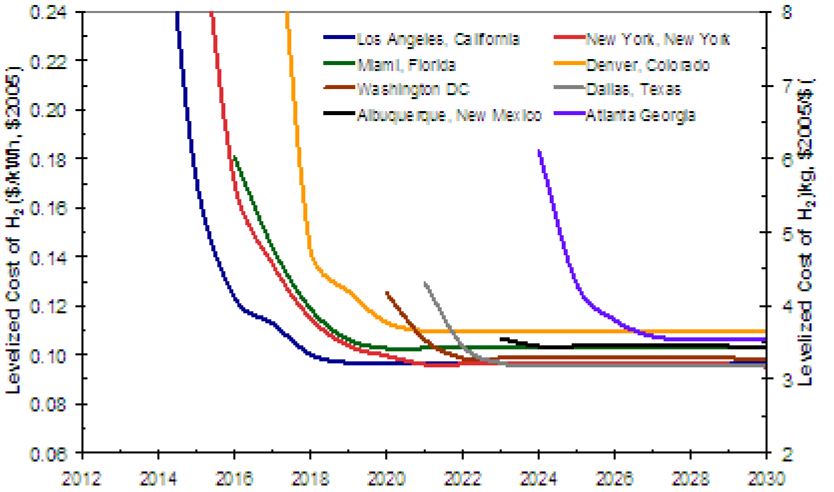


Figure 1.5-1: Cost of Hydrogen in Selected US Cities (UCD SSCHISM Model)

J. Ogden and C. Yang, "Build-up of a hydrogen infrastructure in the US," Chapter 15, in The Hydrogen Economy: Opportunities and Challenges, edited by Dr Michael Ball and Dr Martin Wietschel, Cambridge University Press, 2009, pp.454-482.

In certain regions, such as Los Angeles, hydrogen cost for infrastructure is projected to decrease rapidly between 2015 and 2018 as FCEVs are rolled out.

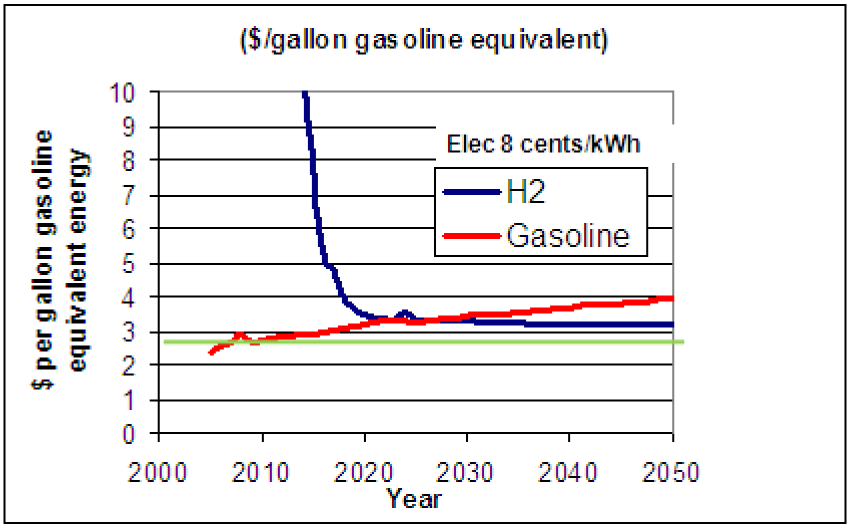
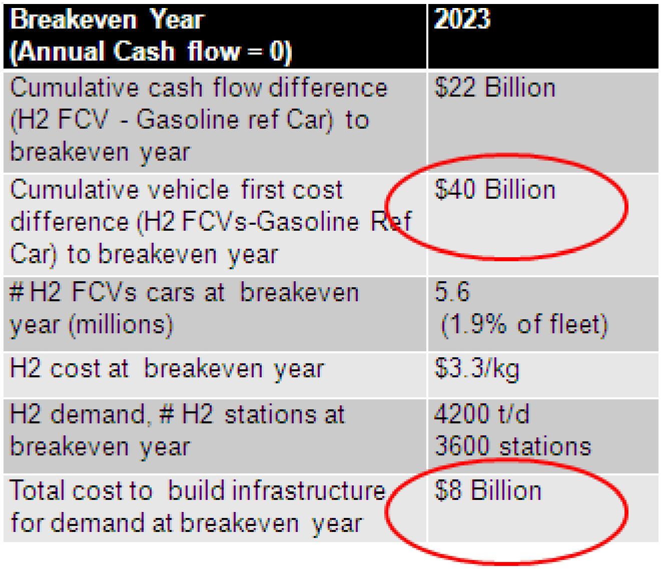


