Vehicle Environmental Regulatory Strategy & Planning
Sustainability, Environment & Safety Engineering
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February 6, 2017

To: Mr. Linc Wehrly
Compliance Division
Light-Duty Vehicle Center
Office of Transportation and Air Quality
U.S. Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

To: Mr. James Tamm
Fuel Economy Division Chief
Office of Rulemaking
National Highway Traffic Safety Administration
1200 New Jersey Avenue SE
Washington, DC 20590

Subject: Request for 2017 MY and Beyond Greenhouse Gas (GHG) and Fuel Economy Off-Cycle Credits

Per 40 CFR 86.1869-12(d), 49 CFR 531.6(b), and 49 CFR 533.6(b) Ford requests GHG off-cycle credits for the following technologies used in 2017 MY and beyond vehicles (technology and methodology outlined in Attachments A through D):

- Thermal Control Technology – Glass/Glazing (Attachment A)
- Thermal Control Technology – Solar Reflective Surface Coating (Attachment B)
- High Efficiency Alternator (Attachment C)
- DENSO SAS Air Conditioning Compressor With Variable Crankcase Suction Valve (Attachment D)

Pursuant to 40 CFR § 86.1869-12 and per 49 CFR 531.6, vehicle manufacturers may obtain off-cycle credits for the use of a technology whose benefits are not adequately captured on the Federal Test Procedure and/or the Highway Fuel Economy Test. This request for off-cycle credits is submitted in accordance with subsection (d) of that rule, which enables manufacturers to earn credits by demonstrating that the technology at issue results in a carbon-related exhaust emissions benefit when tested using an alternative methodology approved by EPA in consultation with NHTSA. 40 CFR § 86.1869-12(a) provides that off-cycle credits may not be earned for crash avoidance technologies, safety critical systems, technologies designed to reduce the frequency of vehicle crashes, or technologies installed to attain compliance with any vehicle safety standard or regulation set forth in CFR title 49. Ford hereby states that the above listed technologies that are the subject of this request are not safety-related technologies and are therefore not subject to any of the exclusions set forth in subsection (a).

This document was revised to provide additional information and analysis requested per the discussions with EPA which occurred January 18th, 2017. Ford kindly requests written/e-mail acknowledgment upon receipt and acceptance of this off-cycle credit proposal. If you have any questions about this letter and the related attachments, please contact Ms. Nancy Homeister at nhomeist@ford.com or (313) 594-1035.

Sincerely,

Todd Fagerman, Associate Director
Vehicle Environmental Regulatory Strategy & Planning

Attachment A: Thermal Control Technology - Glass / Glazing

Definition:

Glass Glazing Technologies which can reduce the amount of solar heat gain in the cabin by reflecting or absorbing some of the infrared solar energy. One measure of solar load-reducing potential for glazing is Total Solar Transmittance or Tts which expresses the percentage of solar energy which passes through the glazing. (p. 5-101 of EPA's Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.)

Rationale for Using The Alternative EPA-approved Methodology:

Ford considered both the 5-cycle and alternative methodologies for this request. Although the 5-cycle methodology would capture a variety of driving conditions (e.g. vehicle speed, ambient temperature, etc.), the key factor in determining the greenhouse gas benefit of glass glazing technologies is the reduced cooling loads on vehicles parked in the sun. The 5-cycle test methodology would minimize the potential impact glass glazing would have on the measured CO2 emissions for three reasons, and the SC03 cycle is they only cycle that incorporates A/C usage and solar loads. The SC03 test requires AC to be run a maximum during the cycle, lower cabin temperature would have minimal impact on the A/C load in the test and would not fully reflect the benefit of glass glazing. The vehicle is preheated at 850 watt/meter solar load for 10 minutes, however, our data demonstrates that it takes hours of sun load for the vehicle interior temperatures to diverge to the 5-10 C range during a soak. Finally the 5-cycle calculation suggests the A/C usage / solar loads are only ~13% of VMT, while literature indicates that it is substantially higher (24 – 29%). Based on this it is determined that the reduced cooling loads on a vehicle are not fully captured in the 5-cycle methodology.

This request largely replicates Chrysler's April 29, 2013 petition requesting credits for the subject technologies on 2009 thru 2013 model year vehicles. The methodology was found to be sound and appropriate and was approved by EPA in September 2015. With this request, we now seek approval for off-cycle credits for 2017 MY and beyond, based on the same technologies covered in the prior petition.

For this reason, Ford is pursuing off-cycle credits under the alternative demonstration methodology pursuant to 40 CFR § 86.1869-12(d).

Description of Ford System:

Ford glass applications are designed in accordance with FMVSS 205/ ANSI Z26.1 glazing standards for Passenger cars, SUV and Trucks.

Below are details on the NREL SAE (2007-01-1194)[1] findings, which quantified the ability of solar thermal technologies to reduce air conditioning (A/C) fuel usage. The goal of this SAE study was to demonstrate that advanced thermal technologies are able to reduce cooling loads by 30% when a vehicle is parked in the sun[1]. Additionally, the study found this 30% reduction in load equates to an average of 26% fuel consumption reduction.

The SAE data is summarized in Table 1[1] below, which shows that the air breath temperature is reduced by 9.7 °C when using solar glass with a 42 Tts rating. Air Breath Temperature is commonly used as standard industry practice to gauge occupant comfort.

[1] SAE (2007-01-1194) Reduction in Vehicle Temperature and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and a New Solar-Reflective Glazing

Temperature Reduction of Solar Reflective Glass (Table 1)

	Air-Foot	Air-Breath	Air	Dashboard	Roof Exterior	Front Driver Seat	Front Pass Seat	Windshield
Solar Reflective Glass-all locations, ventilation	5.6	12.0	8.8	16.8	9.8/6.0	10.3	11.9	20.4
Solar Reflective Glass-all locations	4.4	9.7	7.1	14.5	5.5	8.7	8.7	19.3

Using the data from the SAE study, it can be interpolated that each 1°C reduction in the air breath temperature equates to 2.2% fuel consumption reduction for the average vehicle. These calculations are detailed in Table 2 below:

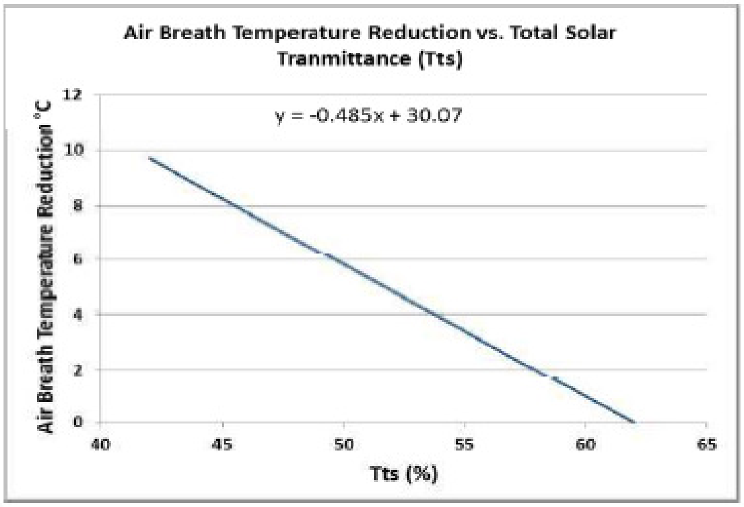
Temperature vs. Fuel Consumption Reduction (Table 2)

Technology	Air Breath Temperature Reduction (°C)	Air Condition Load Reduction (%)	Air Condition Fuel Consumption Reduction (%)	A/C (%) Fuel Consumption Reduction per °C
Solar Glass + Ventilation	12.0	30	26	
Solar Glass	**9.7**	=30*(9.7/12) = 24.25	=26*(9.7/12) **= 21**	= 21 / 9.7 **= 2.2**

When the SAE study was conducted during the summer 2005 through 2006, industry was primarily using solar light green glass with a 62 Tts rating as the baseline glass. Therefore the delta in the air breath temperature reduction of 9.7 °C on the 42 Tts glass in the test vehicle had a 62 Tts glass baseline vehicle. Ford is using solar glass with ratings better than 62 Tts on vehicles to reduce solar loads. The solar glass lowers the vehicle cabin air breath temperatures as detailed above and therefore Ford meets the off-cycle technology criteria. The Air Breath Temperature Reduction vs Tts is detailed in Table 3 and the relationship is plotted in Figure 1:

Air Breath Temperature Reduction vs. Total Solar Energy Transmittance (Table 3)

Glass Technology	Glass Tts (%)	Air Breath Temperature Reduction (°C)
Baseline Glass	62	0
Glass Studied in SAE [2007-01-1194]	42	9.7



Air Breath Temperature Reduction vs. Total Solar Transmittance (Figure 1)

Ford Methodology:

Based on the logic presented above, an example credit calculation can be found below for 58 Tts solar glass[2].

Example Off-Cycle Credit Calculation:
Air Breath Temperature Reduction = (-0.485*58 + 30.07) = 1.94 °C
A/C Fuel Consumption Reduction = 1.94 °C * 2.2% / °C = 4.27%

Off Cycle Credit:
Average Vehicle Off-Cycle Credit Car = 13.2 * 4.27 / 100 = 0.56 g/mile
Average Vehicle Off-Cycle Credit Truck = 15.2 * 4.27/100 = 0.65 g/mile

Where

- 13.2 g/mile and 15.2 g/mile are the average impacts of A/C for car and truck respectively[3]
- 4.27 is the % A/C fuel consumption reduction with 58 Tts rated solar glass

[2] Ford/Supplier production data on the base solar glass/glazing (ISO 13837).
[3] In the 2012-16 MY rule, EPA estimated that the average impact of the A/C system load is 14.0 g CO_2/mile. The Agency also estimated that the car/truck industry mix is 60/40. Utilizing this information, Ford calculates the A/C impact for the car and truck based on the volume mix and normalized to Vehicle Miles Traveled (VMT), giving an A/C impact of 13.2 for the car and 15.2 for the truck.

Vehicle	VMT (Vehicle Miles Travelled)	A/C Impact (g/mi)
Fleet Average	207,504=(0.6*195264+0.4*225,865)	14.0
Car	195,264	13.2 = (14*195264 / 207504)
Truck	225,865	15.2 = (14*225865 / 207504)

*2017-25MY Joint Technical Support Document (on average impact of automotive air conditioning of 14.0 g/mile for the 2012 fleet).

Tts values are provided by our glass suppliers. Values represent modelled nominal values for each glass construction based on methodology outlined in ISO 13837. Note, page 5-102 of EPA's Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards states that EPA considers the April 15, 2008 version of ISO 13837 standard to be the appropriate method for measuring the solar transmittance of glazing used in automotive applications.

Credits due to glazed glass are calculated based on the air breath temperature reduction and A/C fuel consumption reduction for each glass and applied to each vehicle.

$$Credit x = x[Z x \quad \frac{\times}{\quad} \quad]x$$

Where:

Credit = the total glass or glazing credits in grams per mile rounded to the nearest 0.1 grams/mile.

Z = 0.3 for passenger automobiles and 0.4 for light trucks

G_i = the measured glass area of window i. in square meters and rounded to the nearest tenth

G = total glass area of the vehicle, in square meters and rounded to the nearest tenth

T_i = the estimated temperature reduction for the glass area of window i. determined using the following formula:

$$= -0.485 * x \ tx + 30.07x$$

The fleet credit will be calculated based on credit for each type of vehicle, vehicle lifetime miles and U.S. sales volume for applicable 2017 MY and beyond products.

Glass/Glazing technologies are in the pre-approved list of credits under 40 CFR 86.1869-12(b)(1)(viii). Ford is requesting an alternate credit value based on an updated methodology and/or the inclusion of additional manufacturer specific data through 40 CFR 86.1869-12(d). Thermal control technologies were pre-approved with a maximum credit allowed of 3.0 g/mi for passenger automobiles and 4.3 g/mi for light trucks. Ford acknowledges the current rationale for the maximum credit limit due to the potential interactions between all thermal control technologies. At this time we are unable to address the interactions between all the available thermal control technologies. Until such testing can be performed, Ford intends to cap our thermal control technologies at the overall limits stated within 40 CFR 86.1869-12(b)(1)(viii) while approval and calculation of these technology credits will be covered under 40 CFR 86.1869-12(d).

Attachment B: Thermal Control Technology - Solar Reflective Surface Coating

Definition:

Solar reflective surface coating means a vehicle paint or other surface coating which reflects infrared solar energy, as determined using ASTM standards E903-12, E1918-06, or C1549-09 (incorporated by reference in § 86.1). The coating must be applied at a minimum to all of the approximately horizontal surfaces of the vehicle that border the passenger and luggage compartments of the vehicle, (e.g., the rear deck lid and the cabin roof).

Rationale for Using The Alternative EPA-approved Methodology:

Ford considered both the 5-cycle and alternative methodologies for this request. Although the 5-cycle methodology would capture a variety of driving conditions (e.g. vehicle speed, ambient temperature, etc.), the key factor in determining the greenhouse gas benefit of solar reflective surface coating technologies is the reduced cooling loads on vehicles parked in the sun. The 5-cycle test methodology would minimize the potential impact solar reflective surface coating would have on the measured CO2 emissions for three reasons, and the SC03 cycle is they only cycle that incorporates A/C usage and solar loads. The SC03 test requires AC to be run a maximum during the cycle; lower cabin temperature would have minimal impact on the A/C load in the test and would not fully reflect the benefit of glass glazing. The vehicle is preheated at 850 watt/meter solar load for 10 minutes; however, our data demonstrates that it takes hours of sun load for the vehicle interior temperatures to diverge to the 5-10 C range during a soak. Finally the 5-cycle calculation suggests the A/C usage / solar loads are only ~13% of VMT, while literature indicates that it is substantially higher (24 – 29%). Based on this it is determined that the reduced cooling loads on a vehicle are not fully captured in the 5-cycle methodology.

This request largely replicates Chrysler's April 29, 2013 petition requesting credits for the subject technologies on 2009 thru 2013 model year vehicles. The methodology was found to be sound and appropriate and was approved by EPA in September 2015. With this request, we now seek approval for off-cycle credits for 2017 MY and beyond, based on the same technologies covered in the prior petition with the addition of vehicle test data used as the baseline for solar reflecting surface coatings.

For this reason, Ford is pursuing off-cycle credits under the alternative demonstration methodology pursuant to 40 CFR § 86.1869-12(d).

Description of Ford System:

Ford currently utilizes paints that reflect impinging infrared solar energy, which varies based on the Total Solar Reflectance (TSR) of the coating as tested using ASTM standard E903-12. The following outlines the test methods used to determine the TSR of each paint, along with the corresponding scaled credit calculation based on the NREL SAE (2007-01-1194)[1] findings, which quantified the ability of solar thermal technologies to reduce air conditioning (A/C) fuel usage. This follows the methodology previously approved by EPA in September 2015[4], but based off test data of Ford's portfolio of paint coatings. The TSR data from Ford production panels will be used to generate a correlation between TSR and cabin temperature based on the methodology presented in the following sections.

[4] EPA-420-R-15-014 (September 2015) EPA Decision Document: Off-cycle Credits for Fiat Chrysler Automobiles, Ford Motor Company, and General Motors Corporation

Ford Methodology:

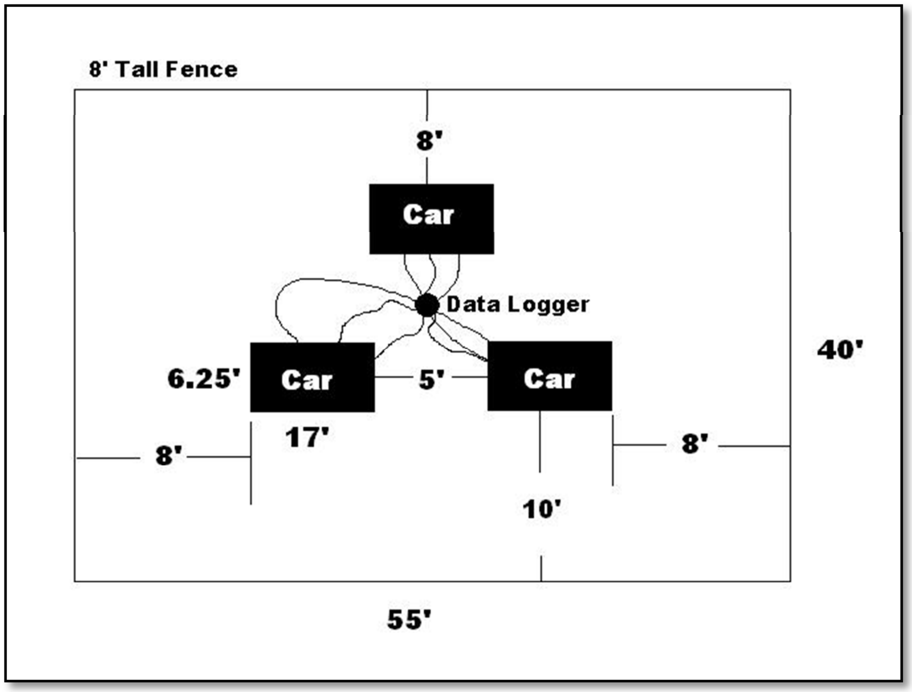
Test Description:

Ford has performed testing in Arizona on fully painted cars to determine the impact of color and solar reflectivity on breath level temperatures. Two vehicles were selected for Arizona exposure testing, a 2006 Black Mercury Montego and a 2005 White Ford Five Hundred. The vehicles had tan interiors with cloth seats. The Five Hundred was painted with conventional white primer, White basecoat and conventional clearcoat. The Montego was painted with conventional dark grey primer, Black basecoat and conventional clearcoat. The resulting total solar reflectance (TSR) values for the exterior paint on the vehicles were: black Montego: [redacted] and white Five Hundred: [redacted].

Test Vehicles (Figure 1)

Note: An experimental gray painted vehicle is also pictured, but not applicable to this study.

The vehicles were shipped to the Q-Lab Weathering Research Service site in Buckeye, AZ, located about 30 miles west of Phoenix. The vehicles were parked on coarse gravel within a 40'x55' chain-link fence enclosure. The fence was 8' high and fitted with vinyl privacy slat inserts to block the wind and reduce testing variability. An in speed anemometer was located between the vehicles to measure the local wind speed. The vehicles were oriented so the driver's side doors faced due south to maximize the impact of painted surfaces (See Figure 2).



