APPENDIX R

PROPOSED

LEV III GREENHOUSE GAS NON-TEST CYCLE PROVISIONS

TECHNICAL SUPPORT DOCUMENT

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1. Motor Vehicle Air Conditioning Credits

As described in section III.A.5.3 of the staff report, staff is proposing to modify the motor vehicle air conditioning (MVAC, or AC) credit provisions in the Pavley regulation to align with the EPA approach in order to provide a consistent program nationwide as well as regulatory continuity across the 2012-2016 MY and 2017-2025 MY regulations. The proposed AC credit provisions offer up to 18.8 gCO_2e/mi for cars and 24.4 gCO_2e/mi for trucks. These AC credit provisions are available for prescribed technologies with credit amounts for improved AC efficiency (indirect credits), and for lower leak refrigerant systems and alternative refrigerants (direct credits). The AC credit opportunities, although optional, are expected to be widely utilized by automakers for compliance with the standards based on staff communication with automakers and the supplier industry involved in the manufacture of the technologies. For this reason and to allow automakers compliance flexibility, staff is not proposing mandatory requirements to use leakage reduction technologies, low GWP refrigerants, or efficiency improvement technologies. This section provides the regulatory context and technical rationale for the AC credit provisions, projects the fleet average credits and associated costs, and reviews activities in developing the provisions.

1.1. Introduction

Modern motor vehicle air conditioning (MVAC, AC) systems enhance travel comfort and safety through features such as integrated cooling, heating, demisting, defrosting, air filtering, and humidity control. However, AC systems contribute to greenhouse gas (GHG) emissions through direct refrigerant releases (AC direct emissions) and tailpipe carbon dioxide (CO_2) emissions due to increased load on the engine (AC indirect emissions) associated with AC operation and with the addition of the AC system’s mass to the vehicle.

The predominant refrigerant currently in use is hydrofluorocarbon-134a (1,1,1,2-tetrafluoroethane, HFC-134a, R-134a), a potent GHG with a global warming potential (GWP) of 1,430[1]. It can slowly leak out of the AC system in a manner that may occur in any closed high-pressure system such as permeation through hoses and seepage through fittings, connections, and seals. Larger loss may occur during accidents, maintenance and servicing, and vehicle disposal at the end of its useful life.

Leakage of HFC-134a can be dramatically reduced by employing low-permeability hoses, improved fitting technologies, and electric compressors that do not have shaft seals. In 2004 and 2005, the Improved Mobile Air Conditioning (IMAC) program, a cooperative research program including experts from industry, government, and academia, and anchored by SAE International, demonstrated that new vehicle AC leak rates can be reduced by 50 percent[2].

An opportunity exists to reduce the impact of direct GHG emissions associated with AC systems by about 90 percent or more by switching from HFC-134a to a substitute with a GWP of 150 or less. Doing so not only reduces the GHG emissions from leakage, but also mitigates the emissions from accident, service, and dismantling.

Use of AC systems adds an extra load on the engine, resulting in increased fuel consumption of 4.6 to 5.9 percent[3]. Based on an estimated 29 percent AC-on time, this increased load translates to 6.2 million metric tons of CO_2 emissions due to AC use in California each year[4]. By improving the efficiency of the AC system, indirect AC emissions can be significantly reduced. Efficiency measures include more efficient compressors, fans, and motors, and control systems that avoid over-chilling and then re-heating the air. By increasing the efficiency of the AC hardware and controls, indirect emissions can be reduced by at least 40 percent[5, 6]. Further increases in efficiency of up to 26 percent can be realized through the use of solar load reducing technologies, such as improved glazing, reflective paint, and active ventilation[7]. By reducing heat build-up in the vehicle, the use of solar control technologies reduces the energy required by the AC system to cool the vehicle during both the initial pull down and steady-state conditions, and in some cases allows smaller, more efficient compressors to be used.

1.2. **Related Regulations**

1.2.1. **European Union Regulatory Actions**

In 2006, the European Parliament and Council issued Directive 2006/40/EC related to AC emissions, commonly referred to as the MAC Directive[8]. The Directive mandates a change in the European Communities from the present refrigerant HFC-134a to a refrigerant with a GWP less than or equal to 150, starting on January 1, 2011 for all new vehicle models. On January 1, 2017, the mandate will extend to all new vehicles, including older models.

The European Commission (EC) is also developing a test procedure to measure AC indirect emissions as part of its vehicle CO_2 reduction strategy[9]. The strategy calls for a mandatory reduction of fleet average CO_2 emissions to reach a target of 130 grams of CO_2 per kilometer (gCO_2/km) through powertrain technology, and a further reduction of 10 gCO_2/km through other technological improvements (e.g., AC efficiency, low rolling resistance tires) and increased use of biofuels. It is expected that the EC AC indirect emissions test procedure will be finalized in early 2012.

1.2.2. **US Environmental Protection Agency Regulatory Actions**

In April 2010, the US Environmental Protection Agency (US EPA, EPA) adopted a final rule for a national program establishing vehicle GHG emission standards for new light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles covering model years 2012 through 2016. US EPA created a national program harmonized and consistent with the California standards to be discussed in the next section, allowing manufacturers to generate and use credits for improved AC systems to comply with CO_2 fleet average standards. US EPA believes that both reducing AC system leakage and increasing efficiency are highly cost-effective and technologically feasible[6]. The use of a low GWP refrigerant would earn the maximum direct emission (leakage) credit. Indirect credits are awarded using a technology-based menu, with credits capped at the theoretical maximum efficiency improvement of 40 percent.

In September, 2011, EPA issued a final rule for reducing GHG emissions associated with AC systems for medium- and heavy-duty vehicles of 2014 and subsequent model years. That rule requires that every AC system of a medium- or heavy-duty vehicle meet a leak rate standard of 1.5% of nominal charge per year. The only exception is Class 2b-8 Vocational Vehicles, for which a leak rate standard is not established due to the complexity in the production process, multiple entities involved in the production and installation, and consequent difficulties in developing a regulatory program. The rule does not include an AC system efficiency standard for those vehicles because EPA believes the relative indirect emissions are minimal[10].

1.2.3. **California Regulatory Actions**

In 2004, the California Air Resources Board (ARB, Board) adopted limits on GHG emissions from new light-duty vehicles of 2009 and subsequent MYs[11]. An AC credit scheme was developed to offset GHG emissions attributed to CO_2, methane (CH_4), and nitrous oxide (N_2O). The regulation, also known as Assembly Bill 1493 or the Pavley regulation, encourages, but does not require, auto manufacturers to improve the refrigerant containment of MVAC systems that use HFC-134a, and/or to use low GWP refrigerants. Through the credit scheme, manufacturers are also encouraged to reduce indirect emissions using proven technologies such as efficient external control mechanisms for compressors, condensers and evaporators with improved heat transfer, and reduced amounts of outside air that must be cooled. Thirteen other states and the District of Columbia adopted this California standard. In 2010, pursuant to a special agreement between the federal government, California, thirteen other state governments, and major automobile manufacturers[12], this ARB regulation was adopted (with modifications) in a EPA rulemaking to establish a national standard for light-duty vehicle GHG emissions[6].

In 2005, the Environmental Performance Label (EPL) regulation, Assembly Bill 1229, was signed into law. The EPL is required on all new vehicles manufactured after January 1, 2009 and sold in California. To enable consumers to make informed decisions in vehicle purchasing, two scores are provided on the EPL, a smog score and a global warming score. The global warming score reflects the emissions of GHG from vehicle operation and from fuel production. Similar to the GHG emission standard, credits associated with reduced emissions from MVAC systems were also included in the calculation for the EPL regulation[13].

Under the California Global Warming Solutions Act of 2006 (Assembly Bill 32, AB 32)[14], the Board approved a list of Early Action measures in 2007[15]. The list included several proposed measures to reduce GHG emissions associated with MVAC systems. The proposed measures were part of an overall strategy for reaching California's 2020 GHG emission reduction target as presented in the ARB Climate Change Scoping Plan[16].

One proposed Early Action measure addressed reduction of emissions from do-it-yourself MVAC recharge. This item was implemented as a stand-alone regulation that was approved by the Board in 2009, and became effective on March 10, 2010[17]. It reduces emissions associated with small containers of automotive refrigerant (small containers, small cans) by adding a self-sealing valve on all small containers, establishing a container deposit and recycling program, and improving the container label and associated consumer education. Another Early Action measure proposed in the early action plan was a requirement to use low GWP refrigerants in new MVAC systems. Transition to low GWP refrigerants is now incorporated as one component of the overall Low-Emission Vehicle (LEV III) program. But instead of proposing a mandatory GWP requirement, the LEV III program proposes to incentivize the transition by including GWP in the calculation of MVAC emission credits.

1.2.4. **US EPA Regulatory Provisions for Refrigerants**

Prior to model year 1993, the predominant automotive refrigerant was chlorofluorocarbon-12 (dichlorodifluoromethane, CFC-12, R-12). CFC-12 is one of the substances found to deplete the stratospheric ozone layer which shields the earth from excessive ultraviolet radiation from the sun. In response to the Montreal Protocol and relevant provisions in the US Clean Air Act to protect the stratospheric ozone layer, the automotive industry made a nearly complete transition from CFC-12 to HFC-134a for the US market in approximately three years[18]. Any substitute for ozone depleting substances (ODSs) needs to be evaluated and approved by EPA's Significant New Alternatives Policy (SNAP) program before it can be used in the US. Under the SNAP program, EPA reviewed and approved HFC-134a based on data for its ozone-depleting potential, global warming potential, flammability, and toxicity characteristics[19]. Approval of new SNAP substitutes often includes conditions to mitigate any safety concerns that may arise with the given chemical. There are currently two SNAP-approved substitutes for MVAC with a low GWP: hydrofluorocarbon-152a (1,1-difluoroethane, HFC-152a) and hydrofluoroolefin-1234yf (2,3,3,3-tetrafluoropropene, HFO-1234yf). Another candidate, CO_2 (R-744), has received proposed findings of SNAP acceptability.

1.2.4.1. HFO-1234yf

On March 29, 2011, EPA published a final rule to find HFO-1234yf acceptable, subject to use conditions, as a substitute for CFC-12 in MVAC systems for new passenger cars and light-duty trucks[20]. The use conditions specified in the SNAP rule include requirements for a flammable refrigerant warning label, a high-pressure compressor cutoff switch and pressure relief devices, unique fittings, and a requirement that vehicle manufacturers must conduct Failure Mode and Effect Analysis (FMEA). HFO-1234yf has a highly desirable GWP of 4[21]. Its physical properties are similar to those of HFC-134a, so AC system design and performance should be similar. It has low toxicity and moderate flammability. Atmospheric decomposition of HFO-1234yf produces trifluoroacetic acid (TFA), a strong organic acid that may accumulate in soil, plants, and aquatic ecosystems over time, and that may have potential to adversely impact plants, animals, and ecosystems. One study showed that although the concentrations of TFA from this source would be significantly higher than previous estimates from all current HFC sources, including HFC-134a, these concentrations would still be well below the lowest level that might have adverse impact on the most sensitive aquatic organisms[22]. US EPA concluded in the final SNAP rule that the proper use of HFO-1234yf in new passenger vehicles does not present a significantly greater risk to human health and the environment than other approved alternatives.

On October 27, 2010, EPA also published a Significant New Use Rule (SNUR) for HFO-1234yf to complement the SNAP rule[23]. The rule addresses potential health concerns associated with inhalation exposure to this chemical from “significant new use” that includes do-it-yourself (DIY) servicing of MVAC. The rule requires that persons who intend to manufacture, import, or process the chemical for an activity that is designated as a significant new use, must notify EPA at least 90 days before commencing the activity.

According to results from system bench testing conducted by the industry[24], an AC system that was designed to use HFC-134a becomes slightly less efficient under most test conditions when its refrigerant is replaced by HFO-1234yf. But minor system modifications such as the addition of an internal heat exchanger can improve the efficiency of an HFO-1234yf AC system to levels as high as those of an HFC-134a AC system[25]. The overall life cycle climate performance (LCCP) of this new refrigerant has been assessed to be superior to that of HFC-134a[26]. Many in industry anticipate that this compound will be the world’s next automotive refrigerant. In fact, General Motors has officially announced that it will use HFO-1234yf in its Chevrolet, Buick, GMC and Cadillac vehicles starting with MY 2013 in the U.S[27]. Aston Martin indicated it will introduce HFO-1234yf in its MY 2014 and 2015 vehicles[28]. Press reports also indicated that German automakers would choose this refrigerant[29].

1.2.4.2. CO_2

CO_2, which by definition has a GWP of 1, has been proposed for acceptability under the SNAP program. A final SNAP rule is expected in 2012[30]. In an AC system, CO_2 operates at higher pressures than current refrigerant, necessitating significant equipment redesign and also heavier equipment. Also, because CO_2 can make a person drowsy, the system must be designed so that the concentration in the passenger compartment will never go above an upper limit in case of an accidental release. Some industry assessment indicates that although CO_2 systems perform well in mild to moderate climates, they are less effective and efficient in hotter climates[31]. In 2007, German automakers announced that they would use CO_2 as their refrigerant of choice for new vehicle models beginning in 2011. After further consideration they rescinded that decision.

1.2.4.3. HFC-152a

HFC-152a has a GWP of 124[1]. It received a final SNAP approval on June 12, 2008[32]. HFC-152a is moderately flammable -- slightly more so than HFO-1234yf. Therefore a system using it must be designed so that concentrations in the passenger area do not exceed a flammability threshold. In the past decade, industry put considerable effort into developing MVAC systems with a secondary loop to utilize this refrigerant while minimizing any release to the passenger cabin[33]. The National Renewable Energy Laboratory (NREL) has calculated a potential 21 percent reduction in AC related fuel use for an HFC-152a secondary loop system that incorporates capacity control to take full advantage of the higher ballast available in secondary loop systems[33]. Over time, interest in this refrigerant decreased, perhaps due to the additional cost and complexity of a secondary loop system, the anticipation of new refrigerants under development, and the desire to implement only one refrigerant change.

1.2.4.4. Petition to Delist HFC-134a from SNAP

On February 14, 2011, EPA agreed to initiate a notice and comment rulemaking in response to a petition to remove HFC-134a from the list of SNAP approved substitutes for CFC-12 in MVAC systems of new light-duty vehicles[34]. The petition was filed by three non-governmental organizations (NGOs): the Natural Resources Defense Council (NRDC), the Institute for Governance & Sustainable Development (IGSD), and the Environmental Investigation Agency (EIA) – US. As of the time of this writing, EPA is working on establishing a timeline for this rulemaking[30].

1.3. Proposed Regulatory Provisions

For this regulation, ARB is proposing to continue offering credits to manufacturers utilizing technologies that reduce direct and indirect MVAC emissions. However, rather than continue the credit schemes adopted in the Pavley regulation, the total number of credits allowed would be aligned with the current EPA rulemaking. In addition, rather than specifying the suite of technologies that must be used by the manufacturer in order to receive credits as was done in the Pavley regulation, ARB is proposing to adopt the technology-based credit menu approach used in the 2012-2016 MY federal rule.

1.3.1. AC Direct Credit

1.3.1.1. Background

Over the past decade, the automotive industry has been gradually phasing in leak reduction technologies in response to existing or anticipated regulatory actions and consumer satisfaction and warranty issues. Data sources have confirmed a decreasing trend for new vehicle AC leak rate. US EPA estimates that leak rate for 2003 MY MVAC was about 18 g/yr[6]. By 2010 MY, the sales-weighted fleet average leak rate is estimated by ARB staff to have decreased to 14.3 g/yr, based on a state of Minnesota AC leak rate database[35] and sales data from Ward's Automotive Group[36, 37]. The AC leak rates are reported by car manufacturers pursuant to a Minnesota reporting rule. The Minnesota database also indicates that around 5 percent of the 2010 MY vehicles already are using AC systems that leak less than 9 g/yr. On the other hand, the Minnesota database and information obtained from the AC certification for Pavley and EPL regulations reveals that premium leak reduction technologies have not been used across-the-board, suggesting room for overall market improvement.

