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AN OVERVIEW OF CAFE CREDITS AND INCORPORATION OF THE BENEFITS OF ON-BOARD CARBON CAPTURE

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16. Abstract

This report discusses the application of Corporate Average Fuel Economy (CAFE) credits that are currently available to vehicle manufacturers in the U.S., and the implications of on-board carbon capture and sequestration ("on-board CCS") on future passenger-vehicle CAFE ratings. The first part of the report describes the underlying fuel economy tests and available options for vehicle manufacturers to earn credits for exceeding the fleet fuel economy standard or for vehicle technologies that reduce greenhouse gas emissions.

The benefits of on-board CCS, discussed in the second part of the report, appear likely to be captured during the standard 2-cycle test administered for CAFE compliance purposes. A simple calculation to correct the final fuel economy value used for CAFE compliance is needed (to reflect the resultant benefits of reduced CO_2 emissions), although this specific correction is not yet reflected in the current regulations.

The benefits in terms of reduced emissions and overall credits appear to be substantially larger with on-board CCS than with the other optional credits available in the CAFE credit program for gasoline-powered vehicles. For example, the on-board CCS benefits at 20% capture would be several times the maximum credits available in the next highest credit category.

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Introduction

The current Corporate Average Fuel Economy (CAFE) standard, in effect for model years 2012 through 2016, simultaneously regulates fuel economy and greenhouse gas (GHG) emissions from new vehicles (EPA/NHTSA, 2010). This dual approach is continued in the recently enacted standard applicable for model years 2017 through 2025 (EPA/NHTSA, 2012). The aim of these standards is to reduce both energy consumption (via fuel economy) as well as GHG emissions—predominantly CO_2—in new light-duty vehicles in the U.S.

However, GHG performance levels are not required to be met purely through fuel economy improvements. Manufacturers are permitted to include alternative credits not related to improvements in fuel economy to assist in reaching established GHG reduction goals. Examples of these credits "include the ability of manufacturers to pay civil penalties rather than achieving required CAFE levels, the ability to use Flexible Fuel Vehicle (FFV) credits, the ability to count electric vehicles for compliance, the operation of plug-in hybrid electric vehicles on electricity for compliance prior to MY 2020, and the ability to transfer and carry forward credits," in addition to air-conditioning-improvement credits and/or off-cycle technology credits (EPA/NHTSA, 2012).

On-board carbon capture and sequestration ("on-board CCS") is a technology currently in development that would allow for direct reduction of CO_2 emissions during driving. The ultimate reductions in CO_2 from on-board CCS should result in an adjustment in the CAFE rating for vehicles employing the technology, either through direct tailpipe measurement of possible CO_2 reduction in the standard 2-cycle (i.e. CAFE) test, or within the credit program described in the regulations.

This report will first outline and discuss the application of CAFE credits currently available to vehicle manufacturers in the U.S.[1] This will be followed by a discussion of the implications of on-board CCS on future passenger-vehicle CAFE ratings.

[1] The discussion of CAFE credit application in this report is not intended to be a complete examination or presentation of the detailed legal requirements of the CAFE program. Detailed information can be found in

CAFE Credit Program Overview

Fuel economy testing procedures

The standard 2-cycle test is the basic set of test cycles developed by NHTSA in the 1970s to measure new-vehicle fuel economy. The "2 cycles" refer to 1) the "city" test cycle (formally called the Federal Test Procedure, or FTP), and 2) the "highway" test cycle (formally called the Highway Fuel Economy Test, or HFET). Average performance on these two tests is weighted—55% city and 45% highway. These two tests are designed to determine the basic fuel economy performance in a laboratory setting, but do not necessarily reflect current on-road performance. The results of the 2-cycle test are the basis for a vehicle's average GHG and CAFE rating (described in the next section). Any additional credits earned by a manufacturer are added to these GHG and CAFE ratings (either per vehicle or fleet-wide, depending on the type of credit).

The purpose of the latest 5-cycle test, finalized for model year 2008 (EPA, 2008), is to more accurately reflect on-road fuel economy performance that an average driver might expect to achieve. The results of this test are the basis for the window sticker fuel economy values required on each new vehicle sold in the U.S. The "5 cycles" refer to the original two city and highway tests (i.e., the 2-cycle test), plus three additional tests to measure performance under the following conditions:

- Cold temperature operation
- Air conditioner usage with high temperature, high humidity, and solar loading
- Aggressive and high-speed driving

The 5-cycle test does not directly affect the CAFE ratings that are derived from the 2-cycle test, unless use of the 5-cycle results is needed to demonstrate additional fuel-consumption (and CO_2) savings not captured by the 2-cycle test. (This option is described in the "Off-cycle technology credits" section of this report.)