Figure 1.5-2: US Average Delivered Hydrogen Cost (NRC 2008), Electricity and Gasoline Price (EIA 2008)

National Research Council, National Academies of Engineering, Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, Pre-publication version available from National Academies website http://www.nap.edu/catalog.php?record_id=12222

Studies by UC Davis indicate that hydrogen costs can be competitive with gasoline in 2020. Note that 1 kg of hydrogen has approximately the same energy content (lower heating value) as 1 gallon of gasoline (1kg hydrogen = 1 gallon gasoline equivalent (gge)

H2 Transition Timing and Costs (NRC 2008)



Breakeven Year (Annual Cash flow = 0)	**2023**
Cumulative cash flow difference (H2 FCV - Gasoline ref Car) to breakeven year	$22 Billion
Cumulative vehicle first cost difference (H2 FCVs-Gasoline Ref Car) to breakeven year	$40 Billion
# H2 FCVs cars at breakeven year (millions)	5.6 (1.9% of fleet)
H2 cost at breakeven year	$3.3/kg
H2 demand, # H2 stations at breakeven year	4200 t/d 3600 stations
Total cost to build infrastructure for demand at breakeven year	$8 Billion

National Research Council, National Academies of Engineering, Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, Pre-publication version available from National Academies website http://www.nap.edu/catalog.php?record_id=12222

In 2008, the NRC‘s Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies released the report, ―Transitions to Alternative Transportation Technologies—A Focus on Hydrogen," which was required by the Energy Policy Act (2005) section 1825. One of the committee's conclusions was that to accelerate the penetration of FCEVs, strong government policies will be required. The NRC estimated that the government cost to support a transition to FCEVs for the period from 2008 to 2023 would be approximately $55 billion (this amounts to slightly more than $3.5 billion/year or about $10,000 per FCEV—the committee compared this value to ethanol subsidies, which were $2.6 billion in 2006 and are expected to grow to $15 billion/year by 2015). The table shows details on government costs required for infrastructure.

G1.5.2 Codes and Standards to Support Hydrogen and Fuel Cell Infrastructure

The United States and most countries in the world have established laws and regulations that require commercial products to meet all applicable codes and standards to demonstrate that they are safe, perform as designed and are compatible in the systems in which they are used. Hydrogen has an established history of industrial use as a chemical feedstock, but not as an energy carrier on a large-scale commercial basis. The development and promulgation of codes and standards are essential to establish a market-receptive environment for commercial, hydrogen-based products and systems for energy use.

The key U.S. and international standards development organizations (SDOs) developing and publishing the majority of hydrogen codes and standards are shown in the table below. These organizations typically work with the public and private sectors to develop codes and standards.

The U.S. Department of Energy (DOE) conducts underlying safety R&D and works with domestic and international SDOs to facilitate the development of applicable codes and standards. These standards are then referenced by building and other codes to expedite regulatory approval of hydrogen technologies. This approach ensures that U.S. consumers can purchase products that are safe and reliable, regardless of their country of origin, and that U.S. companies can compete internationally.[24]

Organizations Involved in Codes and Standards Development and Publication

Organization	Responsibility
Domestic Codes and Standards	
American Society for Testing and Materials (ASTM)	Materials testing standards and protocols
American National Standards Institute (ANSI)	Certifies consensus methodology of and serves as clearinghouse for codes and standards development
American Petroleum Institute (API)	Equipment standards
American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)	Equipment design and performance standards
American Society of Mechanical Engineers (ASME)	Equipment design and performance standards
Compressed Gas Association (CGA)	Equipment design and performance standards
CSA America (CSA)	Equipment standards