Vehicle Placement Diagram (Figure 2)

Type K thermocouples (Omega 5SRTC-TT-K-30 and Datapaq PA0053C) were placed at twelve locations within and outside the vehicles. Temperature and wind speed data were recorded at 5 minute intervals. In addition, temperature, wind velocity, humidity and irradiance data was also obtained at 5 minute intervals from Q-Lab test equipment outside of the fenced enclosure. Glazed glass areas of the vehicles were covered with aluminum foil (Alcoa, Inc., p/n 627), held in place with flexible magnetic strip (Adams Magnetic Products Co., 1.0" wide, 0.06" thick), to eliminate the contribution of glazing and interior color to cabin soak temperatures and isolate the effect of the solar reflective surface coating.

Data Summary

Based on the testing outlined above, below is a summary of the temperature reduction record for the white vehicle with respect to the baseline black paint coating.

Reduction in Temperature (Table 1)

Paint	Black (Baseline)	White
TSR Rating (%)	[redacted]	[redacted]
TSR Difference To Baseline (%)	[redacted]	[redacted]
Temp. Reduction °C	[redacted]	[redacted]

Testing and data collection occurred during the month of September near Phoenix, AZ. Per NREL, 30-year average monthly solar radiation, 1961-1990 for Phoenix, AZ in September is 6.1 kWh/m2/day[5]. To substantiate the testing conditions at which this data was collected the average monthly solar radiation value in September for Arizona of 6.1 kWh/m2/day aligns with the testing referenced by the NREL SAE (2007-01-1194)[1] paper used to establish the EPA pre-approved credit

[5] National Renewable Energy Laboratory. *30-Year Average of Monthly Solar Radiation, 1961-1990*. Retrieved from http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/sum2/state.html

values. The testing conducted within that paper occurred in Colorado form July 2006 to September 2006, the average of the solar radiation values spanning these months' results in a value of 6.2 kWh/m2/day. To further support these testing conditions as a representative national value applicable to the entire fleet, a Vehicle Miles Traveled (VMT) weighted[6] value by state of average solar radiation values containing the middle third of the year which encompasses the meteorological summer results in a value of 6.2 kWh/m2/day. A summary of NREL 30-year average monthly solar radiation values are contained in Appendix B. VMT data and associated values used to calculate the nation average value are contained within Appendix C. Both of these values are aligned with the conditions at which Ford conducted its testing and used for the associated credit calculations.

In addition to the aformentioned test data Ford had conducted similar testing previously on two separate occasions in Dearborn, MI comparing the temperature reduction for vehicles with different paint colors. This additional testing data followed the same experimental procedures with the glazed areas of the vehicle covered with aluminum foil to isolate the affect of the solar reflective surface coating. The Ford Escape platform was tested and resulted in a temperature reduction of 8.2 °C during the month of July. Per NREL, 30-Year Average of Monthly Solar Radiation, 1961-1990 for Detroit, MI in July is 6.1 kWh/m2/day[5]. The Lincoln Town Car platform was also tested and resulted in a temperature reduction of 9.5 °C in the month of August. Per NREL, 30-Year Average of Monthly Solar Radiation, 1961-1990 for Detroit, MI in August is 5.3 kWh/m2/day[5]. This additional testing further confirms there is a measurable temperature reduction for differences in paint color and associated TSR values.

The difference in values between the Ford data and the data used by NREL is expected due to testing methodology differences with regards to the solar reflective surface coating application. The NREL data applied a solar reflective surface coating to the roof of the vehicle only with a film application, alternatively the Ford testing used two separate complete vehicles fully painted of a different color. Ford elected to use the minimum temperature reduction measured of 6.5 °C to determine the off-cycle credit values for the calculation; this was done to establish a conservative credit value to apply across the fleet. Using this data, the off cycle credits can be calculated as follows.

<u>Example Off-Cycle Credit Calculation for Solar Reflective Paint:</u>

A vehicle with total solar reflectance (TSR) rating of [redacted] (White) qualifies for an off-cycle credit as follows:

Air Breath Temperature Reduction (Test Data Table 1) = [redacted] °C
A/C Fuel Consumption Reduction (SAE Paper)[1] = [redacted] °C * 2.2% / °C = [redacted]

<u>Off Cycle Credit:</u>
Average Vehicle Off-Cycle Credit Car = 13.2 * [redacted] / 100 = [redacted] g/mile
Average Vehicle Off-Cycle Credit Truck = 15.2 * [redacted] /100 = [redacted] g/mile

Where

- 13.2 g/mile and 15.2 g/mile are the average impacts of A/C for car and truck respectively[3]
- [redacted] is the % A/C fuel consumption reduction from solar paint (TSR = [redacted])

[6] U.S. Department of Transportation. FUNCTIONAL SYSTEM TRAVEL – 2014 ANNUAL VEHICLE – MILES. Retrieved from https://www.fhwa.dot.gov/policyinformation/quickfinddata/qftravel.cfm

Table 2 shows the magnitude of off-cycle credits for paints based in TSR ratings.

Off-Cycle Credits for Paints Based in TSR Ratings (Table 2)

Color Palette	Total Solar Reflectance (%)	Temperature Reduction (°C)	AC Fuel Reduction (%)	Car Off-Cycle Credit (g/mile)	Truck Off-Cycle Credit (g/mile)
Paint 1	20	1.8	3.9	0.5	0.6
Paint 2	30	2.9	6.4	0.8	1.0
Paint 3	40	4.0	8.9	1.2	1.4
Paint 4	50	5.2	11.4	1.5	1.7
Paint 5	≥ 59	6.2	13.6	1.8	2.1

Ford Methodology:

- Determine the % impinging infrared solar energy for each paint using ASTM standards E903, E1918-06.
- Apply the calculation of credits due to solar reflective paint results based on a sliding scale.
- The fleet credit will be calculated based on credit for each type of vehicle, vehicle lifetime miles and U.S. sales volume for applicable 2017 MY and beyond products.

Solar Reflective Surface Coating technologies are in the pre-approved list of credits under 40 CFR 86.1869-12(b)(1)(viii). Ford is requesting an alternate credit value based on an updated methodology and/or the inclusion of additional manufacturer specific data through 40 CFR 86.1869-12(d). Thermal control technologies were pre-approved with a maximum credit allowed of 3.0 g/mi for passenger automobiles and 4.3 g/mi for light trucks. Ford acknowledges the current rationale for the maximum credit limit due to the potential interactions between all thermal control technologies. At this time we are unable to address the interactions between all the available thermal control technologies. Until such testing can be performed, Ford intends to cap our thermal control technologies at the overall limits stated within 40 CFR 86.1869-12(b)(1)(viii) while approval and calculation of these technology credits will be covered under 40 CFR 86.1869-12(d).

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Appendix A: Paint Credits Based on TSR

Appendix B: NREL 30-Year Average of Monthly Solar Radiation

State	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	May - Aug Average	State VMT %	State SR
ALABAMA	BIRMINGHAM	2.5	3.3	4.4	5.5	6	6.2	5.9	5.6	4.8	4	2.8	2.3	4.4	5.92	0.021729	0.128606
	HUNTSVILLE	2.4	3.1	4.1	5.3	5.9	6.3	6.1	5.7	4.7	3.9	2.7	2.1	4.4			
	MOBILE	2.7	3.5	4.4	5.4	5.9	5.9	5.6	5.2	4.7	4.2	3.1	2.5	4.4			
	MONTGOMERY	2.7	3.5	4.5	5.7	6.2	6.4	6.1	5.7	4.9	4.2	3	2.5	4.6			
ALASKA	ANCHORAGE	0.3	1	2.3	3.6	4.6	4.9	4.6	3.5	2.2	1.1	0.4	0.2	2.4	4.43	0.001607	0.007114
	ANNETTE	0.6	1.2	2.2	3.5	4.7	5	4.9	4	2.7	1.4	0.7	0.5	2.6			
	BARROW	0	0.3	1.6	3.7	4.7	4.9	4.5	2.6	1.3	0.5	0	0	2			
	BETHEL	0.4	1.1	2.5	3.9	4.5	4.8	4.3	3.2	2.2	1.2	0.5	0.2	2.4			
	BETTLES	0.1	0.6	2	3.9	5.3	5.7	5	3.5	2.1	0.8	0.2	0	2.4			
	BIG DELTA	0.2	0.8	2.3	3.9	5.1	5.5	5.2	3.9	2.4	1.1	0.3	0.1	2.6			
	COLD BAY	0.6	1.2	2.2	3.1	3.7	3.9	3.7	3	2.2	1.4	0.7	0.4	2.2			
	FAIRBANKS	0.1	0.8	2.3	4	5.1	5.6	5.1	3.7	2.3	1	0.3	0	2.5			
	GULKANA	0.3	1	2.5	4.1	5.1	5.5	5.3	4.1	2.6	1.2	0.4	0.2	2.7			
	KING SALMON	0.5	1.2	2.4	3.6	4.4	4.6	4.3	3.4	2.3	1.4	0.6	0.3	2.4			
	KODIAK	0.5	1.1	2.3	3.5	4.3	4.6	4.5	3.8	2.5	1.5	0.7	0.3	2.5			
	KOTZEBUE	0.1	0.6	2.1	4.1	5.5	5.5	4.8	3.3	2	0.9	0.2	0	2.4			
	MCGRATH	0.3	1	2.4	4.2	4.8	5.1	4.6	3.5	2.2	1.1	0.4	0.1	2.5			
	NOME	0.2	0.8	2.3	4.3	5.3	5.5	4.6	3.3	2.1	1	0.3	0.1	2.5			
	ST PAUL IS.	0.5	1.2	2.4	3.5	3.9	4	3.6	2.9	2.2	1.3	0.6	0.4	2.2			
	TALKEETNA	0.3	1	2.3	4.1	4.8	5	4.7	3.6	2.3	1.2	0.4	0.2	2.5			
	YAKUTAT	0.4	1	2.2	3.5	4.1	4.4	4.2	3.4	2.2	1.1	0.5	0.3	2.3			
ARIZONA	FLAGSTAFF	3.1	4	5.1	6.3	7.2	7.7	6.4	5.9	5.4	4.4	3.3	2.8	5.1	7.30	0.020724	0.151286
	PHOENIX	3.2	4.3	5.5	7.1	8	8.4	7.6	7.1	6.1	4.9	3.6	3	5.7			
	PRESCOTT	3.1	3.9	5.1	6.6	7.5	8	6.9	6.3	5.7	4.6	3.4	2.8	5.3			
	TUCSON	3.4	4.4	5.6	7.1	7.9	8.1	7.1	6.7	6	5	3.8	3.2	5.7			
ARKANSAS	FORT SMITH	2.6	3.4	4.4	5.4	6	6.5	6.6	6	4.8	3.9	2.8	2.3	4.6	6.25	0.011258	0.070364
	LITTLE ROCK	2.5	3.3	4.3	5.3	6.1	6.5	6.4	5.9	4.8	3.9	2.7	2.2	4.5			
CALIFORNIA	ARCATA	1.8	2.5	3.6	5	5.8	6	5.9	5	4.4	3.1	2	1.6	3.9	7.05	0.110140	0.776762
	BAKERSFIELD	2.3	3.3	4.7	6.2	7.4	8.1	8	7.2	5.9	4.4	2.9	2.1	5.2			
	DAGGETT	3.2	4.2	5.5	7	7.9	8.4	8	7.3	6.3	4.9	3.6	2.9	5.8			
	FRESNO	2.1	3.2	4.7	6.3	7.5	8.1	8	7.2	5.9	4.3	2.7	1.9	5.2			
	LONG BEACH	2.8	3.6	4.7	6	6.4	6.7	7.3	6.7	5.4	4.2	3.1	2.6	5			
	LOS ANGELES	2.8	3.6	4.8	6.1	6.4	6.6	7.1	6.5	5.3	4.2	3.2	2.6	4.9			
	SACRAMENTO	1.9	3	4.3	5.9	7.2	7.9	7.9	7	5.7	4	2.4	1.7	4.9			
	SAN DIEGO	3.1	3.9	4.9	6.1	6.3	6.5	6.9	6.5	5.4	4.4	3.4	2.9	5			
	SAN FRANCISCO	2.2	3	4.2	5.7	6.7	7.2	7.3	6.5	5.4	3.9	2.5	2	4.7			
	SANTA MARIA	2.8	3.7	4.9	6.2	7	7.4	7.5	6.8	5.6	4.4	3.2	2.7	5.2			
COLORADO	ALAMOSA	3	4	5.2	6.4	7.1	7.7	7.2	6.5	5.6	4.5	3.3	2.7	5.3	6.80	0.016209	0.110220
	COLORADO SPRINGS	2.5	3.4	4.5	5.7	6.2	6.9	6.7	6	5.1	4	2.8	2.3	4.7			
	BOULDER	2.4	3.3	4.4	5.6	6.2	6.9	6.7	6	5	3.8	2.6	2.1	4.6			
	EAGLE	2.4	3.3	4.4	5.6	6.4	7.2	6.9	6.1	5.1	3.9	2.5	2.1	4.7			
	GRAND JUNCTION	2.5	3.5	4.6	6	7	7.7	7.4	6.6	5.5	4.1	2.7	2.2	5			
	PUEBLO	2.7	3.6	4.7	6	6.7	7.4	7.2	6.5	5.4	4.2	2.9	2.4	5			
CONNECTICUT	BRIDGEPORT	1.9	2.7	3.7	4.7	5.4	5.9	5.8	5.2	4.2	3.1	2	1.6	3.8	5.58	0.010321	0.057538
	HARTFORD	1.9	2.7	3.7	4.6	5.4	5.9	5.9	5.1	4.1	3	1.9	1.5	3.8			
DELAWARE	WILMINGTON	2	2.9	3.9	4.9	5.6	6.2	6.1	5.4	4.4	3.3	2.2	1.7	4.1	5.83	0.003175	0.018497
FLORIDA	DAYTONA BEACH	3.1	3.9	5	6.2	6.4	6.1	6	5.7	4.9	4.2	3.4	2.9	4.8	5.91	0.066523	0.393197
	JACKSONVILLE	2.9	3.7	4.7	5.9	6.1	6	5.8	5.4	4.6	4	3.2	2.7	4.6			
	KEY WEST	3.7	4.4	5.5	6.3	6.3	6.1	6.1	5.8	5.2	4.6	3.8	3.4	5.1			
	MIAMI	3.5	4.2	5.2	6	6	5.6	5.8	5.6	4.9	4.4	3.7	3.3	4.8			
	TALLAHASSEE	2.9	3.7	4.7	5.9	6.3	6.1	5.8	5.5	4.9	4.3	3.3	2.7	4.7			
	TAMPA	3.2	4	5.1	6.2	6.4	6.1	5.8	5.5	4.9	4.4	3.6	3.1	4.9			
	WEST PALM BEACH	3.3	4	5	5.9	6	5.7	5.9	5.6	4.8	4.2	3.4	3.1	4.7			
GEORGIA	ATHENS	2.6	3.4	4.5	5.6	6.1	6.4	6.1	5.6	4.8	4	2.9	2.4	4.5	6.05	0.036906	0.223128
	ATLANTA	2.6	3.4	4.5	5.7	6.2	6.4	6.2	5.7	4.8	4.1	2.9	2.4	4.6			
	AUGUSTA	2.6	3.5	4.5	5.7	6.1	6.3	6.1	5.5	4.8	4.1	3	2.4	4.6			
	COLUMBUS	2.7	3.5	4.6	5.7	6.2	6.4	6	5.6	4.9	4.2	3.1	2.5	4.6			
	MACON	2.7	3.5	4.6	5.7	6.2	6.3	6	5.6	4.8	4.1	3	2.5	4.6			