Averaging, banking, and trading (ABT) credits

Averaging

Averaging of credits forms the basis for the CAFE assessment program, wherein a fleet-wide, production-weighted average (harmonic) is determined for each manufacturer. Separate 2-cycle test averages are calculated for passenger-car fleets and light-truck fleets for each manufacturer. Actual CO_2 emissions for each vehicle are used for calculating these fleet averages. (The EPA uses a conversion factor of 8,887 grams of CO_2 emitted per gallon of gasoline consumed [EPA, 2014].[2]) This method of production-weighted averaging allows for a mix of vehicles with varying CO_2 emission levels while still achieving an overall fleet average that meets or exceeds the fleet standard.

Banking

The average fleet performance is compared to the fleet standard for each model year. The fleet standard is calculated in the same way as the fleet average (i.e., production weighted for each vehicle model), except that the CO_2 standard prescribed by each vehicle's footprint is used instead of the actual CO_2 emissions for each vehicle. Credits are earned if the fleet average exceeds the fleet standard; debits are created if the fleet average falls short of the fleet standard.

Credits may be 1) used to offset a deficit in a prior year, or 2) saved (banked) for future use, for up to five years. Deficits that are created 1) may be carried forward for three years with the option of offsetting the deficit with future credits, or 2) a fine may be paid for violation (either in the year the deficit occurred or after three years of carrying a deficit forward).

An example of averaging and banking calculations (and an example of generating basic credits) is shown in Table 1 (adapted from Table III.E.5-1, EPA/NHTSA, 2010). In the example, a manufacturer produced 500,000 vehicles, with a fleet average of 290 g/mi of CO_2 emissions (equivalent to 30.6 mpg). The corresponding fleet standard is 300 g/mi (equivalent to 29.6 mpg). The credit is calculated by taking the difference between the fleet standard and the fleet average (300 – 290 = 10 g/mi), multiplied by the number of

[2] Diesel fuel has a conversion factor of 10,180 grams of CO_2 per gallon consumed. However, CAFE calculations generally assume 100% gasoline usage, unless stated otherwise (EPA/NHTSA, 2010).

vehicles produced (500,000), multiplied by the expected lifetime miles per vehicle (195,264 for passenger cars). The result is then divided by 1,000,000 to convert from grams to megagrams (Mg) of CO_2.

Table 1
Example for a hypothetical car manufacturer: earning basic credits
(adapted from Table III.E.5-1, EPA/NHTSA, 2010).

Variable	Value or formula	MPG	CO_2	Total credits
Total production	500,000 vehicles (conventional)	30.6	290 g/mi	-
Fleet average	(500,000 x 290) / 500,000	30.6	290 g/mi	-
Fleet standard	determined by footprints of vehicles produced	29.6	300 g/mi	-
Lifetime miles*	195,264 mi/vehicle	-	-	-
Credits	[(300 – 290) x 500,000 x 195,264] / 1,000,000	-	-	976,320 Mg

* The value used in this example applies to passenger cars for model years 2017-2025. The corresponding value for light trucks is 225,865 miles.

Trading

When credits are created, they may be 1) transferred between the passenger-car and light-truck fleets within a manufacturer or 2) traded between manufacturers. An adjustment factor is used when transferring between the two fleet types ("compliance categories") due to different vehicle lifetime mileage assumptions and the fact that fuel consumption is not a linear function of fuel economy. This also applies when credits are traded between manufacturers from one fleet type to another. The shortfall to be offset must be multiplied by the adjustment factor to determine the number of credits required to offset the deficit. The adjustment factor formula is as follows (EPA/NHTSA, 2012):

$$\textit{Adjustment factor} = (VMT_u \times MPG_{ae} \times MPG_{se}) / (VMT_e \times MPG_{au} \times MPG_{su})$$

Where:

VMT_u	=	Lifetime vehicle miles traveled for the model year and compliance category (i.e., passenger car or light truck) in which the credit is used for compliance.
VMT_e	=	Lifetime vehicle miles traveled for the model year and compliance category in which the credit was earned.
MPG_{ae}	=	Actual fuel economy for the originating (earning) manufacturer, compliance category, and model year in which the credit was earned.
MPG_{se}	=	Required fuel economy standard for the originating manufacturer, compliance category, and model year in which the credit was earned.
MPG_{au}	=	Actual fuel economy for the user (buying) manufacturer, compliance category, and model year in which the credit is used for compliance.
MPG_{su}	=	Required fuel economy standard for the user manufacturer, compliance category, and model year in which the credit is used for compliance.

The following example illustrates the calculation for the adjustment factor when transferring/trading credits from a passenger-car fleet to a light-truck fleet for model years 2017 to 2025. In the hypothetical example, the passenger-car fleet average is 30 mpg, exceeding the applicable standard of 29 mpg by 1 mpg; the light-truck fleet average is 23 mpg, falling short of the applicable standard of 24 mpg by 1 mpg. The resulting adjustment factor means that 1.82 passenger-car credits are required to offset 1 credit of deficit in the light-truck fleet.

$$\textit{Adjustment factor} = (VMT_u \times MPG_{ae} \times MPG_{se}) / (VMT_e \times MPG_{au} \times MPG_{su})$$

$$\textit{Adjustment factor} = (225{,}865 \times 30 \times 29) / (195{,}264 \times 23 \times 24) = \mathbf{1.82}$$