Introduction of a low GWP refrigerant to the US automobile market has not yet occurred. US EPA vehicle GHG emission standards for 2012-2016 MYs and ARB's Pavley and EPL regulations (both for 2009-2016 MYs) provide incentives for using a low GWP refrigerant. In response, several automakers are planning to start using HFO-1234yf as the new refrigerant before 2017 MY[27, 28]. Chemical manufacturers will begin supplying this new refrigerant to the European market in late 2011 or early 2012, and plan to construct a world-scale manufacturing facility to supply the worldwide markets including the US[38]. Nonetheless, widespread adoption of this new technology in the US is not anticipated until after 2017 MY due to the high price and limited availability of the leading alternate refrigerant candidate, HFO-1234yf, in the near future.

This regulation proposes to modify the AC direct credit scheme currently used in the Pavley regulation. The proposed regulation would align with the next phase of the federal light-duty GHG program that EPA has been developing, thus forming an integrated national program. The modification would also better incentivize the employment of AC leakage reduction technologies while transitioning to a low GWP refrigerant.

It is proposed that the AC direct credit scheme in the Pavley regulation be amended as follows for 2017 and subsequent model years.

1.3.1.2. Modified AC Direct Credit Scheme for HFC-134a Systems

For an AC system that uses HFC-134a as the refrigerant, the AC direct credit would be calculated using the following formula:

$$AC\ Direct\ Credit = Direct\ Credit\ Baseline \times \left(1 - \frac{LR}{Avg\ LR}\right) \qquad \text{(R-1)}$$

where *Direct Credit Baseline* is 12.6 gCO_2e/mi for cars and 15.6 gCO_2e/mi for trucks; *LR* is the leak rate as evaluated using SAE standard J2727, with its minimum fixed at 50 percent of *Avg LR* for an AC equipped with a belt-driven compressor, and at 25 percent of *Avg LR* for an AC equipped with an electric compressor; *Avg LR* is the average new vehicle leak rate for 2003 MY, estimated to be 16.6 g/yr for cars and 20.7 g/yr for trucks.

This formula is a direct adaptation of the AC leakage credit formula from EPA's light-duty GHG standard for 2012-2016 MYs[6]. The *Direct Credit Baseline*, equivalent to the term *Max Credit* in EPA's 2012-2016 MY rule, representing lifetime average HFC-134a emissions from leakage and service loss, was evaluated based on national HFC inventories for 2005/2006 reference years. Since then, leakage reduction technologies have been phased in as new AC platforms come into production—partly in response to regulations and partly to improve customer satisfaction and reduce warranty cost through reduced need for service. Correspondingly, the lifetime average emissions would be reduced and so would the *Direct Credit Baseline* if using 2016 (the end of the existing regulations) as the baseline year. However, in order to maintain regulatory consistency with national programs and to provide continuity that is critical to manufacturers' planning, ARB intends to use the same *Direct Credit Baseline* as established in EPA's 2012-2016 MY rule.

SAE Surface Vehicle Standard J2727 (SAE J2727) was developed by a voluntary consensus standard body led by SAE International (SAE). The standard assigns a leak rate to each component of an AC system such as fittings, service ports, hoses, heat exchangers, and compressor. It then uses a formula to sum up these component leak rates to obtain a system leak rate estimate. At the time of this writing, the latest official version of SAE J2727 is dated August 2008. ARB has been using this version to certify improved AC systems under the Pavley and EPL regulations. US EPA incorporated that same version into its 2012-2016 light-duty vehicle GHG emissions standards to calculate emissions due to AC leakage. ARB plans to use the August 2008 version for evaluating the leak rate in the current rulemaking. But ARB is aware of ongoing activity at SAE to revise the standard by refining the leak rate calculation for AC that uses HFC-134a and by extending it to include calculation for AC that uses HFO-1234yf. ARB may allow or require using an updated version of the standard if ARB judges the update to be technically sound.

1.3.1.3. Modified AC Direct Credit Scheme for Low GWP Systems

For an AC system that uses a refrigerant with a GWP of less than or equal to 150, the AC direct credit would be calculated using the following formulas:

$$\mathit{AC\ Direct\ Credit} = \mathit{Low\ GWP\ Credit} - \mathit{High\ Leak\ Penalty} \tag{R-2}$$

$$\mathit{Low\ GWP\ Credit} = \mathit{Max\ Low\ GWP\ Credit} \times (1 - \frac{\mathit{GWP}}{1{,}430}) \tag{R-3}$$

$$\mathit{High\ Leak\ Penalty} = \begin{cases} \mathit{Max\ High\ Leak\ Penalty}, & \mathit{if\ LR} > \mathit{Avg\ LR}; \\ \mathit{Max\ High\ Leak\ Penalty} \times \dfrac{\mathit{LR} - \mathit{Min\ LR}}{\mathit{Avg\ LR} - \mathit{Min\ LR}}, & \mathit{if\ Min\ LR} < \mathit{LR} \le \mathit{Avg\ LR}; \\ 0, & \mathit{if\ LR} \le \mathit{Min\ LR}. \end{cases} \tag{R-4}$$

where *Max Low GWP Credit* is 13.8 gCO_2e/mi for cars and 17.2 gCO_2e/mi for trucks; *GWP* is the global warming potential of the refrigerant over a 100-year horizon, specified in the Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report (AR4) or determined by ARB if such information is not available in the AR4; *Max High Leak Penalty* is 1.8 gCO_2e/mi for cars and 2.1 gCO_2e/mi for trucks; *LR* is the leak rate as evaluated using SAE J2727, with its minimum fixed at *Min LR*; *Avg LR* is the average leak rate for 2010 MY, estimated to be 13.1 g/yr for cars and 16.6 g/yr for trucks; *Min LR* is the minimum leak rate that can be assessed by SAE J2727 with significant certainty, estimated to be 8.3 g/yr for cars and 10.4 g/yr for trucks.

Using a threshold of 150 to define low GWP refrigerant aligns with the definition adopted by the European Parliament and Council in its MAC Directive[8]. Alternative refrigerants that meet this definition include HFC-152a, HFO-1234yf, and CO_2 if it obtains a final SNAP approval.

This formula is established by modifying EPA's 2012-2016 MY AC leakage credit formula. The original EPA formula does not provide significant incentive to promote leakage reduction if an AC system uses a low GWP refrigerant. ARB believes maintaining a low leak rate is important, regardless of the refrigerant in use. Having a low leak rate helps realize the full benefits of a transition to a low GWP refrigerant by reducing the need for AC service, and hence reducing the potential for consumers to recharge their HFO-1234yf AC systems with HFC-134a. HFO-1234yf is much more expensive than HFC-134a, and the current federal regulations do not allow it to be sold in small cans for do-it-yourself use[20,

[23]. With similar physical properties, it is possible an HFO-1234yf AC system can have satisfactory performance when recharged with HFC-134a. A leak-tight system will reduce this possibility, simply because the AC system is less likely to need recharging. Improved refrigerant containment also reduces the possibility of loss of cooling performance and AC efficiency due to undercharging[39].

The *Max Low GWP Credit* reflects the lifetime average HFC-134a emissions from leakage, service loss, and end-of-life loss for the 2005/2006 reference years in the EPA's 2012-2016 MY rule. The lifetime average emissions for newer AC systems with lower leak rates would be lower. For regulatory consistency and manufacturers' planning certainty purposes, however, ARB intends to continue using the lifetime average emission for the reference years as the maximum of a "*Low GWP Credit*". ARB designates the difference between the lifetime average emissions for the reference years and the present as the maximum of a "*High Leak Penalty*". This *High Leak Penalty* is not linked to the GWP of the refrigerant, and hence, provides incentive for manufacturers to keep leak rates low for low GWP AC systems. An AC system would not be penalized if its leak rate is less than or equal to a desirable target (*Min LR*). Otherwise, the AC system would see its *Low GWP Credit* reduced by an amount linearly proportional to its leak rate, up to the *Max High Leak Penalty* if its leak rate is equal to or greater than the average leak rate of the AC systems in the current fleet. The derivation of the key parameters in this credit formula is explained in the following paragraphs.

US EPA's 2012-2016 MY rule estimates that the baseline leak rate (corresponding roughly to 2003 MY) is 18 g/yr. On the other hand, EPA's national HFC inventory suggests the fleet average emission rate of HFC-134a is 16.9 gCO_2e/mi, with cars and trucks emitting 15.5 gCO_2e/mi and 19.6 gCO_2e/mi of HFC-134a, respectively. These emission rates account for not only regular leakage, but also service loss and end-of-life loss. Applying the same relative proportions for cars and trucks to the fleet average leak rate of 18 g/yr for the 2003 MY leads to car and truck leak rates of 16.6 g/yr and 20.7 g/yr, respectively.

The State of Minnesota tracks the AC leak rates assessed by SAE J2727 for all 2009 and subsequent model year light-duty vehicles and medium-duty passenger vehicles sold in that state. The most recent, complete, reporting of AC leak rate is for 2010 MY vehicles[35]. Based on this Minnesota database and Ward's Automotive Group's Factory-installed Equipment database for 2010 MY vehicles[36,37], the sales-weighted fleet average leak rate is estimated to be 14.3 g/yr for 2010 MY vehicles. Using the same method as in the last paragraph to break out this fleet average leak rate, the leak rates for 2010 MY cars and trucks are 13.1 g/yr and 16.6 g/yr, respectively.

The leak rate for the 2005/2006 reference years (corresponding roughly to 2006 MY) is not readily available. But a linear interpolation between 2003 and 2010

MYs suggests that new, 2006 MY cars and trucks leak 15.1 g/yr and 18.9 g/yr, respectively.

Assuming the lifetime average HFC-134a emissions are proportional to the AC system's leak rate (an assumption embedded in EPA's 2012-2016 MY rule), the lifetime average emission rate for 2010 MY vehicles is 12.0 gCO_2e/mi for cars and 15.1 gCO_2e/mi for trucks, respectively. Compared with the reference years, these 2010 MY lifetime average emissions represent a decrease of 1.8 gCO_2e/mi for cars and 2.1 gCO_2e/mi for trucks, respectively. These numbers are designated as the *Max High Leak Penalty*.

Because the baseline leak rate in this formula is for 2010 MY vehicles, *Avg LR* assumes the average leak rate for that MY instead of an older MY vehicle.

Table R-1. Summary of Proposed AC Direct Credit Formulas

Refrigerant	Parameter	Car	Truck
HFC-134a	Formula	$AC\ Direct\ Credit = Direct\ Credit\ Baseline \times (1 - \frac{LR}{Avg\ LR})$	
	Direct Credit Baseline	12.6 gCO_2e/mi	15.6 gCO_2e/mi
	LR	from SAE J2727; min 8.3 g/yr for belt-driven compressor, 4.1 g/yr for electric compressor	from SAE J2727; min 10.4 g/yr for belt-driven compressor, 5.2 g/yr for electric compressor
	Avg LR	16.6 g/yr	20.7 g/yr
Low GWP	Formulas	$AC\ Direct\ Credit = Low\ GWP\ Credit - High\ Leak\ Penalty$ $Low\ GWP\ Credit = Max\ Low\ GWP\ Credit \times (1 - \frac{GWP}{1{,}430})$ $High\ Leak\ Penalty$ $= \begin{cases} Max\ High\ Leak\ Penalty, & if\ LR > Avg\ LR; \\ Max\ High\ Leak\ Penalty \times \frac{LR - Min\ LR}{Avg\ LR - Min\ LR}, & if\ Min\ LR < LR \le Avg\ LR; \\ 0, & if\ LR \le Min\ LR. \end{cases}$	
	Max Low GWP Credit	13.8 gCO_2e/mi	17.2 gCO_2e/mi
	GWP	100-year GWP	100-year GWP
	Max High Leak Penalty	1.8 gCO2e/mi	2.1 gCO2e/mi
	LR	from SAE J2727; min 8.3 g/yr	from SAE J2727; min 10.4 g/yr
	Avg LR	13.1 g/yr	16.6 g/yr
	Min LR	8.3 g/yr	10.4 g/yr

1.3.2. Modification of AC Indirect Credit Scheme

1.3.2.1. Background

Under the Pavley rule, ARB offered indirect AC credits of up to 9 gCO_2e/mi for vehicles with one evaporator and up to 11 gCO_2e/mi for vehicles with dual evaporators, provided the manufacturer demonstrated that the MVAC system met specific requirements for an "efficient system"[40]. Specifically, in order to receive credits the system needed to have management of outside and recirculated air; be optimized for energy efficiency by utilizing state-of-the-art high efficiency evaporators, condensers, and other components; and have an externally controlled compressor that adjusts evaporative temperature to minimize the necessity of reheating cold air to satisfy occupant comfort. If all of the criteria were met, manufacturers were awarded credits that were prorated based on the size of the compressor.

The federal 2012-2016 MY GHG rule similarly offers indirect air conditioning credits, although the number of credits is capped at 5.7 gCO_2e/mi because a different methodology is used to calculate indirect emissions. Credits are awarded using a technology-based menu approach, whereby different efficiency technologies are assigned a specific credit based on the estimated reduction in CO_2 equivalent emissions each technology can provide. The manufacturer identifies those advanced air conditioning features that are used on each vehicle, and credits are awarded based on the value assigned in the menu. If a manufacturer utilizes all components on the menu, the maximum number of credits that can be awarded is 5.7 gCO_2e/mi.

Despite differences between the EPA and ARB approaches to determe the level of indirect AC credits available, for the LEVIII rulemaking ARB is proposing to align with the EPA approach. To date, all vehicle manufacturers have indicated they will opt into the federal program beginning with the 2012 MY, which California will accept as complying with the Pavley program. Assuming the ARB and federal 2017-2025 MY light-duty GHG rulemakings are substantially the same, California anticipates continuing to accept compliance with the federal standards as compliance with California standards. As such, it is important to ensure regulatory consistency between the federal 2012-2016 MY and 2017-2025 MY rules. Maintaining the level of MVAC credits from the 2016 to 2017 MYs also ensures the overall stringency of the fleet CO_2 equivalent standard is not impacted and creates investment certainty for automobile manufacturers.

1.3.2.2. Modified Indirect AC Credit Scheme

The proposed menu for LEVIII is slightly modified from the menu in the 2012-2016 MY federal rule. The primary difference is that instead of a single menu for both cars and trucks, separate credit values have been determined for each class based on EPA modeling results that estimated the impact of AC use separately for cars and trucks. The modeling indicated a smaller impact of MVAC on cars (11.9 gCO_2e/mi) and a larger impact on light trucks (17.1 gCO_2e/mi) compared to the estimated impact for cars and trucks combined from the 2012-2016 MY rule (14.3 gCO_2e/mi). A second difference is that the estimated level of efficiency improvement using a “best-of-the-best” technology package is assumed to be 42 percent instead of 40 percent. US EPA based their initial estimate of 40 percent effectiveness of hardware and control efficiency technologies on the 2007 SAE IMAC study[5, 6]. However, because automobile manufacturers are expected to incrementally utilize AC efficiency hardware to obtain credits during the 2012 through 2016 timeframe, we expect the overall efficiency of MVAC systems to improve by 2017 due to learning and optimization of the AC controls. Thus, we are proposing to increase the assumed efficiency improvement from 40 to 42 percent. As a result of the increase in expected technology and control effectiveness, the fleet-wide credit programs are similar between the 2012-2016 MY and 2017-2025 MY federal rules.