	SAVANNAH	2.8	3.5	4.7	5.8	6.2	6.3	6.1	5.5	4.7	4.1	3.1	2.6	4.6			
HAWAII	HILO	3.8	4.3	4.6	4.8	5.2	5.4	5.2	5.3	5	4.3	3.7	3.5	4.6	6.08	0.003367	0.020473
	HONOLULU	3.9	4.7	5.4	5.9	6.4	6.5	6.6	6.5	5.9	5	4.1	3.7	5.4			
	KAHULUI	4	4.7	5.4	5.9	6.4	6.7	6.7	6.5	6.1	5.1	4.3	3.9	5.5			
	LIHUE	3.7	4.3	4.9	5.3	5.9	6.1	6	5.9	5.6	4.7	3.8	3.5	5			
IDAHO	BOISE	1.6	2.5	3.8	5.3	6.5	7.2	7.6	6.6	5.1	3.4	1.9	1.4	4.4	6.84	0.005345	0.036548
	POCATELLO	1.7	2.6	3.8	5.1	6.2	7	7.3	6.3	5	3.5	2	1.5	4.3			
ILLINOIS	CHICAGO	1.8	2.6	3.5	4.6	5.7	6.3	6.1	5.4	4.2	3	1.8	1.5	3.9	5.98	0.034712	0.207407
	MOLINE	1.9	2.7	3.6	4.7	5.7	6.4	6.3	5.5	4.3	3.2	2	1.6	4			
	PEORIA	2	2.8	3.6	4.8	5.8	6.4	6.3	5.5	4.4	3.2	2	1.6	4			
	ROCKFORD	1.9	2.7	3.5	4.6	5.7	6.3	6.1	5.4	4.2	3	1.8	1.5	3.9			
	SPRINGFIELD	2.1	2.9	3.7	5	6	6.5	6.4	5.7	4.6	3.4	2.2	1.7	4.2			
INDIANA	EVANSVILLE	2.1	2.9	3.8	5	5.9	6.5	6.3	5.7	4.6	3.5	2.3	1.8	4.2	5.94	0.026208	0.155609
	FORT WAYNE	1.8	2.6	3.5	4.6	5.6	6.2	6.1	5.3	4.3	3	1.8	1.4	3.9			
	INDIANAPOLIS	2	2.8	3.7	4.9	5.9	6.5	6.3	5.6	4.6	3.3	2.1	1.6	4.1			
	SOUTH BEND	1.7	2.5	3.4	4.6	5.6	6.2	6	5.3	4.1	2.9	1.7	1.4	3.8			
IOWA	DES MOINES	2	2.8	3.8	4.9	5.8	6.5	6.5	5.7	4.4	3.2	2.1	1.7	4.1	6.06	0.010395	0.062952
	MASON CITY	1.9	2.7	3.7	4.7	5.8	6.3	6.3	5.5	4.3	3	1.8	1.5	4			
	SIOUX CITY	1.9	2.8	3.8	4.9	5.8	6.6	6.5	5.7	4.4	3.2	2	1.6	4.1			
	WATERLOO	1.9	2.7	3.6	4.7	5.7	6.4	6.3	5.5	4.3	3	1.9	1.5	4			
KANSAS	DODGE CITY	2.7	3.6	4.7	5.9	6.5	7.2	7.2	6.3	5.1	4	2.8	2.4	4.9	6.54	0.010162	0.066432
	GOODLAND	2.5	3.3	4.5	5.7	6.3	7.2	7.1	6.3	5.1	3.9	2.7	2.2	4.7			
	TOPEKA	2.3	3	4	5.1	5.9	6.5	6.6	5.8	4.6	3.5	2.4	1.9	4.3			
	WICHITA	2.5	3.3	4.3	5.4	6.1	6.7	6.8	6.1	4.9	3.8	2.6	2.2	4.6			
KENTUCKY	COVINGTON	1.9	2.7	3.6	4.8	5.7	6.2	6	5.5	4.5	3.3	2.1	1.6	4	5.88	0.015863	0.093329
	LEXINGTON	2	2.8	3.7	4.9	5.7	6.2	6	5.5	4.4	3.4	2.2	1.7	4.1			
	LOUISVILLE	2	2.8	3.8	5	5.8	6.3	6.1	5.6	4.5	3.5	2.2	1.7	4.1			
LOUISIANA	BATON ROUGE	2.6	3.5	4.4	5.4	5.9	6	5.7	5.4	4.8	4.3	3	2.5	4.5	5.94	0.015966	0.094899
	LAKE CHARLES	2.7	3.6	4.5	5.4	6	6.3	6	5.6	5	4.3	3.2	2.6	4.6			
	NEW ORLEANS	2.7	3.6	4.5	5.5	6.1	6.1	5.7	5.5	4.9	4.3	3.1	2.6	4.6			
	SHREVEPORT	2.6	3.4	4.4	5.4	6	6.4	6.4	6	5	4.1	3	2.5	4.6			
MAINE	CARIBOU	1.6	2.6	3.8	4.6	5.2	5.7	5.6	4.8	3.6	2.3	1.4	1.2	3.6	5.55	0.004732	0.026264
	PORTLAND	1.9	2.8	3.8	4.7	5.6	6.1	6	5.4	4.2	2.9	1.8	1.5	3.9			
MARYLAND	BALTIMORE	2.1	2.9	3.9	4.9	5.6	6.2	6	5.3	4.4	3.3	2.2	1.8	4	5.78	0.018673	0.107836
MASSACHUSETTS	BOSTON	1.9	2.7	3.7	4.7	5.6	6.1	6.1	5.4	4.3	3	1.9	1.5	3.9	5.73	0.019044	0.109025
	WORCHESTER	1.9	2.8	3.8	4.7	5.5	6	5.9	5.2	4.2	3	1.9	1.5	3.9			
MICHIGAN	ALPENA	1.6	2.5	3.7	4.7	5.7	6.2	6.1	5.1	3.8	2.5	1.5	1.2	3.7	5.78	0.032224	0.186360
	DETROIT	1.6	2.5	3.4	4.6	5.6	6.2	6.1	5.3	4.1	2.8	1.7	1.3	3.8			
	FLINT	1.6	2.5	3.4	4.6	5.6	6.1	6	5.2	4	2.7	1.6	1.3	3.7			
	GRAND RAPIDS	1.6	2.5	3.5	4.7	5.7	6.3	6.2	5.3	4.1	2.7	1.6	1.3	3.8			
	HOUGHTON	1.3	2.2	3.5	4.6	5.5	6	6	5	3.6	2.3	1.3	1.1	3.6			
	LANSING	1.6	2.5	3.5	4.6	5.6	6.2	6.1	5.2	4	2.7	1.7	1.3	3.8			
	MUSKEGON	1.6	2.4	3.5	4.7	5.9	6.4	6.4	5.4	4.1	2.7	1.6	1.2	3.8			
	SAULT STE. MARIE	1.6	2.6	3.9	4.8	5.7	6.1	6	5	3.5	2.2	1.4	1.2	3.7			
	TRAVERSE CITY	1.5	2.4	3.5	4.6	5.6	6.2	6.1	5.1	3.7	2.4	1.4	1.2	3.6			
MINNESOTA	DULUTH	1.6	2.6	3.8	4.8	5.6	6	6.1	5.1	3.7	2.5	1.5	1.2	3.7	5.77	0.018992	0.109486
	INTERNATIONAL FALLS	1.4	2.4	3.7	4.8	5.5	5.8	5.8	4.9	3.5	2.2	1.4	1.1	3.6			
	MINNEAPOLIS	1.8	2.7	3.8	4.7	5.7	6.3	6.3	5.4	4.1	2.8	1.7	1.4	3.9			
	ROCHESTER	1.8	2.7	3.7	4.6	5.6	6.2	6.2	5.3	4	2.8	1.7	1.4	3.8			
	SAINT CLOUD	1.7	2.7	3.8	4.7	5.6	6.2	6.3	5.4	4	2.7	1.7	1.3	3.8			
MISSISSIPPI	JACKSON	2.6	3.5	4.5	5.5	6.1	6.4	6.2	5.8	4.9	4.2	3	2.4	4.6	6.01	0.013070	0.078583
	MERIDIAN	2.6	3.4	4.4	5.4	5.9	6.2	5.9	5.6	4.8	4.1	2.9	2.4	4.5			
MISSOURI	COLUMBIA	2.2	3	4	5.2	6	6.6	6.6	5.9	4.6	3.5	2.3	1.9	4.3	6.19	0.023463	0.145326
	KANSAS CITY	2.2	3	3.9	5.1	5.9	6.5	6.6	5.8	4.6	3.6	2.3	1.9	4.3			
	SPRINGFIELD	2.4	3.1	4.1	5.2	5.9	6.4	6.6	5.9	4.7	3.7	2.5	2	4.4			
	ST. LOUIS	2.2	2.9	3.9	5	5.9	6.4	6.4	5.7	4.6	3.5	2.3	1.8	4.2			
MONTANA	BILLINGS	1.7	2.6	3.8	5	5.9	6.7	7	6.1	4.5	3.1	1.9	1.4	4.1	6.25	0.004023	0.025131
	CUT BANK	1.4	2.2	3.5	4.9	5.9	6.6	6.9	5.8	4.2	2.8	1.6	1.1	3.9			
	GLASGOW	1.5	2.3	3.6	4.7	5.7	6.5	6.7	5.7	4.1	2.7	1.6	1.2	3.9			
	GREAT FALLS	1.4	2.4	3.7	4.9	5.8	6.7	7.1	5.9	4.3	2.8	1.7	1.2	4			
	HELENA	1.5	2.3	3.5	4.8	5.8	6.5	7	5.9	4.4	2.9	1.7	1.2	4			
	KALISPELL	1.2	2	3.1	4.3	5.4	6.1	6.7	5.6	4	2.5	1.3	1	3.6			
	LEWISTOWN	1.5	2.3	3.6	4.8	5.7	6.4	6.8	5.8	4.2	2.8	1.7	1.2	3.9			
	MILES CITY	1.7	2.6	3.8	4.9	5.9	6.8	7	6	4.4	3	1.8	1.4	4.1			

	MISSOULA	1.3	2.1	3.2	4.5	5.5	6.3	6.9	5.8	4.2	2.7	1.4	1.1	3.8			
NEBRASKA	GRAND ISLAND	2.2	3	4.1	5.3	6.1	6.9	6.8	6	4.7	3.5	2.3	1.9	4.4	6.38	0.006490	0.041404
	NORFOLK	2.1	2.9	4	5.1	6	6.7	6.7	5.8	4.5	3.3	2.2	1.7	4.3			
	NORTH PLATTE	2.2	3.1	4.2	5.3	6	6.8	6.8	6	4.8	3.6	2.4	1.9	4.4			
	OMAHA	2.1	2.9	3.9	5	5.9	6.7	6.6	5.7	4.5	3.3	2.1	1.7	4.2			
	SCOTTSBLUFF	2.1	3	4.1	5.3	6	6.9	7	6.2	4.9	3.5	2.3	1.9	4.4			
NEVADA	ELKO	2.1	2.9	4	5.3	6.3	7.1	7.4	6.6	5.4	3.8	2.3	1.9	4.6	7.25	0.008372	0.060733
	ELY	2.6	3.4	4.5	5.8	6.6	7.5	7.3	6.5	5.6	4.1	2.8	2.2	4.9			
	LAS VEGAS	3	4	5.4	6.9	7.8	8.4	7.9	7.2	6.2	4.7	3.4	2.8	5.7			
	RENO	2.3	3.2	4.5	5.9	7	7.6	7.8	6.9	5.7	4.1	2.6	2.1	5			
	TONOPAH	2.7	3.6	4.8	6.2	7.1	7.9	7.8	7	5.9	4.4	3	2.4	5.2			
	WINNEMUCCA	2.1	2.9	4.1	5.5	6.6	7.4	7.7	6.7	5.5	3.8	2.3	1.9	4.7			
NEW HAMPSHIRE	CONCORD	1.9	2.8	3.9	4.7	5.6	6.1	6.1	5.3	4.2	2.9	1.8	1.5	3.9	5.78	0.004292	0.024785
NEW JERSEY	ATLANTIC CITY	2	2.8	3.9	4.9	5.6	6.1	5.9	5.3	4.4	3.3	2.2	1.8	4	5.69	0.024769	0.140876
	NEWARK	1.9	2.7	3.8	4.8	5.5	6	5.9	5.2	4.3	3.2	2	1.6	3.9			
NEW MEXICO	ALBUQUERQUE	3.2	4.2	5.4	6.8	7.7	8.1	7.5	6.9	5.9	4.7	3.5	2.9	5.6	7.30	0.008387	0.061227
	TUCUMCARI	3	3.9	5.1	6.4	7	7.5	7.2	6.5	5.5	4.5	3.3	2.7	5.2			
NEW YORK	ALBANY	1.8	2.6	3.6	4.7	5.5	6	6.1	5.2	4.1	2.8	1.7	1.4	3.8	5.68	0.042772	0.242885
	BINGHAMTON	1.7	2.5	3.5	4.5	5.3	5.8	5.8	5	3.9	2.7	1.7	1.4	3.7			
	BUFFALO	1.6	2.4	3.4	4.5	5.5	6.1	6	5.2	3.9	2.6	1.6	1.3	3.7			
	MASSENA	1.7	2.6	3.7	4.6	5.5	6	6.1	5.1	3.9	2.6	1.5	1.3	3.7			
	NEW YORK CITY	1.9	2.7	3.8	4.9	5.7	6.1	6	5.4	4.3	3.2	2	1.6	4			
	ROCHESTER	1.6	2.4	3.4	4.6	5.5	6.1	6	5.2	4	2.7	1.6	1.3	3.7			
	SYRACUSE	1.7	2.5	3.5	4.6	5.5	6.1	6	5.2	4	2.7	1.6	1.3	3.7			
NORTH CAROLINA	ASHEVILLE	2.5	3.3	4.3	5.4	5.8	6	5.8	5.3	4.5	3.8	2.7	2.2	4.3	5.95	0.035740	0.212656
	CAPE HATTERAS	2.4	3.3	4.4	5.6	6.1	6.4	6.2	5.6	4.8	3.7	2.8	2.2	4.5			
	CHARLOTTE	2.5	3.3	4.4	5.5	6	6.3	6.1	5.6	4.7	3.9	2.8	2.3	4.4			
	GREENSBORO	2.4	3.2	4.3	5.4	6	6.3	6.1	5.5	4.6	3.7	2.7	2.2	4.4			
	RALEIGH	2.4	3.2	4.4	5.5	6	6.3	6.1	5.5	4.6	3.8	2.7	2.2	4.4			
	WILMINGTON	2.6	3.4	4.5	5.7	6.1	6.3	6	5.4	4.6	3.9	2.9	2.4	4.5			
NORTH DAKOTA	BISMARCK	1.7	2.6	3.8	4.9	6	6.6	6.8	5.8	4.2	2.8	1.7	1.4	4	6.12	0.003478	0.021274
	FARGO	1.6	2.5	3.7	4.7	5.7	6.2	6.4	5.5	4	2.7	1.6	1.3	3.8			
	MINOT	1.5	2.4	3.6	4.9	5.8	6.4	6.6	5.6	4	2.7	1.6	1.2	3.9			
OHIO	AKRON	1.7	2.4	3.4	4.6	5.5	6.1	6	5.2	4.2	2.9	1.8	1.4	3.8	5.74	0.037314	0.214020
	CLEVELAND	1.6	2.4	3.3	4.6	5.6	6.2	6.1	5.3	4.1	2.8	1.7	1.3	3.8			
	COLUMBUS	1.8	2.5	3.5	4.6	5.5	6	5.9	5.3	4.3	3.1	1.9	1.5	3.8			
	DAYTON	1.9	2.6	3.6	4.7	5.7	6.2	6	5.4	4.4	3.2	2	1.5	3.9			
	MANSFIELD	1.7	2.5	3.4	4.6	5.5	6.1	6	5.3	4.2	3	1.8	1.4	3.8			
	TOLEDO	1.7	2.6	3.5	4.7	5.8	6.3	6.2	5.4	4.3	3	1.8	1.4	3.9			
	YOUNGSTOWN	1.6	2.4	3.3	4.4	5.3	5.9	5.8	5	4	2.8	1.7	1.3	3.6			
OKLAHOMA	OKLAHOMA CITY	2.8	3.5	4.6	5.7	6.2	6.8	6.9	6.2	5	4	2.9	2.4	4.8	6.39	0.015783	0.100815
	TULSA	2.5	3.3	4.3	5.3	5.9	6.4	6.7	6	4.7	3.8	2.7	2.2	4.5			
OREGON	ASTORIA	1.1	1.8	2.8	3.9	4.9	5.3	5.4	4.8	3.8	2.4	1.3	1	3.2	6.27	0.011452	0.071831
	BURNS	1.8	2.6	3.8	5.2	6.4	7.1	7.5	6.5	5.1	3.4	1.9	1.5	4.4			
	EUGENE	1.3	2	3.1	4.4	5.5	6.2	6.7	5.8	4.4	2.7	1.4	1	3.7			
	MEDFORD	1.5	2.4	3.7	5.2	6.5	7.3	7.7	6.7	5.2	3.3	1.7	1.2	4.4			
	NORTH BEND	1.5	2.2	3.4	4.7	5.7	6.2	6.5	5.6	4.5	3	1.8	1.3	3.9			
	PENDLETON	1.4	2.1	3.4	4.9	6.2	6.9	7.4	6.3	4.8	3	1.6	1.1	4.1			
	PORTLAND	1.2	1.9	3	4.2	5.3	5.9	6.3	5.4	4.1	2.5	1.4	1	3.5			
	REDMOND	1.7	2.5	3.8	5.3	6.5	7.2	7.6	6.6	5.1	3.3	1.9	1.4	4.4			
	SALEM	1.3	2	3.1	4.4	5.5	6.1	6.6	5.7	4.4	2.7	1.4	1.1	3.7			
PENNSYLVANIA	ALLENTOWN	1.9	2.7	3.7	4.7	5.4	6	5.9	5.2	4.2	3.1	2	1.6	3.9	5.67	0.033050	0.187456
	BRADFORD	1.8	2.6	3.6	4.6	5.4	5.9	5.8	5	3.9	2.8	1.7	1.4	3.7			
	ERIE	1.6	2.4	3.4	4.6	5.7	6.3	6.2	5.3	4.1	2.7	1.6	1.3	3.8			
	HARRISBURG	2	2.8	3.8	4.8	5.5	6.1	5.9	5.3	4.3	3.2	2	1.6	3.9			
	PHILADELPHIA	2	2.8	3.8	4.8	5.5	6.1	6	5.4	4.4	3.2	2.1	1.7	4			
	PITTSBURGH	1.7	2.5	3.5	4.6	5.5	6.1	5.9	5.2	4.2	3	1.8	1.4	3.8			
	WILKES-BARRE	1.8	2.5	3.6	4.6	5.4	6	5.9	5.2	4.1	2.9	1.8	1.4	3.8			
	WILLIAMSPORT	1.8	2.6	3.6	4.6	5.4	6	5.9	5.1	4	2.9	1.8	1.4	3.8			
RHODE ISLAND	PROVIDENCE	1.9	2.7	3.7	4.7	5.6	6	5.9	5.2	4.2	3.1	1.9	1.6	3.9	5.68	0.002540	0.014416
SOUTH CAROLINA	CHARLESTON	2.7	3.5	4.7	5.9	6.2	6.2	6.1	5.5	4.7	4.1	3.1	2.5	4.6	5.98	0.016522	0.098856
	COLUMBIA	2.6	3.4	4.5	5.7	6.1	6.3	6.1	5.5	4.8	4	2.9	2.4	4.5			
	GREENVILLE	2.6	3.3	4.4	5.6	6	6.3	6	5.5	4.7	3.9	2.8	2.3	4.5			
SOUTH DAKOTA	HURON	1.8	2.6	3.7	4.9	5.8	6.5	6.6	5.8	4.4	3	1.9	1.5	4.1	6.28	0.003052	0.019154
	PIERRE	1.8	2.7	3.9	5	6	6.7	6.8	6	4.5	3.1	2	1.5	4.2			