Advanced technology vehicle incentives

Until model year 2017, electric vehicles (EV), plug-in hybrid electric vehicles (PHEV), and fuel cell vehicles (FCV) are counted as emitting 0 g/mi of CO_2 for the first 200,000 such vehicles produced per manufacturer each year.[3] Beginning with model year 2017, emissions for these vehicle types will be calculated as follows:

1) Electricity consumption (in watt-hours/mile) during the standard 2-cycle test will be measured.
2) The consumption value will then be adjusted to account for losses during electricity transmission and charging (divide by 0.93 to account for transmission losses; divide by 0.90 to account for losses while charging).
3) The adjusted consumption value (in watt-hours/mile) is then multiplied by the average upstream GHG emission rate for electric power plants in the U.S. (0.642 g/watt-hour) to determine the effective GHG emission rate (in g/mi).
4) The final GHG emission rate (in g/mi) is determined by subtracting the average upstream GHG emission rate for a comparable gasoline vehicle from the effective GHG emission rate calculated in step 3.

For model years 2017 to 2021, three alternative-technology vehicle types are allowed to use an incentive multiplier so that each vehicle produced can count more than once for compliance calculations. These multipliers are shown in Table 2 (adapted from Table III-15, EPA/NHTSA, 2012).

Table 2
Incentive multipliers allowed, by vehicle type, for model years 2017 through 2021 (adapted from Table III-15, EPA/NHTSA, 2012).

Model year	Vehicle type	
	EV and FCV	PHEV
2017-2019	2.00	1.60
2020	1.75	1.45
2021	1.50	1.30

[3] A manufacturer that sold 25,000 or more of these vehicle types during model year 2012 may count the first 300,000 such vehicles produced each year until model year 2017.

An example of calculating credits for a fleet that includes PHEVs is shown in Table 3 (adapted from Table III.E.5-2, EPA/NHTSA, 2010). In the example, a manufacturer produced 500,000 vehicles: 475,000 conventional vehicles averaging 290 g/mi, and 25,000 PHEVs averaging 80 g/mi. (For the PHEV vehicle production used in these examples, 15,625 vehicles were hypothetically produced, resulting in 25,000 vehicles for the credit calculations after applying the 1.60 multiplier from Table 2.) The other values and formulas used in Table 3 are continuations of the example first presented in Table 1.

Table 3
Example for a hypothetical car manufacturer: earning basic and advanced technology credits (adapted from Table III.E.5-2, EPA/NHTSA, 2010).

Variable	Value or formula	MPG	CO_2	Total credits
Total production	475,000 vehicles (conventional)	30.6	290 g/mi	-
	25,000 vehicles (PHEV)	111.1	80 g/mi	-
Fleet average	[(475,000 x 290) + (25,000 x 80)] / 500,000	31.7	280 g/mi	-
Fleet standard	determined by footprints of vehicles produced	29.6	300 g/mi	-
Lifetime miles*	195,264 mi/vehicle	-	-	-
Credits	[(300 – 280) x 500,000 x 195,264] / 1,000,000	-	-	1,952,640 Mg

* The value used in this example applies to passenger cars for model years 2017-2025. The corresponding value for light trucks is 225,865 miles.

Advanced technology vehicle incentives for full-size pickup trucks

Beginning with model year 2017, a new incentive category is available for full-size pickup trucks (as defined within the regulations). Two paths exists for attaining credits within this advanced technology category, either by employing 1) hybrid electric vehicle (HEV) technology, or 2) non-hybrid electric technology improvements (performance based). The credit options available for each path are similar in how they are applied. (A vehicle model may not earn credit for both HEV and performance-based improvements.)

For HEV technology, credit may be earned based on the type of technology installed. For mild hybrids, a credit of 10 g/mi is available for model years 2017-2021 if at least 20% of the full-size pickups for that manufacturer use the technology (increasing to 80% by model year 2021). For strong hybrids, a credit of 20 g/mi is available for model years 2017-2025 if at least 10% of the full-size pickups for that manufacturer use the technology (with no requirement to increase penetration rates over time).

If GHG emissions and fuel economy are improved using non-HEV technology, analogous performance-based credits are available for outperforming the applicable CO_2 targets. A credit of 10 g/mi is available for model years 2017-2021 if the applicable CO_2 target is surpassed by at least 15% and at least 15% of the full-size pickups for that manufacturer use the applicable technology (increasing to 40% by model year 2021). A credit of 20 g/mi is available for model years 2017-2025 if the CO_2 target is surpassed by 20% or more and at least 10% of the full-size pickups for that manufacturer use the applicable technology (with no requirement to increase penetration rates over time).

