WHITE PAPER

MARCH 2018

HOW WILL OFF-CYCLE CREDITS IMPACT U.S. 2025 EFFICIENCY STANDARDS?

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ACKNOWLEDGMENTS

This work is conducted with generous support from the Blue Marble Fund. John German, Drew Kodjak, and Uwe Tietge provided critical reviews on an earlier version of the report. Any errors are the authors' own.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Regulations are in place in most major vehicle markets around the world to ensure that new vehicles achieve lower carbon dioxide (CO_2) emissions and fuel use per mile. The U.S. standards are projected to decrease emissions by about 4% per year from 2016 to 2025. This means the regulated fleet of new vehicles will average 51 miles per gallon (mpg) on the regulatory test cycle. Due to various crediting provisions and the gap between the official test cycle and real-world operation, the associated consumer label fuel economy is expected to increase from approximately 25 mpg in 2016 to 35 mpg in 2025.

An important crediting provision in the U.S. regulation, but one that has not been studied adequately, is the off-cycle program. The intent of the off-cycle crediting program is to identify and reward technologies that deliver real-world benefits but are insufficiently counted on the official test cycle. This study brings the U.S. off-cycle credit program into clearer view. Our analysis shows how the off-cycle credits were used in model years 2015 and 2016, and assesses trends among automakers with the most credits. We believe this is the first study to examine the potential for greater use of credits through the 2025 vehicle efficiency and CO_2 regulation.

Figure ES-1 illustrates the projected decrease in new light-duty vehicle emissions from 268 grams of CO_2 per mile (g/mi) in 2016 to 173 g/mi in 2025. Based on emerging trends in off-cycle credit use, they are expected to make up a much greater percentage of automakers' vehicle compliance through 2025. Off-cycle technology credit use of 3 g/mi in 2016 amounts to just 3% of the 95 g/mi reduction required for 2016–2025. Based on our analysis, increased off-cycle credit use through 2025 amounts to 18% of regulated CO_2 reductions in model year 2025, with error bars from a low of 11% to a high of 26%. The remainder of the CO_2 reductions are expected to come from air-conditioning credits (23%, the maximum for such use) and vehicle efficiency improvements that are counted over the regulated test procedure (the remaining 50%–66% of regulated CO_2 reductions). These findings indicate that off-cycle credit use in 2025 is 3.7 to 9.3 times the credit use projected by the latest U.S. Environmental Protection Agency regulatory analysis.

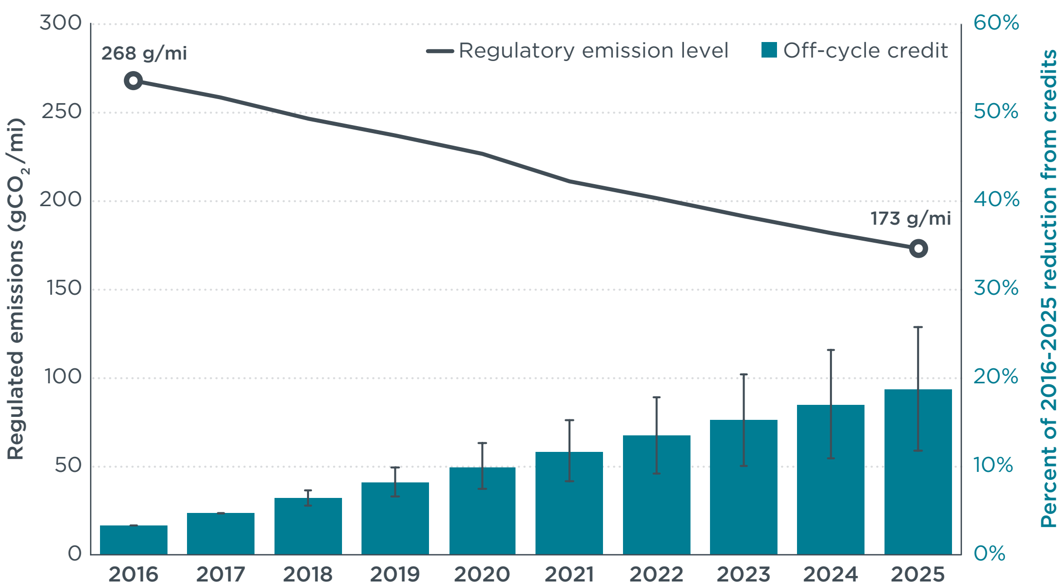

Figure ES-1. Increase in off-cycle credit use as a percentage of regulated CO_2 reduction.

Based on this analysis, the developments and potential impact of the off-cycle credit program are far greater than generally understood by policymakers, researchers, and even the applicable regulatory agencies. We highlight the following three high-level findings:

Off-cycle credit use is likely to greatly increase by 2025. Although average off-cycle credit use was just 3 g/mi in 2016, pathways for more credit have opened up. Individual automakers have received credits in 14 separate areas. Each off-cycle area amounts to less than 0.6 g/mi fleetwide, but leading companies have received from 1 to more than 4 g/mi in credit in 11 different technology areas. Companies such as BMW, Fiat Chrysler, Ford, and Jaguar Land Rover have led in average credit use through 2016, and credit requests proliferate, indicating automakers are looking to capitalize more broadly. Based on our analysis, off-cycle credit use could increase to 10–25 g/mi in CO_2 reduction.

Off-cycle credit use greatly reduces the deployment of other efficiency technology. Off-cycle credits, under current trends, could amount to a substantial portion of industry compliance action in the later years of the 2025 regulations. The increased use of off-cycle credits would amount to 26%–65% of the expected CO_2 reduction from the 2022–2025 regulations that are being investigated in the midterm evaluation. In terms of deploying more advanced technologies, this is the equivalent of delaying implementation of the 2025 standards by several years and lowering consumer label fuel economy from 35 mpg to 31–33 mpg for new 2025 vehicles.

Existing off-cycle credits have not been properly validated and applied. There are numerous problems and uncertainties with the off-cycle program. Such issues include the use of absolute credits instead of percentage reductions, high uncertainty of real-world operation of the technologies, allowance of credit for technologies that occur regardless of the off-cycle program, lack of transparency regarding models the technologies are employed upon, unknown synergies between associated credits, and lack of resources to validate manufacturer claims.