The individual efficiency technologies on the credit menu and their effectiveness in improving AC efficiency were based on the SAE IMAC study and are described in detail in the Regulatory Impact Analysis for the 2012-2016 MY federal rule. Briefly, the technologies for improving AC efficiency fall into two general categories: improved hardware, such as compressors, evaporators, and condensers; and improved controls, such as default to recirculated air. Externally-controlled variable displacement compressors (VDC) that limit the degree to which over-cooled air must be reheated to the requested temperature provide the greatest efficiency benefit among AC hardware. Other credited hardware technologies that improve efficiency are: other forms (non-VDC) of externally-controlled compressors; more efficiently designed blower motors, condensers, and evaporators; internal heat exchangers that reduce compressor power consumption; and oil separators that contain oil in the compressor thereby reducing coolant dilution and improving heat transfer effectiveness. The most effective control strategy is making the MVAC system default to recirculated air rather than outside air in order to reduce the cooling demand on the system. For vehicles that have a sensor to maintain the desired air quality and humidity (to reduce the need for demisting) inside the cabin, maximum efficiency gains are estimated at 30 percent. Those systems without sensor feedback will still experience efficiency gains due to default recirculation, although the benefit will be reduced.

To determine the technology-specific credits for cars and trucks, the efficiency improvement for each technology, as estimated by EPA for the 2012-2016 MY rule, was applied to the maximum AC efficiency for cars (5.0 gCO_2e/mi) and trucks (7.2 gCO_2e/mi) respectively based on an estimated 42 percent efficiency improvement (Table R-2). Due to synergistic effects of the efficiency technologies, credits are capped at 5.0 gCO_2e/mi for cars and 7.2 gCO_2e/mi for trucks, even though the individual technologies sum to more than the cap levels. Manufacturers would be eligible to use this credit menu to claim car and truck indirect AC credits beginning with model year 2017. As with 2014-2016 MY vehicles under the federal regulation, the AC Idle Test would be required in order to utilize the credit menu for 2017 and subsequent model years.

Table R-2. Efficiency-improving AC technologies and credits

Technology Description	Estimated Reduction in AC CO_2 Emissions	Car AC Credit (gCO_2e/mi)	Truck AC Credit (gCO_2e/mi)
Reduced reheat, with externally-controlled, variable displacement compressor	30%	1.5	2.2
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor	20%	1.0	1.4
Default to recirculated air with closed-loop control of the air supply (with sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	30%	1.5	2.2
Default to recirculated air with open-loop control (no sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	20%	1.0	1.4
Blower motor control that limits wasted electrical energy (e.g., pulse-width modulated power control)	15%	0.8	1.1
Internal heat exchanger (or suction line heat exchanger)	20%	1.0	1.4
Improved evaporators and condensers (with engineering analysis on each component indicating a coefficient of performance (COP) improvement greater than 10%, when compared to previous design)	20%	1.0	1.4
Oil Separator (internal or external to compressor)	10%	0.5	0.7

1.3.2.3. Test Procedures

For model years 2014 through 2016, the current federal rule stipulates that, in order for a particular model to qualify for indirect emission credits, it must pass the AC Idle Test. To qualify for the full credit, the test vehicle must receive a result equal to or less than 14.9 gCO_2e/min, which is 30 percent less than the average value (21.3 gCO_2e/min) observed during EPA testing. Credits are scaled for models receiving scores between 14.9 gCO_2e/min and 21.3 gCO_2e/min, with vehicles above 21.3 gCO_2e/min deemed ineligible for indirect emission credits. Although EPA received comments from automobile manufacturers regarding the inadequacy of the idle test to evaluate the range of efficiency technologies and problems with test variability, EPA opted to keep the test in place for the 2014 through 2016 MYs while a more accurate and comprehensive test was developed[41].

In preparation for application of the AC Idle Test in MY 2014, EPA and automobile manufacturers have recently tested a number of new vehicles using this test procedure. This testing has revealed a number of issues with the procedure: (1) vehicles with advanced downsized, turbocharged engines have more difficulty passing the AC Idle Test than vehicles with higher powered engines but equivalent MVAC systems, (2) test variability is greater than originally anticipated, and (3) the test does not demonstrate the benefit of the primary efficiency technology, reduced reheat (Table R-3).

Table R-3. Industry Idle Test Data

Eng. Displacement (L)	Idle Test Result (g/min)
2.4	28.0
3.6	24.0
5.7	26.0
2.0	22.4
2.0	20.0
3.5	12.0
1.4	19.4
2.4	18.3
3.6	16.0

Thus, in order to continue incentivizing the use of efficient AC technologies without penalizing manufacturers for using certain engine efficiency technologies, EPA is proposing to modify the way in which the AC Idle Test results are applied to determine credit qualification for 2014-2016 MY vehicles. Namely, EPA is proposing to add an engine displacement correction factor to the threshold used for determining credit qualification on the Idle test (Equation R-5).

$$Idle\ Test\ Threshold = 20.5 - 1.58 \times (Engine\ Displacement) \qquad \text{(R-5)}$$

While allowing the idle test threshold to be scaled to engine displacement addresses the issue of some vehicles not being able to pass the AC Idle Test even when equipped with efficient AC technologies, it does not address the issues of test variability or the inability of the test to evaluate all efficiency technologies. Thus, we believe that a true performance-based test procedure should be used to determine indirect emission credits.

US EPA, ARB, and US automobile manufacturers have been working cooperatively since early 2010 to develop an alternative test to the AC Idle Test, which would accurately and reliably measure the impact of AC use on tailpipe CO_2 emissions. The proposed test procedure (or AC17 test cycle), would contain a period of soak under solar lamps, a transient cycle to measure the emissions during the initial pull down (SC03 test cycle), and a highway cycle (HFET) to measure the emissions during steady state conditions (Figure R-1). Combining these elements along with moderate ambient test cell conditions (77 °F and ~50% relative humidity), allows the efficiency of the whole MVAC system, including solar control, to be measured. The complete proposed test procedure is described in the “California 2015 and Subsequent Model Criteria Pollutant Exhaust Emission Standards and Test Procedures and 2017 and Subsequent Model Greenhouse Gas Exhaust Emission Standards and Test Procedures for Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles” (Appendix D).

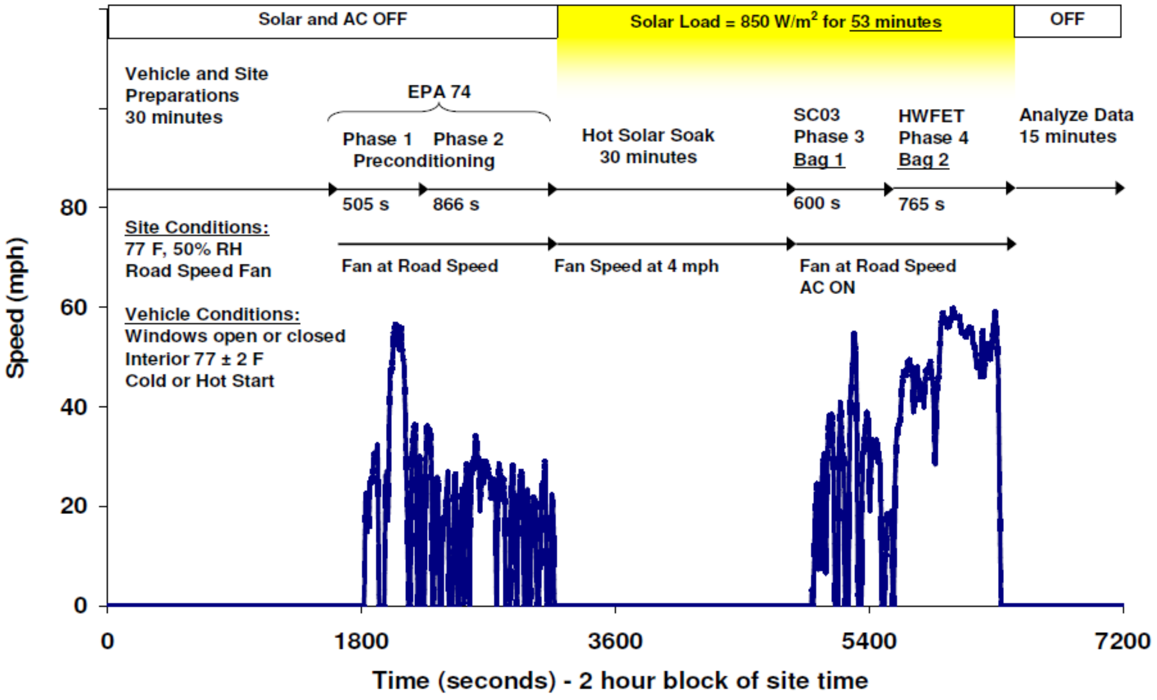


Figure R-1. Proposed MAC Test

ARB staff is proposing that manufacturers run the AC17 test to validate the performance of a vehicle’s AC technology, relative to a baseline vehicle which does not incorporate the efficiency-improving technologies for which credit is being earned. Although it may not be possible for manufacturers to find a baseline vehicle which is identical (in terms of powertrain characteristics, as well as aerodynamic and parasitic losses) to the new vehicle, vehicle model simulations conducted by EPA indicate that the fuel used to operate the AC system is largely dependent on the compressor size and cooling capacity of the system, and not engine displacement or brake-specific fuel consumption. As such, we believe that it is appropriate for manufacturers to use the AC17 test to demonstrate that their efficient AC systems can provide CO_2 emission reductions commensurate to the amount of credit that a particular vehicle can earn (Table R-2). Because of the complexity and increased length of the AC17 test in comparison to the AC Idle Test, staff is proposing that manufacturers would only conduct the test on a sufficient subset of vehicles to be representative of available MVAC configurations.

Thus, for this rulemaking ARB is proposing to require that automobile manufacturers conduct the AC17 to demonstrate that the AC efficiency technologies incorporated onto the vehicle platform result in indirect emission reductions at least as large as the credits available under the LEVIII credit menu. In their NPRM for the 2017-2025 MY rule, EPA will be seeking comment on the details of the AC17 test procedure. However, even though some aspects of the AC17 test are still being developed and improved, staff believes that the basic procedure is sufficiently complete for ARB to propose it as a replacement for the Idle Test beginning with MY 2017, as a prerequisite for generating efficiency credits. Staff proposes that the LEVIII/GHG regulatory proposal, as part of the Advanced Clean Cars rulemaking package, be finalized with the final federal AC17 test procedure and credit qualification requirements, provided it is substantially similar to that described herein and depicted in Figure R-1. ARB staff anticipates that USEPA will incorporate the AC17 test and associated requirements when the 2017-2025 MY rulemaking is finalized in 2012, at which time the finalized federal regulatory language, as modified for California, would be subject to additional public comment before being incorporated into the final LEVIII/GHG rule. If the finalized federal regulatory language cannot be incorporated into California's LEV III/GHG rule before it is finalized, ARB staff proposes that AC17 test procedure as currently proposed in the "California 2015 and Subsequent Model Criteria Pollutant Exhaust Emission Standards and Test Procedures and 2017 and Subsequent Model Greenhouse Gas Exhaust Emission Standards and Test Procedures for Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles" (Appendix D) be used to qualify for efficiency credits, with the final federal test procedures possibly being incorporated into LEVIII through a subsequent Board action in order to promote harmonization within the national program.

1.3.3. Summary of Maximum AC Credits

The maximum credits allowable in the AC credits provisions in the proposed rulemaking are summarized in Table R-4. The corresponding values in the existing EPA rule for 2012-2016 MYs are also included for comparison. As discussed in section 1.4.2.2, the proposed maximum indirect credits are different from their counterparts in the existing EPA rule due to new modeling data that evaluated the indirect emissions for cars and trucks separately rather than combined.

Table R-4. Summary of Maximum AC Credit (in gCO_2e/mi)

	EPA Existing 2012-2016 MYs Rule		**LEV III Proposed (2017-2025 MYs)**	
	Car	Truck	Car	Truck
Max Direct Credit for HFC-134a AC	6.3/9.5*	7.8/11.7*	6.3/9.5*	7.8/11.7*
Max Direct Credit for Low GWP AC	13.8	17.2	13.8	17.2
Max Indirect Credit	5.7	5.7	5	7.2

* Values for AC systems with electric compressors

1.4. Projection of AC Credits and Costs

1.4.1. AC Credits Projection

A model year by model year progression of AC credits is projected in this section. Most manufacturers are expected to opt into EPA's light-duty GHG program for 2012-2016 MYs as a compliance path under California's AB 1493 regulation. Therefore, the projection starts with the last model year for that program, 2016 MY, using credits estimated by the EPA for that program[6], and ends with the last model year of the current rulemaking, 2025 MY.

If HFC-134a continued to be used by all the AC systems, the fleet would to be able to claim the maximum direct (leakage) credits within just one or two model years from 2016 MY under the proposed direct credit provisions for HFC-134a AC systems. This is because most of the leakage reduction technologies are expected to have already been adopted prior to 2016 MY[6]. Although continued use of HFC-134a by all the AC systems is an unrealistic scenario, the projected progression of direct credits shows the progression of leakage reduction technologies, and is useful in estimating the costs associated with those technologies, as discussed in the next section.

Under the proposed direct credit provisions for low GWP AC systems, the fleet would be able to claim the max credits within 5 model years from 2016 MY. This projected progression shows the phase-in of low GWP AC technologies, and can be used to gauge the phase-out of HFC-134a AC systems, which can then be used to discount the direct credits calculated for the unrealistic scenario of the previous paragraph to obtain the direct credit for AC systems that actually use HFC-134a.

The overall direct credit for a fleet with composition of HFC-134a and low GWP AC systems is then the sum of the direct credit for low GWP AC systems and the discounted direct credit for HFC-134a AC systems.

For indirect emission credits, the fleet would be able to claim the max indirect credits within one or three model years from 2016 MY because much of the efficiency improvement technologies are expected to have already been adopted prior to 2016 MY. It is expected that the efficiency technologies will be applied to passenger cars first, with roll-out onto truck platforms occurring later.

The total AC credit is simply the sum of the overall direct credit and the indirect credit. After assuming the fraction of cars in the new vehicle population (see section III.A.5.5 of the staff report), fleet average credits can also be calculated.

The projected credits are detailed in Table R-5.

Table R-5. Projection of AC Credits

Model Year		**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Credit - Car	**Direct Credit if All HFC-134a AC**	5.4	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
	Direct Credit for Low GWP AC	0.0	2.8	5.5	8.3	11.0	13.8	13.8	13.8	13.8	13.8
	Direct Credit for Actual HFC-134a AC	5.4	5.0	3.8	2.5	1.3	0.0	0.0	0.0	0.0	0.0
	Overall Direct Credit	5.4	7.8	9.3	10.8	12.3	13.8	13.8	13.8	13.8	13.8
	Indirect Credit	4.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Total Credit	10.2	12.8	14.3	15.8	17.3	18.8	18.8	18.8	18.8	18.8
Credit - Truck	**Direct Credit if All HFC-134a AC**	6.6	7.0	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
	Direct Credit for Low GWP AC	0.0	0.0	5.8	10.3	13.8	17.2	17.2	17.2	17.2	17.2
	Direct Credit for Actual HFC-134a AC	6.6	7.0	5.1	3.1	1.6	0.0	0.0	0.0	0.0	0.0
	Overall Direct Credit	6.6	7.0	11.0	13.4	15.3	17.2	17.2	17.2	17.2	17.2
	Indirect Credit	4.8	5.0	6.5	7.2	7.2	7.2	7.2	7.2	7.2	7.2
	Total Credit	11.5	12.1	17.5	20.6	22.5	24.4	24.4	24.4	24.4	24.4
Car Share		62%	61%	61%	61%	61%	60%	60%	60%	61%	61%
Fleet Average Credit		10.7	12.5	15.5	17.7	19.4	21.0	21.0	21.0	21.0	21.0

1.4.2. Costs Associated with AC Credits

1.4.2.1. Low Leak Technologies

In its 2012-2016 MY rule, EPA estimated the direct manufacturing cost (DMC) of AC leakage reduction to be $17.5 (2007$)[6]. This DMC becomes $18 when converted to 2009 dollars, using a GDP price deflator of 1.031 derived from the Bureau of Economic Analysis Price Indexes for Gross Domestic Product[42]. This estimated DMC (in 2009$) is considered to be applicable to 2012 MY vehicles[6].