Flexible fuel vehicle credits

Until model year 2016, emissions for "dual-fueled" flexible-fuel vehicles (FFV)[4] are calculated by averaging 1) the CO_2 emissions when using gasoline and 2) the CO_2 emissions when using the alternative fuel multiplied by 0.15. (This assumes equal weighting of each condition or that each fuel type will be used 50% of the time.) The FFV "credit" during these model years is represented by the 0.15 multiplier used to reduce the emissions value for the alternative fuel condition. For example, if a manufacturer produces a vehicle that emits 280 g/mi using gasoline and 260 g/mi using E85, the calculation to determine the final emissions value is as follows (adapted from EPA/NHTSA, 2010):

FFV emissions value (pre-2016) = [280 g/mi + (260 g/mi x 0.15)] / 2 = **160 g/mi**

For model years 2012 through 2014, the maximum number of FFV credits that may be claimed is 1.2 mpg per vehicle, dropping to 1.0 mpg for model year 2015. Beginning with model year 2016, emissions for these vehicle types will be based on the actual CO_2 emission values when calculating a vehicle model's average rating. For model years 2016 and beyond, the EPA will assume that FFVs are normally operated on conventional fuel (gasoline), with insignificant usage of the alternative fuel, and will use the CO_2 emissions value generated when operating on conventional fuel only. However, if a manufacturer feels that this assumption is incorrect for a specific vehicle model, two options are available to correct the emissions value for that model.

Under the first option, a manufacturer may request that the EPA establish a weighting factor, based on a determination of likely proportions of conventional fuel versus alternative fuel usage for a specific alternative fuel type. This weighting factor would be available to all manufacturers for correcting emissions calculations for that fuel type. The second option allows each manufacturer to determine this weighting factor independently (following EPA guidelines), based on an accurate assessment of actual proportions of real-world usage of each fuel type. Regardless of which method is used to determine the weighting factor, the formula for determining a corrected emissions value would be as follows (adapted from EPA/NHTSA, 2010):

[4] FFVs typically operate on gasoline (100%), E85 (85% ethanol, 15% gasoline), or a combination of the two fuel types.

$$\textit{Corrected FFV emissions value} = (Wt_{conv} \times CO2_{conv}) + (Wt_{alt} \times CO2_{alt})$$

Where:

Wt_{conv}	=	Weighting factor (proportion of use) for conventional fuel
$CO2_{conv}$	=	CO_2 emissions using conventional fuel
Wt_{alt}	=	Weighting factor (proportion of use) for alternative fuel
$CO2_{alt}$	=	CO_2 emissions using alternative fuel

Using the values from the previous example for calculating pre-2016 FFV emissions, the default emissions value for that same vehicle beginning in model year 2016 would be 280 g/mi (as opposed to 160 g/mi for pre-2016 vehicles). However, if it is determined that the actual proportion of conventional fuel to alternative fuel usage is, for example, 60% versus 40%, respectively, then the calculation for the corrected emissions value is as follows:

$$\textit{Corrected FFV emissions value} = (0.6 \times 280 \text{ g/mi}) + (0.4 \times 260 \text{ g/mi}) = \mathbf{272\ g/mi}$$

An example of calculating credits for a fleet that includes FFVs is shown in Table 4 (adapted from Table III.E.5-3, EPA/NHTSA, 2010). In the example, a manufacturer produced 500,000 vehicles: 445,000 conventional vehicles, 25,000 PHEVs, and 30,000 FFVs. The pre-2016 FFV emissions value example is used in this calculation. The other values and formulas used in Table 4 are continuations of the examples first presented in Tables 1 and 3.

Table 4
Example for a hypothetical passenger car manufacturer: earning basic, advanced technology, and flexible fuel vehicle credits (adapted from Table III.E.5-3, EPA/NHTSA, 2010).

Variable	Value or formula	MPG	CO_2	Total credits
Total production	445,000 vehicles (conventional)	30.6	290 g/mi	-
	25,000 vehicles (PHEV)	111.1	80 g/mi	-
	30,000 vehicles (FFV)	55.5	160 g/mi	-
Fleet average	[(445,000 x 290) + (25,000 x 80) + (30,000 x 160)] / 500,000	32.7	272 g/mi	-
Fleet standard	determined by footprints of vehicles produced	29.6	300 g/mi	-
Lifetime miles*	195,264 mi/vehicle	-	-	-
Credits	[(300 – 272) x 500,000 x 195,264] / 1,000,000	-	-	2,733,696 Mg

* The value used in this example applies to passenger cars for model years 2017-2025. The corresponding value for light trucks is 225,865 miles.

Dedicated alternative fuel vehicle credits

For vehicles using a dedicated alternative fuel source (i.e., the vehicle exclusively uses the alternative fuel and does not use gasoline; not "dual fueled"), the credit calculation is similar to FFVs, except that average emissions using gasoline are not included in the calculation. Until 2016, the "credit" multiplier of 0.15 is simply applied to the alternative fuel emissions value for that vehicle model. For example, if a manufacturer produces a vehicle that emits 220 g/mi using a dedicated alternative fuel (such as compressed natural gas [CNG]), the calculation to determine the final emissions value is as follows (adapted from EPA/NHTSA, 2010):

Alternative fuel emissions value (pre-2016) = 220 g/mi x 0.15 = **33 g/mi**

Beginning with model year 2016, emissions for these vehicle types will be based on the actual CO_2 emission values when calculating a vehicle model's average rating.