U.S. Department of Transportation	Vehicle standards and regulations
International Association of Plumbing and Mechanical Officials (IAPMO)	Mechanical building code
Institute of Electrical and Electronic Engineers (IEEE)	Electrical standards
National Fire Protection Association (NFPA) Natural Gas Institute (NGI)	Model building codes, standards Natural gas vehicle standards
Society of Automotive Engineers (SAE)	Vehicle system and subsystem design and performance standards
Underwriters Laboratories (UL)	Equipment and performance testing standards
International Electrotechnical Commission (IEC)	International Performance Standards
International Organization for Standardization (ISO)	International Performance Standards

In February 2010, the National Renewable Energy Laboratory (NREL) published the Vehicle Codes and Standards: Overview and Gap Analysis. The gap analysis includes a list of applicable codes and standards for alternative fuels including hydrogen infrastructure. The list of applicable codes and standards is below:[25]

ANNUAL INSPECTIONS
CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association 2005)
CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association 2004)
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

BALANCE OF PLANT
Piping & Tubing
ASME B31.12, Hydrogen Piping and Pipelines
CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association 2005)
IFC (International Code Council 2006)
International Fuel Gas Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)
CGA H-3 Cryogenic Hydrogen Storage (Compressed Gas Association 2006)

Pressure Relief
CGA S-1.3, PRD Standards Part 3 - Stationary Storage Containers for Compressed Gases (Compressed Gas Association 2005)
IFC (International Code Council 2006)

International Fuel Gas Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Valving and Fittings
ASME B31.3, Process Piping (American Society of Mechanical Engineers 2006)
CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association 2005)
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Venting and Other Equipment
CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association 2004)
IFC (International Code Council 2006)
International Fuel Gas Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

CANOPY TOPS
International Building Code (International Code Council 2009)
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

COMPRESSED HYDROGEN GAS STORAGE
Equipment Location
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

General Safety Requirements
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Storage Containers
CGA PS-20, Direct Burial of Gaseous Hydrogen Storage Tanks (Compressed Gas Association 2006)
CGA PS-21, Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (Compressed Gas Association 2005)
IFC (International Code Council 2006)

NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

COMPRESSION SYSTEMS AND EQUIPMENT
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

DESIGN
Barrier Walls
IFC (International Code Council 2006)
Equipment

International Fire Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
Fuel Stations

IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
Equipment

International Fire Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
Fuel Stations

IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Weather Protection
IFC (International Code Council 2006)

DISPENSING
Electrical Equipment
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Fuel Lines
CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association 2005)
IFC (International Code Council 2006)
International Fuel Gas Code (International Code Council 2006)

NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Gaseous Dispensers
IFC (International Code Council 2006)
Facilities
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Hoses and Connectors
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Liquid Dispensers
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Vehicle Connectors
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
SAE J2600, Compressed Hydrogen Surface Vehicle Refueling Connection Devices (Society of Automotive Engineers 2002)

DISPENSING, OPERATIONS, AND MAINTENANCE SAFETY

Gaseous Hydrogen
CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association 2004)
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Liquid Hydrogen
CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association 2004)
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

FIRE SAFETY

Construction
IFC (International Code Council 2006)
International Fuel Gas Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Equipment
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Signage

IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

LIQUID HYDROGEN STORAGE

Equipment Location

IFC (International Code Council 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

General Safety Requirements

IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Storage Containers

IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)
CGA H-3 Cryogenic Hydrogen Storage (Compressed Gas Association 2006)

ON-SITE HYDROGEN PRODUCTION

IFC (International Code Council 2006)
International Fuel Gas Code (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

OPERATION APPROVALS

Dispensing

IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)

Fire And Emergency Planning

IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Fuel Delivery
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Ignition Control
IFC (International Code Council 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Personnel Issues and Training
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Signage
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Vehicle Access
IFC (International Code Council 2006)
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association 2003)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

SETBACKS AND FOOTPRINTS

Liquid Systems
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Outdoor Gaseous Systems
IFC (International Code Council 2006)

NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

TRANSPORTATION
Compressed Hydrogen Gas
CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association 2006)
IFC (International Code Council 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Liquid Hydrogen
CGA P-12, Safe Handling of Cryogenic Liquids (Compressed Gas Association 2005)
IFC (International Code Council 2006)
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

Natural Gas
ASME B31.8, Gas Transmission and Distribution Systems (American Society of Mechanical Engineers 2003)

VAPORIZERS
IFC (International Code Council 2006)
IFC (International Code Council 2006)
NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association 2005)

The table below provides a summary of the identified Code and Standards Gaps for the expanded use of hydrogen as an alternative fuel. Also, the table presents the impacted document and proposed means to address the gap. It also illustrates the various areas of hydrogen codes and standards that require additional work in order to create a complete and standardized control strategy.

