Vehicle Environmental Regulatory Strategy & Planning
Sustainability, Environment & Safety Engineering
Ford Motor Company

Word Headquarters
One American Road
Dearborn, Michigan 48126-2798

June 21, 2016

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 48102

Subject: Application for High Efficiency Alternator Off-Cycle GHG Credit

This is an application for off-cycle CO2 credits using the alternative EPA-approved methodology outlined in 40 CFR § 86.1869-12(d) to demonstrate credit for the High Efficiency Alternator.

Regulatory Framework:

Pursuant to 40 CFR § 86.1869-12, vehicle manufacturers may obtain off-cycle credits for the use of a CO2-reducing 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 EPA-approved methodology. 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 High Efficiency Alternator technology that is the subject of this request is not a safety-related technology and is therefore not subject to any of the exclusions set forth in subsection (a).

Ford kindly requests written/e-mail acknowledgment upon EPA receipt and acceptance of this off-cycle credit request. If EPA has any questions about this letter and the related attachments, please contact Ms. Nancy Homeister at nhomeist@ford.com or (313) 594-1035.

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 2009 and subsequent model year vehicles. In addition, off-cycle fuel consumption credits will be calculated using the procedure provided at 40 CFR 600.510-12(c)(3) for 2017 and subsequent model year vehicles.

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

$$Credit\ \left(\frac{g}{mi}\right) = On\ Road\ Electrical\ Saving\ \times \left(\frac{3.2\,\frac{g}{mi}}{100\ Watts}\right) - 2\ Cycle\ Electrical\ Saving\ \times \left(\frac{2.5\,\frac{g}{mi}}{100\ Watts}\right)$$

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.

---

[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 CO_2 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.

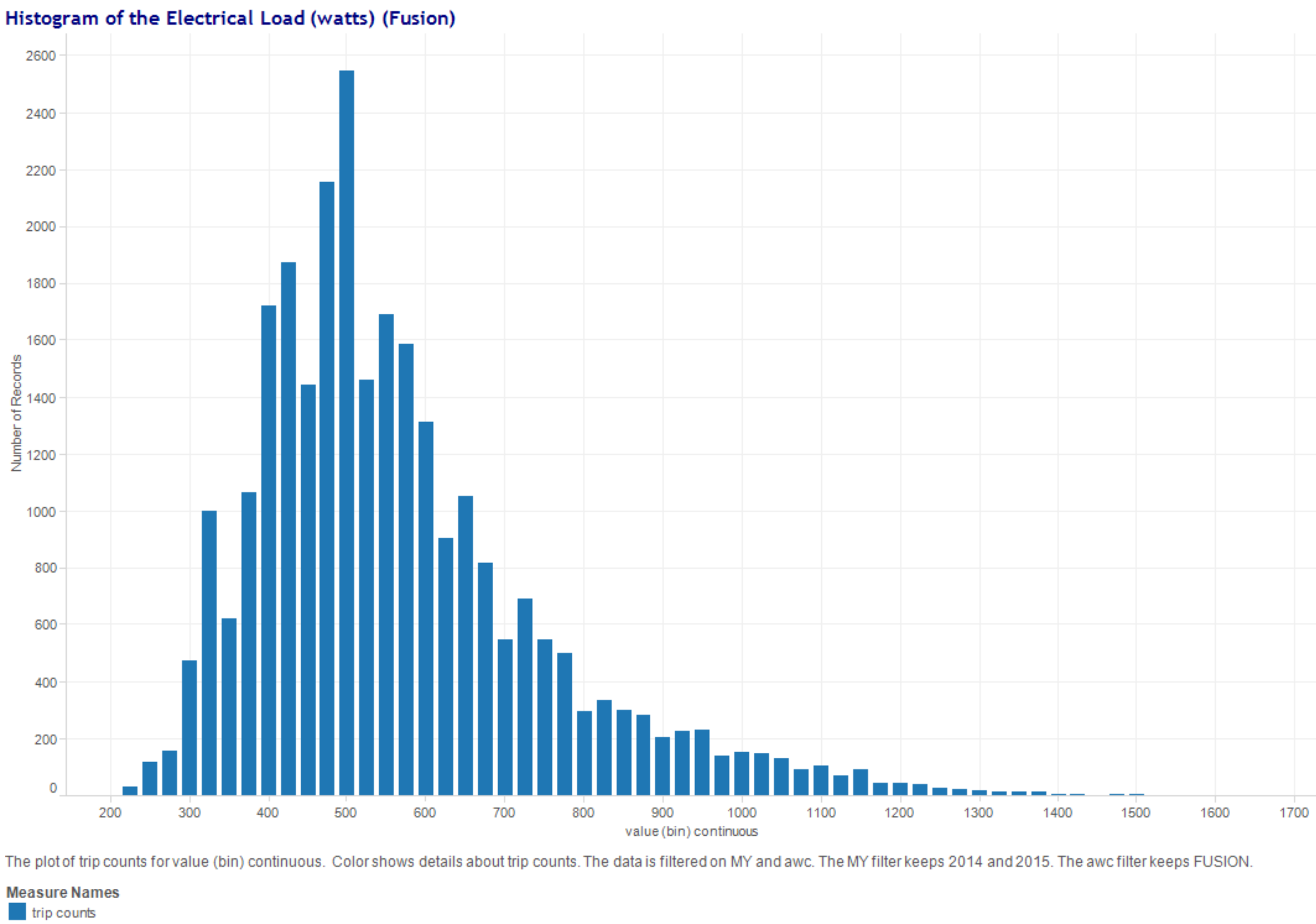
The standard 2-cycle and environmentally weighted on-road electrical loads are used to determine the reduction in GHG emission for all vehicle types using a high efficiency alternator. Results show that the off-cycle benefit is similar for all vehicle types and a single credit value may be applied to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