An example of calculating credits for a fleet that includes dedicated alternative fuel vehicles is shown in Table 5 (adapted from Table III.E.5-4, EPA/NHTSA, 2010). In the example, a manufacturer produced 500,000 vehicles: 425,000 conventional vehicles, 25,000 PHEVs, 30,000 FFVs, and 20,000 CNG-fueled vehicles. The other values and formulas used in Table 5 are continuations of the examples first presented in Tables 1, 3, and 4.

Table 5
Example for a hypothetical car manufacturer: earning basic, advanced technology, flexible fuel vehicle, and dedicated alternative fuel vehicle credits (adapted from Table III.E.5-4, EPA/NHTSA, 2010).

Variable	Value or formula	MPG	CO_2	Total credits
Total production	425,000 vehicles (conventional)	30.6	290 g/mi	-
	25,000 vehicles (PHEV)	111.1	80 g/mi	-
	30,000 vehicles (FFV)	55.5	160 g/mi	-
	20,000 vehicles (CNG)	269.3	33 g/mi	-
Fleet average	[(425,000 x 290) + (25,000 x 80) + (30,000 x 160) + (20,000 x 33)] / 500,000	34.0	261 g/mi	-
Fleet standard	determined by footprints of vehicles produced	29.6	300 g/mi	-
Lifetime miles*	195,264 mi/vehicle	-	-	-
Credits	[(300 – 261) x 500,000 x 195,264] / 1,000,000	-	-	3,807,648 Mg

* The value used in this example applies to passenger cars for model years 2017-2025. The corresponding value for light trucks is 225,865 miles.

Air conditioning related credits

Air conditioning-related credits may be generated in several ways, as described below in this section. However, these credits do not change the final fleet average for a manufacturer. Instead, these credits (when earned) are added to the current balance of credits or deficit created by the average fleet performance for that manufacturer. As with the credits described in the previous sections, air conditioning-related credits are calculated separately for the passenger-car fleets and light-truck fleets within a manufacturer. However, the resulting credits for both fleets are added together before inclusion in the final credit balance for a manufacturer. The inclusion of air-conditioning credits in a manufacturer's final credit balance is optional.

Leakage and refrigerant credits

Leakage and refrigerant credits can be earned by making improvements to the air conditioning (A/C) system to reduce or eliminate refrigerant leaks, and by substituting newer refrigerants with lower global warming potential (GWP) than current refrigerants. An example calculation for generating A/C leakage and refrigerant credits is shown below (adapted from EPA/NHTSA, 2010). In the example, an initial credit expressed in g/mi is determined. Then, the final A/C leakage credit is calculated by multiplying that initial credit by the number of vehicles produced, multiplied by the expected lifetime miles per vehicle (195,264 for passenger cars). The result is then divided by 1,000,000 to convert from grams to megagrams (Mg) of CO_2. The formulas are described in detail below. (The value of 1,430 in the first formula is the GWP of the current reference refrigerant, HFC-134a.)

$$\textit{Initial A/C leakage credit} = (\text{MaxCredit}) \times [1 - (\text{LeakScore}/\text{AvgImpact}) \times (\text{GWP}_{refrig}/1{,}430)] - \text{HLD}$$

Where:

MaxCredit	=	12.6 and 15.6 g/mi for passenger cars and light trucks, respectively. If low-GWP refrigerant is used, the values are 13.8 and 17.2 g/mi for passenger cars and light trucks, respectively.
LeakScore	=	Leakage rate of the A/C system per EPA methodology, in g/yr.
AvgImpact	=	Average current A/C leakage rate, using 16.6 and 20.7 g/yr for passenger cars and light trucks, respectively.
GWP_{refrig}	=	Global warming potential of the actual refrigerant used in the system.
HLD	=	High leak disincentive. The value is 0 until model year 2017. Starting in 2017, the HLD formulas are as follows:

Passenger cars: HLD = 1.8 x [(LeakScore – LeakThreshold) / 3.3]

Light trucks: HLD = 2.1 x [(LeakScore – LeakThreshold) / 3.3]

Where:

LeakThreshold	=	11.0 for air conditioning systems with a refrigerant capacity ≤ 733 g; otherwise LeakThreshold = (Refrigerant Capacity x 0.015) for air conditioning systems with a refrigerant capacity > 733 g, where Refrigerant Capacity is the maximum refrigerant capacity specified for the air conditioning system.

However, if GWP_{refrig} > 150 or if the calculated HLD < 0, then a value of 0 g/mi is used for HLD, or if the calculated HLD > 1.8 g/mi for passenger cars (2.1 g/mi for light trucks), then a value of 1.8 g/mi is used for HLD for passenger cars (2.1 g/mi for light trucks).