	RAPID CITY	1.9	2.8	4	5.1	6	6.7	6.8	6.1	4.7	3.3	2.1	1.6	4.3			
	SIOUX FALLS	1.9	2.7	3.8	4.8	5.8	6.5	6.6	5.7	4.3	3.1	1.9	1.5	4.1			
TENNESSEE	BRISTOL	2.2	2.9	4	5.1	5.7	6.1	5.8	5.4	4.5	3.6	2.4	1.9	4.1	5.97	0.023935	0.142894
	CHATTANOOGA	2.4	3.1	4.1	5.3	5.8	6.1	5.9	5.5	4.5	3.8	2.6	2.1	4.3			
	KNOXVILLE	2.3	3	4	5.2	5.8	6.2	5.9	5.5	4.5	3.7	2.5	2	4.2			
	MEMPHIS	2.5	3.2	4.2	5.4	6.1	6.6	6.5	6	4.8	4	2.7	2.2	4.5			
	NASHVILLE	2.3	3.1	4.1	5.4	6	6.5	6.3	5.7	4.7	3.8	2.5	2	4.4			
TEXAS	ABLIENE	3.1	3.9	5.1	6.1	6.5	7	7	6.3	5.2	4.4	3.3	2.9	5.1	6.47	0.080432	0.520679
	AMARILLO	3	3.8	4.9	6.1	6.6	7.1	7	6.3	5.2	4.4	3.2	2.7	5			
	AUSTIN	3	3.8	4.7	5.4	5.9	6.6	6.8	6.3	5.2	4.4	3.3	2.8	4.9			
	BROWNSVILLE	2.9	3.7	4.6	5.3	5.8	6.4	6.5	6	5.2	4.5	3.4	2.7	4.8			
	CORPUS CHRISTI	2.8	3.6	4.4	5	5.5	6.1	6.3	5.8	5	4.3	3.3	2.7	4.6			
	EL PASO	3.5	4.5	5.9	7.1	7.8	8	7.4	6.8	5.9	4.9	3.8	3.2	5.7			
	FORT WORTH	2.9	3.7	4.7	5.6	6.2	6.9	7	6.4	5.2	4.2	3.1	2.7	4.9			
	HOUSTON	2.7	3.4	4.2	5	5.6	6	5.9	5.6	4.9	4.2	3.1	2.5	4.4			
	LUBBOCK	3.1	3.9	5.1	6.2	6.7	7.1	7	6.3	5.2	4.4	3.3	2.8	5.1			
	LUFKIN	2.7	3.5	4.5	5.3	5.9	6.4	6.4	6	5.1	4.3	3.1	2.5	4.6			
	MIDLAND	3.3	4.2	5.5	6.5	7	7.3	7	6.5	5.4	4.6	3.6	3	5.3			
	PORT ARTHUR	2.7	3.5	4.3	5.2	5.8	6.3	6.1	5.7	5	4.3	3.1	2.6	4.6			
	SAN ANGELO	3.2	4.1	5.2	6.1	6.5	7	6.9	6.4	5.3	4.5	3.5	3	5.1			
	SAN ANTONIO	3.1	3.9	4.8	5.5	6	6.7	6.9	6.4	5.4	4.5	3.4	2.9	4.9			
	VICTORIA	2.8	3.6	4.4	5.1	5.7	6.2	6.2	5.8	5	4.3	3.3	2.7	4.6			
	WACO	2.9	3.7	4.7	5.5	6	6.7	6.9	6.4	5.2	4.3	3.2	2.7	4.9			
	WICHITA FALLS	2.9	3.7	4.8	5.8	6.4	6.9	7	6.3	5.2	4.2	3.1	2.6	4.9			
UTAH	CEDAR CITY	2.7	3.5	4.6	6	7	7.8	7.3	6.5	5.7	4.3	2.9	2.4	5	7.04	0.009118	0.064165
	SALT LAKE CITY	1.9	2.9	4.1	5.4	6.5	7.4	7.3	6.5	5.2	3.7	2.2	1.7	4.6			
VERMONT	BURLINGTON	1.6	2.6	3.6	4.6	5.5	6	6.1	5.2	4	2.6	1.6	1.2	3.7	5.70	0.002336	0.013314
VIRGINIA	LYNCHBURG	2.4	3.2	4.3	5.4	6	6.5	6.2	5.6	4.7	3.7	2.6	2.1	4.4	5.90	0.026797	0.158104
	NORFOLK	2.3	3	4.1	5.1	5.8	6.2	5.9	5.4	4.5	3.5	2.5	2	4.2			
	RICHMOND	2.3	3	4.1	5.2	5.8	6.3	6	5.4	4.5	3.5	2.5	2	4.2			
	ROANOKE	2.3	3.1	4.1	5.2	5.8	6.2	5.9	5.5	4.5	3.6	2.5	2	4.2			
	STERLING	2.1	2.9	4	5	5.8	6.3	6	5.4	4.4	3.4	2.3	1.8	4.1			
WASHINGTON	OLYMPIA	1	1.7	2.8	4	5	5.6	5.9	5.1	3.8	2.2	1.2	0.9	3.3	5.76	0.019212	0.110659
	QUILLAYUTE	1	1.6	2.6	3.7	4.7	5.1	5.2	4.5	3.5	2.1	1.2	0.8	3			
	SEATTLE	1	1.7	2.8	4.1	5.3	5.8	6.1	5.2	3.8	2.2	1.2	0.8	3.3			
	SPOKANE	1.3	2	3.2	4.6	5.8	6.5	7	5.9	4.4	2.7	1.4	1.1	3.8			
	YAKIMA	1.4	2.2	3.6	5	6.2	6.9	7.2	6.2	4.7	3	1.6	1.1	4.1			
WEST VIRGINIA	CHARLESTON	2	2.7	3.7	4.8	5.6	6	5.8	5.3	4.3	3.3	2.1	1.7	3.9	5.57	0.006326	0.035214
	ELKINS	1.9	2.6	3.6	4.5	5.3	5.7	5.5	5	4.1	3.1	2	1.6	3.8			
	HUNTINGTON	2	2.7	3.7	4.8	5.6	6	5.8	5.2	4.3	3.3	2.1	1.7	3.9			
WISCONSIN	EAU CLAIRE	1.7	2.7	3.7	4.6	5.6	6.1	6.1	5.2	3.9	2.7	1.6	1.4	3.8	5.88	0.019871	0.116843
	GREEN BAY	1.7	2.6	3.7	4.7	5.7	6.3	6.1	5.2	3.9	2.7	1.6	1.4	3.8			
	LA CROSSE	1.8	2.7	3.7	4.7	5.7	6.3	6.2	5.4	4	2.8	1.7	1.4	3.9			
	MADISON	1.9	2.8	3.7	4.7	5.8	6.4	6.2	5.4	4.1	2.8	1.7	1.5	3.9			
	MILWAUKEE	1.8	2.6	3.5	4.6	5.8	6.4	6.3	5.4	4.1	2.9	1.8	1.4	3.9			
WYOMING	CASPER	2	2.9	4.1	5.2	6.1	7	7	6.3	4.9	3.4	2.2	1.7	4.4	6.56	0.003129	0.020513
	CHEYENNE	2.2	3.1	4.2	5.3	6	6.7	6.7	5.9	4.9	3.6	2.4	1.9	4.4			
	LANDER	2.2	3.2	4.4	5.6	6.4	7.1	7	6.3	5	3.6	2.3	1.9	4.6			
	ROCK SPRINGS	2.1	3	4.2	5.4	6.4	7.2	7.2	6.4	5.2	3.7	2.3	1.9	4.6			
	SHERIDAN	1.8	2.7	3.9	5	5.8	6.7	6.9	6	4.6	3.1	2	1.6	4.2			
																May-Aug Solar Radiation	6.16

Appendix C: FUNCTIONAL SYSTEM TRAVEL - 2014

ANNUAL VEHICLE - MILES

OCTOBER 2015 TABLE VM-2

STATE	TOTAL	STATE VMT %
Alabama	65,667	0.021729
Alaska	4,857	0.001607
Arizona	62,631	0.020724
Arkansas	34,024	0.011258
California	332,857	0.110140
Colorado	48,985	0.016209
Connecticut	31,190	0.010321
Delaware	9,596	0.003175
Florida	201,040	0.066523
Georgia	111,535	0.036906
Hawaii	10,174	0.003367
Idaho	16,154	0.005345
Illinois	104,906	0.034712
Indiana	79,204	0.026208
Iowa	31,414	0.010395
Kansas	30,710	0.010162
Kentucky	47,941	0.015863
Louisiana	48,252	0.015966
Maine	14,301	0.004732
Maryland	56,432	0.018673
Massachusetts	57,552	0.019044
Michigan	97,384	0.032224
Minnesota	57,395	0.018992
Mississippi	39,499	0.013070
Missouri	70,909	0.023463
Montana	12,157	0.004023
Nebraska	19,613	0.006490
Nevada	25,302	0.008372
New Hampshire	12,970	0.004292
New Jersey	74,856	0.024769
New Mexico	25,347	0.008387
New York	129,263	0.042772
North Carolina	108,012	0.035740
North Dakota	10,511	0.003478
Ohio	112,766	0.037314
Oklahoma	47,699	0.015783
Oregon	34,610	0.011452
Pennsylvania	99,882	0.033050
Rhode Island	7,677	0.002540
South Carolina	49,931	0.016522
South Dakota	9,225	0.003052
Tennessee	72,336	0.023935
Texas (2)	243,076	0.080432
Utah	27,554	0.009118
Vermont	7,059	0.002336
Virginia	80,985	0.026797
Washington	58,060	0.019212
West Virginia	19,117	0.006326
Wisconsin	60,053	0.019871
Wyoming	9,457	0.003129
U.S. Total	3,022,128	1.000000

Attachment C: High Efficiency Alternator

Request for High Efficiency Alternator Credits

Pursuant to 40 CFR 86.1869-12(d), 49 CFR 531.6(b), and 49 CFR 533.6(b) Ford hereby requests approval for the following methodology to determine off-cycle CO2 credits from high efficiency alternators for 2017 MY and beyond vehicles.

Ford proposes the use of a scalable off-cycle credit value as calculated by the following formula for all vehicle categories.

$$Credit\Big(\ \overline{\ \ }_{i}\Big(= \Big(\quad d \quad e\Big(tri\Big(\quad i\Big(\ \times\Big(\frac{3.2\Big(\overline{\ \ }_{i}\Big(}{100\Big(\quad tt\Big(} - 2\ C \quad e \quad e\Big(tri\Big(\quad i\Big(\ \times\Big(\frac{2.5\ \overline{\ \ }_{i}}{100\Big(\quad tt\Big(}$$

Ford recommends the use of 67% VDA as the industry average baseline alternator efficiency for the credit calculation. This credit value is supported by numerous analyses in U.S. Environmental Protection Agency's (EPA) rulemaking documents, by the EU Technical Guidelines for Eco-Innovations, and analytical calculations described in the following sections.

Description of System

Automotive alternators convert mechanical energy from an internal combustion engine to electrical energy for a vehicle's electrical systems. The additional mechanical load on the engine from the alternator results in the increased consumption of fuel and CO2 emissions. A variety of mechanical and electrical losses are inevitable in this energy conversion process, and high efficiency alternators use new technologies to reduce these loses thereby reducing the alternator load on the engine and resulting in better fuel economy and lower CO2 emissions.

The efficiency of the alternator is the ratio of the alternator output power to the power supplied to the alternator. The Verband der Automobilindustrie (VDA) efficiency is the accepted industry standard for measuring alternator efficiency. The EU released methodology[1] recommends a baseline VDA of 67% for calculating the eco-innovation credit for high efficiency alternators on new vehicles types that is a scalable credit based on alternator % VDA values similar to what is derived in the following sections. The EPA also used a baseline alternator efficiency of 65% in its Joint TSD for the 2017-2025 GHG regulation, based on a 2008 Delco-Remy Alternator. In addition, in the discussion of high efficiency alternator off-cycle credits in the Federal Register Final Rule for 2017-2025 EPA indicated that 68% VDA would be an appropriate threshold to begin awarding high efficiency alternator off-cycle credits:

The 68% VDA number stated by the Alliance of Automobile Manufacturers seems to be appropriate starting point given current technology…[2]

Based on the Joint TSD comments and EU methodology Ford recommends that 67% VDA be used as the baseline alternator efficiency in the high efficiency alternator off-cycle credit calculation to harmonize with the European Commission.

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[1] COMMISSION IMPLEMENTING DECISION (EU) 2016/588 of 14 April 2016 [2016] OJ L 101/25

[2] 77 FR 62731

Methodology to Determine the Off-Cycle Benefit of High Efficiency Alternators

The following sections and supporting documentation describe the methodology and justifications for the high efficiency alternator off-cycle credit request. This includes an explanation of (A) why the high efficiency alternator credit meets the general requirements of the off-cycle credit program, (B) why the CO2 benefits of high efficiency alternators are best demonstrated using the alternative EPA approved methodology presented in 40 CFR 86.1869-12(d), and (C) the proposed alternative off-cycle credit methodology in detail.

A. General Requirements for Off-Cycle Credit

High efficiency alternators are components that are well recognized as a technology that increases a vehicle's mechanical-to-electrical energy conversion efficiency. Although greenhouse gas emission reduction is realized during the 2-cycle test, increased electrical loads on the vehicle in on road conditions allow high efficiency alternators to generate a higher greenhouse gas benefit outside the conditions of the Federal Test Procedure and the Highway Fuel Economy Test. Although high efficiency alternators were considered for the pre-approved technology menu, they were not included due to the limited amount of vehicle data available at that time. Therefore, Ford proposes the use of a single scalable credit value that accounts for all vehicle categories, which is supported by in-use vehicle data, and analytical calculations.

B. Rationale for Using The Alternative EPA-approved Methodology

Since high efficiency alternators are not available as a credit on the pre-approved technology menu, Ford considered both the 5-cycle and alternative methodologies for this request. Although the 5-cycle methodology would capture a variety of driving conditions (e.g. vehicle speed, ambient temperature, etc.), the key factor in determining the greenhouse gas benefit of high efficiency alternators is the fact that customers experience high accessory loads on a regular basis, and these loads are not fully captured in the 5-cycle methodology. Examples of some such accessory loads include:

- Climate Control
- Entertainment accessories (radio, phone chargers, etc.)
- Exterior lighting (headlamps, high beams, and brake light usage above and beyond the EPA75)
- Interior lighting (instrument panel, ambient lighting, reading lamps)
- Windshield wipers

For this reason, Ford is pursuing off-cycle credits under the alternative demonstration methodology pursuant to 40 CFR § 86.1869-12(d).

C. Proposed Alternative EPA-approved Methodology

Standard 2-cycle testing will reveal some of the benefit of a high efficiency alternator; however on-road driving conditions frequently demand a higher vehicle electrical load than what is seen in the test cycle. As a result of these higher off-cycle loads, a high efficiency alternator will be more beneficial in on-road driving than it gets credit for in the regulated test cycles. It is this additional benefit for which Ford is pursuing off-cycle credits.

The standard 2-cycle and environmentally weighted on-road electrical loads are used to determine the reduction in GHG emission for all vehicle types using a high efficiency alternator. Results show that the off-cycle benefit is similar for all vehicle types and a single credit value may be applied to all vehicle types.

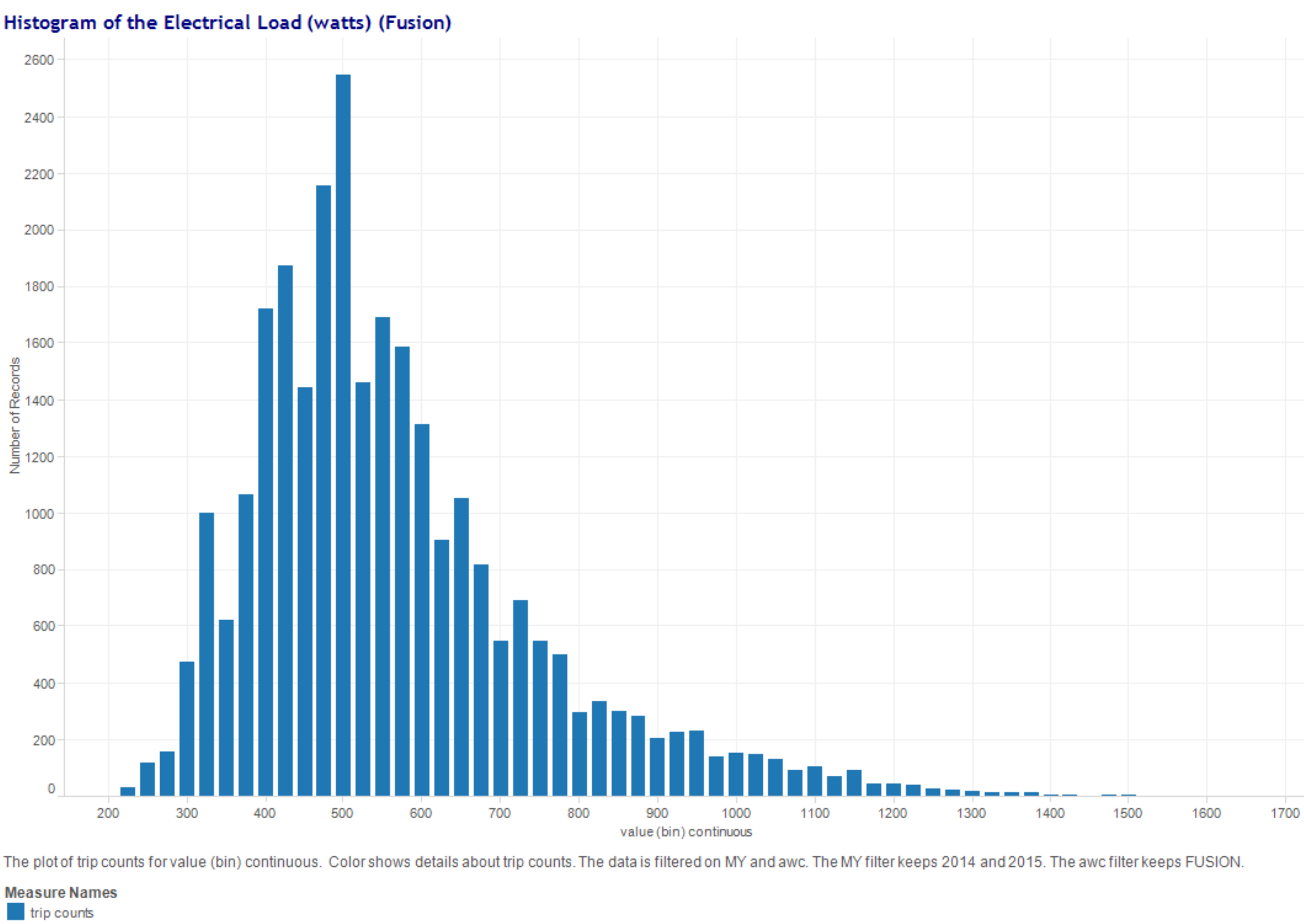
1. Electrical load during 2-cycle and on-road driving conditions

To assess the electrical loads during 2-cycle testing a series of tests were conducted within Ford's testing lab on a Fusion and an F-150 model measuring the electrical load during each phase. The phase weighted values for each test result in a mean vehicle on cycle load of 297 watts.