Based on the above findings, we find that the off-cycle program offers an important concept with well-intentioned goals, but the program has proceeded without the data necessary to make it robust and reliably linked with real-world benefits. We emphasize the following two policy recommendations:

In the near-term, a more transparent system with clear constraints would lead to off-cycle program credibility. Without transparently sharing data about the applicable vehicle models with the off-cycle credits, it creates the appearance that automakers and regulatory agencies lack confidence in their real-world benefits. A clearer statement of principles and constraints on credits, for example additionality and minimum data requirements, will help ensure that petitions and the approval rationale will not evolve and inappropriately expand over time. Considering the great uncertainty regarding the off-cycle program's real-world benefits and lack of data validation, clear constraints on the use of off-cycle credits for compliance flexibility are in order. A reasonable constraint would be to limit the program's impact to 3% of the regulated CO_2 emission target, in line with the original 10 g/mi limit on preapproved credits based on simulated and tested vehicles at that time. Such a limit would be reasonable through 2025, while longer-term issues are addressed with the collection of more data.

A viable long-term off-cycle program would show a clear commitment to comprehensive real-world data validation. A program with comprehensive, statistically sampled data that covers representative nationwide vehicles and year-round driving and environmental conditions would be able to demonstrate much greater fidelity between the off-cycle program and real-world results. With improvements, a new-and-improved off-cycle program could help standardize off-cycle credits, transparently share data, ensure consistent calculations of their benefits, and also lead to better credit certainty and quicker approvals for manufacturers. A truly robust off-cycle program would be linked with fleetwide assessment of whether the gap between real-world and test-cycle fuel economy is shrinking; as the test-to-real-world gap increases it greatly undermines the off-cycle program and the fuel economy program more broadly. Without improvements, the U.S. CO_2 program runs the risk of a much greater issue—that a new testing procedure will be the only viable correction to the continued divergence between the regulatory goals and real-world outcomes.

Although this study is focused on the U.S. situation, the topic of off-cycle credits is pertinent around the world. Efficiency and emission standards are critical tools to steer the fleet toward more advanced technologies to help achieve national and local climate change and air quality goals. As real-world vehicle emission performance continues to lag expected regulatory benefits, opaque and poorly understood regulatory provisions like the U.S. off-cycle program exacerbate such concerns and accelerate the call to shift to an all-electric fleet. Other regulatory agencies around the world would be wise to take the uncertain U.S. off-cycle program as an example of a path to avoid until full transparency, clear principles and constraints, and rigorous real-world data validation are assured.

I. INTRODUCTION

Vehicle efficiency regulations are in place in most major automobile markets around the world. Standards in Brazil, Canada, China, Europe, India, Japan, Mexico, Saudi Arabia, South Korea, and the United States apply to more than 80% of global automobile sales. These standards regulate the new vehicle fuel economy, fuel consumption, or carbon dioxide (CO_2) emissions over particular, established testing procedures.

Efficiency standards typically require that new vehicles add efficiency technologies that reduce fuel use or CO_2 per mile by roughly 3% per year, as averaged across the new vehicle fleet. The U.S. and Canadian standards apply through 2025. The standards in the European Union apply to vehicles through 2021, and new standards proposed in late 2017 apply through 2030. In the near term, the standards are promoting primarily engine technologies such as turbocharging, direct injection, cylinder deactivation; transmission technologies such as 8-speed and dual-clutch; and load reduction technologies such as lightweighting, improved aerodynamics, and reduced rolling resistance. Over the longer term, beyond 2025, advanced hybrid and plug-in electric vehicle technologies become more important for compliance with the standards.

The efficiency and emissions characteristics of new vehicles are measured using prescribed laboratory procedures that simulate a variety of speeds and conditions to approximate how vehicles are driven. Vehicles, and their particular efficiency technologies, operate in a world with much more diverse conditions than on the test cycle. As a result, efficiency technologies could generate more or less fuel-saving benefit in the real world than on the test. Some technologies can deliver greater efficiency benefit than what they do on the prescribed U.S. regulatory test procedure. For example, on-vehicle solar panels that use solar energy to power auxiliary electrical devices in the real world would receive no value on tested vehicles. Active grill shutters that open and close to control the airflow through the grill in the front of the vehicle can provide aerodynamic benefits in the real world beyond those realized in the laboratory test procedure.

Because several of these off-cycle technologies were known during the development of the 2016 and 2025 U.S. regulations, off-cycle credit provisions were directly included in the rulemakings. The principle was that even though the regulations are developed based on the set procedure, with sufficient data as evidence of real-world benefits, efficiency technologies could receive off-cycle credits that would count toward automaker compliance with the standards. Following the finalization of the 2012–2016 standards, automakers called on the agencies to streamline the process for credits. The resulting 2017–2025 standards incorporate a predefined list of 12 technologies—which are eligible for up to 10 grams CO_2 per mile (g/mi) in credits in total—and more detailed guidelines for automakers to petition for more credit with additional data.

This assessment investigates the off-cycle provisions and the implications for their potential use through 2025. First, in Section II, we review background information, including overall trends with test-cycle and consumer fuel consumption in the United States and the use of off-cycle credits in various global regulations. Then, in Section III, we analyze the use of the off-cycle provisions by automakers in the United States based on the latest available 2015–2016 data and the regulatory assessment of the expected use of off-cycle credits to comply with the 2025 standards. Based on automakers' petitions for more off-cycle credits, and their likely incorporation of preapproved off-cycle credits, we assess the range of possible off-cycle credit use for 2017–2025 in Section IV. Finally, in Section V, we discuss the findings and associated issues, implications, and policy recommendations to ensure the off-cycle technology program is robust with a positive impact on energy and emissions.

II. BACKGROUND

Preceding our analysis of the U.S. off-cycle technology, we first review applicable background information. We include overall trends with test-cycle and consumer fuel consumption as the fleet sees the introduction of more fuel-efficient vehicles. We also briefly review the off-cycle credit systems in place across the various global regulations to provide broader context on the topic.

TRENDS IN REAL-WORLD VERSUS TEST-CYCLE EFFICIENCY

The particular test procedures that are used in vehicle efficiency regulations have received increased scrutiny in the past several years. Much of the scrutiny has been due to on-road vehicle performance drifting further away from the tested regulatory values. The growing gap between regulatory and real-world data has received the most attention in Europe. Analysis of data on vehicles in Europe shows the divergence between regulatory test and real-world CO_2 has increased from 25% in 2010 to 42% in 2016 (Tietge, Mock, German, Bandivadekar, & Ligterink, 2017). A broader global analysis finds the keys to effective regulations include independent lab testing, conducting in-use surveillance testing, using more realistic test cycles and more rigorous procedures, and collecting more extensive real-world data to manage the test-to-real-world gap (Tietge, Diaz, Yang, & Mock, 2017).