As with other credits, these credits must be converted from g/mi to total Mg, and passenger-car and light-truck fleet calculations are performed separately. The formula for converting to Mg is conceptually the same as with other credits:

Final A/C leakage credit = (Initial A/C leakage credit x Vehicles x VMT_{type}) / 1,000,000

Where:

Vehicles	=	Total number of vehicles produced with the A/C leakage improvement.
VMT_{type}	=	Lifetime vehicle miles traveled for the vehicle type (i.e., passenger car or light truck). Lifetime VMT is 195,264 for passenger cars and 225,865 for light trucks.

For example, if a manufacturer produces 500,000 passenger cars with improvements resulting in an improved A/C leakage rate of 15 g/yr, and employing a new refrigerant with a low-GWP of 200, the calculation for determining A/C leakage and refrigerant credits is as follows:

Initial A/C leakage credit = (13.8) x [1 – (15/16.6) x (200/1,430)] – 0 = **12.1 g/mi**

Final A/C leakage credit = (12.1 x 500,000 x 195,264) / 1,000,000 = **1,181,347 Mg**

As a result of these improvements, the manufacturer would be able to add 1,181,347 Mg of credits to its final balance.

Efficiency credits

Credits may also be earned by designing more efficient A/C systems that require lower demand on the engine during operation (and thus lower fuel consumption). The regulations currently contain a detailed menu of items and corresponding credits that a manufacturer may claim when improving A/C efficiency (see Table III.C.1-2, EPA/NHTSA, 2010; Table II-21, EPA/NHTSA, 2012). Examples include credits for efficiency improvements in compressors, condensers, or evaporators. Until model year 2017, the maximum total number of credits that may be claimed from any combination of items on the off-cycle menu is 5.7 g/mi (for both passenger cars and light trucks). Beginning with model year 2017, the maximum total number of credits that may be claimed is 5.0 g/mi for passenger cars and 7.2 g/mi for light trucks. As with other credits, these credits must be converted from g/mi to total Mg, and passenger-car and light-truck fleet calculations are performed separately. The formula for converting to Mg is conceptually the same as with other credits:

Total A/C efficiency credit = (Sum of efficiency credits x Vehicles x VMT_{type}) / 1,000,000

Where:

Vehicles	=	Total number of vehicles produced with the A/C efficiency improvement.
VMT_{type}	=	Lifetime vehicle miles traveled for the vehicle type (i.e., passenger car or light truck). Lifetime VMT is 195,264 for passenger cars and 225,865 for light trucks.

For example, if a manufacturer produces 500,000 passenger cars with the maximum allowed A/C efficiency credit (5.7 g/mi), the calculation for determining the total A/C efficiency credits is as follows:

Total A/C efficiency credit = (5.7 x 500,000 x 195,264) / 1,000,000 = **566,502 Mg**

As a result of these improvements, the manufacturer would be able to add 556,502 Mg of credits to its final balance.

Off-cycle technology credits

If a manufacturer makes improvements to a vehicle that result in CO_2 reductions not captured by the standard 2-cycle test, there are several options available to gain credit for such improvements. Currently, the manufacturer may demonstrate the improvement using either the standard 5-cycle test (comparing test results with and without the technology), or the manufacturer may develop (with EPA approval) an alternative test to demonstrate the reduced CO_2 output required to claim a new credit. Under both scenarios, the EPA will play a role in approving any credits generated by off-cycle technology. Furthermore, the regulation applicable to model years 2017 and beyond contains detailed menus of off-cycle technology items that a manufacturer may claim credits for, such as high-efficiency exterior lighting and idle start-stop technology, among others (see Table II-22 and Table II-23, EPA/NHTSA, 2012). The maximum number of credits that may be claimed from any combination of items on these menus is 10.0 g/mi. As with other credits, these credits must be converted from g/mi to total Mg, and passenger-car and light-truck fleet calculations are performed separately. The formula for converting to Mg is conceptually the same as with other credits:

Total off-cycle credits = (Sum of off-cycle credits x Vehicles x VMT_{type}) / 1,000,000

Where:

Vehicles	=	Total number of vehicles produced with the A/C efficiency improvement.
VMT_{type}	=	Lifetime vehicle miles traveled for the vehicle type (i.e., passenger car or light truck). Lifetime VMT is 195,264 for passenger cars and 225,865 for light trucks.

For example, if a manufacturer produces 500,000 passenger cars with off-cycle credits totaling 5.0 g/mi, the calculation for determining the total off-cycle credits is as follows:

Total off-cycle credit = (5.0 g/mi x 500,000 x 195,264) / 1,000,000= **488,160 Mg**

As a result of these improvements, the manufacturer would be able to add 488,160 Mg of credits to its final balance.

Possible carbon-capture technology credits

Effects of CO_2 capture on vehicle fuel economy and CAFE rating

On-board carbon capture and sequestration ("on-board CCS") technology allows for an overall decrease in CO_2 emissions with only a small reduction in the underlying fuel economy performance for a particular vehicle model.[5] Using either pre-combustion or post-combustion carbon sequestration methods (Sullivan and Sivak, 2012), the total CO_2 tailpipe emissions of a vehicle are reduced. For the purposes of CAFE performance (as opposed to GHG performance), this net benefit from CO_2 reductions should result in credit for a higher "effective" CAFE rating for that vehicle model, as reduced tailpipe emissions from on-board CCS are independent from improvements in actual fuel economy.