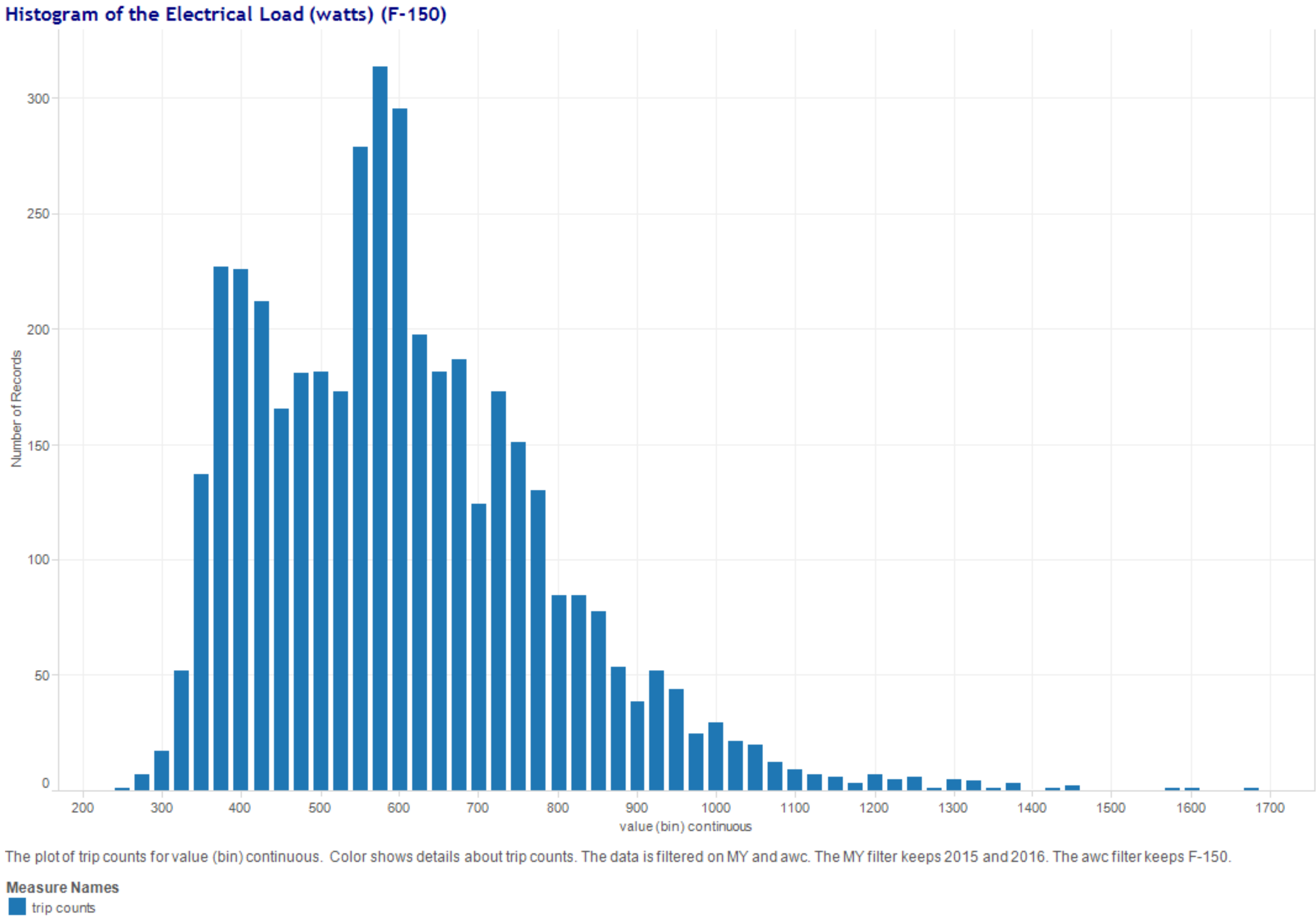
Fusion 2-Cycle Testing		F-150 2-Cycle Testing	
Mean	275	Mean	318