Because all the leakage reduction technologies are existing technologies that already have been commercially used by the industry for some models, they are considered to be mature technologies and to be on the flat portion of the learning curve. It is assumed that through learning, DMC will be reduced by 3 percent each model year from MY 2012 to MY 2016, and 2 percent each model year thereafter through MY 2025. A detailed discussion on the generic methodology for learning can be found in section 3.3.2.2.4 of the Joint Technical Support Document for EPA's 2012-2016 MY rule[43].

The framework for estimating Indirect Cost Multipliers (ICM) is discussed in section III.A.4.3 of the staff report, and takes into account the complexity of the technology. The low-leak technologies are minor modifications that only require incorporation of existing technologies in the system design, and are thus of low complexity. The indirect cost multiplier (ICM) for warranty is therefore 0.012 through MY 2018 and 0.005 thereafter. And the ICM for other indirect costs is 0.230 through MY 2018 and 0.187 thereafter. Note that the indirect cost for warranty is affected by learning, whereas other indirect costs are not.

Because the progression of direct (leakage) credit if all AC systems use HFC-134a reflects the phase-in of leakage reduction technologies, it is reasonable to scale the costs associated with leakage reduction with that credit.

1.4.2.2. Low GWP Refrigerant

There is strong indication that the automobile industry is moving toward adopting HFO-1234yf as the next-generation automotive refrigerant[27, 28, 29]. The DMC of HFO-1234yf for an average AC system is estimated to be $66 (2008$), assuming an average charge of 550 g for cars and 780 g for trucks[44], a car share of 50 percent, and a DMC of HFO-1234yf of $100 per kg ($45 per pound)[45]. This DMC becomes $66.6 when converted to 2009 dollars, using a GDP price deflator of 1.009 derived from the Bureau of Economic Analysis Price Indexes for Gross Domestic Product[42]. That DMC (in 2009$) is considered to be applicable to 2016 MY vehicles.

HFO-1234yf is a newly developed compound. Chemical manufacturers will start supplying it to the European market in late 2011 or early 2012, and plan to construct a world-scale manufacturing facility to supply the worldwide market, including the US. Its widespread adoption is not anticipated until around or after 2017 MY in the US market. Therefore, this technology is considered to be on the steep portion of the learning curve for the first few years. Correspondingly, it is assumed that the DMC will be reduced by 20 percent every two years from 2012 MY through 2020 MY, and 3 percent per year thereafter. A detailed discussion on the generic methodology for learning can be found in section 3.3.2.2.4 of the Joint Technical Support Document for EPA's 2012-2016 MY rule.

The framework for estimating Indirect Cost Multipliers (ICM) is discussed in section III.A.4.3 of the staff report, and takes into account the complexity of the technology. Although this refrigerant is new, the technology uses established chemical engineering principles and is of low complexity. The ICM for warranty is therefore 0.012 through MY 2022 and 0.005 thereafter. And the ICM for other indirect costs is 0.230 through MY 2022 and 0.187 thereafter.

The fleet-wide cost for adopting the low GWP refrigerant is calculated proportionally to the direct credit that manufacturers will be able to claim for this technology.

1.4.2.3. Low GWP AC Hardware

In its ongoing 2017-2025 MY rulemaking, EPA estimates the DMC of the hardware modification to accommodate HFO-1234yf, is $15 (2009$), based on input from automobile manufacturers. The primary modification is the addition of an internal heat exchanger (IHX) to ensure the system efficiency is at least as high as the previous HFC-134a system. EPA considers this DMC to be applicable to 2016 MY vehicles.

These technologies are considered to be on the flat portion of the learning curve because they are not entirely new. For example, IHX have been researched for and used in various refrigeration and air conditioning applications[46]. Correspondingly, it is assumed that the DMC will be reduced by 3 percent per year from 2012 MY through 2016 MY, and 2 percent per year thereafter. A detailed discussion on the generic methodology for learning can be found in section 3.3.2.2.4 of the Joint Technical Support Document for EPA's 2012-2016 MY rule[43].

The framework for estimating Indirect Cost Multipliers (ICM) is discussed in section III.A.4.3 of the staff report, and takes into account the complexity of the technology. The modification of AC systems to use low GWP refrigerants only require minor additions of known technologies to the current system design, and are thus of low complexity. The ICM for warranty is therefore 0.012 through MY 2018 and 0.005 thereafter. And the ICM for other indirect costs is 0.230 through MY 2018 and 0.187 thereafter.

As was done for the low GWP refrigerant, the cost for low GWP AC hardware is calculated proportionally to the direct credit for low GWP AC.

1.4.2.4. AC Indirect Emission Reduction Technologies

The DMC for the suite of AC efficiency technologies is estimated at $52.50 (2007$) per vehicle[6], which becomes $54 in MY 2012 when converted to 2009 dollars, using a GDP price deflator of 1.031.

Because AC efficiency technologies are widely available and are used in vehicles manufactured today, these technologies are considered to be on the flat portion of the learning curve. Thus, as with low leak technologies, it is assumed that the DMC will be reduced by 3 percent per year from the 2012 MY through the 2016 MY and 2 percent per year thereafter. A detailed discussion on the generic methodology for learning can be found in section 3.3.2.2.4 of the Joint Technical Support Document for EPA's 2012-2016 MY rule[43].

The framework for estimating Indirect Cost Multipliers (ICM) is discussed in section III.A.4.3 of the staff report, and takes into account the complexity of the technology. Also, because AC efficiency technologies are widely available and are used in vehicles manufactured today, efficiency technologies are considered to be of low complexity. The ICM for warranty is therefore 0.012 through MY 2018 and 0.005 thereafter and the ICM for other indirect costs is 0.230 through MY 2018 and 0.187 thereafter.

Applying the ICMs and cost reductions due to learning to the DMC results in a $60 total cost for indirect efficiency technologies in MY 2017, assuming full adoption of indirect AC credits. The actual yearly cost for efficiency technologies are scaled to the $60 total MY 2017 cost using the level of indirect efficiency credit adoption, which reduces to $50 by MY 2025.

1.4.2.5. Total Cost

The costs estimated in the above sections are combined to yield the total additional cost per vehicle (2009$) incurred by manufacturers' responses to the AC credit provisions of the proposed regulation. The above discussion and calculation is summarized in Table R-6.

Table R-6. Cost per Vehicle (2009$) for Proposed AC Credit Program

Model Year		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Learning Curve	Leakage Reduction	0.89	0.87	0.85	0.83	0.82	0.80	0.78	0.77	0.75	0.74
	Low GWP Refrigerant	1.00	1.00	0.80	0.80	0.64	0.62	0.60	0.58	0.57	0.55
	Low GWP AC Hardware	1.00	0.98	0.96	0.94	0.92	0.90	0.89	0.87	0.85	0.83
	Efficiency Improvements	0.89	0.87	0.85	0.83	0.82	0.80	0.78	0.77	0.75	0.74
Direct Manufacturing Cost	Leakage Reduction	$16	$16	$15	$15	$15	$14	$14	$14	$14	$13
	Low GWP Refrigerant	$67	$67	$53	$53	$43	$41	$40	$39	$38	$37
	Low GWP AC Hardware	$15	$15	$14	$14	$14	$14	$13	$13	$13	$13
	Efficiency Improvements	$48	$47	$46	$45	$44	$43	$42	$42	$41	$40
Indirect Cost	Leakage Reduction	$4	$4	$4	$3	$3	$3	$3	$3	$3	$3
	Low GWP Refrigerant	$16	$16	$16	$16	$16	$16	$16	$13	$13	$13
	Low GWP AC Hardware	$4	$4	$4	$3	$3	$3	$3	$3	$3	$3
	Efficiency Improvements	$13	$13	$13	$10	$10	$10	$10	$10	$10	$10
Overall Cost per Unit	Leakage Reduction	$20	$20	$20	$18	$18	$18	$18	$17	$17	$17
	Low GWP Refrigerant	$83	$83	$69	$69	$58	$57	$56	$52	$50	$49
	Low GWP AC Hardware	$19	$18	$18	$17	$17	$16	$16	$16	$16	$15
	Efficiency Improvements	$61	$60	$59	$55	$55	$54	$53	$52	$51	$50
Cost - Car	Leakage Reduction	$17	$20	$20	$18	$18	$18	$18	$17	$17	$17
	Low GWP Refrigerant	$0	$17	$28	$42	$47	$57	$56	$52	$50	$49
	Low GWP AC Hardware	$0	$4	$7	$10	$13	$16	$16	$16	$16	$15
	Efficiency Improvements	$59	$60	$59	$55	$55	$54	$53	$52	$51	$50
	Total Cost	$76	$100	$114	$126	$133	$145	$142	$137	$134	$132
Cost - Truck	Leakage Reduction	$17	$18	$20	$18	$18	$18	$18	$17	$17	$17
	Low GWP Refrigerant	$0	$0	$24	$42	$47	$57	$56	$52	$50	$49
	Low GWP AC Hardware	$0	$0	$6	$10	$13	$16	$16	$16	$16	$15
	Efficiency Improvements	$41	$42	$53	$55	$55	$54	$53	$52	$51	$50
	Total Cost	$58	$60	$102	$126	$133	$145	$142	$137	$134	$132
Car Share		62%	61%	61%	61%	61%	60%	60%	60%	61%	61%
Fleet Average Cost		$69	$85	$109	$126	$133	$145	$142	$137	$134	$132

1.5. Other Mitigation Strategies Discussed During Development of Proposed Regulation

An earlier staff proposal for this regulation was to require transition to a low GWP refrigerant, require a low leak rate regardless of the refrigerant, and require a limit on the indirect emissions. Staff believed such mandatory requirements would provide regulatory certainty at the state level to ensure substantial GHG emissions reductions from this sector. Such a proposal, however, would not harmonize with the credit approach that EPA intends to continue using in its upcoming federal rulemaking for 2017-2025 MY light-duty vehicles, and would thus create an inconsistency at the national level. Therefore, ARB is now proposing a revised credit scheme for AC systems. Such an approach would create a uniform national program, and provide auto manufacturers with flexibility for compliance, while still achieving the same goal of greatly reducing direct and indirect GHG emissions from this sector.

ARB staff considered instituting a requirement for high efficiency AC systems through the use of a standard, which would need to be met using a whole-vehicle test procedure. There are currently two federal test procedures in place to measure indirect emissions, the SC03 and the AC Idle Test. Although these tests evaluate the effect of AC use on tailpipe CO_2 emissions, both of these tests have serious limitations[41]. As a result, ARB staff is working with EPA and the automotive industry to develop a test procedure that can be used to quantify the increased load on a vehicle's engine due to air conditioner use. This new test would also include a solar soak condition to measure the effectiveness of solar load reducing technologies. Until such time as a comprehensive test procedure and standard can be developed, improved MVAC efficiency will be incentivized through the use of a credit program.

GHG emission reductions can also be realized from the heavy-duty fleet. Staff contacted refrigerant manufacturers, AC system manufacturers, and EPA staff to learn about the progress and feasibility of requiring a low GWP refrigerant in heavy-duty vehicles. Industry representatives indicated they had done preliminary work with HFO-1234yf to determine the feasibility of using it in heavy-duty vehicle applications. Preliminary testing was promising, but additional work would be required to bring a system to market[47]. In September, 2011, EPA issued a final rule for reducing GHG emissions associated with AC systems for medium- and heavy-duty vehicles of 2014 and subsequent model years. That rule requires that every AC system of a medium- or heavy-duty vehicle meet a leak rate standard of 1.5 percent of nominal charge per year. The only exception is Class 2b-8 Vocational Vehicles, for which a leak rate standard is not established due to the complexity in the production process, multiple entities involved in the production and installation, and consequent difficulties in developing a regulatory program. The rule does not include an AC system efficiency standard for those vehicles because EPA believes the relative indirect emissions are minimal[10]. Because the heavy-duty fleet is a much more fragmented sector than the light-duty fleet in term of vehicle types, AC system characteristics, and stakeholders, ARB believes the GHG emissions associated with AC systems for this sector can be reduced most cost-effectively by a national program. Therefore, a California-specific program for this sector is not envisioned at this time.

1.6. **Public Outreach Efforts**

A proposal to require use of low GWP refrigerants in new AC systems was initially approved by the Board in June 2007 to be included as an AB 32 Early Action item to address the objectives of AB 32. The requirement was suggested in the 2006 Climate Action Team report and by the Environmental Justice Advisory Committee. This strategy was not intended to be a stand-alone measure, but was anticipated to be integrated into a larger suite of new measures focused on GHG emission standards for new vehicles.

A previous proposal on mandatory requirements for MVAC was first presented at an ARB public workshop in El Monte, California on May 18, 2010[48].

Staff was then invited to present the concepts of the proposal at United Nation sponsored workshops in Nanjing, China and New Delhi, India in early June, 2010[49]. The workshops were on next-generation technologies for MVAC systems with the purpose of promoting technologies with lower environmental impact for the growing fleets of those developing countries.

Staff also presented the mandatory requirements proposal at a Mobile Air Conditioning Society Worldwide (MACS Worldwide) / US EPA webinar in June, 2010[50], an SAE Automotive Refrigerant and System Efficiency Symposium in July, 2010[51], and a MACS Worldwide Convention and Trade Show in January, 2011[52].

Currently, the proposal for mandatory use of low GWP refrigerant has been replaced by a proposal to include refrigerant GWP as one component of the AC credit calculations. Such calculations are being incorporated into the overall LEV III regulation which sets new standards for both criteria pollutants and GHGs.

Staff presented the AC credit proposal at an SAE Automotive Refrigerant and System Efficiency Symposium in September, 2011[53].

Throughout this process, staff has interacted with stakeholders on an individual basis, including staff at EPA, European regulatory agencies, automakers, AC equipment suppliers, refrigerant suppliers, SAE International, and MACS Worldwide.

2. Off-Cycle Credits

As described in Section III.A.5.3 of the staff report, ARB staff is proposing to adopt the same off-cycle crediting provisions as EPA at this time and revise, as needed, to maintain alignment with the federal program in future years. With these provisions, ARB staff acknowledges the importance of off-cycle CO_2-emission reductions that verifiably occur in real world conditions but are not acknowledged in standard test-cycle CO_2 measurement. Examples of these off-cycle technologies include active grill shutters that improve aerodynamics at high vehicle speeds, solar panels that significantly offset accessory electric loads and/or charge hybrid and electric-drive batteries, and solar control glazing that reduces the load from air conditioning. Conceptually these technologies are handled in a way that is similar to the “menu-driven” approach as utilized in the air conditioning provisions. Similar to the MVAC credit provisions, these optional provisions can be used to offset some tailpipe emissions and thus provide additional flexibility for achieving compliance with the CO_2 standards. Through these off-cycle credit provisions, ARB staff is integrating vehicle thermal control innovations that had formerly been considered in the Cool Cars rulemaking. Any vehicle model or vehicle test family receiving off-cycle credits from the various approved technologies can receive up to a maximum of 10 gCO_2e/mi in credits.

This section provides additional technical rationale for the off-cycle crediting provisions. ARB staff notes that these estimations for available off-cycle crediting are preliminary values that will be refined and finalized only after EPA's final rulemaking in 2012.