The U.S. vehicle certification data indicate the trend in the United States is in the same direction as in Europe, but less severe. The harmonic average regulatory test-cycle fuel economy of all U.S. vehicles sold in 2016 was 32 miles per gallon (mpg). The consumer label fuel economy adjusts those values to provide an estimate of real-world driving, including factors such as more aggressive acceleration and use of air-conditioning, and for variable temperatures, both warmer and colder. The harmonic average consumer label for new vehicles sold in 2016 was 25 mpg. This implies fuel economy in mpg is 23% lower, and the inverse—fuel consumed per mile—is 31% higher, as experienced by consumers in the real-world compared to the test cycle.

Figure 1 shows how the divergence in fuel consumption increases with fuel economy across more than 1,200 certified model year 2016 vehicles from U.S. Environmental Protection Agency (EPA) data (U.S. EPA [EPA], 2017a). As shown, for the 25–30 mpg category data, the EPA estimate of consumer fuel economy is 23% higher than the test-cycle fuel economy. This is equivalent to saying the consumer fuel consumption is 31% higher than the test-cycle miles per gallon. The number of vehicle models associated with each range of fuel economy values is also shown on the horizontal axis. As shown for model year 2016, higher test-cycle fuel economy is associated with proportionally less consumer fuel efficiency benefit. These data illustrate a trend where automakers are increasingly deploying more efficiency technologies that further diverge from their test-cycle performance. These data provide important broader context, namely that efficiency technology impacts can deliver more or less benefit in the real world than on the test cycle on a percentage basis, and efficiency technologies more often do not deliver greater benefits outside the regulatory test cycle. Real-world data corroborate this trend over a 5-year period; comparing test-cycle to real-world data indicates an increasing gap between test-cycle and real-world fuel economy, from about 18% in 2009 to 24% in 2014 (Tietge, Diaz, et al., 2017).

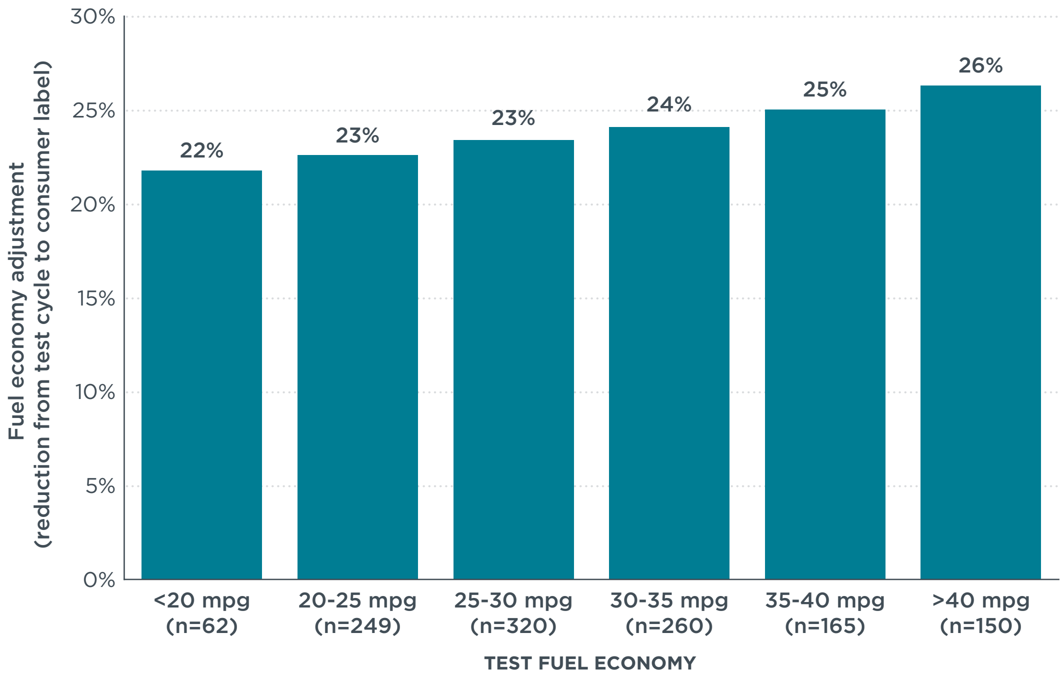

Figure 1. Fuel economy difference from test cycle to consumer label, for increasing test-cycle fuel economy for model year 2016 U.S. vehicles.

Understanding the link between the test-cycle and real-world fuel economy provides important background for the implications of the off-cycle program in the analysis below. The trend shown in Figure 1 is significant because the U.S. efficiency standards aim to increase the efficiency of all vehicle models. The model year 2025 CO_2 regulation would decrease test-cycle CO_2 emissions in new vehicles from about 268 g/mi in 2016 to 173 g/mi in 2025, which would increase test-cycle fuel economy from 32 mpg in 2016 to 51 mpg in 2025 (EPA, National Highway Transportation Safety Administration [NHTSA], & California Air Resources Board [CARB], 2016). However, factoring in air-conditioning credits, up to 21 g/mi CO_2 in 2025, the test-cycle fuel economy drops to about 46 mpg in that year. Based on the regulatory agencies' assumption that future consumer fuel economy remains 23% lower than test-cycle fuel economy, the corresponding new vehicle fuel economy in model year 2025 is 35 mpg.

OFF-CYCLE PROVISIONS IN INTERNATIONAL REGULATIONS

Even with the overall trend toward consumers getting less-than-test-cycle efficiency benefits, regulatory agencies have developed a system to provide credit for select technologies for their purported off-cycle benefits. California's 2009 proposed *cool cars* regulation, which ultimately was not finalized, was a precursor to some of the U.S. off-cycle provisions that followed in 2011. Off-cycle efficiency technologies were adopted into the European and U.S. CO_2 regulations in 2011 and 2012, respectively. Since then, off-cycle provisions with similar mechanisms have been used in nearly every major automobile efficiency or CO_2 regulation.

Table 1 summarizes the off-cycle provisions and their approximate magnitude in grams of CO_2 per mile within the efficiency regulations. The off-cycle credit schemes generally provide lists of applicable technologies and provisions for inclusion of additional technologies beyond the original list. The technologies that are listed within several of the off-cycle technology provisions are start-stop technology, active aerodynamic grill shutters, gearshift indicators, and tire-pressure monitoring. In every case there are provisions for automakers to apply for more credits for technologies by submitting additional data. In the case of South Korea, there is a cap of 6 g/mi of additional credit beyond the listed technologies. The details within the regulatory provisions all differ somewhat. For example, the U.S. regulation sets a low threshold of 0.05 g/mi for technology credit applications, whereas the EU regulation sets a higher threshold of 1.6 g/mi to limit credits to more substantial technologies.