Credit calculation for CO_2 capture technology

Based on the likely embodiments of on-board CCS and the expected method of operation (Sullivan and Sivak, 2012), it seems likely that reductions in CO_2 emissions would be captured under the standard 2-cycle test in the applicable GHG and CAFE regulations (or possibly under the 5-cycle test within the "Off-cycle technology credit" category, if not adequately captured by the standard 2-cycle test). In the discussion below, it will be assumed that on-board CCS performance would not be affected (positively or negatively) when operating under the additional test conditions of the 5-cycle test. Consequently, we will assume that any benefit would be captured by the more basic 2-cycle test. (However, corrections based on the 5-cycle test would be analogous to those described here.)

Assuming that any benefit is captured by the 2-cycle test, a correction in the CAFE rating (in mpg) for a vehicle is required to reflect the final, actual CO_2 emissions levels using on-board CCS. Using the conversion factor adopted by the EPA (2014) of 8,887 grams of CO_2 emitted per gallon of gasoline consumed, a simple calculation to convert the final CO_2 emissions performance (in g/mi) to an equivalent fuel economy value (in mpg) can be performed. (The basic procedure for converting between CO_2

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[5] To simplify the discussion, no change in fuel economy will be assumed. Once a specific fuel economy reduction is known for a particular embodiment of the technology, an appropriate correction to the calculations could easily be made.

emissions and fuel economy is described in the CAFE regulations [EPA/NHTSA, 2010; 2012].) The formula would be as follows:

Final corrected fuel economy = 8,887 / Final CO_2 emissions

Where:

Final CO_2 emissions = The actual (measured) CO_2 emissions (in g/mi) when using on-board CCS technology.

For example, if a manufacturer produces a vehicle model with actual fuel economy performance of 29.6 mpg (equivalent to 300 g/mi) for CAFE purposes, but employs on-board CCS technology that reduces CO_2 emissions by 20% (resulting in actual emissions of 240 g/mi) while maintaining the same fuel economy (29.6 mpg), the calculation for determining the corrected fuel economy rating would be as follows:

Final corrected fuel economy = 8,887 / 240 = **37.0 mpg**

In other words, as a result of these improvements, the manufacturer would be able to adjust the actual CAFE rating of 29.6 mpg up by 7.4 mpg, for a final corrected CAFE rating of 37.0 mpg for each such vehicle model produced.

Table 6 presents a matrix of corrected ("effective") CAFE ratings versus actual CAFE ratings, based on varying levels of carbon capture. Capturing 50% of the carbon emissions results in a doubling of the effective fuel economy (calculated based on the final carbon emissions). However, CO_2 emissions (and fuel consumption) are not a linear function of fuel economy. Figure 1 shows CO_2 emissions and fuel economy at various levels of carbon capture (using 20 mpg as the baseline fuel economy value at 0% captured). Note that while CO_2 emissions decrease at a linear rate, the corresponding fuel economy values increase at an exponential rate.

Table 6
Corrected CAFE ratings versus actual CAFE ratings (both in mpg), based on level of carbon capture. (The corresponding CO_2 emissions levels, in g/mi, are shown in parentheses.)

Actual CAFE rating (CO_2 value)	Percent CO_2 captured							
	15%	20%	25%	30%	35%	40%	45%	50%
20 (444)	23.5 (377)	25.0 (355)	26.7 (333)	28.6 (311)	30.8 (289)	33.4 (266)	36.4 (244)	40.0 (222)
25 (355)	29.4 (302)	31.3 (284)	33.3 (267)	35.7 (249)	38.5 (231)	41.7 (213)	45.5 (195)	50.0 (178)
30 (296)	35.3 (252)	37.5 (237)	40.0 (222)	42.9 (207)	46.2 (193)	50.0 (178)	54.6 (163)	60.0 (148)
35 (254)	41.2 (216)	43.8 (203)	46.7 (190)	50.0 (178)	53.8 (165)	58.3 (152)	63.6 (140)	70.0 (127)
40 (222)	47.1 (189)	50.0 (178)	53.3 (167)	57.1 (156)	61.5 (144)	66.7 (133)	72.8 (122)	80.0 (111)