2.1. **Introduction**

US EPA developed off-cycle GHG crediting provisions for the 2012-2016 MY standards and is further developing the provisions for the 2017-2025 MY program. ARB is proposing to align its off-cycle crediting provisions with those of the federal EPA program. The major modification for the 2017-2025 MY regulations is to provide manufacturers with a list of pre-approved technologies for which EPA can quantify a default credit value. Instead of the default values, a manufacturer can demonstrate to EPA that a different value for its technology is appropriate.

EPA staff utilizes a variety of measurement and modeling tools to derive default off-cycle credits for pre-approved technologies. For GHG and CAFE compliance, ARB and EPA use the established 2-cycle (i.e., city FTP, highway HFET) test methodology. EPA also employs a 5-cycle (i.e., city, highway, cold city, hot SC03 air conditioning, and aggressive US06) test methodology to offer an improved assessment of real-world consumer GHG emissions and fuel economy for consumer labeling purposes. As a result one primary tool is simply evaluating the difference between the 2-cycle regulatory result and the 5-cycle real-world estimated result (with and without the technology). Other technologies, such as more efficient lighting show no benefit over any test cycle. In these cases, EPA will estimate the average amount of usage using Motor Vehicle Emissions Simulator (MOVES) data to the extent possible to calculate a duty-cycle-weighted benefit (or credit), with the intent to allow any technologies with incremental benefits in the real-world that are significantly better than on the 2-cycle test. Below is a summary report of EPA's ongoing technical work in this area to inform the off-cycle credits for the pre-approved technologies.

2.2. Technologies to Reduce or Offset Electrical Loads

Regulatory test cycles do not require that all electrical components be turned on during testing, and therefore the effect of many electrical loads would not directly accounted for in the drive cycle testing. Headlights, for example, are always turned off during testing. Turning the headlights on during normal driving will add an additional load on the vehicle's electrical system and will affect CO_2 emissions. More efficient electrical systems or technologies that offset electrical loads will have a real-world impact on fuel use and GHG emissions but are not captured in the EPA test cycles.

To evaluate technologies that reduce or offset electrical loads, the EPA conducted an analysis of the reduction in emissions corresponding to a general reduction of electrical demand in a vehicle. Based on EPA's full vehicle simulation tool, the change in fuel consumption for a 100 W reduction in electrical load for typical vehicles was estimated. The impact of this load reduction was modeled on the combined 2-cycle city-highway cycle, and over the 5-cycle drive tests. The results of this analysis form the basis for a consistent methodology that the EPA applied to several technologies to determine the appropriate off-cycle credits for those technologies. For the vehicle simulation, EPA assumed that high-efficiency alternators will be prevalent in most vehicles within the 2017-2025 timeframe of this rule. Based on available data (e.g., see Figure R-2 and Bradfield, 2008[54]), EPA assumed a global average alternator efficiency of 65 percent for use in its modeling calculations.

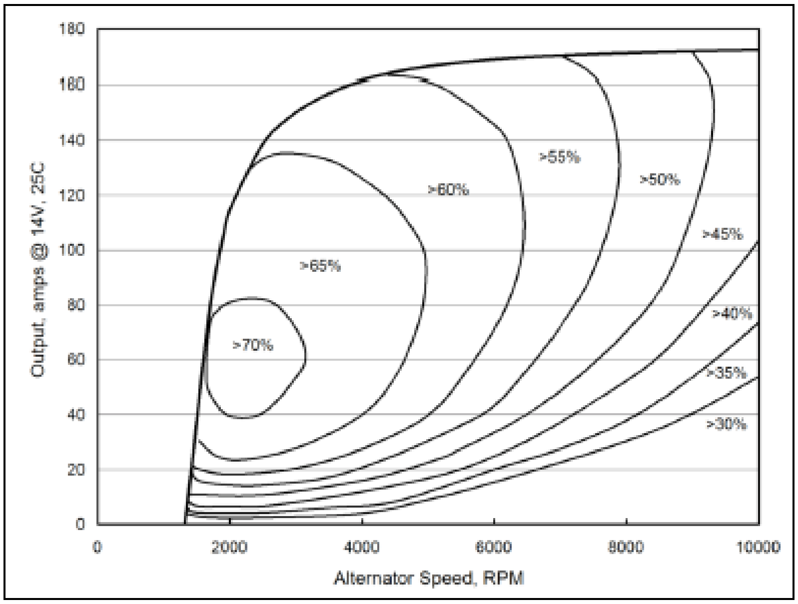


Figure R-2. Alternator efficiency map (Bradfield, 2008[54])

Table R-7 below shows the results of the simulation for four vehicle classes. Reducing the electrical load on a vehicle by 100 W will result in an average of 3.0 gCO_2e/mi reduction over the course of a 2-cycle test, or 3.7 gCO_2e/mi over a 5-cycle test. A 100-W reduction in electrical load yields a reduction in required engine power of roughly 0.15 kW (=0.1 kW / 65 percent), or 1 to 2 percent over the 2-cycle test. To determine the off-cycle benefit of certain 100 W electrical load reduction technologies, the benefit of the technology on the 2-cycle test is subtracted from the benefit of the technology on the 5-cycle test. This determines the unrealized benefit of the technology on the 2-cycle test methodology. In this 100 W example case, the off-cycle benefit is 3.7 gCO_2e/mi minus 3.0 gCO_2e/mi, or 0.7 gCO_2e/mi.

Table R-7. Simulated GHG reduction benefits of 100-W reduction in electrical load over FTP/HW and 5-cycle tests

Driving Cycle		Small Car [g/mile]	Mid-Sized Car [g/mile]	Large Car [g/mile]	Pick-up Truck [g/mile]	Average
FTP/Highway	100W Load Reduction	160.8	188.0	245.7	414.7	
	Baseline	164.0	190.8	248.8	417.9	
	Difference	3.2	2.8	3.0	3.2	3.0
5-Cycle	100W Load Reduction	221.2	252.8	325.9	539.0	
	Baseline	225.0	256.2	329.5	542.8	
	Difference	3.8	3.4	3.6	3.9	3.7

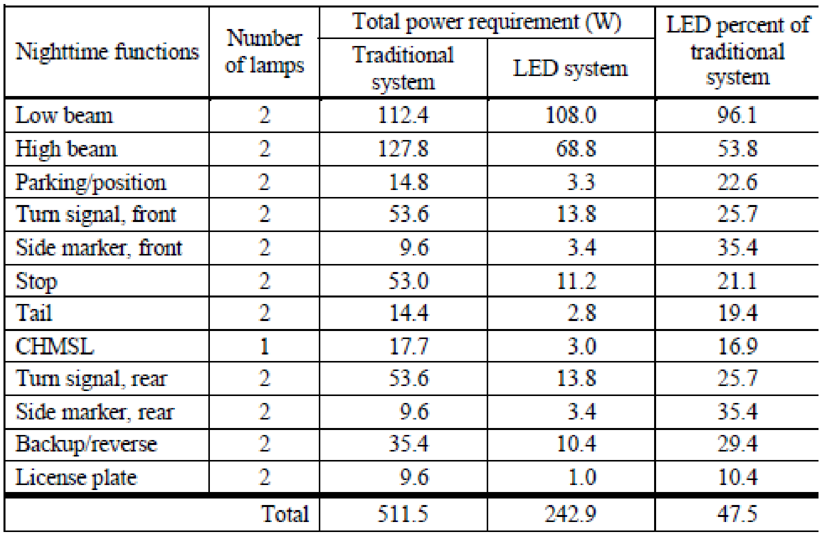
2.2.1. High Efficiency Exterior Lights

The current EPA test procedures are performed with vehicle lights (notably, headlights) turned off. Because of this, improvement to the efficiency of a vehicle's headlights is not captured in the existing test procedures and is appropriately addressed through the off-cycle crediting scheme. Vehicle manufacturers are commonly using advanced technology LEDs in taillights and offering new light producing technologies for headlights. If these technologies require less energy to operate, they will reduce the CO_2 emissions and be eligible for off-cycle credit.

High-efficiency LEDs can substantially reduce the energy consumption and resulting CO_2 emissions from the use of conventional headlamps in vehicles. Schoettle et al. (2008)[55] studied the effects of high-efficiency LED versus conventional lighting and found significant LED efficiency improvements, as indicated in Table R-8.

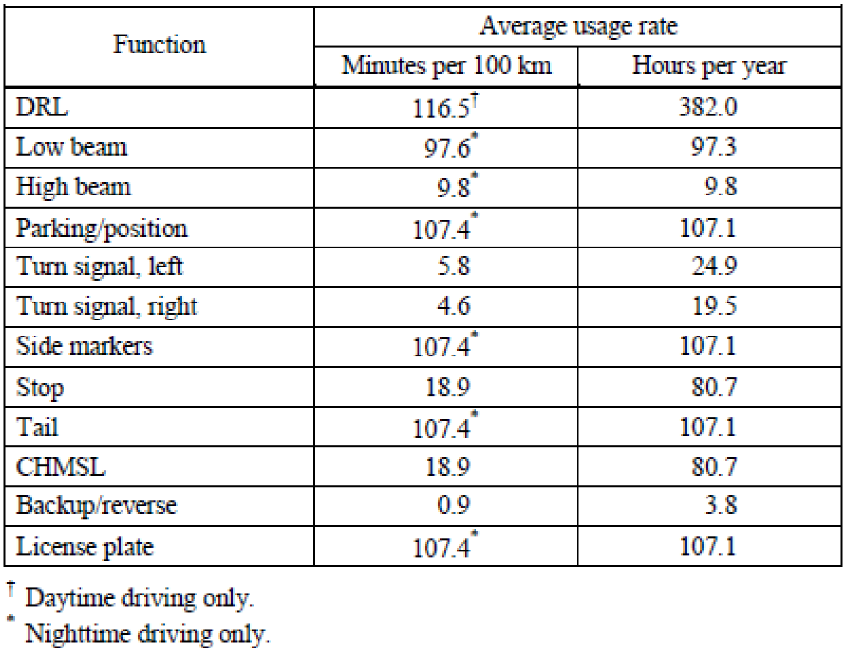
Schoettle et al. (2008)[55] also provided usage rate estimates for lighting components, reproduced below in Table R-9. Using this data, headlight operation at night is split into 91 percent low beam operation and 9 percent high beam operation. The parking/position, side markers, taillights, and license plate light are all considered to be on 100 percent of nighttime driving. Turn signals are estimated to be in operation for 5 percent of all driving. Off-cycle credit for braking lights is considered negligible, because of the prevalence of vehicle braking on the 2-cycle test.

Table R-8. Average power requirement for various exterior lights on a late-model vehicle for traditional and LED systems



Nighttime functions	Number of lamps	Total power requirement (W)		LED percent of traditional system
		Traditional system	LED system	
Low beam	2	112.4	108.0	96.1
High beam	2	127.8	68.8	53.8
Parking/position	2	14.8	3.3	22.6
Turn signal, front	2	53.6	13.8	25.7
Side marker, front	2	9.6	3.4	35.4
Stop	2	53.0	11.2	21.1
Tail	2	14.4	2.8	19.4
CHMSL	1	17.7	3.0	16.9
Turn signal, rear	2	53.6	13.8	25.7
Side marker, rear	2	9.6	3.4	35.4
Backup/reverse	2	35.4	10.4	29.4
License plate	2	9.6	1.0	10.4
	Total	511.5	242.9	47.5

Table R-9. Usage rates for various lighting components on a late-model vehicle[55]



Function	Average usage rate	
	Minutes per 100 km	Hours per year
DRL	116.5[†]	382.0
Low beam	97.6[*]	97.3
High beam	9.8[*]	9.8
Parking/position	107.4[*]	107.1
Turn signal, left	5.8	24.9
Turn signal, right	4.6	19.5
Side markers	107.4[*]	107.1
Stop	18.9	80.7
Tail	107.4[*]	107.1
CHMSL	18.9	80.7
Backup/reverse	0.9	3.8
License plate	107.4[*]	107.1

[†] Daytime driving only.
[*] Nighttime driving only.

A simple activity-weighted average of the lighting energy requirements and their usage rates yields average nighttime power consumption (for the categories in question) of roughly 180 W for a baseline vehicle and 120 W for a vehicle with high efficiency lights. These calculations for the lights are shown in Table R-10. As shown in the final calculation row, the sales weighted average energy reduction from shifting all the exterior lighting to high efficiency technologies results in a 60 W – or 33 percent – reduction from the baseline during nighttime driving.

Table R-10. EPA calculations of High Efficiency Light Savings Potential (Nighttime Driving)

Lighting Component	Baseline W	High Eff W	night use %	savings %
Low beam	112.4	108.0	91%	4%
High beam	127.8	68.8	9%	46%
Parking/position	14.8	3.3	100%	78%
Turn signal, front	53.6	13.8	5%	74%
Side marker, front	9.6	3.4	100%	65%
Stop	53.0	11.2	8%	79%
Tail	14.4	2.8	100%	81%
CHMSL	17.7	3.0	8%	83%
Turn signal, rear	53.6	13.8	5%	74%
Side marker, rear	9.6	3.4	100%	65%
Backup/reverse	35.4	10.4	1%	71%
License plate	9.6	1.0	100%	90%
Totals (rounded)	**180**	**120**		**33%**

Assuming that a set of standard exterior lights are replaced with high-efficiency LEDs, it would represent approximately a 60 W reduction during nighttime driving, and that nighttime driving represents approximately 50 percent of nationwide VMT (based on Schoettle et al., 2008[55]), the savings in the above example would amount to the equivalent of 30 W averaged over all driving. Based on the GHG savings for a 100 W electrical load reduction, as presented above, and scaling to 30 W, EPA estimates that high-efficiency LEDs would be eligible for a credit of approximately 1.1 gCO_2e/mi. To be eligible for that level of credit, manufacturers would have to include high efficiency lights for all components listed in Table R-10 with the exception of headlights (low and high beam). The 60 W energy reduction shown above largely excludes headlights (low and high beam) due to their relatively small weighting in the averaged power savings estimate and lack of rigorous data on their potential energy savings. LEDs used for decorative or accent lighting is not eligible for the credit as they are considered optional accessories or “features.” Additionally, daytime running lights (DRLs) are not required by law, and are also therefore considered optional and ineligible for off-cycle credits.

2.2.2. Engine Heat Recovery

The fuel combustion process in conventional vehicle engines results in a significant amount of lost exhaust heat. This heat primarily leaves the engine in the hot exhaust gases, as well as through engine coolant-radiator system. Recapturing some portion of this wasted heat energy and using it to offset the electrical requirements of the vehicle could lead to improved overall vehicle efficiency and lower CO_2 emissions. Recovered energy could be in the form of electricity and be used to recharge the vehicle's battery (primarily for hybrid or plug-in hybrid vehicles), which is consistent with some proposed manufacturer designs. Engine heat recovery systems are likely to provide some benefit on the 2-cycle tests; therefore, the off-cycle credit would be based on the difference between the 2-cycle and 5-cycle tests. From Table R-7 above, this difference is 0.7 gCO_2e/mi per 100 W of electric load reduction. Based on those above calculations, for every 100 W of thermoelectric device capacity, the vehicle off-cycle credit will be 0.7 gCO_2e/mi.

2.2.3. Solar Roof Panels

Several manufacturers have offered the option of installing solar cells on the roof of a vehicle (e.g., on the Toyota Prius). The initial implementation of this idea has currently been limited to cabin ambient temperature control (see thermal/solar load control below), but manufacturers have raised the possibility of using roof-top solar cells to charge plug-in hybrid and battery electric vehicles battery packs (which, in turn would provide energy to operate the vehicle, thereby increasing the vehicle's all electric range). Due to their substantial energy capacity, only plug-in hybrid and battery electric vehicles would be eligible for such a credit. This electrical energy cannot be accounted for on the regulatory 2-cycle testing.