Table 1. Vehicle efficiency regulation off-cycle technology credit

Regulation	Regulation adopted	Target year	Maximum credits from technology list (g CO_2/mi)	Percentage of regulation CO_2 reduction	Additional approvable technology beyond listed technology?
European Union	2011	2021	11	30%	Yes (not limited)
United States[a]	2012	2025	10	11%	Yes (not limited)
Brazil	2012	2017	6	29%	Yes (not limited)
South Korea	2014	2020	16	33%	Yes (limited to 6 g/mi)
China	2015	2020	19	27%	Yes (not limited)
Saudi Arabia[a]	2015	2020	10	22%	Yes (not limited)
India	2016	2022	15	55%	Yes (not limited)

Based on Yang & Bandivadekar (2017).
[a] *The United States and Saudi Arabia air-conditioning credits are excluded as they are treated separately from the off-cycle provisions.*

The allowances from the crediting systems represent a substantial amount of the overall regulated reduction in emissions for the regulatory programs. The exact extent of the off-cycle flexibilities depends on both how large the off-cycle allowances are and the overall required regulatory CO_2 reduction. In the United States, the maximum credits allowed from the predefined off-cycle technologies of 10 g/mi amounts to about 11% of the reduction in CO_2 emissions established by the 2016–2025 regulation targets, which are from 268 g/mi in 2016 to 173 g/mi in 2025. In the European Union, the 7 g/km (11 g/mi) maximum from eco-innovation credits represents up to 30% of the 2016–2021 regulated reduction in CO_2 emissions from 118 to 95 g/km. In China, the off-cycle technologies contribution of up to 19 g/mi represents 27% of the 2016–2020 emission reduction. In South Korea, the 22 g/mi would present up to 33% of the total regulated 2016–2020 reduction. Finally, in the case of India, using the maximum 15 g/mi in off-cycle technologies would amount to more than half of the regulated CO_2 reduction for 2017–2022 efficiency standards.

Text within the regulatory provisions helps to define how the agencies consider credit applications from the auto manufacturers. In the United States, there are 13 predefined technologies, which are quantified, in detail, below. Beyond these, automakers can apply for credits based on the difference between the regulatory test and consumer label *5-cycle* test or submit their own analysis for consideration. In the European Union regulation, the technologies' effect must not be covered within the regulatory certification procedure, and the automaker is accountable for technology CO_2 reductions. Also, air-conditioning, gearshift indicator, tire pressure, low rolling resistance tires, biofuels, and technologies under driver control are excluded from European eco-innovation credits. Several of these technologies that are excluded from the European system are allowed in the Chinese and South Korean systems. The uncertainty about which technologies are being deployed, and how much credit they may receive under what procedures, provides additional international motivation for this U.S.-based study.

III. ANALYSIS OF OFF-CYCLE TECHNOLOGIES

This section assesses the baseline use of off-cycle technologies in new U.S. vehicles in model year 2015 and 2016, the latest two years for which compliance data were available. Given the nearly unlimited variability of driving conditions, habits, and patterns, determining exact and robust off-cycle impact is difficult. Ideally, an off-cycle credit would be valued according to real-world nationwide, year-round fleet average conditions based on sufficient, reliable, and representative data. Such data have been either nonexistent or scarce. As a result of such difficulties, the efficiency and CO_2 standards were developed to be achievable without requiring deployment of off-cycle vehicle technology. Instead, flexibility provisions for off-cycle technology credits were adopted where there is sufficient data showing off-cycle benefits. The EPA initially placed the burden of proof on the manufacturers supplying such data within the 2012–2016 standards. Manufacturers seeking off-cycle credits had to show that the benefits of the off-cycle technology beyond the 2-cycle test are demonstrable on either the 5-cycle test, which has long been used for consumer fuel economy labels, or under an alternate methodology that is open to public comment and approved by EPA.

The EPA, the National Highway Traffic Safety Administration (NHTSA), and automakers then worked toward a clearer understanding of how the off-cycle credit technology program could more effectively function as they worked toward the next phase of standards. To this end, the regulatory agencies' Supplemental Notice of Intent in August 2011 indicated they would develop a preapproved and predefined list of at least six technologies with established off-cycle credit values for model year 2017–2025 standards. As described in the notice, the total off-cycle CO_2 grams per mile credit from the preapproved list for any given model year would not be allowed to exceed a 10 g/mi impact on the company's combined fleet average. Automakers would still be able to apply for additional credits beyond the minimum credit value of listed technologies with sufficient supporting data.

In 2012, EPA and NHTSA greatly increased automakers' access to off-cycle credits in their adopted 2017–2025 regulatory provisions. EPA streamlined the off-cycle credit evaluation process by creating a preapproved menu of credits for 13 technology areas, essentially eliminating case-by-case testing for those technologies. Automakers could receive credit simply by indicating they were using the applicable technologies. Also, NHTSA introduced equivalent fuel consumption credits to automakers for the off-cycle technologies to align with EPA's CO_2 credits. These credits were then made available for new vehicles as early as model year 2014 and continuing through 2025. A cap of 10 g/mi in predefined off-cycle credit technologies on average across a manufacturer's fleet was finalized, and automakers could apply for additional credit beyond the 10 g/mi cap.

REFERENCE OFF-CYCLE CREDIT USE

Within the 2017–2025 standards rulemaking, EPA has established default CO_2 credit values for 13 preapproved off-cycle technologies. Several of these technologies are scalable and some have maximum values based on application and use. Based on the EPA compliance data (2016a, 2018a), the maximum credit value for each of these technologies is summarized in Table 2. Also shown in the table are the estimated totals of vehicles in the most recent model year with the applicable technology and the associated fleet-average credits, based on the same EPA reports. The most recent data year is model year 2016 for most technologies; however, for the thermal control technologies, the last year with detailed technology credit reporting was model year 2015. Most of the technologies could attain a maximum of 1 to 4 g/mi for each vehicle they are deployed on. However, the maximum per-vehicle credit levels are not generally deployed, and most of the technologies are deployed on less than half of the more than 16 million light-duty vehicle sales in 2015 and 2016. Most the technologies in the table are part of the preapproved list of off-cycle credit technologies. The exceptions are the final two technologies, which have been approved based on data submitted by General Motors (GM), as reported by EPA.