2-Cycle Electrical Load (Table 1)

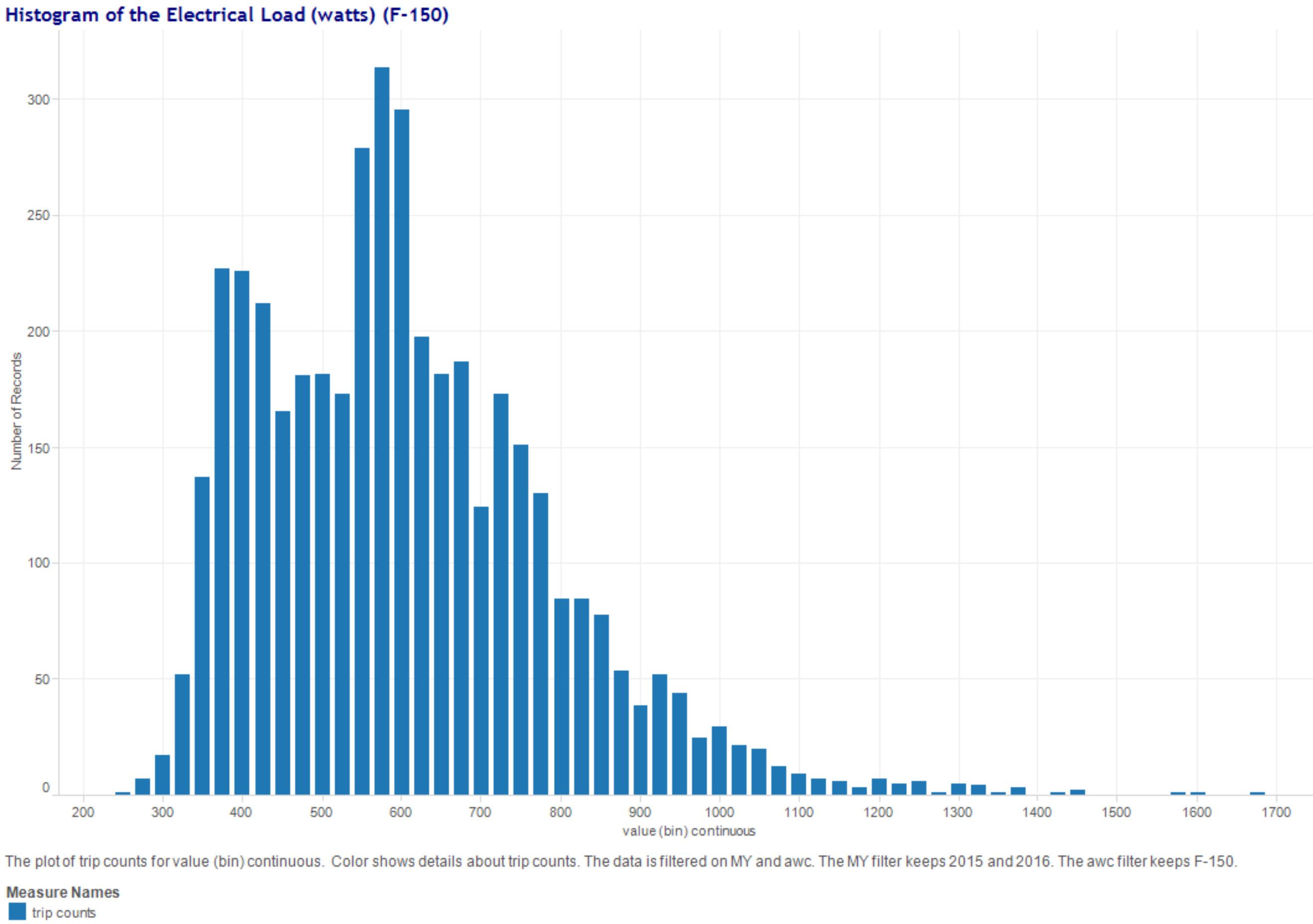
Fusion 2-Cycle Testing		F-150 2-Cycle Testing	
Mean	275	Mean	318

Alternator current was measured and extracted from 47 unique MY 2014 and 2015 Ford Fusions driving in southeast Michigan for over a year, from January 2015 through March 2016. This data covers 27,000 trips covering 325,000 miles in temperatures from below -15 through above 100 degrees Fahrenheit. From this data the average trip duration was 20 minutes and the average distance covered was 11.7 miles. Ford has computed the in-trip mean current draw for each trip. The resulting value from this data collection is a mean of 552 watts for the on-road electrical load.



Fusion On-Road Electrical Load (Figure 1)

Alternator current was also measured and extracted from 9 unique MY 2015 and 2016 Ford F-150 vehicles driving in southeast Michigan for over a year, from January 2015 through March 2016. This data covers 4,000 trips covering 40,000 miles in temperatures from below -15 through above 100 degrees Fahrenheit. From this data the average trip duration was 24 minutes and the average distance covered was 9.3 miles. Ford has computed the in-trip mean current draw for each trip. The resulting value from this data collection is a mean of 623 watts for the on-road electrical load.



F-150 On-Road Electrical Load (Figure 2)

The on-road data collection was performed on a Ford employee volunteer vehicle fleet. The vehicles were instrumented with an OBD-II port plug-in device to collect and upload data. Participants in the experiment are informed that vehicle data will be used for product design and research purposes, but are not instructed how to drive or told that specific vehicle conditions are of interest as that would bias experimental results. Short trips of less than 0.5 miles were also excluded from the data pool to remove both extremely short and trips with zero odometer change which have extremely high electrical loads. This results in a lower conservative on-road electrical load, with all trips included the mean electrical load would have become 605 Watts.

Based on the laboratory testing and on-road data collection mean values shown below, determined from a combination of Fusion and F-150 data will be used to calculate a credit value that will be applied to all vehicle types. The on-road electrical load values for each vehicle type were weighted by temperature using the EPA MOVES data in the TSD Table 5-28[3].

[3] EPA-420-R-12-901 (August 2012) Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Page 5-87

- 2-Cycle electrical load: 297 Watts
- On-road electrical load: 588 Watts

Table 5-28 MOVES data of vehicle miles traveled (VMT) as a function of ambient temperature.

VMT	tempAvg	Fraction	Temp Range VMT Fraction
1181.656796	-25	0.00000157	
4400.79767	-20	0.00000585	
12905.217	-15	0.00001714	
40874.20742	-10	0.00005429	
174939.1854	-5	0.00023235	
762497.0884	0	0.00101274	
1915732.576	5	0.00254446	
4924729.91	10	0.00654097	
12353230.63	15	0.01640743	0.21958689
23259876.93	20	0.03089353	(< 40 deg F)
31418211.75	25	0.04172934	
41033016.47	30	0.05449962	
49426375.28	35	0.06564760	
55404781.78	40	0.07358805	
60396251.48	45	0.08021767	
63018086.25	50	0.08369996	
68380740.42	55	0.09082259	
73176481.47	60	0.09719224	0.68343503
72473451.14	65	0.09625848	(> 40 deg F, < 80 deg F)
67073984.17	70	0.08908697	
54637578.9	75	0.07256906	
39382139.05	80	0.05230695	
24182451.73	85	0.03211888	
7635253.418	90	0.01014106	
1203687.536	95	0.00159873	0.09697809
593360.565	100	0.00078810	(>80 deg F)
18352.30991	105	0.00002438	
752904571.9	TotalVMT	1.00000000	

EPA MOVES VMT by Temperature (Figure 3)

2. **For a given engine torque, derive the relationship between a high efficiency alternator and its equivalent electrical load on the 2-Cycle Test.**

Standard physics equations relates alternator efficiency and mechanical power to engine torque which is used to calculate an electrical load reduction as follows:

$$\frac{i(\quad (\quad)}{i \; i(\quad (\%)} = (\quad h(\; i(\quad ((\quad) = (\quad i(\quad d((\; d/(\quad) \times (\quad i(\quad ((\quad)($$

For the purposes of developing this methodology, an assumed average engine speed of 2000 rpm was used (this is a close approximation to the average engine speed on the 2-Cycle test). A mean 2-Cycle electrical load of 297 watts was used for this example. Using a starting alternator VDA of 67%, one can determine the input torque that's required to generate 297 watts of electrical power:

$$\frac{297(}{67\%(} = (2000(\quad \times \frac{2(\quad d}{} \times \frac{1(\; i(}{60(}) \times ((\quad i(\quad)($$

$$i \quad = \frac{297(}{67\%} \times (\frac{1(}{209.4(\quad d/(} = .($$

LE Alternator input torque required to generate 297 watts of electrical power.

By performing the same calculations using a high efficiency alternator VDA efficiency of 72%, one can realize the reduction in engine torque that's required to generate the same electrical load of 297 watts:

$$\frac{297(}{72\%(} = (2000(\quad \times \frac{2(\quad d}{} \times \frac{1(\; i(}{60(}) \times ((\quad i(\quad)$$

$$i \quad = (\frac{297(}{72\%} \times (\frac{1}{209.4(\quad d/(} \; = \; .($$

HE Alternator input torque required to generate 297 watts of electrical power.

The engine torque value of 1.97 Nm represents the alternator input torque that's required to generate 297 watts at an engine speed of 2000 rpm when a high efficiency alternator is installed. By inserting the reduced torque value of 1.97 Nm into the baseline alternator equation, one can calculate the *Equivalent HE Electrical Load* when the torque input of a high efficiency alternator is used:

$$\frac{i(\quad i(\quad d}{(\%)(} = (2000(\quad \times \frac{2(\quad d}{} \times \frac{1(\; i(}{60(}) \times ((\quad i(\quad)($$

$$\frac{i(\quad i(\quad d}{67\%(} = (2000(\quad \times \frac{2(\quad d}{} \times \frac{1(\; i(}{60(}) \times (1.97(\quad)$$

$$=($$

LE alternator electrical power output when HE alternator input torque is used.

This reduced electrical load represents what the equivalent 2-Cycle electrical load would be when the alternator input torque is lowered to match the required torque input of a high efficiency unit. In the example above, the 2-Cycle benefit of a high efficiency alternator on the Vehicle is **21 watts** (297 – 276 = 21 watts).

Using a mean on-road electrical load of 588 watts and applying it to the methodology outlined above, the electrical load savings of a high efficiency alternator in on-road conditions would be: 588 – 547 = **41 watts**.

3. Calculate a general GHG benefit that can be applied to all vehicles.

Ford proposes to use the electrical load reduction factors developed by the EPA's full vehicle simulation analysis and established in the TSD Table 5-18[4] shown below. The average electrical load reduction factors shown were developed from an average of all vehicle types based on a 100 watt load reduction and the corresponding g/mile CO_2 reduction. These values are also used to determine the pre-approved menu credit levels for waste heat recovery and high efficiency lighting and it is Ford's intent to calculate the benefit of the high efficiency alternator implementation using the same methodology.

[4] EPA-420-R-12-901 (August 2012) Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Page 5-66

Table 5-18: Simulated GHG reduction benefits of 100W reduction in electrical load over FTP/HW and 5-cycle tests

Driving Cycle	Electrical Load	Small Car [g/mile]	Mid-Size Car [g/mile]	Large Car [g/mile]	Pick-up Truck [g/mile]	Average* [g/mile]
FTP/Highway	100W Load Reduction	156.8	187.7	246.5	416.6	
	Base	154.2	185.5	244.1	413.9	
	2-Cycle Difference	2.5	2.2	2.4	2.7	2.5
5-Cycle	100W Load Reduction	217.8	256.9	331	544.5	
	Base	214.6	254.1	327.9	541.1	
	5-Cycle Difference	3.2	2.8	3.1	3.4	3.2
	5-Cycle/2-Cycle Difference	**0.7**	**0.6**	**0.6**	**0.7**	**0.7**

EPA TSD Electrical Load Reduction Benefit (Figure 4)

$$C \quad di(\quad \overline{\ \ }_{i}(= (\quad d \quad i(\quad i(\times (\frac{3.2(\overline{\ \ }_{i}(}{100(} - 2\,C(\quad i(\quad i(\times \frac{2.5\,\overline{\ \ }_{i}}{100(}$$

$$C(\quad C \quad di(= 41(\quad * (\frac{3.2(\overline{\ \ }_{i}(}{100(} - 21(\quad * (\frac{2.5\,\overline{\ \ }_{i}}{100(} = 0.8(\ /(\ i($$

The proposed calculation methodology would result in a credit of 0.8 g/mi for a 5% alternator efficiency increase from 67% to 72%.

Based on the above methodology and using the Ford mean electrical load values determined through laboratory and in use testing the following table represents the scalable off-cycle credit values.

Scalable Credit	
% VDA	Credit g/mi
67	0.0
68	0.2
69	0.3
70	0.5
71	0.7
72	0.8
73	1.0
74	1.1
75	1.2
76	1.4
77	1.5
78	1.6
79	1.8
80	1.9

Additional analysis was conducted using the EPA ALPHA full vehicle simulation model. Ford used the recently updated ALPHA Version 2.1. To determine the most representative estimates for technology effectiveness EPA classified vehicles according to the attributes of engine power to vehicle weight and vehicle road load power within ALPHA. Ford conducted analysis using the various combinations and configurations available within ALPHA v2.1 to validate the above scalable credit table of proposed values. The complete ALPHA analysis inputs and outputs are attached in Appendix C. The summary table below of the ALPHA analysis values confirms that the scalable credit values presented above are representative of a varying mix of configurations. The analysis supports the proposed application of a single credit value to apply to the fleet for the purpose of high efficiency alternator off-cycle credits.

	Credit Data Summary			
	Efficiency			
Model	67	70	75	80
LPW HRL	0	0.4	1.3	1.9
LPW LRL	0	0.5	1.2	1.9
MPW HRL	0	0.5	1.3	2.0
MPW LRL	0	0.5	1.2	2.0
Truck	0	0.5	1.2	1.8
Ford	0	0.5	1.2	1.9

Durability

Alternators installed within Ford vehicles meet all the durability requirements of 40 CFR § 86.1869-12(d) and are not subject to any deterioration factors that would reduce the benefits of the high efficiency alternator. Durability testing is conducted by suppliers to meet Ford specifications. A sample alternator durability test report is included in Appendix A.

Conclusion

Based on the data presented Ford recommends the use of 67% VDA as the industry average baseline alternator efficiency for the credit calculation. Results show that the off-cycle benefit is similar for all vehicle types and a single scalable credit formula may be applied to all vehicle types for 2017 MY and beyond. A list of the vehicle models which are equipped with the technology along with an estimate of the off-cycle benefit by vehicle model and the fleet wide benefit based on sales of vehicle models equipped with the technology is provided in Appendix B. Per the methodology described above regarding credit determination, we intend to apply the scalable methodology described above for each high efficiency alternator application starting at 68% VDA. The fleet credit will be calculated based on credit for each type of vehicle, vehicle lifetime miles and U.S. sales volume for 2017 MY and beyond products.