Using engineering judgment, the EPA staff has made an approximate estimate the amount of real-world benefit solar panels might reasonably provide for vehicles. Vehicles with a solar roof could be parked in sunlight on average four hours a day with a solar panel capable of generating 50 W. Assuming that the solar cells will produce 50 percent of the rated 50 W (due to the solar angle, weather conditions, etc.), a battery efficiency of 80 percent, the vehicle could save up to 80 Wh/day of electrical energy. Using an assumption (based on MOVES) of 1 hour/day average vehicle usage, this yields an average avoided electrical load of 80 W. EPA estimates that a reduction of 80 W in electrical load represents a reduction potential (for large batteries) of approximately 2.7 to 3.1 gCO_2e/mi for a 50 W-capable solar roof panel. These reductions are subject to revision based on changes to key assumptions (such as maximum potential electrical consumption rate during vehicle operation, solar cell efficiency and exposure rates, scaling to different solar panel ratings). The agencies will also consider scaling this credit for solar roof panels that provide more or less power than 50W.

2.3. Active Aerodynamic Improvements

The aerodynamics of a vehicle plays an important role in determining vehicle CO_2 emissions. Improving the aerodynamics of a vehicle reduces drag forces that the engine must overcome to propel the vehicle, resulting in lower fuel consumption and CO_2 emissions. The aerodynamic efficiency of a vehicle is usually captured in a coast down test that is used to determine the dynamometer parameters used during both the two-cycle and five-cycle tests. This section discusses active aerodynamic technologies that are activated only at certain speeds to improve aerodynamic efficiency while preserving other vehicle attributes or functions. Two examples of active aerodynamic technologies are active grill shutters and active ride height control. Active aerodynamic features can change the aerodynamics of the vehicle according to how the vehicle is operating, and the benefit of these vehicle attributes may not be fully captured during the FTP and highway compliance test cycles.

Staff is proposing to limit credits to active aerodynamic systems only (not passive). The reason for this is that passive systems are too difficult to define and isolate as a technology. For example, the aerodynamic drag on the vehicle is highly dependent on the vehicle shape, and the vehicle shape is (in turn) highly dependent on the design characteristics for that brand and model. Staff believes that it would be inappropriate to grant off-cycle credits for vehicle aesthetic and design qualities that are passive and fundamentally inherent to the vehicle.

To evaluate technologies that reduce aerodynamic drag, the EPA conducted an analysis of the reduction in emissions corresponding to a general reduction of aerodynamic drag on a vehicle. Using EPA's full vehicle simulation tool described in EPA's draft RIA, the EPA evaluated the change in fuel consumption for increasing reductions in aerodynamic drag for a typically configured vehicle. The results of this analysis form the basis for a consistent methodology that the EPA applied to technologies that provide active aerodynamic improvements.

Vehicle aerodynamic properties impact both the combined FTP-Highway and 5-cycle tests. However, these impacts are larger at higher speeds and have a larger impact on the 5-cycle tests. By their nature of being "active" technologies, the agencies understand that active aerodynamic technologies will not be in use at all times. While deployment strategies for different active aerodynamic technologies will undoubtedly vary by individual technology, the impact of these technologies will mostly be realized at high speeds. Since aerodynamic loading is highest at higher speeds, the agencies expect that active aerodynamic technologies will generally be in use at high speeds, and that the 5-cycle tests will capture the additional real world benefits not quantifiable with the combined FTP-Highway test cycle procedure.

Using EPA's simulation tools, the impact of reducing aerodynamic drag was simulated on both the combined FTP-Highway cycles, and over the 5-cycle drive tests. To determine the fuel consumption and CO_2 reductions per amount of aerodynamic drag reduction, the CO_2 reduction on the FTP-Highway test cycle was subtracted from the CO_2 reduction on the 5-cycle tests. This is consistent with the approach taken for other technologies. Table R-11 below shows the results of the vehicle simulation.

Table R-11. Simulated Maximum GHG Reduction Benefits of Active Aerodynamic Improvements

Reduction in Aerodynamic Drag (C_d)	Car Reduction in Emissions (g/mile)	Truck Reduction in Emissions (g/mile)
1%	0.2	0.3
2%	0.4	0.6
3%	0.6	1.0
4%	0.8	1.3
5%	0.9	1.6
10%	1.9	3.2

One example of an active aerodynamic technology is active grill shutters. This technology is a new innovation that is beginning to be installed on vehicles to improve aerodynamics. Nearly all vehicles allow air to pass through the front grill of the vehicle to flow over the radiator and into the engine compartment. This flow of air is important to prevent overheating of the engine (and for proper functioning of the AC system), but it creates a significant drag on the vehicle and is not always necessary. Active grill shutters close off the area behind the front grill so that air does not pass into the engine compartment when additional cooling is not required by the engine. This reduces the drag of the vehicle, reduces CO_2 emissions, and increases fuel economy. When additional cooling is needed by the engine, the shutters open until the engine is sufficiently cooled.

Based on manufacturer data, active grill shutters provide a reduction in aerodynamic drag (C_d) from 0-5% when deployed. The agencies expect that most other active aerodynamic technologies will provide a reduction of drag in the same range as active grill shutters. Therefore, staff would provide a credit for active aerodynamic technologies that can demonstrate a reduction in aerodynamic drag of 3% or more. The credit will be 0.6 gCO_2e/mi for cars and 1.0 gCO_2e/mi for trucks, in accordance with the simulation results above in Table R-11.

2.4. **Advanced Load Reduction**

The final category of off-cycle credits includes technologies that reduce engine loads by using advanced vehicle controls. These technologies range from enabling the vehicle to turn off the engine at idle, to reducing cabin temperature and thus air conditioning load. In each case, the benefit of these technologies is not fully captured on the combined two-cycle tests, so their technology-specific off-cycle credits are evaluated separately.

2.4.1 Engine Start-Stop (Idle-Off)

Engine start-stop technologies enable a vehicle to turn off the engine when the vehicle comes to a rest, and then quickly restart the engine when the driver applies pressure to the accelerator pedal. The benefit of this technology is that it can largely eliminate CO_2 emissions at idle. The EPA FTP city test does contain short periods of idle, but the combined 2-cycle testing does not contain as much time at idle as is often encountered in real-world vehicle operation. Hybrids and plug-in hybrids can also disengage the engine when the vehicle is at rest, and are thus eligible for this credit; however, engine-less technologies (e.g., battery electric and fuel cell vehicles) would not be eligible.

Based on a MOVES estimate that 13.5 percent of all driving (in terms of vehicle hours operating) nationwide is at idle, and compared to a 9 percent idle rate for the combined (2-cycle) test, idle-off could theoretically approach an extra 50 percent of the existing benefit seen on the FTP-Highway test. Vehicle simulation data was used to quantify the potential for CO_2 reduction in idle conditions over the FTP and Highway tests across a range of vehicle classes. For each vehicle class reviewed, an FTP-Highway combined fuel consumption was calculated and compared to total fuel consumption during the combined test. The ratio of idle fuel to total fuel represents a maximum theoretical fuel consumption, and hence GHG emissions, that could be reduced by eliminating idling[a].

Table R-12, below, shows the impact of idle-off technology for four vehicle classes. Based on these data, EPA suggests that idle-off technology is theoretically capable of providing 3.8 gCO_2e/mi credit for passenger vehicles and 6.0 gCO_2e/mi for full-size trucks[b]. However, cold and hot ambient conditions will prevent idle-off in all cases, due to the required use of the engine to provide cabin heating and cooling. The percentage of nationwide vehicle operation at above a 45°F ambient temperature is approximated by EPA to be roughly 75 percent. Therefore, EPA and NHTSA propose 75 percent of the theoretical savings above will be appropriate for an idle-off credit; this equates to 2.9

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[a] Note that aggressive fuel cutoff upon vehicle decelerations are technically possible and could increase the total amount of avoided "idle" fuel consumption; at the same time, the idle-off enable conditions might reduce the total idle avoidance. Given the accuracy level of this methodology, EPA assumes these caveats to cancel each other out.

[b] Full size trucks typically consume more fuel at idle than passenger vehicles due to additional accessory loads and larger displacement engines.

gCO_2e/mi for passenger vehicles and 4.5 gCO_2e/mi for trucks. Electric heater circulation pump credits, described below, may be added to this credit.

Table R-12. Calculation of Off-Cycle Credit for Stop-Start Technologies

	Standard Car	Large Car	Large MPV	Full size Truck
Total FTP fuel consumption (g)	1044	1276	1412	1868
FTP fuel consumed at idle (g)	68	71	69	97
Total HWFE fuel consumption (g)	675	862	970	1240
HWFE fuel consumed at idle (g)	0.0	0.0	0.0	0.0
FTP-HWFE combined fuel consumption (g)	878	1090	1213	1585
FTP-HWFE combined fuel consumed at idle (g)	37	39	38	53
potential % GHG reduction benefit	**4.2%**	**3.6%**	**3.1%**	**3.4%**
% FTP idle time	16%	16%	16%	16%
% HWFE idle time	0%	0%	0%	0%
FTP-HWFE combined % idle time	9%	9%	9%	9%
Real-world % idle time (via MOVES)	13.5%	13.5%	13.5%	13.5%
Real-world % GHG reduction benefit	**6.3%**	**5.3%**	**4.6%**	**5.0%**
Off-cycle GHG benefit	**2.1%**	**1.7%**	**1.5%**	**1.6%**
Assumed GHG for advanced vehicle (g/mi)	165	235	255	365
Off-cycle GHG benefit	**3.4**	**4.1**	**3.9**	**6.0**

2.4.2 Electric Heater Circulation Pump

Conventional vehicles use engine coolant circulated by the engine’s water pump to provide heat to the cabin during operation in cold ambient conditions. Since the coolant is only circulated when the engine is running, very little heat is available to the cabin occupants if the engine is stopped during idle in vehicles equipped with stop-start. Stop-start equipped vehicles generally disable the feature during cold ambient temperatures to ensure cabin heat is always available. However, stop-start operation can be expanded to include much colder ambient temperatures if a means of continuing to circulate coolant when the engine is disengaged. An electric heater circulation pump takes the place of the engine’s water pump to continue circulating hot coolant through the heater core when the engine is stopped during a stop-start event. Vehicles with stop-start, hybrid, and plug-in hybrid technologies are the only vehicles that are eligible for this credit.

Because the engine does not generate any more heat when it is shut off during idle, the amount of heat available to be moved to the cabin is limited by the thermal mass of the engine. The heater core acts like a radiator to remove heat from the engine and deliver it to the cabin. After some period of time, depending on engine mass, ambient temperature, and desired cabin temperature, the coolant temperature would drop to a level where comfort would not be maintained and the engine could cool off to a point where cold start features would be needed (which would increase fuel consumption and CO_2 emissions). The stop-start control system would turn the engine back on before either of these conditions is reached. The coolant circulation pump is electrically powered and therefore uses some energy when in use.

US EPA evaluated the effectiveness of this system using the same approach used above for start-stop technology. Based on MOVES data, the percentage of nationwide vehicle operation that is below 45 °F is approximated to be 25 percent. US EPA assumes that vehicles with start-stop systems will have to keep the engine running for cabin heat if the ambient temperature is less than 45 °F, unless the vehicle also has an electric heater circulation system. Therefore, a vehicle with both systems can utilize the start-stop technology 25 percent more of the time. Based on the maximum credit of 3.8 gCO_2e/mi and 6.0 gCO_2e/mi calculated in the previous section, the credit available for an electric heater circulation pump is 1.0 gCO_2e/mi for passenger vehicles and 1.5 gCO_2e/mi for trucks. US EPA determined that the electrical draw on the pump itself is small enough to be negligible in this calculation.

2.4.3 Active Transmission Warm-Up

When a vehicle is started and operated at cold ambient temperatures, there is additional drag on drivetrain components due to cold lubricants becoming more viscous, which increases CO_2 emissions. This effect is more pronounced at colder temperatures and diminishes as the vehicle warms up. Components affected by this additional drag include the engine, torque converter, transmission, transfer case, differential, bearings and seals. Some components, such as the transmission, can take a long time to warm to operating temperature. Automakers sometimes delay the application of very effective fuel-saving measures such as torque converter lockup in order to help the transmission reach operating temperature more quickly.

Active transmission warm-up uses waste heat from a vehicle's exhaust system to warm the transmission oil to operating temperature quickly using a heat exchanger in the exhaust system. This heat exchanger loop must have a means of being selectable, so that the transmission fluid is not overheated under hot operating conditions. In cold temperatures, the exhaust heat warms the transmission fluid much more quickly than if the vehicle relies on passive heating alone. Other methods of heating the fluid can be implemented using electric heat for example, but these are not included in this analysis because of the additional energy consumption that would likely eliminate most of the benefit. This technology could also be used for other driveline fluids such as axle and differential lubricant on rear-wheel-drive vehicles or even engine oil, but only transmission fluid warming is considered here.

There is a lot of variability in which components are affected by cold temperatures and for how long due to the type of vehicle and how it is operated. Active transmission warm-up applied to a conventional front-wheel-drive vehicle will warm the transmission, torque converter, and differential lubricants because in most cases these components share the same lubricant. On a rear-wheel-drive vehicle such as a truck, active transmission warm-up would only affect the transmission and torque converter. The rear axle and differential lubricant, and the transfer case and front axle and differential lubricants in a four-wheel-drive vehicle would not be heated. Additionally, a vehicle operated under a heavy load will tend to warm these lubricants more quickly with or without active heating.

Using Ricardo modeling data and environmental data from EPA's MOVES model, EPA calculated the estimated benefit of active transmission warm-up. The Ricardo data indicates that there is a potential to improve CO_2 emissions by 7 percent at 20 °F if the vehicle is fully warm. US EPA assumed that given that this technology only affects the transmission (and differential on a front-wheel-drive vehicle) and that the technology does take some time to warm the transmission fluid, one third of this benefit would be available, or 2.3 percent. EPA then assumed the benefit would decay in a linear fashion to 0 percent at 72 °F.

Using MOVES data, EPA calculated the weighted average vehicle-miles-traveled at temperatures below about 70 to 80 °F, where the 2-cycle testing is conducted. These temperatures were arranged in 10 °F bins and a temperature and vehicle mileage-weighted benefit of 1.8 gCO_2e/mi was calculated for a midsize car in real-world conditions. No benefit is assumed during the regulatory 2-cycle testing, so nothing is subtracted from this result. As a result the agencies believe an off-cycle benefit of 1.8 gCO_2e/mi is possible using active transmission warm-up technology.

2.4.4 Active Engine Warm-Up

Like active transmission warm-up, active engine warm-up uses waste heat from a vehicle's exhaust system to warm targeted parts of the engine, reducing drag and increasing fuel economy. US EPA assumed that of the 7 percent emission reduction available due to active drive train warming, that one third would be available for actively warming the transmission. US EPA also assumes that another one third would be available for active engine warm-up, resulting in a possible 1.8 gCO_2e/mi off-cycle benefit. Active engine warm-up test data provided by manufacturers resulted in the calculation of a similar emission reduction.

2.4.5 Thermal and Solar Control Technologies

Staff is proposing a credit for technologies which reduce the amount of solar energy which enters a vehicle's cabin area, reduce the amount of heat energy build-up within the cabin when the vehicle is parked, and/or reduce the amount of cooling/heating energy required through measures which improve passenger comfort. ARB staff previously examined these technologies under Cool Cars program[56], although that rule was never finalized. The National Renewable Energy Laboratory (NREL) conducted an extensive research project as part of the SAE's Improved Mobile Air Conditioning Cooperative Research Program (I-MAC). The purpose of this program was to study the effectiveness of a variety of technologies that can reduce the amount of fuel used for the purpose of climate control in light-duty vehicles. In this study, known as the Vehicle Ancillary Loads Reduction Project, NREL estimated the effectiveness of window glazing/shades, paint, insulation, and seat and cabin ventilation technologies in reducing A/C-related fuel consumption and emissions. ARB and EPA have evaluated these technologies and assigned a credit amount for each, based on their ability to reduce cabin air temperatures during soak periods and improve passenger comfort.