Table 2. Off-cycle technologies, credits, and use

Off-cycle technology		Maximum per-vehicle credits (g/mi)		Fleetwide reported credit usage in most recent year available		
		Cars	Light trucks	Estimated annual vehicle sales with credit	Average credit on vehicles with technology (g/mi)	Fleet average credit across all vehicles (g/mi)
Active aerodynamics[a]	Grill shutters	0.9	1.6	3,300,000	0.8	0.2
	Ride height adjustment	0.9	1.6	65,000	0.5	<0.1
Thermal control[b]	Passive cabin ventilation	1.7	2.3	3,900,000	2.0	0.5
	Active cabin ventilation	2.1	2.8	380,000	2.2	0.1
	Active seat ventilation	1.0	1.3	2,000,000	1.2	0.1
	Glass or glazing	2.9	3.9	8,700,000	1.2	0.6
	Solar reflective surface coating	0.4	0.5	2,200,000	0.4	0.1
Powertrain warm-up	Active engine warm-up	1.5	3.2	3,300,000	2.4	0.5
	Active transmission warm-up	1.5	3.2	3,700,000	2.0	0.5
Other	Engine idle stop	2.5	4.4	1,600,000	2.3	0.3
	High efficiency exterior lights	1.0	1.0	9,900,000	0.3	0.2
	Waste heat recovery	0.7	0.7	0	0.1	0.0
	Solar panel(s)	3.3	3.3	1,000	2.6	<0.1
Off-menu[c]	Electric heater circulation pump	1.6	-	90,000	1.6	<0.1
	Variable crankcase suction compressor	1.4	1.4	1,300,000	1.1	0.1

Source: U.S. EPA (2016a, 2018a)
[a]*Active aerodynamics scaled to a 5% drag reduction.*
[b]*Thermal control technologies combined are limited to a maximum of 3.0 g/mi for cars, 4.3 g/mi for light trucks; reported credits are for model year 2015, the latest data available for this category.*
[c]*These technologies have been granted credit based on General Motors' petitions to the EPA; these are the maximum credit values achieved, but higher values are possible.*

Including all credits, averaged across all vehicles in the fleet, the average model year 2016 off-cycle credit use was approximately 3 g/mi. In addition to the maximum technology credits shown, there is also an important maximum constraint for thermal control technologies. For this category, up to 3.0 g/mi (for cars) and 4.3 g/mi (for light trucks) in credits are allowed per vehicle, due to theoretical maximum benefits based on representative environmental, temperature, and driving conditions experienced by vehicles. The summary data in the table show that, although some technologies—specifically glazing and high efficiency lighting—were implemented on more than half of new vehicle sales, most technologies show relatively low penetration levels. Off-cycle technologies with fleetwide penetration between 20% and 30% include grill shutters, passive cabin ventilation, active engine warm-up, and transmission warm-up. Technologies at 10%–20% penetration levels include solar reflective paint, active seat ventilation, and engine idle start-stop. We examine the company-specific credit use of these technologies in more detail below.

We note that some off-cycle credits have not yet been fully accounted for or reported in Table 2. For example, Ford has submitted its request for glazing, solar reflective paint, and alternator credits that have been granted to other automakers. These and other credits have been approved, but not all of them are reported in the latest EPA data (2018a). In addition, companies continue to apply for and receive credits for 2009–2016 model years, so more credits could be reported later. We provide further explanation below on credit requests and approvals by technology. As a result, the credits shown in the table likely underestimate the final compliance tallies.

The relationship of the actual off-cycle technology credit levels available per vehicle to the technical specifications is complex. Several of the off-cycle technologies are scalable based on system and vehicle specifications. For example, solar panels used for charging the battery of hybrids or electric vehicles scale at 0.04 g/mi per watt of rated power. Another example of the credit scaling can be seen in the active aerodynamics, where the credit scales at 0.19 g/mi per percent reduction in drag coefficient for cars, and 0.33 g/mi per percent drag reduction for trucks. The table values for the two active aerodynamic technologies, active grill shutters and ride adjustment, of 0.9 g/mi for cars and 1.6 g/mi for light trucks are based on 5% aerodynamic drag reduction. The glazing credit scales up with the applicable window area with glazing that has reduced solar transmittance.

DEPLOYMENT OF OFF-CYCLE TECHNOLOGY EQUIPMENT

Each off-cycle technology involves varying degrees of equipment and engineering changes and the costs of these changes have only been partially investigated. The exterior light, window glazing, and reflective paint credit technologies involve among the most minimal changes compared to conventional vehicles.

To be eligible for the high efficiency light credit, lighting requiring less energy than conventional lights must be installed on at least one light: low beam, high beam, parking, front and rear turn signals, front and rear side markers, taillights, reverse lights, or license plate lighting. Based on credit applications, high efficiency lights already were being deployed in BMW, Fiat Chrysler, Ford, and GM models by 2011, and were on about 61% of all new model year 2016 vehicles.

The glass or glazing credit is based on the glazing specifications in ISO standard 13837 and the applicable glazing surface area. Glazing technologies were being deployed on vehicles manufactured by BMW, Fiat Chrysler, Ford, and GM by 2011 and were already on 30% of new 2016 vehicles.

Solar reflective paint, which reflects at least 65% of infrared solar energy, according to ASTM standards E903, E1918–06, or C1549–09, is credited for about 13% of model year 2015 vehicle models. Solar reflective paints already were deployed on vehicles produced by Fiat Chrysler, Ford, and GM by 2011. The agencies have not estimated the costs of these technologies nor their potential deployment toward 2025 compliance.

Other off-cycle credits involve more significant new technical changes. Active aerodynamic technologies involve grill shutters and ride height adjustments that generally engage at high vehicle speeds. Whereas engines generally allow air to pass through the engine compartment to cool the engine, active grill shutters can close the front grill at higher speeds to reduce aerodynamic drag. Ride height adjustment uses chassis and suspension components, such as hydraulic shock absorbers, to lower the height of the vehicle, reducing ground clearance and aerodynamic drag at higher vehicle speeds. These types of active aerodynamic technologies were deployed on Ford and GM vehicles by 2011, based on those companies' applications to the EPA. Grill shutters are deployed on about 20% of model year 2016 vehicles, based on EPA data. The agencies included active grill shutters within their analysis of projected 2025 regulatory compliance of aerodynamic improvement packages.