Appendix A: Durability Test Reports

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Appendix B: Carline Volumes and Credit Estimate

ALPHA Inputs						
On Cycle				Off Cycle		
Volts	Amps @ 297W	Watts		Volts	Amps @ 588W	Watts
0.00	59.40	297		0.00	117.60	588
5.00	59.40	297		5.00	117.60	588
5.89	50.43	297		5.89	99.85	588
6.78	43.82	297		6.78	86.75	588
7.67	38.74	297		7.67	76.70	588
8.56	34.71	297		8.56	68.73	588
9.44	31.45	297		9.44	62.26	588
10.33	28.74	297		10.33	56.90	588
11.22	26.47	297		11.22	52.40	588
12.11	24.52	297		12.11	48.55	588
13.00	22.85	297		13.00	45.23	588
13.89	21.38	297		13.89	42.34	588
14.78	20.10	297		14.78	39.79	588
15.67	18.96	297		15.67	37.53	588
16.56	17.94	297		16.56	35.52	588
17.44	17.03	297		17.44	33.71	588
18.33	16.20	297		18.33	32.07	588
19.22	15.45	297		19.22	30.59	588
20.11	14.77	297		20.11	29.24	588
21.00	14.14	297		21.00	28.00	588

LPW HRL Config 7

297W	67%
ftp_FE_mpg	30.0899
hwfet_FE_mpg	42.358
city_highway_FE_mpg	34.5993
city_highway_GHG_gCO2pmi	256.8548
297W	70%
ftp_FE_mpg	30.1708
hwfet_FE_mpg	42.4095
city_highway_FE_mpg	34.6736
city_highway_GHG_gCO2pmi	256.3042
297W	75%
ftp_FE_mpg	30.2776
hwfet_FE_mpg	42.4881
city_highway_FE_mpg	34.7748
city_highway_GHG_gCO2pmi	255.5586
297W	80%
ftp_FE_mpg	30.3716
hwfet_FE_mpg	42.5563
city_highway_FE_mpg	34.8635
city_highway_GHG_gCO2pmi	254.9081
588W	67%
ftp_FE_mpg	28.579
hwfet_FE_mpg	41.1748
city_highway_FE_mpg	33.1412
city_highway_GHG_gCO2pmi	268.1558
588W	70%
ftp_FE_mpg	28.7053
hwfet_FE_mpg	41.2744
city_highway_FE_mpg	33.2637
city_highway_GHG_gCO2pmi	267.1685
588W	75%
ftp_FE_mpg	28.896
hwfet_FE_mpg	41.4803
city_highway_FE_mpg	33.4646
city_highway_GHG_gCO2pmi	265.5639
588W	80%
ftp_FE_mpg	29.0667
hwfet_FE_mpg	41.6096
city_highway_FE_mpg	33.6283
city_highway_GHG_gCO2pmi	264.2712

Summary			
Efficiency	On Cycle	Off Cycle	Credit
70	0.5506	0.9873	0.4367
75	1.2962	2.5919	1.2957
80	1.9467	3.8846	1.9379

LPW LRL Config 1

297W	67%
ftp_FE_mpg	32.7711
hwfet_FE_mpg	50.2351
city_highway_FE_mpg	38.8486
city_highway_GHG_gCO2pmi	228.7601
297W	70%
ftp_FE_mpg	32.8572
hwfet_FE_mpg	50.3192
city_highway_FE_mpg	38.9377
city_highway_GHG_gCO2pmi	228.2362
297W	75%
ftp_FE_mpg	32.985
hwfet_FE_mpg	50.4313
city_highway_FE_mpg	39.0666
city_highway_GHG_gCO2pmi	227.4833
297W	80%
ftp_FE_mpg	33.0981
hwfet_FE_mpg	50.4861
city_highway_FE_mpg	39.1687
city_highway_GHG_gCO2pmi	226.8903
588W	67%
ftp_FE_mpg	30.899
hwfet_FE_mpg	48.6793
city_highway_FE_mpg	36.9766
city_highway_GHG_gCO2pmi	240.3411
588W	70%
ftp_FE_mpg	31.0514
hwfet_FE_mpg	48.8187
city_highway_FE_mpg	37.1328
city_highway_GHG_gCO2pmi	239.3303
588W	75%
ftp_FE_mpg	31.2817
hwfet_FE_mpg	48.9789
city_highway_FE_mpg	37.3556
city_highway_GHG_gCO2pmi	237.9029
588W	80%
ftp_FE_mpg	31.4877
hwfet_FE_mpg	49.1645
city_highway_FE_mpg	37.5657
city_highway_GHG_gCO2pmi	236.5725

Summary			
Efficiency	On Cycle	Off Cycle	Credit
70	0.5239	1.0108	0.4869
75	1.2768	2.4382	1.1614
80	1.8698	3.7686	1.8988

MPW HRL Config 43

297W	67%
ftp_FE_mpg	25.1649
hwfet_FE_mpg	34.9219
city_highway_FE_mpg	28.7839
city_highway_GHG_gCO2pmi	308.7494
297W	70%
ftp_FE_mpg	25.2077
hwfet_FE_mpg	34.9568
city_highway_FE_mpg	28.8253
city_highway_GHG_gCO2pmi	308.3059
297W	75%
ftp_FE_mpg	25.2717
hwfet_FE_mpg	35.0082
city_highway_FE_mpg	28.8871
city_highway_GHG_gCO2pmi	307.6464
297W	80%
ftp_FE_mpg	25.3275
hwfet_FE_mpg	35.0535
city_highway_FE_mpg	28.941
city_highway_GHG_gCO2pmi	307.0729
588W	67%
ftp_FE_mpg	24.1508
hwfet_FE_mpg	34.1478
city_highway_FE_mpg	27.8152
city_highway_GHG_gCO2pmi	319.5016
588W	70%
ftp_FE_mpg	24.2371
hwfet_FE_mpg	34.2143
city_highway_FE_mpg	27.898
city_highway_GHG_gCO2pmi	318.5531
588W	75%
ftp_FE_mpg	24.3713
hwfet_FE_mpg	34.3132
city_highway_FE_mpg	28.0253
city_highway_GHG_gCO2pmi	317.1061
588W	80%
ftp_FE_mpg	24.4876
hwfet_FE_mpg	34.4015
city_highway_FE_mpg	28.1364
city_highway_GHG_gCO2pmi	315.8542

Summary			
Efficiency	On Cycle	Off Cycle	Credit
70	0.4435	0.9485	0.505
75	1.103	2.3955	1.2925
80	1.6765	3.6474	1.9709

MPW LRL Config 1

297W	67%
ftp_FE_mpg	28.8993
hwfet_FE_mpg	44.618
city_highway_FE_mpg	34.344
city_highway_GHG_gCO2pmi	258.7646
297W	70%
ftp_FE_mpg	28.9663
hwfet_FE_mpg	44.6737
city_highway_FE_mpg	34.4108
city_highway_GHG_gCO2pmi	258.2618
297W	75%
ftp_FE_mpg	29.066
hwfet_FE_mpg	44.7574
city_highway_FE_mpg	34.5105
city_highway_GHG_gCO2pmi	257.5157
297W	80%
ftp_FE_mpg	29.1547
hwfet_FE_mpg	44.831
city_highway_FE_mpg	34.599
city_highway_GHG_gCO2pmi	256.8573
588W	67%
ftp_FE_mpg	27.458
hwfet_FE_mpg	43.4166
city_highway_FE_mpg	32.8998
city_highway_GHG_gCO2pmi	270.1232
588W	70%
ftp_FE_mpg	27.5797
hwfet_FE_mpg	43.5228
city_highway_FE_mpg	33.0233
city_highway_GHG_gCO2pmi	269.1128
588W	75%
ftp_FE_mpg	27.7463
hwfet_FE_mpg	43.682
city_highway_FE_mpg	33.1959
city_highway_GHG_gCO2pmi	267.7139
588W	80%
ftp_FE_mpg	27.9446
hwfet_FE_mpg	43.8221
city_highway_FE_mpg	33.3883
city_highway_GHG_gCO2pmi	266.1709

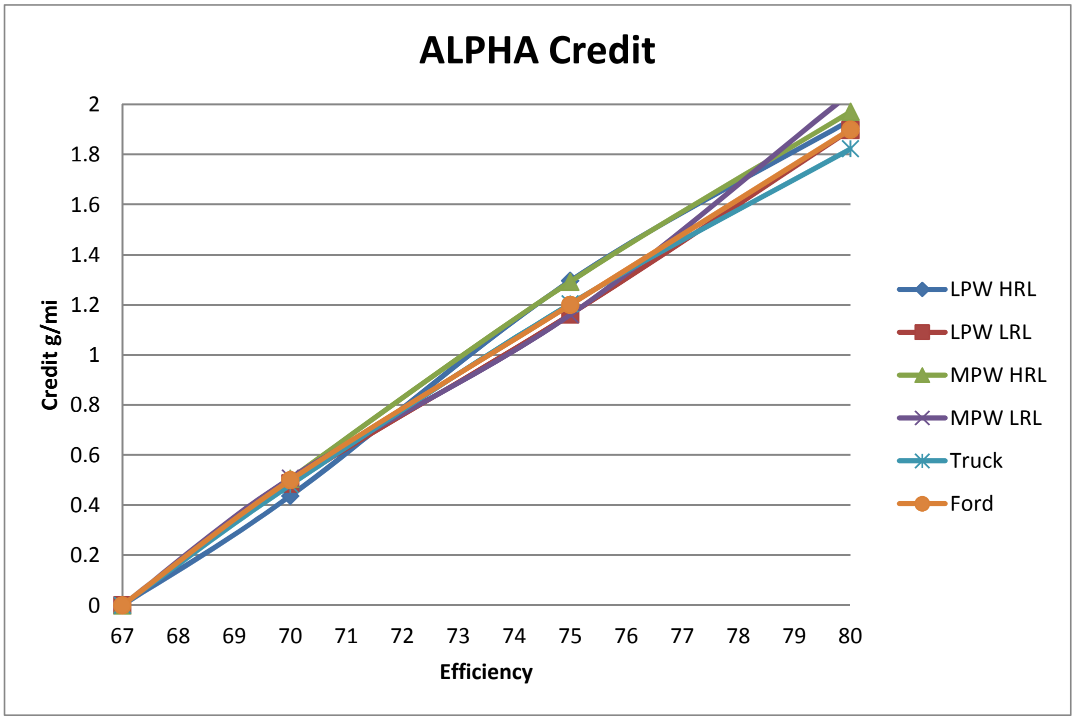
Summary			
Efficiency	On Cycle	Off Cycle	Credit
70	0.5028	1.0104	0.5076
75	1.2489	2.4093	1.1604
80	1.9073	3.9523	2.045

Truck	Config 8
297W	67%
ftp_FE_mpg	20.4612
hwfet_FE_mpg	28.9007
city_highway_FE_mpg	23.5567
city_highway_GHG_gCO2pmi	377.2599
297W	70%
ftp_FE_mpg	20.4941
hwfet_FE_mpg	28.9245
city_highway_FE_mpg	23.5878
city_highway_GHG_gCO2pmi	376.7622
297W	75%
ftp_FE_mpg	20.5439
hwfet_FE_mpg	28.9603
city_highway_FE_mpg	23.6348
city_highway_GHG_gCO2pmi	376.0132
297W	80%
ftp_FE_mpg	20.5875
hwfet_FE_mpg	28.9911
city_highway_FE_mpg	23.6758
city_highway_GHG_gCO2pmi	375.3627
588W	67%
ftp_FE_mpg	19.7702
hwfet_FE_mpg	28.366
city_highway_FE_mpg	22.8918
city_highway_GHG_gCO2pmi	388.2176
588W	70%
ftp_FE_mpg	19.8305
hwfet_FE_mpg	28.4117
city_highway_FE_mpg	22.9496
city_highway_GHG_gCO2pmi	387.2392
588W	75%
ftp_FE_mpg	19.9211
hwfet_FE_mpg	28.4826
city_highway_FE_mpg	23.0372
city_highway_GHG_gCO2pmi	385.7671
588W	80%
ftp_FE_mpg	20.0009
hwfet_FE_mpg	28.5418
city_highway_FE_mpg	23.1133
city_highway_GHG_gCO2pmi	384.4976

Summary			
Efficiency	On Cycle	Off Cycle	Credit
70	0.4977	0.9784	0.4807
75	1.2467	2.4505	1.2038
80	1.8972	3.72	1.8228

Appendix C. Alpha Analysis

	Data Summary			
	Efficiency			
Model	67	70	75	80
LPW HRL	0	0.4	1.3	1.9
LPW LRL	0	0.5	1.2	1.9
MPW HRL	0	0.5	1.3	2.0
MPW LRL	0	0.5	1.2	2.0
Truck	0	0.5	1.2	1.8
Ford	0	0.5	1.2	1.9



Attachment D: DENSO SAS Air Conditioning Compressor

Request for DENSO SAS Air Conditioning Compressor Credits

Pursuant to 40 CFR 86.1869-12(d), 49 CFR 531.6(b), and 49 CFR 533.6(b) Ford hereby requests approval for the following methodology to determine off-cycle CO2 credits from the DENSO SAS air conditioning compressor with variable crankcase suction valve technology for 2017 and subsequent model year vehicles.

Ford proposes the use of a single off-cycle credit value of 1.1 g/mi for all vehicle categories. This value is determined from bench testing procedures and verified with associated vehicle testing described by the information provided below and in Appendix B and C. This application largely replicates GM's June 2015 request for off-cycle credits for the same technology[1]. That application was approved by EPA in August 2015[2]. With this application Ford seeks approval for off-cycle credits based on the same technology and credit level covered in that prior request.

Description of System

DENSO's SAS air conditioning compressor with variable crankcase suction valve improves energy consumption compared to the current generation technology. Current technology has a fixed crankcase suction (CS) throttle which is required to handle both high and low flow rate situations. This can be inefficient at low and average flow rates due to CS valve sizing required to handle max flow rates. The variable CS valve improves this design by being able to adjust the flow rate to optimally handle different situations. Under maximum flow conditions the larger CS valve opening can provide stable increased flow rate to achieve maximum capacity more quickly at compressor start up. Likewise operating under lower flow rates the valve can control the flow through the crank chamber reducing internal compressor losses and increasing efficiency at variable conditions. The optimized valves reduce suction and discharge pressure loss within the A/C compressor increasing efficiency. The additional variable CS valve improves the compressor over previous externally-controlled variable displacement compressor designs.

Rationale for Using The Alternative EPA-approved Methodology:

Since the DENSO SAS A/C Compressor with variable crankcase suction valve technology is not currently available as a credit on the pre-approved technology menu, Ford considered both the 5-cycle and alternative methodologies for this request. Although the 5-cycle methodology would capture a variety of driving conditions (e.g. vehicle speed, ambient temperature, A/C usage etc.), the key factor in determining the greenhouse gas benefit of the DENSO SAS air conditioning compressor with variable CS valve is the increased efficiency improvements when the air conditioning system is turned on. The 5-cycle test methodology would minimize the potential impact the DENSO SAS compressor would have on the measured CO2 emissions for the following reasons. The SC03 cycle is the only cycle that incorporates A/C usage. The SC03 test requires A/C to be run a maximum during the cycle. Finally the 5-cycle calculation suggests the A/C usage is only ~13% of VMT, while literature indicates that it is substantially higher (24 – 29%). Based on this it is determined that the improved air conditioning efficiency on a vehicle is not fully captured in the 5-cycle methodology.

For this reason, Ford is pursuing off-cycle credits under the alternative demonstration methodology pursuant to 40 CFR § 86.1869-12(d).

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[1] 80 FR 31598, June 3, 2015

[2] EPA-420-R-15-014 (September 2015) EPA Decision Document: Off-cycle Credits for Fiat Chrysler Automobiles, Ford Motor Company, and General Motors Corporation

Proposed Alternative EPA-approved Methodology

1. **Bench Testing Results**

An engineering analysis of the DENSO compressors was conducted by DENSO to demonstrate the benefit of the improved compressor design. The methodology used was developed during the Society of Automotive Engineers (SAE) Improved Mobile Air Conditioning Cooperative Research Program for evaluating U.S. system efficiency that have become formal SAE standards. Bench testing was conducted per SAE J2765 for each compressor. SAE J2765 is the procedure for measuring system coefficient of performance (COP) for a mobile air conditioning system on a test bench. The procedure is designed to give maximum repeatability and minimum error in determining cooling capacity and efficiency of the refrigeration system of the mobile air conditioner. The SAE J2765 standard specifies a series of bench tests conducted at various compressor speeds to measure the system COP. The results were used in combination with the Global Refrigerants Energy & Environmental – Mobile Air Conditioning – Life Cycle Clime Performance model (GREEN-MAC-LCCP) jointly developed by GM, SAE, EPA, and the Japanese Automobile Manufacturers Association (JAMA). The LCCP model estimates greenhouse gas (GHG) emissions for mobile air conditioning systems based on harmonized inputs and has been adopted as SAE standard J2766.

The engineering analysis was conducted by DENSO and resulted in an average U.S. vehicle indirect CO2 emissions value of 18.7 g/mi based on the LCCP model for the DENSO SBH compressor without the variable CS valve. The same analysis was conducted on the DENSO SAS compressor with the variable CS valve and resulted in an average U.S. vehicle indirect CO2 emissions value of 17.6 g/mi based on the LCCP model. Both compressors are externally-controlled variable displacement compressors. The analysis shows an improvement of 1.1 g/mi for the SAS compressor with the variable CS valve and vehicles equipped with this technology should receive this value as off-cycle credit. These results are documented in Appendix A and B.

2. **Vehicle Testing Results**

To validate the bench testing methodology a series of vehicle tests were also run using the two DENSO compressors. Due to issues previously discussed concerning the SC03 test, the AC17 test was chosen to quantify the compressor improvement as it is more representative of the average U.S. air conditioner operating conditions. A 2017 Lincoln MKC was chosen as the test vehicle as it is one of the first models to use this technology. The MKC was retrofitted to run a series of tests with both DENSO compressors the SBH and SAS installed. To validate the benefit, 6 tests were conducted with the variable CS valve SAS compressor installed and 5 tests were conducted with the fixed CS valve SBH compressor installed. The differing number of tests conducted for each compressor was a result of a combination of testing difficulties and limited test site availability. Both compressors were externally-controlled variable displacement compressors.

Upon review of the test results, it was determined that a refrigerant leak had occurred during the testing. This was confirmed by performing a refrigerant refill procedure on the vehicle. The refrigerant leak was determined to be caused by the additional instrumentation installed on the vehicle and compressors used to collect data as well as the removal and installation of different compressors. The leak was determined to be influencing the results of the test data. Based on good engineering judgment, data outliers were identified and four test points were removed from the overall data -- two from the SAS compressor and two from the SBH compressor. The full data set had showed a coefficient of variation of 11.8 % for the SAS compressor and 7.5% for the SBH compressor. After removing outlier data points, the reduced data set had a coefficient of variation of 3.7% for the SAS compressor and 2.1% for the SBH compressor, indicating that the reduced data set is more consistent and provides a more reliable basis for making estimates. The complete set of test data is available in

Appendix C. The following tables summarize the results of both conditions the full data set and the reduced data set with the outlier points removed.

Ford AC17 Testing (Table 1)

Full Data Set			
Grams CO2 per mile	SCO3	Highway	Combined
SAS Compressor (6 Tests)	52	12	32
SBH Compressor (5 Tests)	54	14.2	34.1
Credit			2.1

Reduced Data Set			
Grams CO2 per mile	SCO3	Highway	Combined
SAS Compressor (4 Tests)	55.8	12.9	34.3
SBH Compressor (3 Tests)	57.4	14.2	35.8
Credit			1.5

The results indicated above demonstrate that the DENSO SAS compressor displays a benefit and validates the bench testing and modeling done by DENSO. With all data points included the result is 2.1 g/mi benefit, but this value is overstated by the inclusion of test points with high variability and improper refrigerant levels identified as outliers. After removing the outlier test points, the result is a benefit of 1.5 g/mi. This value is comparable to the bench testing and LCCP model analysis conducted by DENSO that resulted in a benefit of 1.1 g/mi. Due to the variability that results from full vehicle testing and the AC17 test procedure it is recommended to use the more conservative value from the bench testing data conducted by DENSO and apply a credit value of 1.1 g/mi for vehicles equipped with this technology.

Durability

Air conditioning compressors installed within Ford vehicles meet all the durability requirements of 40 CFR § 86.1869-12(d) and are not subject to any deterioration factors that would reduce the benefits of the DENSO SAS air conditioning compressor with variable CS valve. Durability testing is conducted to meet Ford specifications and meet full useful life requirements. A durability test report for the DENSO SAS compressor is included as Appendix E.