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

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

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].

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

[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

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	

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:

$$\frac{Electrical\ Power\ (watts)}{Alternator\ VDA\ Efficiency\ (\%)} = Mechanical\ Power\ (watts)\ = Engine\ Speed\ (rad/sec) \times Engine\ Torque\ (Nm)$$

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:

$$\frac{297\ watts}{67\%} = \left(2000\ RPM \times \frac{2\pi\ rad}{rev} \times \frac{1\ min}{60\ sec}\right) \times (LE\ Engine\ Torque)$$

$$LE\ Engine\ Torque = \frac{297}{67\%} \times \left(\frac{1}{209.4\ rad/sec}\right) = \mathbf{2.11\ Nm}$$

> LE Alternator input torque required to generate 350 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:

$$\frac{297\ watts}{72\%} = (2000\ RPM \times \frac{2\pi\ rad}{rev} \times \frac{1\ min}{60\ sec}) \times (HE\ Engine\ Torque)$$

$$HE\ Engine\ Torque = \frac{297}{72\%} \times \left(\frac{1}{209.4\ rad/sec}\right) = \mathbf{1.97\ Nm}$$

HE Alternator input torque required to generate 350 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:

$$\frac{Equivalent\ HE\ Electrical\ Load}{LE\ Alternator\ VDA\ (\%)} = (2000\ RPM \times \frac{2\pi\ rad}{rev} \times \frac{1\ min}{60\ sec}) \times (HE\ Engine\ Torque)$$

$$\frac{Equivalent\ HE\ Electrical\ Load}{67\%} = (2000\ RPM \times \frac{2\pi\ rad}{rev} \times \frac{1\ min}{60\ sec}) \times (1.97\ Nm)$$

$$\mathbf{Equivalent\ HE\ Electrical\ Load = 276\ watts}$$

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**

$$Credit\ \left(\frac{g}{mi}\right) = On\ Road\ Electrical\ Saving\ \times \left(\frac{3.2\,\frac{g}{mi}}{100\ Watts}\right) - 2\ Cycle\ Electrical\ Saving\ \times \left(\frac{2.5\,\frac{g}{mi}}{100\ Watts}\right)$$

$$Off\ Cycle\ Credit = 41\ Watts * \left(\frac{3.2\,\frac{g}{mi}}{100\ Watts}\right) - 21\ Watts * \left(\frac{2.5\,\frac{g}{mi}}{100\ Watts}\right) = 0.8\ g/mi$$

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.

% 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

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 Attachment 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 2009 and subsequent model years. 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 Attachment 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 2009 model year products and beyond.

Sincerely,

Cynthia Williams

Cynthia Williams, Associate Director
Vehicle Environmental Regulatory Strategy & Planning

Attachment A. Alternator Durability Report

Attachment B. Carline Volumes and Credit Estimate