Several of the off-cycle technologies do not require any new equipment because they involve granting additional credit beyond the existing technology benefit resulting from established test procedures. In such cases, it must be demonstrated that the technologies are engaged more frequently in the real world than during the test procedure. For example, automakers can make the case, providing representative data as evidence, that stop-start technology is engaged more often in the real-world than on the test-cycle vehicles. Such technologies include stop-start technology, high efficiency alternators, and air-conditioning technology. Ford and GM have applied for stop-start off-cycle technology credits for deployment dating back to model year 2010. Stop-start technology was deployed on about 10% of new model year 2016 vehicles, and EPA's more recent regulatory assessment indicated about 35% of new model year 2025 vehicles would have stop-start technology, including stop-start, mild hybrid, and full hybrid packages (EPA, 2016b). High efficiency alternators are broadly deployed by automakers for their test-cycle benefits, and Ford is requesting additional off-cycle credits for model year 2010 and later vehicles. For these technologies, the agencies have already included the cost of these technologies within their regulatory analysis, but without yet including their full off-cycle credit. Similarly, variable displacement crankcase suction technology for the air-conditioning compressor already has been considered as part of the air-conditioning crediting provisions. Since GM was granted the credit, several automakers have followed up with petitions and have been granted credit for the same technology.

IDENTIFYING LEADING OFF-CYCLE CREDIT USE

Figure 2 illustrates the reported off-cycle technology credit use by automaker from the same EPA data sources as above for model years 2015 and 2016 (EPA, 2016a, 2018a). We report both model years to help point out several dynamics related to the off-cycle credit approvals. The 12 companies shown make up 92% of new light-duty vehicle sales in 2016. Three companies—Jaguar Land Rover, Fiat Chrysler, and BMW—with about 4.6–7.0 g/mi each in 2016 well exceeded the fleet average of 3 g/mi. Mercedes, GM, and Ford were near the average, with 2.8–3.4 g/mi in 2016, followed by Toyota, Nissan, and Honda, each reporting about 1.9–2.2 g/mi in average credit use in 2016, whereas the other companies were well below the fleet average. Because these are the company fleet averages, some vehicle models have more off-cycle credit than what is shown in Figure 2. However model-by-model credit values are not available through EPA reports or automaker petitions. In general, although it is not shown in the figure, vehicle models that are categorized as light trucks receive more credits than passenger cars. To provide a sense of how the credits differ, BMW generated 3.8 g/mi in off-cycle credits on average for cars, 6.9 g/mi for light trucks, and 4.6 g/mi for the sales-weighted average across cars and light trucks. We also note that although the figure data do not include all the off-cycle credits that have been petitioned for or approved, they are the most recent data reported publically.

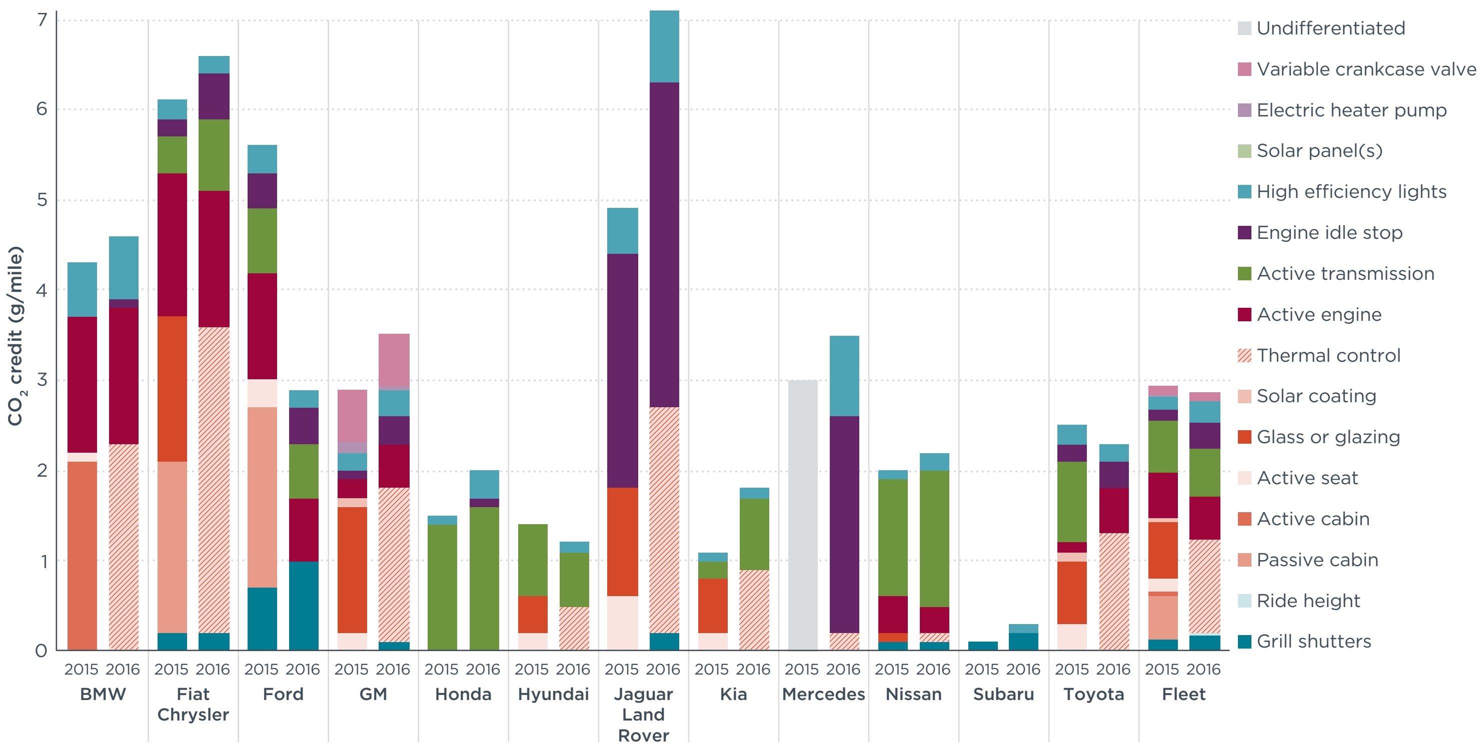

Figure 2. Use of off-cycle credits for compliance in model years 2015 and 2016.

Figure 2 also illustrates the relatively uneven early use of the various credits used by major automakers. Most of the manufacturers shown make use of at least four different predefined off-cycle credits, and none with the same combination or shares of technologies. With more than five different off-cycle credits, Jaguar Land Rover had the highest fleetwide credit average of 7 g/mi in 2016. Fiat Chrysler reported nearly 7 g/mi in 2016 and had credits in the most technology areas, with 10. GM, with the fifth highest average g/mi, received credits for nine separate off-cycle technology credit areas. We note that GM has submitted credit petitions that would, if granted, could put the company among the overall credit-generating leaders. Nissan had credits for eight different technology areas. Because the credit levels in Figure 2 represent each company's fleet average, it understates the achieved credit per vehicle on the specific models on which off-cycle technologies are applied; however, model-specific data are not made available. The figure shows that, although each company's usage has not been widespread, greater adoption of technologies already deployed by other companies could greatly increase the overall off-cycle CO_2 credits.