One key area that may require additional work is operations and maintenance requirements for fuel dispensing systems. This area is of particular concern because relatively little data for the use of vehicular hydrogen dispensing systems exists. As data is accrued, it may become apparent that additional safety measures are needed to address operations and maintenance. A second area of concern is potential releases of hydrogen in confined spaces such as indoor fueling operations, tunnels, and parking garages. The release characteristics and prevention and mitigation measures vary for these different locations, but many of the same analytical tools can be used to characterize the hazards of these releases. A third area of concern is the potential energy contained in high-pressure storage and dispensing systems. The following table lists several other important gaps that require further work.

Codes and Standards Gaps for Hydrogen [25]

Codes or Standard Gap	Documents Impacted	Gap Resolution
No final fuel quality standard	ISO Fuel Quality Draft International Standard, ASTM analysis standards, SAE Technical Information Report (TIR) J2719	Provide data to ensure that draft standards become final standards
Potentially incomplete requirements for indoor hydrogen vehicle dispensing	NFPA 52, IFC	Evaluate indoor release characteristics and accident scenarios for potential application to code development
Off road vehicle storage tank standards are incomplete	CSA America Heavy Goods Vehicle (HGV) 4.3, SAE J2601	Support standards development work with direct committee involvement and data support
Bulk liquefied hydrogen storage requirements lack technical basis documentation	NFPA 55, NFPA 2, IFC	Evaluate liquid release impacts and frequencies and provide this information to relevant technical committees to validate or revise bulk liquefied hydrogen storage requirements
Requirements for tunnels, parking garages, and repair garages need review to determine whether additional requirements for hydrogen are needed [meeting with New York Port Authority January 2009]	NFPA 505, IFC, NFPA 88B, NFPA 30A, IBC, International Mechanical Code (IMC)	Evaluate safety concerns in these environments and work with the technical committees to provide data required to address codes and standards requirements

Operations and maintenance procedures lack supporting operational history data [conversation with Larry Fluer]	NFPA 52, NFPA 30A, IFC	Evaluate existing procedures to determine where they might be incomplete. Evaluate operations and maintenance history for similar fuels to determine whether useful information can be retrieved and applied to hydrogen
Steam Methane Reformation (SMR) plants do not have a safety standard [conversation with Roger Smith]	No current code specifically addresses SMR plants	Develop a code or standard that addresses SMR plants
New storage systems, such as metal hydrides, are minimally addressed in codes and standards	NFPA 55, CGA H-1 and H-2, IFC	Determine whether new chemical storage systems are adequately addressed in codes and standards
Limited familiarity with relevant hydrogen codes and standards among project developers and code officials [conversation with Larry Fluer]	All hydrogen codes and standards	Regional codes and standards workshops as well as web training and background information can help address this issue
Incomplete requirements for sensing technologies [Rivkin analysis of NFPA 52]	NFPA 52, NFPA 55	Support the use of sensing technologies that replace odorants through evaluating sensing technologies and supporting code and standards development work in sensing technologies
High-pressure storage, handling, and use of hydrogen [David Farese DOE Safety Panel meeting]	NFPA 52, NFPA 55, CGA H series of documents	Evaluate codes and standards that address high-pressure storage to determine if requirements are adequate and if

		additional work is required
Global Technical Regulations (GTR)	Coordination with SAE and DOT regulations	Continue to represent the United States in GTR development meetings and evaluate impacts of GTR in domestic regulations, codes, and standards
Coordination of international (primarily ISO) standards and domestic codes and standards	Multiple documents: SAE, CSA, UL, NFPA	Evaluate component standards to ensure that there are not unnecessary conflicts
The DOT guidance documents for incidents involving flammable gases are too general and prescriptive	DOT Emergency Response Guide	Add additional material to the DOT guide for hydrogen incidents

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