Conclusion

Based on the data presented Ford recommends the use of a 1.1 g/mi credit for all vehicles equipped with the DENSO SAS air conditioning compressor with variable CS valve technology. The credit will be applicable for vehicles with the technology installed for 2017 and subsequent model years. A list of the vehicle models which are equipped with the technology and projected future vehicles along with an estimate of the off-cycle benefit by vehicle model and the fleet wide benefit based on sales of vehicle models equipped with the technology is provided in Appendix D. Per the methodology described above regarding credit determination, we intend to apply the methodology described above for each compressor application using the DENSO SAS compressor with variable crankcase suction valve technology. The fleet credit will be calculated based on credit for each type of vehicle, vehicle lifetime miles and U.S. sales volume for 2017 model year products and beyond.

Appendix A: DENSO Presentation

Indirect CO_2 Credit for DENSO SAS Compressor

April 5, 2013
DENSO International America, Inc.

Updated July 14, 2016

DENSO

Agenda

- DENSO Corporation
- Background / Objective
- SAS Efficiency Improvement Mechanism
- Off-cycle Engineering Analysis Method
- Testing Details
- Test Results
- LCCP Results
- Conclusions

DENSO Corporation

- **Established: Dec. 16, 1949**
- **Capital: US$2.3 billion**
- **Net Sales: US$38.4 billion**
- **Net Income: US$1,086.5 million**
- **Employees: 126,000 in 35 countries**

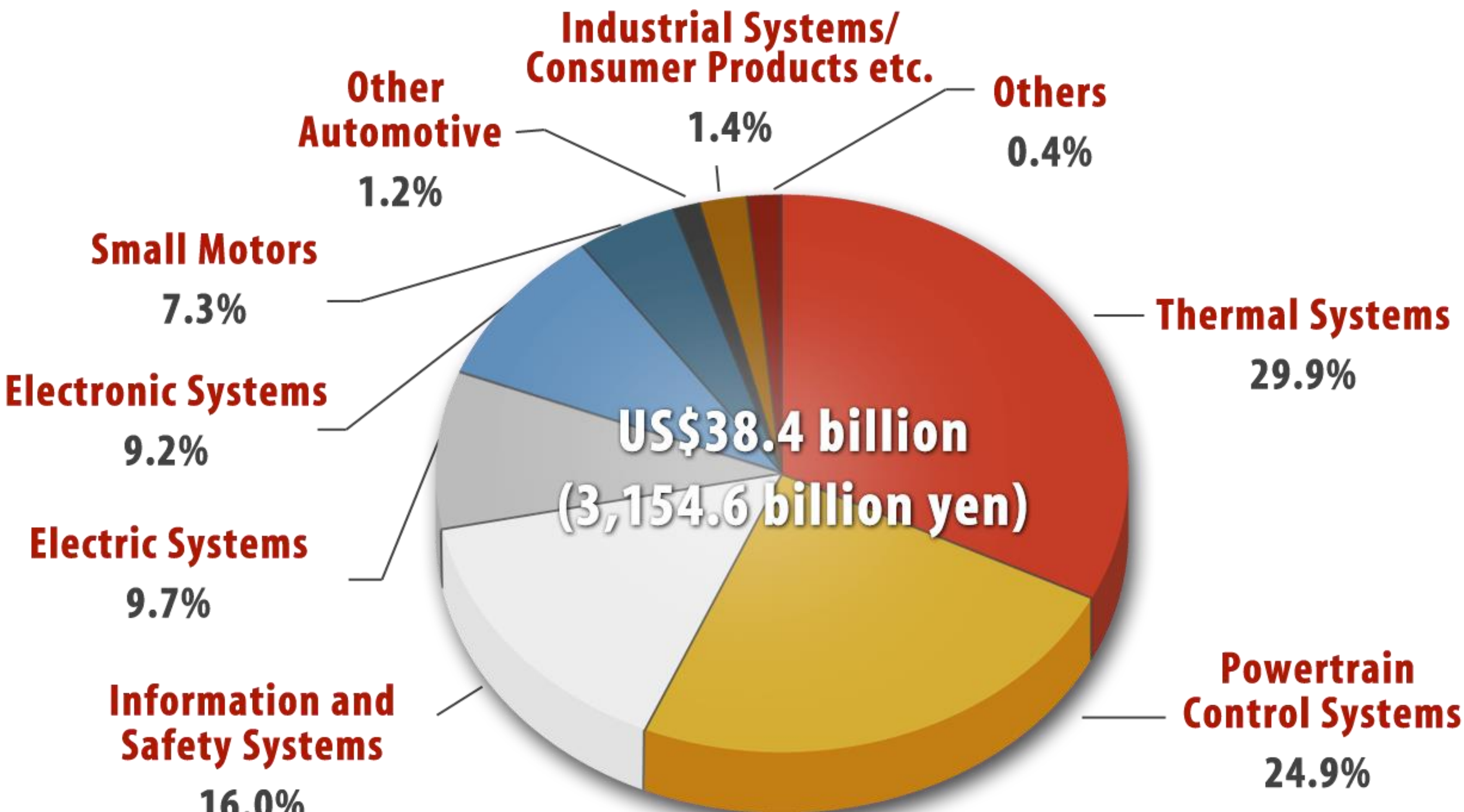
Data are consolidated base

- As of March 31, 2012
- U.S. dollar amounts have been translated from Japanese yen for convenience only at the rate of 82.19 yen= US$1

DENSO

Sales by Business Groups

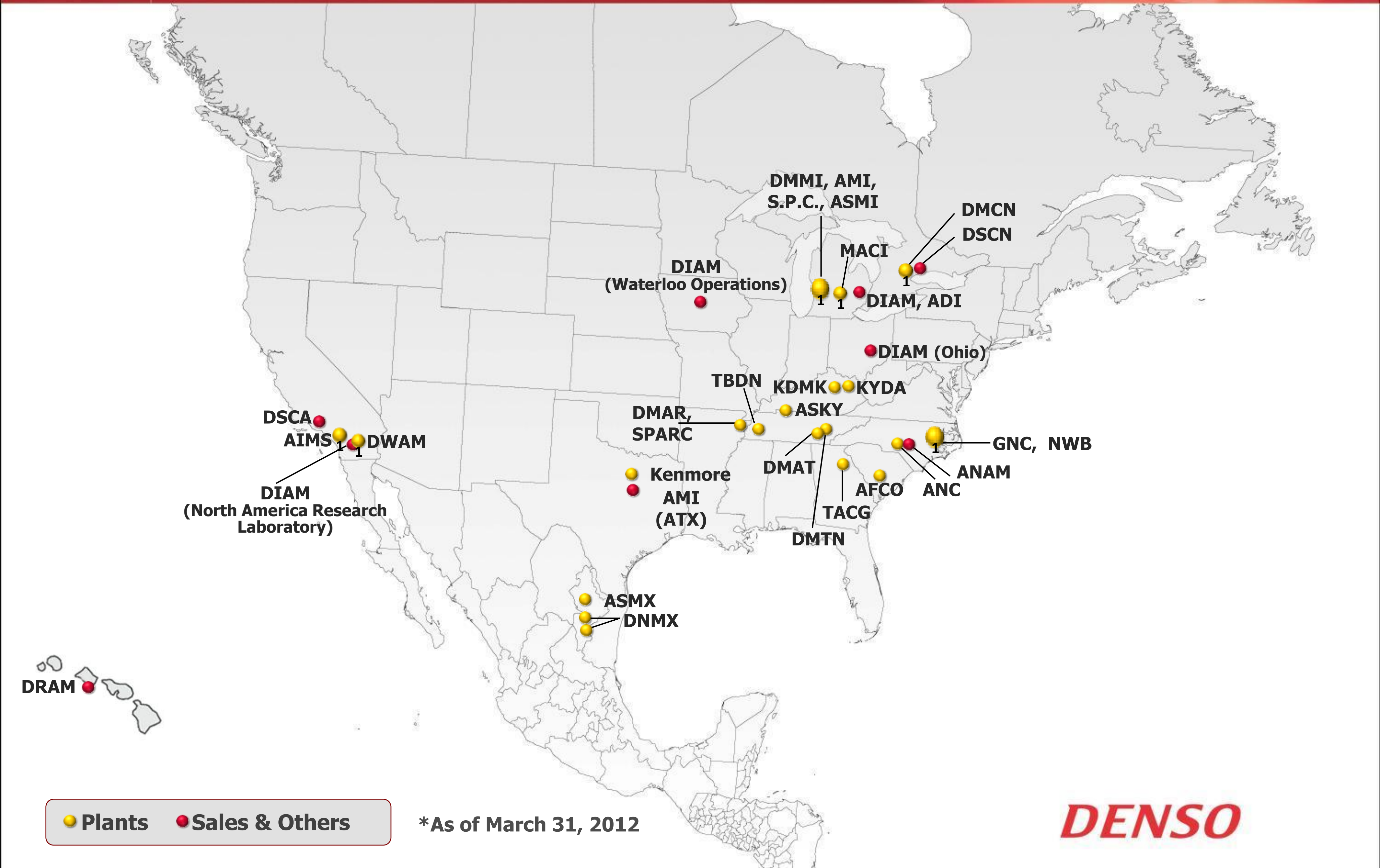
Consolidated Base



*For fiscal year ended March 31, 2012

DENSO

DENSO Operations in North America



Plants Sales & Others

*As of March 31, 2012

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Background / Objective

Federal fuel economy tests do not include A/C usage, but A/C usage generates CO_2 and reductions to these emissions benefit the environment.

DENSO's new SAS external variable displacement compressor (EVDC) improves energy consumption compared to current generation technology. Therefore, we feel SAS compressor should qualify for CO_2 off cycle credits.

Objective: Perform an engineering analysis to quantify the amount of indirect CO_2 credit that the SAS compressor should receive. Use this information to support customer applications to the EPA for credit.

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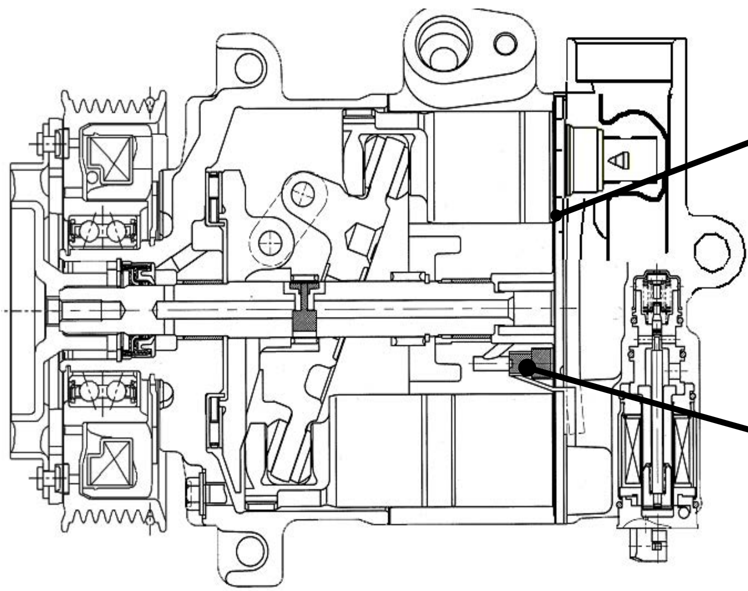
SAS Efficiency Improvement Mechanism

The new SAS compressor has two efficiency improvements over the existing SBU/SBH (referred to collectively as SB*) compressor: optimized suction and discharge valves and a CS valve.



<Efficiency>
Change the structure of valve to optimize suction and discharge pressure loss.

<Efficiency at Variable Condition>
Crankcase Suction Valve (CS valve)
(*optimize suction/ discharge pressure loss*)
(quick start-up under full liquid condition)

Clutch less version (called SES) is available and has same internal design.

The optimized valves reduce suction and discharge pressure loss within the compressor, increasing efficiency.

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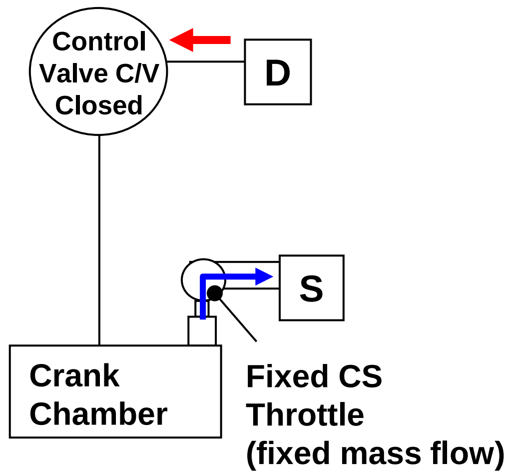
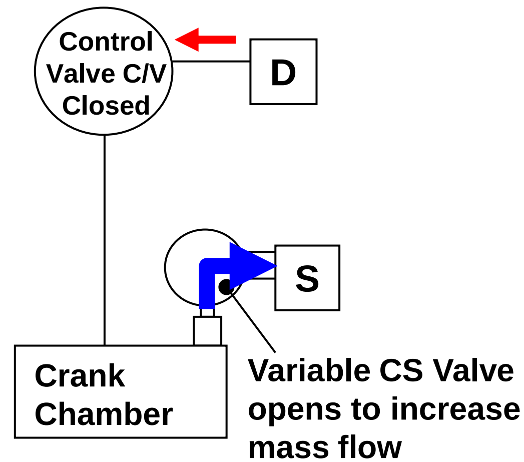
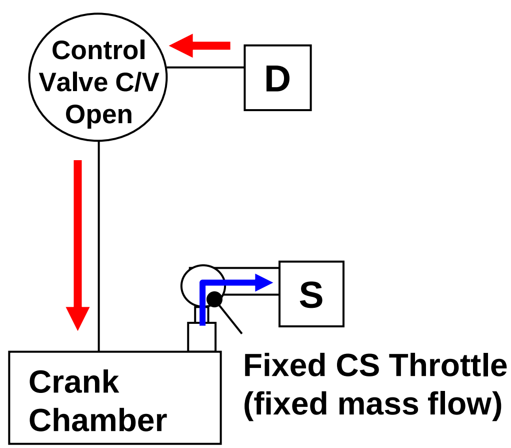
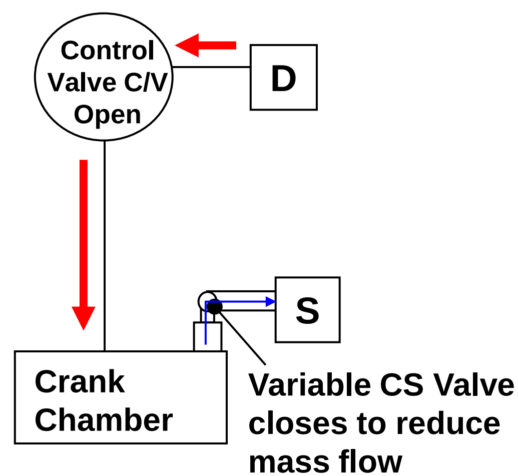
SAS & SES Efficiency Improvement Mechanism

Condition	Current Design (SBU/SBH)	New Technology (SAS)	Benefit of Variable CS Valve
Max Capacity and Compressor Start-up			Large opening allows a large mass flow. This allows for a stable max capacity condition and for the compressor to achieve max capacity more quickly at compressor start-up.
Variable (Mid) Capacity			Small opening results in a reduction of contol gas flow through the crank chamber, thus reducing internal compressor losses and **increasing efficiency** at variable condition.

The CS valve increases efficiency of the SAS compressor at mid displacement.

DENSO

A/C Indirect CO_2 Credits

For A/C there are three CO_2 credit types available which can be used to meet the fleet average CO_2 emissions requirements:

Leakage credits for low refrigerant leakage rate or low GWP refrigerant.

Menu credits for improving system efficiency.

Off-cycle credits for advanced technology not on the menu. The technology must reduce emissions levels compared to current technology.

DENSO will do testing to show SAS/SES compressor may get off-cycle credits.

DENSO

Off-cycle Engineering Analysis Method

Bench Testing Per SAE J2765 for Each Compressor

Analysis Using LCCP Model (CO_2 Emission Per City)

Calculate US Average CO_2 For Each Compressor

http://www.epa.gov/cppd/mac/compare.htm

LCCP is an existing method to estimate CO_2 impact of MAC systems. It was developed by EPA, GM, SAE, and JAMA.

LCCP analysis can be used as an acceptable engineering analysis method for determining the off-cycle CO_2 emissions impact for SAS compressor.

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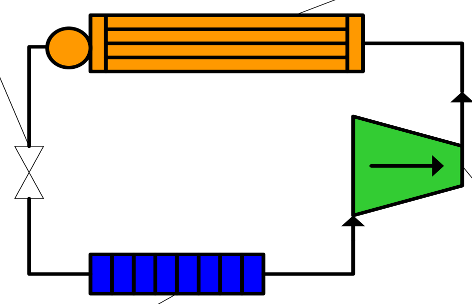
Test Bench System

Thermal Expansion Valve
-Set Point = 2.1kPa @ 0°C (1.0ton)
- Slope = 0.7 bar

Condenser
- W600mm x H422.4mm x D16mm
- Fin Height = 5.5 mm
- Tube Thickness = 1.0mm
- Fin pitch ~ 3.15mm
- Configuration: 1 Pass + Sub-cool (55-11)
- Integrated Receiver / Dryer



Evaporator
-W306.5mm x H201mm x D38mm
- Fin Height = 5 mm
- 4 pass : 22-23-23-22
- Tube Thickness = 1.7 mm

Compressor 6SBU14 & 6SAS14
- Pulley Ratio = 2.15
- Oil Amount = 100 g
- Refrigerant Charge:
R-134a: 650 grams

All components were common during testing of the 6SB*14 and 6SAS14 compressors.