We note several trends when comparing the model year 2015 and 2016 off-cycle data in Figure 2. Nine of the 12 automakers earned an increase in off-cycle credits from 2015 to 2016. Of the three automakers that saw decreases, two were small changes (-0.2 to -0.3 g/mi). Ford's credit decrease was more substantial, from 5.6 g/mi in 2015 to 2.9 g/mi in 2016. This is due largely to Ford not having yet reported any thermal control credits in 2016 versus reporting 2.3 g/mi in 2015. Due to this, and Ford's approved high efficiency alternator credits (approved, but not reported in EPA data, as discussed below), increased 2016 credits are likely to be reported later for Ford. EPA's presentation of the credits changed from 2015 to 2016; in 2016, all the thermal control technologies—including solar coating, glass, active seat ventilation, active cabin ventilation, passive cabin ventilation—were reported in aggregated form. Note that Fiat Chrysler's 2016 credits are under investigation by EPA and/or subject to corrective action. Similarly, Volkswagen's data are excluded for the same reason. In addition, the individual technology credits for Mercedes in 2015 were not publicly shared, so we present only aggregated data as undifferentiated. These caveats underscore how inconsistent the automaker and EPA reporting of these credits has been in these early years of the off-cycle program.

These company and fleet-average off-cycle credits in Figure 2 for 2015 and 2016 are also likely to further increase due to additional automaker petitions. There are additional petitions that are under review by EPA in 2018, and the petitions typically refer to technologies that go back several model years into the past. Per a February notice by the EPA (Regulations, 2018), GM is petitioning for active climate control seats at the levels of 2.3 g/mi for cars and 2.9 g/mi for trucks for model year 2010 through 2016 vehicles. These requested higher credit values are over twice the levels of the default predefined credits (i.e., 1.0 for cars and 1.3 for trucks). GM is also requesting additional off-cycle credits for a high-efficiency alternator technology, which is not in the predefined list and therefore does not have a cap. In addition, based on the same notice, Toyota is applying for 1.1 g/mi in credits for crankcase variable suction valve technology for air conditioning compressor systems for 2013 and later model years. This type of credit has previously been approved for other manufacturers.

With the technology penetration rates compiled by EPA, we further investigate the technology-specific credits each manufacturer received for the vehicles that had the off-cycle technology installed. Based on the same EPA compliance data cited above (EPA 2016a, 2018a), we sought to isolate the companies with the most credit in each technology area. Figure 3 compares the companies with the highest off-cycle credits in each technology area for the most recent available data. The data for the highest off-cycle credits are generally for model year 2016, except for the thermal control, active cabin and seat ventilation, glazing, and solar reflective coating, which are for model year 2015. These leading credit levels are compared with the overall model year 2016 fleetwide average credits. As shown, the fleet average use of off-cycle credits is far less than the leading companies' credit generation in each technology area.

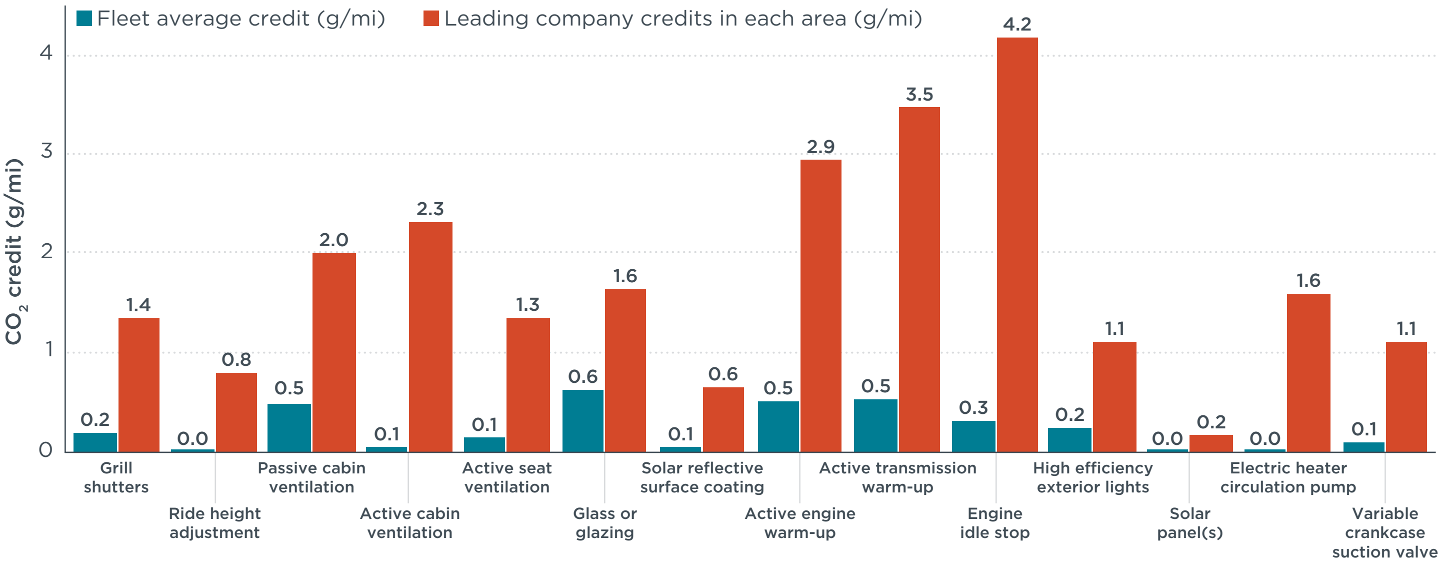

Figure 3. Fleet average off-cycle credit use and maximum off-cycle technology used by leading company in each technology area.

By comparing the fleet average credit to the leading company, it is evident that, for 12 of 14 technology areas, the penetration of the off-cycle technology is less than 20% of the highest level. Stated another way, for those 12 technologies, the technology leader has at least 5 times the fleet average use of that particular off-cycle technology. Glazing technology is the highest average usage with fleet average 0.6 g/mi, at about 38% of the 1.6 g/mi credit by the leading company in that category, Fiat Chrysler. The largest gap between the average and leading credits is in engine idle stop, where the leading credit generation per vehicle with the technology—about 4.2 g/mi from Ford in 2015 and Fiat Chrysler in 2016—has not yet been widely adopted by other automakers. This shows that, if each automaker receives credits near the currently leading companies, much greater credit use is possible.