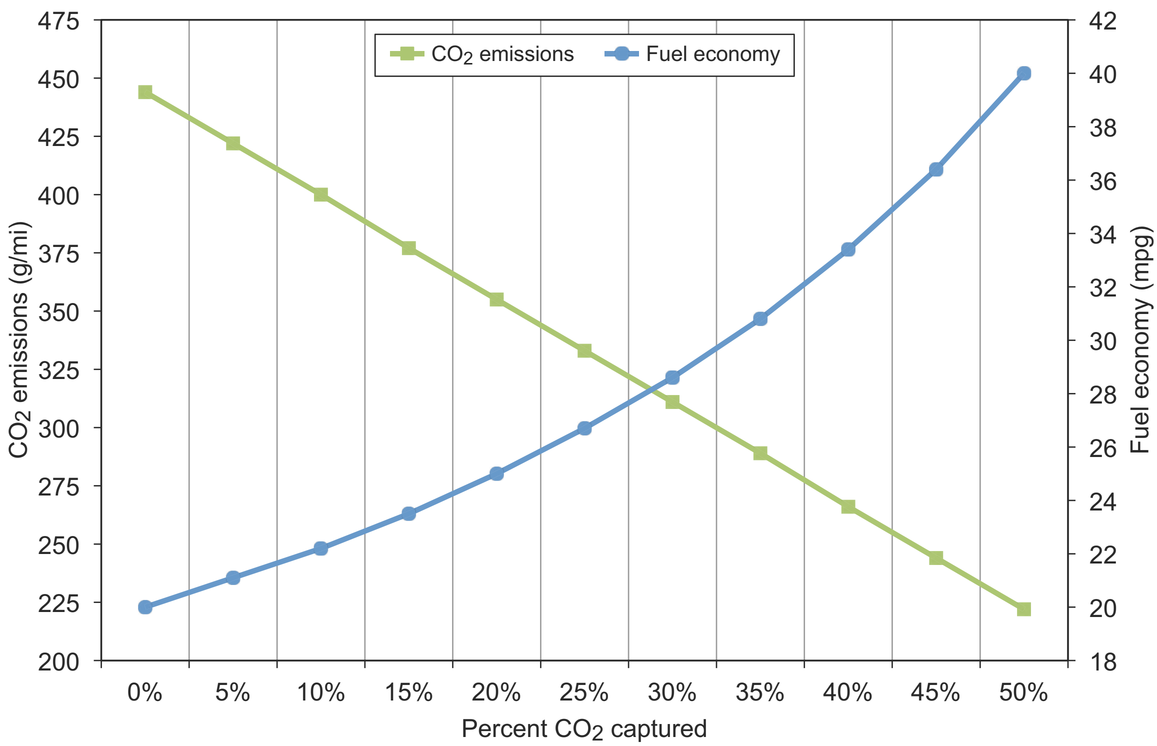

Figure 1. CO_2 emissions and fuel economy at various levels of carbon capture (using 20 mpg as the baseline fuel economy value at 0% captured).

Discussion

As outlined in the CAFE credit overview of this report, a variety of options exist for vehicle manufacturers to earn credits for exceeding the fleet fuel economy standard or for vehicle technologies that reduce GHG emissions. New, GHG-reducing technologies like on-board CCS fit within the current scheme of credit options described in the combined GHG and CAFE regulations. The benefits of on-board CCS appear likely to be captured during the standard 2-cycle test administered for CAFE compliance purposes. (The ability to capture the benefits of on-board CCS during the main test of the CAFE reporting system would avoid the need to demonstrate the expected CO_2 reductions using one of the other methods available within the credit program.) As described in this report, a simple calculation to correct the final fuel economy value used for CAFE compliance is needed (to reflect the resultant benefits of reduced CO_2 emissions), although this specific correction is not yet reflected in the current regulations.

Importantly, the benefits in terms of reduced emissions and overall credits (in g/mi) are substantially larger than the other optional credits available in the CAFE credit program for gasoline-powered vehicles. (Alternative-fueled vehicles such as PHEV and EV currently offer the greatest benefits in terms of overall reductions in CO_2 emissions.) Table 7 shows a comparison of other optional credits versus on-board CCS. The credits in Table 7 represent the maximum possible credits per vehicle allowed in the respective category, with the exception of the on-board CCS examples, which assume either a 20% or 40% capture rate. The emissions reduction for each credit category is based on a passenger car with a fuel economy rating of 20 mpg.[6] The on-board CCS benefits at 20% capture (88.8 g/mi) are more than 6 times the maximum available credits in the next highest category (A/C leakage and refrigerant credits, 13.8 g/mi), and approximately 3 times the sum of maximum credits available across the three optional credit categories used for comparison (29.5 g/mi).

The calculations presented assume no fuel economy reduction due to the operation of on-board CCS. Once a specific fuel economy reduction is known, an appropriate correction to the calculations could easily be made.

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[6] Operation of on-board CCS technology will result in some penalty to fuel economy. To simplify the example shown here, no change in fuel economy is assumed.

Table 7
Comparison of other credit options versus on-board CCS, with examples of CO_2 emissions reductions based on a 20-mpg passenger car.

Credit category	Credit per vehicle (g/mi)	Emissions reduction
A/C efficiency (max. credit)	5.7 g/mi	1.3%
Off-cycle technology (max. credit)	10.0 g/mi	2.3%
A/C leakage and refrigerant (max. credit)	13.8 g/mi	3.1%
On-board CCS (20% capture)*	88.9 g/mi	20.0%
On-board CCS (40% capture)*	177.7 g/mi	40.0%

* Assuming no change in the underlying fuel economy.

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