NREL's studies estimated that when these technologies are combined, a 12°C reduction in cabin air temperature during soak will result in a 26 percent reduction in AC-related fuel consumption, or a 2.2 percent reduction in fuel consumption and CO_2 emissions for each 1°C reduction in cabin air temperature.[57] If the AC-related CO_2 emissions impact is 13.8 gCO_2e/mi for cars and 17.2 gCO_2e/mi for trucks, this 2.2 percent reduction in CO_2 emissions results in a credit of 0.3 gCO_2e/mi for cars (13.8 gCO_2e/mi x 0.022) and a credit of 0.4 gCO_2e/mi for trucks (17.2 gCO_2e/mi x 0.022) for each degree centigrade reduction in cabin air temperature. Potential off-cycle credits for each thermal and solar load control technology were determined as follows.

2.4.5.1. Glazing

When a vehicle is parked in the sun, more than half of the thermal energy that enters the passenger compartment is solar energy transmitted through, and absorbed by, the vehicle's glazing (or glass). The solar energy is both transmitted through the glazing and directly absorbed by interior components, which are then heated, and absorbed by the glass, thus heating the air in the passenger compartment through convection and interior components through re-radiation. By reducing the amount of solar energy that is transmitted through the glazing, interior cabin temperatures can be reduced, which results in a reduction in the amount of energy needed to cool the cabin and maintain passenger comfort. Glazing technologies exist today that can reduce the amount of solar heat gain in cabin by directly reflecting or by absorbing and then re-radiating the infrared solar energy. NREL's study determined that cabin air temperature could be reduced by up to 9.7 °C with use of glazing technologies on all window locations. Technologies such as window films and coatings and absorptive or solar-reflective material within the glass itself are currently used in automotive glazing, both for privacy (e.g. tinting) and improved passenger comfort. One measure of the solar load-reducing potential for glazing is Total Solar Transmittance, or Tts, which is expressed in terms of the percentage of solar energy which passes through the glazing. Lower Tts values for glazing result in lower cabin temperatures during solar soak periods. The April 15, 2008 version of the International Organization for Standardization's (ISO) 13837 – is considered to be the appropriate method for measuring the solar transmittance of glazing used in automotive applications.[58]

A method for estimating the effect of the solar performance of glazing technologies was developed by EPA and CARB, with input from NREL and the Enhanced Performance Glass Automotive Association (EPGAA). This method utilizes the measured Tts of the glazing used in a vehicle to estimate its effect on cabin temperature during soak conditions. The contribution that each glass/glazing location on the vehicle has on the overall interior temperature reduction is determined by its Tts (relative to a baseline level) and its area. For purposes of this proposal, EPA considers the baseline Tts to be 62 percent for all glazing locations, except for rooflites, which have a baseline Tts of 40 percent. The relationship between the Tts value for glass/glazing and a corresponding reduction in interior temperature is has been established using data from NREL testing. Using the NREL data and estimated temperature reductions, the linear correlation between Tts and cabin air (also referred to as "breath air") temperature reduction was developed, and is shown in Figure R-3.

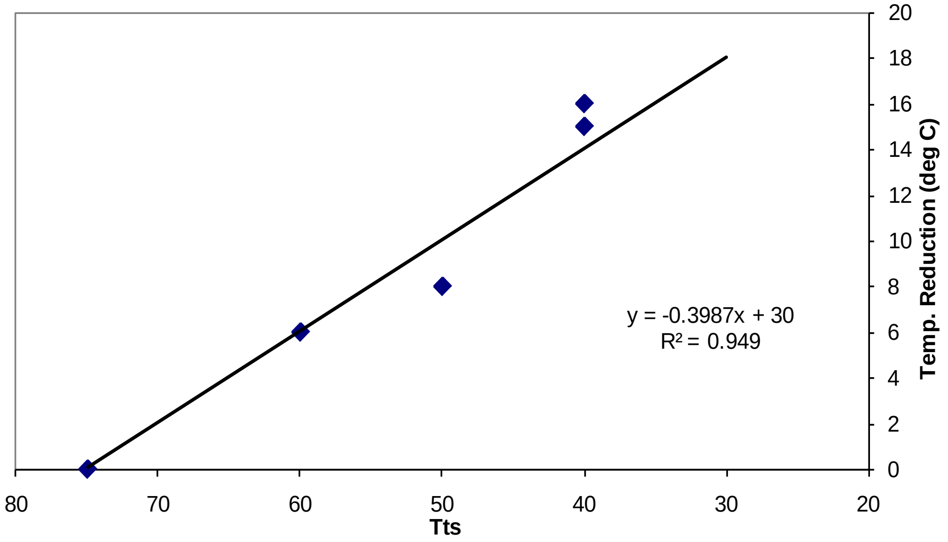

Figure R-3. Correlation Between Tts and Estimated Interior Temperature Reduction

From the slope of this correlation between the Tts value and reduction in breath-air temperature, the amount of interior temperature reduction (in degrees Celsius) for a specific glass location and its Tts specification was calculated as:

$$T_i = 0.3987 \times (Tts_{base} - Tts_{new}) \quad \text{(R-6)}$$

Where:
Tts_{new} = the total solar transmittance of the glass; and
Tts_{base} = baseline total solar transmittance of the glass (62 for the windshield, side-front, side-rear, rear-quarter, and backlite locations, and 40 for rooflite locations).

To determine the total amount of glass/glazing credit earned for a given vehicle, the contribution (in terms of estimated temperature reduction) for each glazing location is calculated using the glass manufacturer's Tts specification. The contribution of each glass location is then normalized to determine the effect each glazing location on the overall vehicle temperature reduction. The method for normalizing the contributions is to multiply the estimated temperature reduction of Equation R-6 by the ratio of the glass area of each location divided by the total glass area of the vehicle. The total vehicle temperature reduction is the sum of the normalized contributions for each location. To calculate the glazing credit earned (in grams of CO_2 per mile), the sum of the total vehicle temperature reduction (in degrees Celsius) multiplied by 0.3 for cars, or 0.4 for trucks.

2.4.5.2. Active Seat Ventilation

The NREL study investigated the effect that ventilating the seating surface has on the cooling demand for a vehicle. By utilizing a fan to actively remove heated, humid air that is typically trapped between the passenger and the seating surface, passenger comfort can be improved, and NREL's Thermal Comfort Model predicted that AC system cooling load could be reduced, and a 7.5 percent reduction in AC-related emissions can be realized. While seat ventilation technology does not lower the cabin air temperature, it indirectly affects the load placed on the AC system through the occupants selecting a reduced cooling demand due to their perception of improved comfort. Using the estimates for the AC-related CO_2 emissions impacts of 13.8 gCO_2e/mi for cars and 17.2 gCO_2e/mi for trucks, a 7.5 percent reduction in CO_2 emissions with active seat ventilation results in a credit of 1.0 gCO_2e/mi for cars (13.8 gCO_2e/mi x 0.075) and a credit of 1.3 gCO_2e/mi for trucks (17.2 gCO_2e/mi x 0.075).

2.4.5.3. Solar reflective paint

As the vehicle's body surface is heated by solar energy when parked, heat is transferred to the cabin through conduction and convection. Paint or coatings that increase the amount of infrared solar energy that is reflected from the vehicle surface can reduce cabin temperature during these solar soak periods. While the amount of heat entering the cabin through the body surface is less than that which enters through the glazing, its effect on cabin air heat gain is measureable. NREL testing estimated that solar-reflective paint and coatings can reduce cabin air temperature by approximately 1 °C, whereas glazing technologies can reduce cabin air temperature by up 10 °C. Using the estimates for credits due to cabin air temperature reductions of 0.3 gCO_2e/mi for cars 0.4 gCO_2e/mi for trucks for each degree centigrade of temperature reduction, a 1.2 °C reduction due to solar reflective paint results in a credit of 0.3 gCO_2e/mi for cars and 0.4 gCO_2e/mi for trucks.

2.4.5.4. Passive and Active Cabin Ventilation

Given that today's vehicle are fairly well sealed (from an air leakage standpoint), the solar energy that enters the cabin area through conductive and convective heat transfer is effectively trapped within the cabin. During soak periods, this heat gain builds, increasing the temperature of the cabin air as well as that of all components inside the cabin (i.e. the thermal mass). By venting this heated cabin air to the outside of the vehicle and allowing fresh air to enter, the heat gain inside the vehicle during soak periods can be reduced. The NREL study demonstrated that active cabin ventilation technology, where electric fans are used to pull heated air from the cabin, a temperature reduction of 6.9 °C can be realized. For passive ventilation technologies, such as opening of windows and/or sunroofs are and use of floor vents to supply fresh air to the cabin (which enhances convective airflow), a cabin air temperature reduction of 5.7 °C can be realized. Using the estimate for credits due to cabin air temperature reductions of 0.3 gCO_2e/mi for cars 0.4 gCO_2e/mi for trucks for each degree centigrade of temperature reduction, a 6.9 °C reduction due to active cabin ventilation results in a credit of 1.7 gCO_2e/mi for cars and 2.3 gCO_2e/mi for trucks. For passive cabin ventilation, a 5.7 °C temperature reduction results in a credit of 2.1 gCO_2e/mi for cars and 2.8 gCO_2e/mi for trucks.

2.4.5.5. Summary of Thermal and Solar Control Credits

The amount of credit that a manufacturer can earn for the various thermal and solar control technologies is shown in Table R-13. To earn off-cycle thermal control credits – up to a maximum of 3.0 gCO_2e/mi for cars, and 4.3 gCO_2e/mi for trucks – a vehicle must be equipped with the thermal control technology in accordance with the specifications and definitions in this proposed rulemaking. If a technology meets the specifications, its use in a vehicle will generate credits, in accordance with the value set forth in the thermal control technology list. The one exception to a single credit value for a technology is glazing technologies, where the method for determining the credit is described in the glazing section (2.4.5.1) above.

Table R-13. Estimated Off-cycle Credits for Thermal and Solar Control Technologies

Thermal Control Technology	Estimated Breath-Air Temp. Reduction	Proposed Car Credit (gCO_2e/mi)	Proposed Truck Credit (gCO_2e/mi)
Solar Control Glass or Glazing	Up to 9.7 °C	Up to 2.9	Up to 3.9
Solar Reflective Paint	1.2 °C	0.4	0.5
Passive Cabin Ventilation	5.7 °C	1.7	2.3
Active Cabin Ventilation	6.9 °C	2.1	2.8
Active Seat Ventilation[1]	N/A	1.0	1.3

[1] Active seat ventilation is not a temperature reduction technology, but rather a comfort control technology capable of reducing AC-related emissions by 7.5%

Credit for solar control technologies can be earned for MY 2017-2025 vehicles that utilize them. For all solar control technologies except glazing, ARB and EPA will rely on manufacturers complying with a specification for, or description of, each technology to assure that the emissions reducing benefits are being realized in real-world applications. Below are the descriptions and specifications that ARB and EPA are proposing for the thermal and solar control technologies listed in Table R-13. EPA will use these definitions and specifications to determine whether the credits are applicable to a vehicle:

- *Active Seat Ventilation* – device which draws air from the seating surface which is in contact with the occupant and exhausts it to a location away from the seat
- *Solar Reflective Paint* – vehicle paint or surface coating which reflects at least 65 percent of the impinging infrared solar energy, as determined using ASTM standards E903,[59] E1918-06,[60] or C1549-09[61]
- *Passive Cabin Ventilation* – ducts or devices which utilize convective airflow to move heated air from the cabin interior to the exterior of the vehicle
- *Active Cabin Ventilation* – devices which mechanically move heated air from the cabin interior to the exterior of the vehicle

It is envisioned that thermal load reduction technologies will eventually be evaluated through a performance-based indirect emissions standard due to the synergies between the AC hardware and controls, and solar control. In particular, the thermal load reduction provided by solar control technologies interacts with the temperature and solar intensity sensors in vehicles, allowing externally-controlled compressors to cycle down and operate in a more efficient manner. The benefit of solar control is further enhanced by recirculation because the thermal load reduction allows cooler air to be supplied to the evaporator than would be the case in the absence of solar control. While the benefits of solar control are maximized by externally controlled compressors and recirculation, solar control provides a benefit that is not duplicative with the AC hardware and control technology improvements. Thus, a future performance-based indirect emissions standard would provide the greatest flexibility for automobile manufacturers to meet AC efficiency goals. However, until a performance test is developed and validated, off-cycle credits for thermal load reduction technologies provide manufacturers with increased flexibility in meeting their fleet CO_2 equivalent targets.

In addition to thermal load reduction technologies, additional technologies that may lead to improvements in MVAC efficiency have been identified. Technologies that may improve AC efficiency include phase-change materials for stop-start applications, which have been estimated to reduce fuel use by 8 percent in city driving[62, 63], adsorption chillers that are operated by engine waste heat[64], intelligent controls for increased comfort in hybrid/stop-start applications[65], and adaptive/intelligent ventilation to increase passenger comfort while reducing AC loads[66]. Because the benefits of these technologies have not been well defined, they are not included on the current list of off-cycle technologies. However, it is envisioned that many of these innovative technologies will eventually be captured on the whole-vehicle performance test. Until then, automobile manufacturers may apply to EPA for inclusion of new technologies to the list of approved off-cycle credits based on a demonstration of their effectiveness.

2.5. **Summary of Off-Cycle Credits**

Table R-14 provides a summary of the estimates for the GHG emission credits that are expected to have default credit values. With these provisions, ARB staff acknowledges the importance of off-cycle CO_2-emission reductions that verifiably occur in real world conditions but are not acknowledged in standard test-cycle CO_2 measurement. In addition, manufacturers will also be able to submit verifiable data to apply for off-cycle credit for technologies not on this list. Any vehicle or family of vehicles receiving credits from this list can receive a maximum of 10 gCO_2e/mi in credits.

Table R-14. Initial estimates of maximum available off-cycle GHG credit from pre-approved technology

Technology	Car credit (gCO_2/mile)	Truck credit (gCO_2/mile)
High-efficiency headlights	1.1	1.1
Engine heat recovery	0.7	0.7
Solar roof panels	3.0	3.0
Active aerodynamic improvements	0.6	1.0
Engine stop-start	2.9	4.5
Electric heater circulation pump	1.0	1.5
Active transmission warm up	1.8	1.8
Active engine warm-up	1.8	1.8
Thermal control (e.g., solar control) and Thermal comfort ((e.g., ventilated seats)	Up to 3.0	Up to 4.3

3. Hybrid and Performance-Based Full-Size Pickup Truck Technology Credits

As described in Section III.A.5.3 of the staff report, ARB staff is proposing to adopt the EPA full-size pickup truck technology incentive provisions. The full-size pick-up provisions provide special emission-reduction credit for technology innovations on the largest of pickup trucks that fall within the light duty vehicle regulations, in order to facilitate the widespread deployment of technologies that are likely to otherwise remain in relatively small numbers. This section provides additional detail on the pickup truck incentive provisions, including details on minimum technology penetration, applicable full-size pickup trucks, hybrid technology credit conditions, and performance-based (non-hybrid) technology credit conditions. Ultimately ARB staff intends to adopt the final version of these full-size pickup technology incentive provisions, once finalized in the federal EPA rules in the summer of 2012.