DENSO

Test Conditions (J2765)

Test Name	Simulated Ambient Temp. [C]	Compressor Speed [RPM]	Cond Air In Temp [C]	Cond Face Velocity [m/s]	Evap Air In Temp [C]	Evap Humidity [%]	Air Mass Flow [kg/min]	Air Flow Volume [m3/h]	Air Flow Volume [CFM]	Simulated Air Selection	Evap Air Out Target Temp [C]
I60	45	900	60	1.5	35	25	9.0	475	280	Recirc	3
I45	45	900	45	1.5	35	25	9.0	475	280	Recirc	3
L45	45	1800	45	2.0	35	25	9.0	475	280	Recirc	3
M45	45	2500	45	3.0	35	25	9.0	475	280	Recirc	3
H45	45	4000	45	4.0	35	25	9.0	475	280	Recirc	3
I50a	35	900	50	1.5	35	40	9.0	477	281	OSA	3
I35a	35	900	35	1.5	35	40	9.0	477	281	OSA	3
L35a	35	1800	35	2.0	35	40	9.0	477	281	OSA	3
M35a	35	2500	35	3.0	35	40	9.0	477	281	OSA	3
H35a	35	4000	35	4.0	35	40	9.0	477	281	OSA	3
I40a	25	900	40	1.5	25	80	6.5	337	198	OSA	3/10
I25a	25	900	25	1.5	25	80	6.5	337	198	OSA	3/10
L25a	25	1800	25	2.0	25	80	6.5	337	198	OSA	3/10
M25a	25	2500	25	3.0	25	80	6.5	337	198	OSA	3/10
H25a	25	4000	25	4.0	25	80	6.5	337	198	OSA	3/10
I40c	25	900	40	1.5	25	50	6.5	334	197	OSA	3/10
I25c	25	900	25	1.5	25	50	6.5	334	197	OSA	3/10
L25c	25	1800	25	2.0	25	50	6.5	334	197	OSA	3/10
M25c	25	2500	25	3.0	25	50	6.5	334	197	OSA	3/10
H25c	25	4000	25	4.0	25	50	6.5	334	197	OSA	3/10
I30	15	900	30	1.5	15	80	6.5	322	190	OSA	3/10
I15	15	900	15	1.5	15	80	6.5	322	190	OSA	3/10
L15	15	1800	15	2.0	15	80	6.5	322	190	OSA	3/10
M15	15	2500	15	3.0	15	80	6.5	322	190	OSA	3/10
H15	15	4000	15	4.0	15	80	6.5	322	190	OSA	3/10

All conditions were run for each compressor

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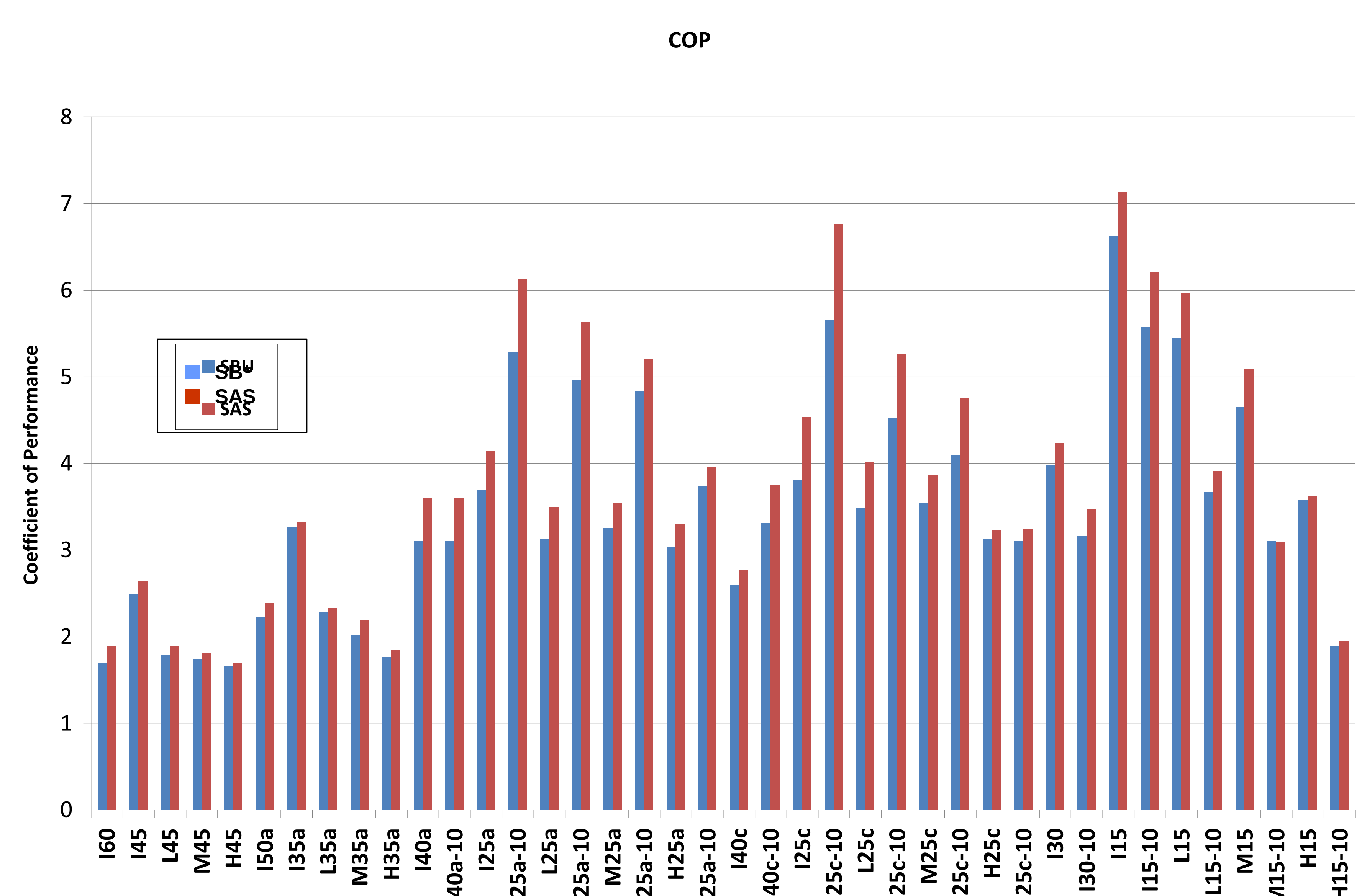
Test Results



COP for SAS is higher at middle ambient (as expected due to CS valve)

These values were entered into the LCCP model.

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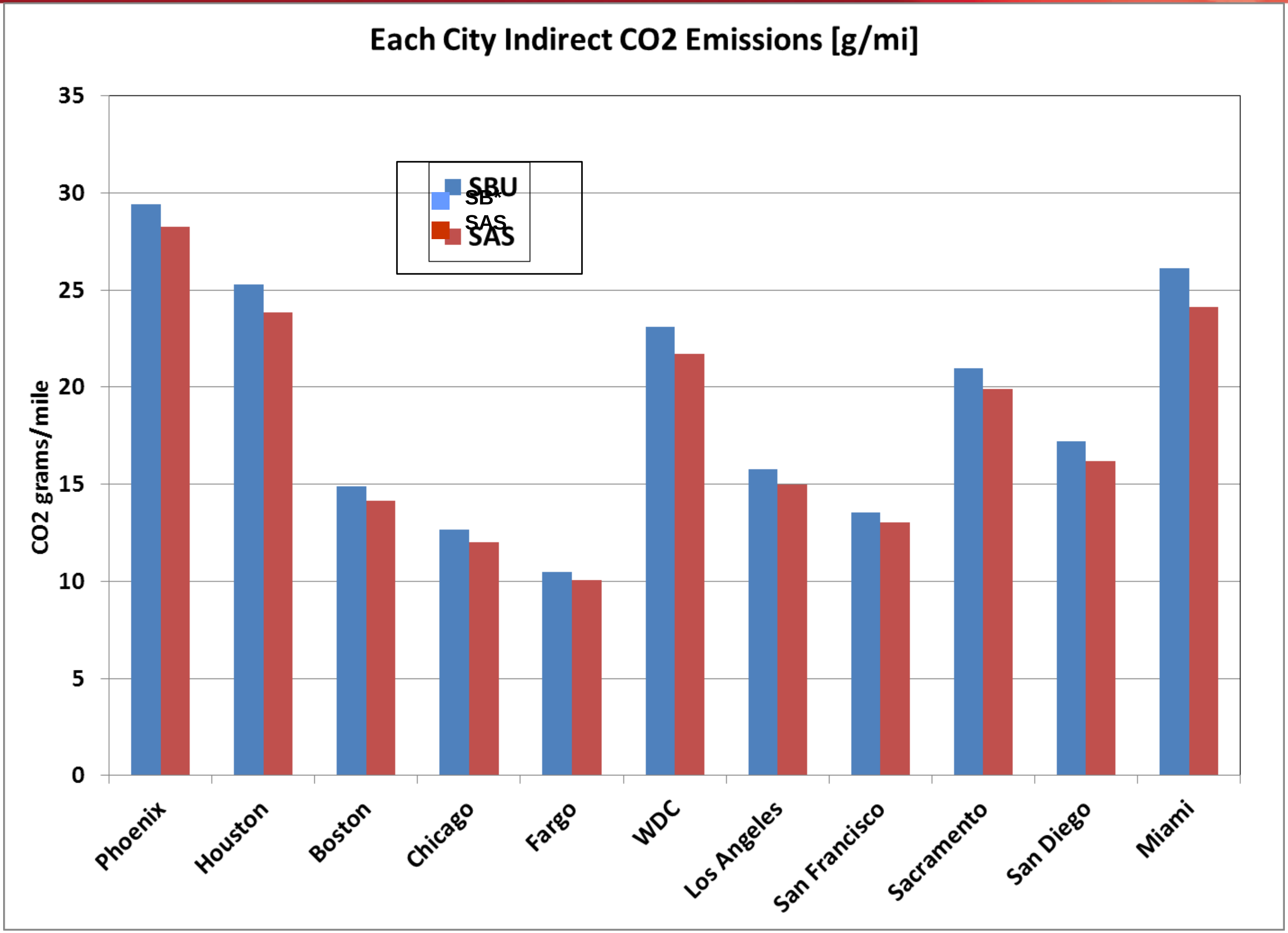
LCCP Results (per city)



Indirect CO_2 emissions for each US city.

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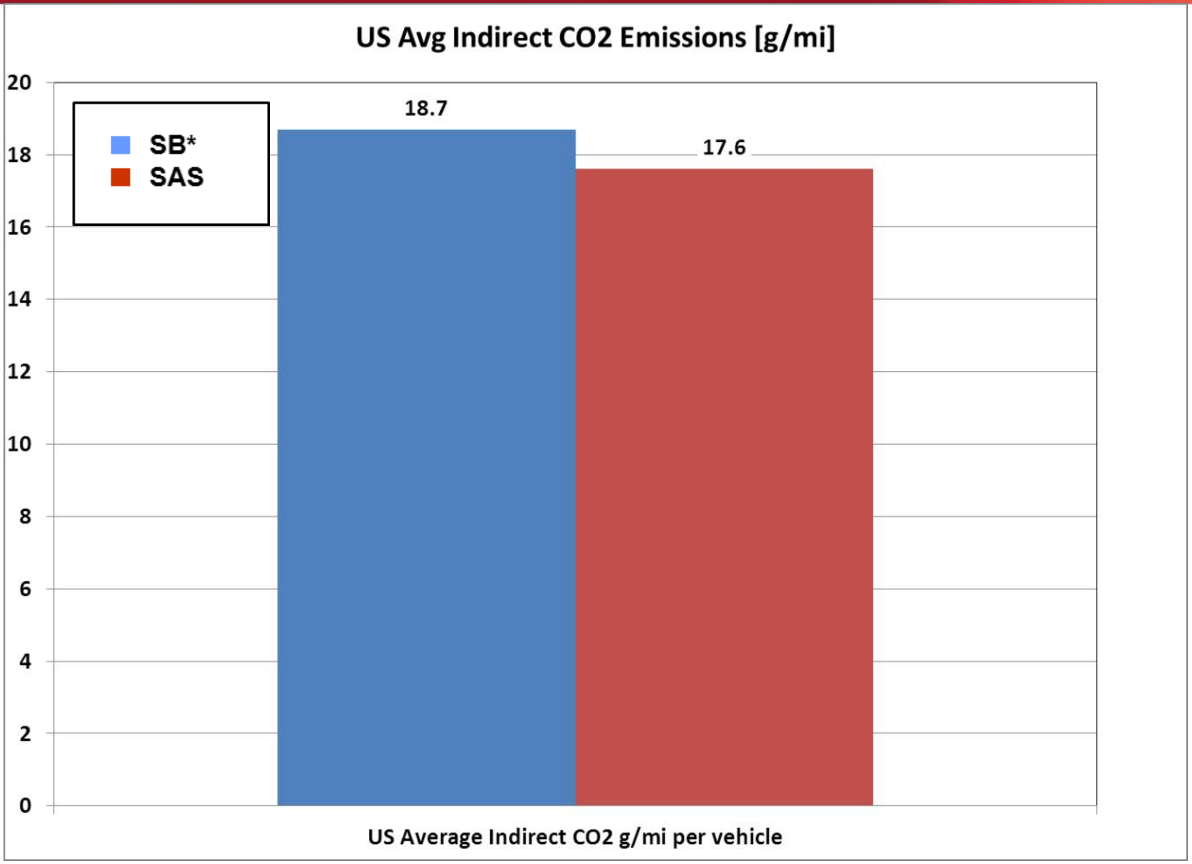
LCCP Results (US Average)



Average US Vehicle Indirect CO_2 Emissions	
SB* compressor	18.7 g/mi
SAS compressor	17.6 g/mi
Benefit of SAS compressor	**1.1 g/mi**

Off-cycle CO_2 credit of 1.1g/mi should be requested for the SAS compressor.

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Conclusion

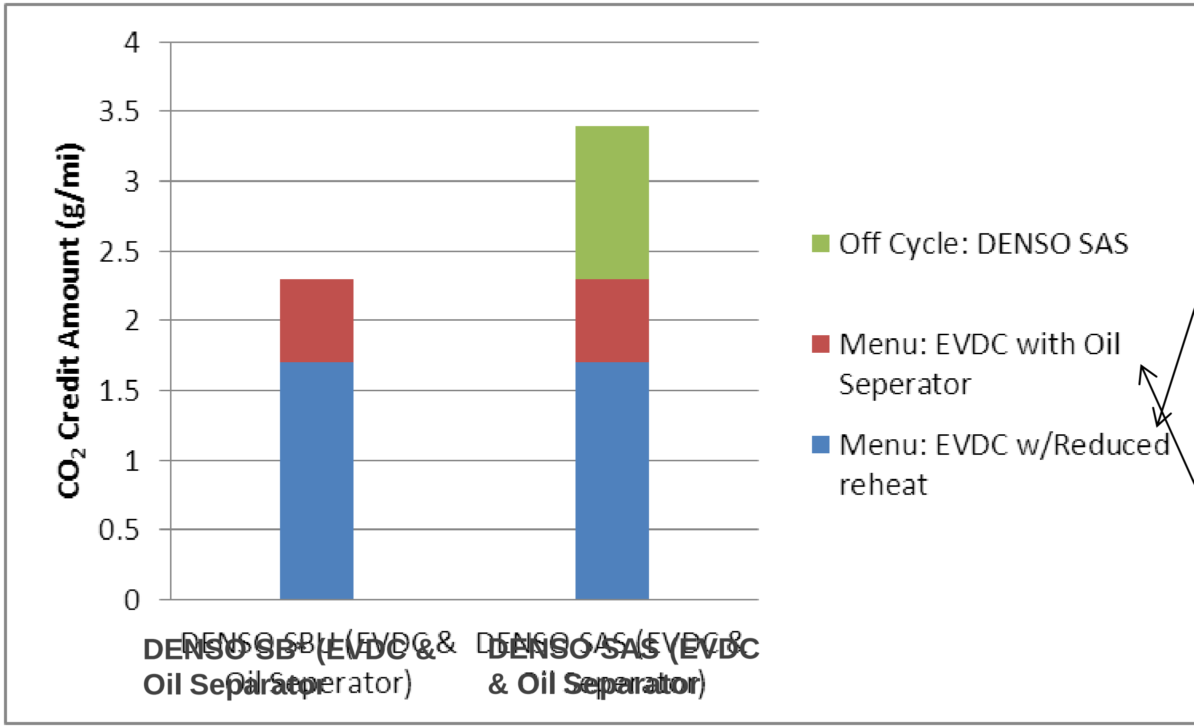

Table III.C.1-2 Efficiency-Improving A/C Technologies and Credits

Technology Description	Estimated Reduction in A/C CO_2 Emissions	A/C Efficiency Credit (g/mi CO_2)
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	1.7
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable-displacement compressor	20%	1.1
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	30%	1.7
Default to recirculated air with open-loop control air supply (no sensor feedback) whenever the ambient temperature 75 °F or higher lower temperatures are allowed)	20%	1.1
Blower motor controls which limit wasted electrical energy (e.g., pulse width modulated power controller)	15%	0.9
Internal heat exchanger	20%	1.1
Improved condensers and/or evaporators (with system analysis on the component(s) indicating a COP improvement greater than 10%, when compared to previous industry standard designs)	20%	1.1
Oil Separator (with engineering analysis demonstrating effectiveness relative to the baseline design)	10%	0.6

We believe the total benefit for SAS or SES compressor should be 3.4 g/mi credit (Menu Credits + Off Cycle)

Based on 2012-2016 Regulation

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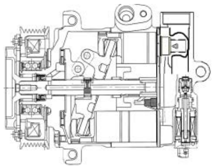
Conclusion

SAS/SES Compressor Off Cycle
(1.1 g/mi)



- OEM A
  - C Segment
    6SAS14
  - SUV
    7SAS17
- OEM B
  - C Segment
    6SAS14
  - Mini Van
    7SAS18
- OEM C
  - C Segment
    6SES14
- OEM D
  - C Segment
    CD Segment
    SUV
    Pick up
    7SAS17
  - SUV
    7SAS18

Our assumption is this data supporting the 1.1 g/mi credit can be applied to any vehicle using SAS or SES compressor.

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Appendix B: DENSO SAS Bench Testing Results

See separately included Microsoft Excel results file.

Appendix C: Ford SAS AC17 Testing Results

See separately included Microsoft Excel results file.

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Appendix D: Sales Volumes and Credit Estimate

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Appendix E: Durability Test Reports