3.1. Minimum technology penetration thresholds

Access to this credit is conditioned on a minimum penetration of the technology in a manufacturer’s full-size pickup truck fleet with defined criteria for a full size pickup truck (minimum bed size and minimum towing capability). Staff proposes that mild HEV pickup trucks are eligible for a 10 gCO_2e/mi credit during 2017-2021 if the technology is used on a minimum percentage of a company’s full-size pickups, beginning with at least 30 percent of a company’s full size pickup production per year in 2017 and ramping up to at least 80 percent per year in 2021. Strong HEV pickup trucks would be eligible for a 20 gCO_2e/mi credit during 2017-2025 if the technology is used on at least 10 percent per year of the company’s full size pickups. Table R-15 shows the minimum technology penetration thresholds as applicable for the full-size pickup truck credits.

Table R-15. Penetration Thresholds for Full-Size Pickup Truck Credits

Model Year	Mild HEV	Strong HEV	10 gCO_2e/mi performance	20 gCO_2e/mi performance
2017	30%	10%	15%	10%
2018	40%	10%	20%	10%
2019	55%	10%	28%	10%
2020	70%	10%	35%	10%
2021	80%	10%	40%	10%
2022	N/A	10%	N/A	10%
2023	N/A	10%	N/A	10%
2024	N/A	10%	N/A	10%
2025	N/A	10%	N/A	10%

3.2. Definition of Applicable Full-Size Trucks for Hybrid and Performance-Based Credits

The full-size pickup technology incentive crediting provisions have minimum truck capacity criteria in order to preferentially provide incentives for the largest of the light duty trucks. In order to qualify as a full-size pickup truck for the sake of the pickup truck technology incentives, there are three required conditions that must be satisfied:

- <u>Minimum cargo bed width between the wheelhouses of 48 inches</u>: the vehicle must have an open cargo box with a minimum width between the wheelhouses of 48 inches measured as the minimum lateral distance between the limiting interferences (pass-through) of the wheelhouses. The measurement would exclude the transitional arc, local protrusions, and depressions or pockets, if present. An open cargo box means a vehicle where the cargo bed does not have a permanent roof. Vehicles sold with detachable covers are considered “open” for the purposes of these criteria (this dimension is also known as W202 in SAE Recommended Practice J1100).
- <u>Minimum cargo bed length of 60 inches</u>: this is defined by the lesser of (a) the pickup bed length at the top of the body, defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate measured at the height of the top of the open pickup bed along vehicle centerline and the pickup bed length at the floor; and (b) the pickup bed length at the floor, defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate, measured at the cargo floor surface along vehicle centerline (these dimensions are also known as dimensions L506 and L505, respectively, in SAE Recommended Practice J1100).
- <u>Minimum towing capability</u> (gross combined weight rating, minus gross vehicle weight rating) of 5000 pounds; or minimum payload capability (gross vehicle weight rating, minus curb weight) of 1700 pounds.

The weight-related conditions are further defined as follows:

- Curb weight has the meaning given in 40 CFR 86.1803, consistent with the provisions of §1037.140.
- Gross combination weight rating (GCWR) means the value specified by the vehicle manufacturer as the maximum weight of a loaded vehicle and trailer, consistent with good engineering judgment.
- Gross vehicle weight rating (GVWR) means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment

In addition, for reference, illustrations of the various pickup truck dimensions are shown in Figures R-4 and R-5.

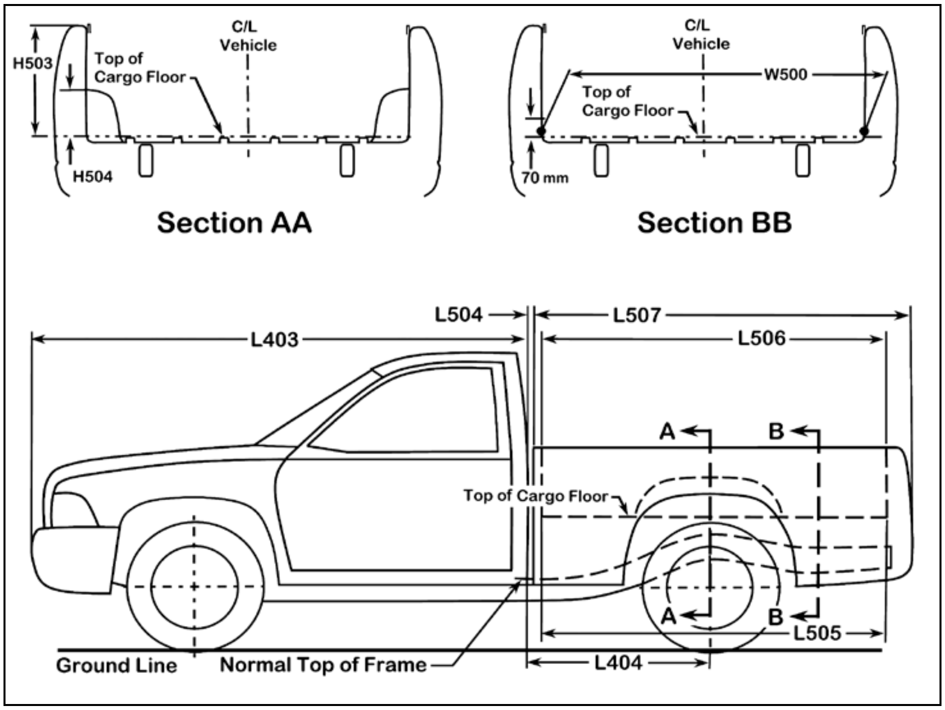

Figure R-4. Illustrations of pickup truck dimension

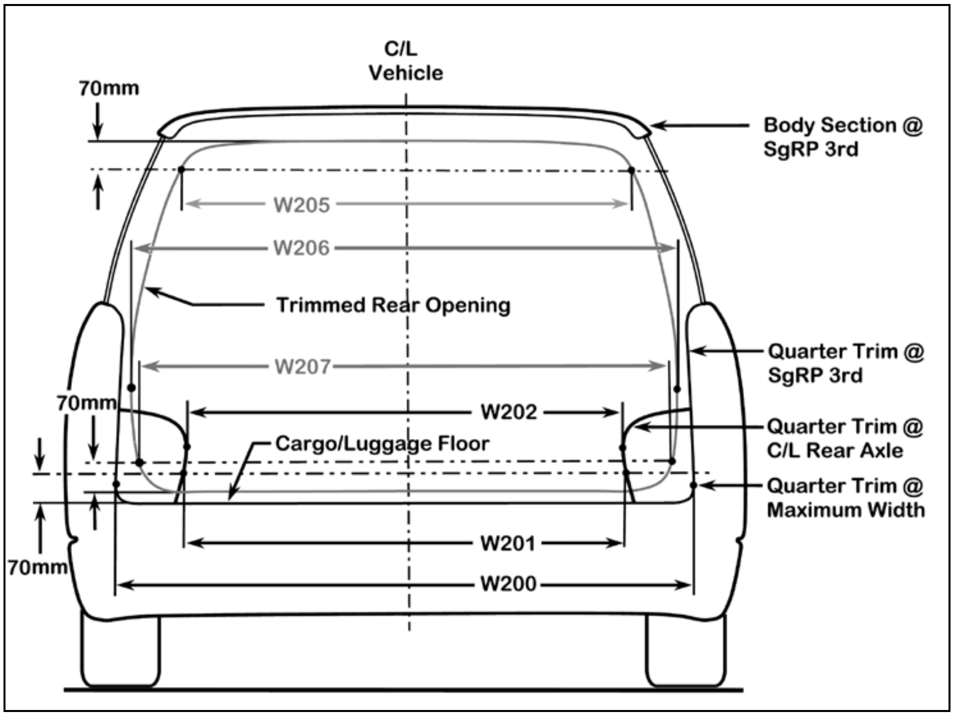

Figure R-5. Illustration of pickup truck bed dimensions

3.3. Performance-Based Full-Size Pickup Credit

For applicable full-size pick-up trucks that satisfy the above conditions, there are a number of other requirements and minimum qualifying criteria in order to be eligible for performance-based technology credits. The performance-based credits have two levels – 10 and 20 gCO_2e/mi – with differing conditions. These requirements are listed below.

Conditions for 10 gCO_2e/mi full-size pickup performance-based credit:

- Vehicle must satisfy full-size pickup truck definition (see above)
- GHG emission level must be achieved by at least the minimum technology threshold of the company's sales of full-size pickup trucks in given model year (see above)
- Available only for model years 2017 through 2021
- Test vehicle combined city-highway gCO_2e/mi must be at or below 15 percent below the GHG target for given model year and footprint
- Once a test vehicle qualifies and achieves credit for a given model year, it can receive credit in subsequent years through 2021, provided that there is no increase in gCO_2e/mi from the previous model year
- Vehicle cannot receive hybrid incentive credit at the same time

Conditions for 20 gCO_2e/mi full-size pickup performance-based credit:

- Vehicle must satisfy full-size pickup truck definition (see above)
- GHG emission level must be achieved by at least 10 percent of the company's sales of full-size pickup trucks in given model year
- Available only for model years 2017 through 2025
- Test vehicle combined FTP-Highway gCO_2e/mi must be at or below 20 percent below the GHG target for given model year and footprint
- Once a test vehicle qualifies and achieves credit for given model year, it can receive credit for four additional model years for a maximum of five years (but not beyond model year 2025), provided that there is no increase in gCO_2e/mi from the previous model year
- Vehicle cannot receive hybrid incentive credit at the same time

3.4. Hybrid Full-Size Pickup Credit

For applicable full-size pick-up trucks that satisfy the above conditions for threshold penetration and minimum size and utility attributes, there are a number of other requirements and minimum qualifying criteria in order to be eligible for hybrid technology credits. The hybrid technology credits have two levels – 10 and 20 gCO_2e/mi – with differing conditions. These requirements are listed below.

Conditions for 10 gCO_2e/mi full-size pickup hybrid credit:

- Vehicle must satisfy full-size pickup truck definition (see above)
- Technology must be deployed on at least the minimum technology threshold of the company's sales of full-size pickup trucks in given model year (see above)
- Available only for model years 2017 through 2021
- Vehicle capable of stop-start operation
- Vehicle capable of regenerative braking
- Between 15 and 75 percent of the theoretical available braking energy as electrical battery energy (as determined by vehicle test weight and A, B, and C test coefficients, and EPA equations for total net energy in to battery divided by total braking energy on FTP city cycle)
- Vehicle cannot receive performance-based incentive credit at the same time

Conditions for 20 gCO_2e/mi full-size pickup hybrid credit:

- Vehicle must satisfy full-size pickup truck definition (see above)
- Technology must be deployed on at least 10 percent of the company's sales of full-size pickup trucks in given model year
- Available only for model years 2017 through 2025
- Vehicle capable of stop-start operation

- Vehicle capable of regenerative braking
- Minimum recovery of 75 percent of the theoretical available braking energy as electrical battery energy (as determined by vehicle test weight and A, B, and C test coefficients, and EPA equations for total net energy in to battery divided by total braking energy on FTP city cycle.
- Technology must be used on at least 10 percent of all the company's full-size pickup trucks sold in each model year that it is to receive credit.
- Vehicle cannot receive performance-based incentive credit at the same time

ARB staff proposes to align with EPA's definition on the two types of hybrids (i.e., Mild for 10 gCO_2e/mi and Strong for 20 gCO_2e/mi credit). The following shows the draft procedure to qualify as either of the two hybrid types; however, as noted above, ARB staff notes its intent to align its final provisions for these hybrid definitions with EPA's final rulemaking in 2012.

EPA and ARB propose to incorporate a metric – the total percentage of available vehicle braking energy recovered over the test cycle – as a way to define levels of hybrid vehicles. For a given vehicle and road load profile (characterized by ETW and A, B and C chassis dynamometer test "coastdown" coefficients), a theoretical amount of required braking energy can be calculated over the city and highway test cycles. This maximum braking energy is the sum of the extra braking force needed to slow the vehicle enough to follow the test cycle trace upon decelerations. Hybrids recapture a portion of this energy by driving the electric motor (in reverse) as a generator, which ultimately provides electrical power to the battery pack. Depending on the level of hybridization, this amount of recaptured energy can range between a few percent of total available braking energy up to theoretically almost 100 percent of all braking energy.

This metric is a way to simplify the characterization of a hybrid as a "Mild" or "Strong" hybrid. Batteries and motors must increase in scale to recover braking energy at a greater rate. As the power rating of the motor and battery increases, a greater percentage of braking energy can be recovered on rapid decelerations. As a result, all components of a hybrid system – the battery pack size and power rating, the motor rating, etc. – are implicitly reflected in the percentage of braking energy recovered.

The procedure involves calculating the available braking energy on the FTP city cycle using the equation derived below. This value is compared to the actual energy recovered by the vehicle during FTP city cycle testing. Since energy into and out of the hybrid drive system battery is a standard part of emissions testing of hybrid vehicles, this procedure introduces no additional test burden. However, energy flow into the battery must be separated from the sum of energy into and out of the battery which is typically less than 1 percent of total fuel energy used during the test.

The measured energy into the battery is divided into the total calculated braking energy to determine if the vehicle is a mild or strong hybrid. For a mild hybrid, the recovered energy must be greater than 15percent and less than 75 percent of the calculated available braking energy. For a strong hybrid, the recovered braking energy must be greater than 75 percent of the calculated available braking energy.

3.4.1. Spreadsheet Documentation for Calculation of Hybrid Braking Energy Recovery

Equation R-7 defines the brake energy recovery efficiency (expressed as a percentage), or $\eta_{recovery}$:

$$\eta_{recovery} = \frac{E_{recovered}}{E_{brake\_max}} \tag{R-7}$$

$E_{recovered}$, the total brake energy recovered over the 4-bag FTP test (in kWh) is calculated in Equation R-8:

$$E_{recovered} = \frac{V\int i(t)dt}{3600*1000} \tag{R-8}$$

With *i(t)* defined as measured current into the battery (in amps) and V defined as the nominal battery pack voltage. Current flowing out of the battery (discharge) is not included.

Equations to calculate the maximum theoretical braking energy:
E_{brake_max} (kWh) is calculated by integrating required braking power (P_{brake}) at each point in the test cycle[c] over the entire test, shown in Equation R-9.

$$E_{brake\_max} = \frac{\int P_{brake}(t)dt}{3600} \tag{R-9}$$

P_{brake} (kW) – the vehicle braking power required to follow the drive trace during decelerations – represents the amount of braking force (expressed as power) in addition to the existing road load forces which combine to slow the vehicle. It is expressed in Equation R-10. By convention, only negative values are calculated for braking[d].

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[c] *These calculations assume a "4-bag" FTP schedule, or 2 consecutive UDDS cycles, as is common for testing HEVs for charge balancing purposes.*

[d] *All power terms are negative when power is applied to the vehicle (as in braking). Power provided by the vehicle (such as tractive power – in the case of acceleration) would be positive.*

$$P_{brake} = P_{accel\_reqd} - P_{roadload} \qquad \text{(R-10)}$$

P_{accel_reqd} (kW), in represents the total applied deceleration power necessary to slow the vehicle. It is calculated as the vehicle speed, v (in m/s) multiplied by the deceleration force (vehicle mass * required deceleration rate), as shown in Equation R-11.

$$P_{accel\_reqd} = v * m_{ETW} * \frac{dv}{dt} \qquad \text{(R-11)}$$

Where m_{ETW} (kg) is the vehicle mass, based on equivalent test weight (ETW) and dv/dt (m/s^2) is the required acceleration/deceleration for the vehicle to match the next point on the vehicle trace.

$P_{roadload}$ (kW) is the sum of the road load forces (N) as calculated from the experimental vehicle coastdown coefficients, A, B and C. It is calculated in Equation R-12:

$$P_{roadload} = v * \left(A + Bv + Cv^2\right) \qquad \text{(R-12)}$$

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