As shown in Figure 3, Fiat Chrysler topped all manufacturers with five credit-leading technologies: ride height adjustment, passive cabin ventilation, glazing, active engine warm-up, and active transmission warm-up. Engine idle stop-start credits have high potential to increase in years ahead, even though deployment has been relatively low through 2016. BMW, Ford, Fiat Chrysler, Honda, Jaguar Land Rover, Mercedes, and Toyota have applied the technology with an average of about 3 g/mi in credits. EPA notes that engine stop-start is only eligible for off-cycle credits if the technology's predominant operating mode is on, making it less likely for drivers to disable its function (EPA, 2018a); the percentage of 2016 vehicles that have stop-start and those that receive the stop-start credit are both 10% (EPA, 2018a, 2018c). Ford leads on off-cycle credits for grill shutters and led on passive cabin ventilation based on 2015 data. BMW had the leading credit generation for two technologies: active seat ventilation and active cabin ventilation. Nissan led with the highest credits for solar reflective paint and solar panels. GM had the only reported, and thus largest, credits in the final two technologies of auxiliary electric heat circulation pump and the variable crankcase suction compressor.

We emphasize that the off-cycle credit values shown do not necessarily equal the maximum actual credit being granted to vehicles, which could be higher, because detailed model-by-model credit values were not available. Hyundai applied for a higher value of credit for its variable crankcase suction valve (1.4 g/mi), which was granted in December 2017, but this is not yet reported in official EPA manufacturer reports. Ford's petition for high efficiency alternator credits could be valued at up to 1.9 g/mi, but they are not shown. These credits were granted in December 2017, but Ford has not yet reported their per-vehicle or fleet-wide values. In addition, there are pending EPA off-cycle credit decisions that are applicable. GM is also requesting additional off-cycle credits for a high efficiency alternator technology similar to Ford's, with credit up to about 2.1 g/mi per application, and apply for model years 2010 to 2016 (Regulations, 2018). In addition, GM's latest petition in the active climate control seats, if granted, would result in a new credit-leading application in the active seat ventilation category of between 2.3 and 2.9 g/mi. Underreporting is likely for other technologies as well, based on our review of automaker petitions and the increased practice of requesting back credits for previous model years.

PETITIONS FOR ADDITIONAL OFF-CYCLE CREDIT USE

This section summarizes the recent activity in petitions for off-cycle credit use. By describing several of the 2013–2017 approved and pending petitions, we show the overall status of the off-cycle program through the end of 2017. With a fleet average of 3 g/mi, off-cycle credits based on the predefined list already have been helpful to manufacturers. Overall, the predefined list has greatly simplified the path for automakers to generate credits, accounting for more than 96% of all reported off-cycle credits through 2015. As introduced above, however, automakers also can receive off-cycle credits based on technologies on the preapproved technology list, from new data submitted based on the 5-cycle method or some other approved method.

Automakers already test vehicles over five EPA test cycles: city (the federal test procedure, or FTP), highway (the highway fuel economy test, or HFET), higher speed and acceleration (called US06), hot ambient temperature test (95 °F) with air-conditioning and full sun load (called SC03), and a cold ambient temperature test (20 °F) to simulate a variety of driving conditions. The latter three test cycles originally were developed to account for emissions under more varied driving conditions. They were incorporated into the 5-cycle procedure now used to more accurately inform consumers of the real-world fuel economy in the official EPA fuel economy labels that are displayed in dealer showrooms and used on marketing materials by automakers. Using the 5-cycle approach, automakers compare the efficiency benefits of prospective off-cycle-credit technologies on the 5-cycle test with the benefits on the official 2-cycle regulatory test. If there is a greater efficiency benefit on the 5-cycle test, automakers can submit data to seek credit. There is no mechanism that works in the other direction to identify and account for technologies that receive less efficiency benefit on the 5-cycle test than on the regulatory test.

Through model year 2016, GM was the only automaker that petitioned for, and received, off-cycle credits based on the 5-cycle methodology. The credit is for an auxiliary electric heat circulation pump that is able to maintain cabin heating when the stop-start system shuts off the engine. The credit is applicable only on certain GM gasoline hybrids. In 2016, GM reported credits for this technology only on passenger cars. Based on aggregated EPA data on the number of vehicles sold with this technology, we estimate the credit value for each vehicle with the technology is about 1.6 g/mi. Since being granted this credit, GM requested stop-start off-cycle credits for these vehicles via an alternate methodology. Combined, these engine idle stop-start and the auxiliary electric heater circulation systems would generate the maximum credits allowed for this technology area, which are 2.5 g/mi for cars and 4.4 g/mi for light trucks.

The other way automakers can generate off-cycle credits, beyond those on the predefined list and using the 5-cycle method, is by petitioning the EPA for an alternate demonstration of off-cycle benefits. Keys to this demonstration are the use of data showing statistically significant, robust, and verifiable real-world emissions benefits. The data may come from modeling, on-road data collection, or another approved method. Such a manufacturer petition for credits would describe how the off-cycle technology reduces fuel consumption under conditions beyond the test cycles. This would include the amount of operation experienced in-use, in the real world, as well as evidence of reduced emissions compared to a baseline without the technology. To minimize uncertainty, the data are supposed to cover a wide range of driving conditions, driver behavior, and number of vehicles. Although studies continually improve data availability, uncertainty remains because the studies usually focus on urban areas; nationwide, year-round data on driving patterns and conditions are generally lacking. Thus, credits under this methodology remain inherently controversial.

Through the end of 2017, only GM has reported approved off-cycle credits based on alternate methodologies. GM received credit for a variable crankcase suction valve compressor. The technology improves air-conditioning system efficiency more than the default value of the air-conditioning efficiency credit. This is significant because the *off-cycle provisions* are separate from the established *air-conditioning credits*, which have their own set of crediting provisions and more rigorous testing requirements, including maximum theoretical values that are constrained by real-world air-conditioning system energy requirements and use. As a result, GM effectively used the alternate methodology to generate additional air-conditioning credits beyond what those crediting provisions had otherwise allowed. The credit accounted for about 19% of GM's 2015 off-cycle credits. Subsequently, three other manufacturers—BMW, Ford, and Hyundai—applied for the same or greater credit with the same technology. Based on the approval of GM's petition, these credits were granted to the other automakers in December 2017.

The petition that most broadly explored the boundaries of off-cycle petitions was Mercedes' application for stop-start technology credit. In its September 2013 application, Mercedes sought additional off-cycle credit for its engine idle stop-start technology. Their method for determining the default menu stop-start credit value was similar to EPA's, except Mercedes used its own idle time and percentage-improvement effectiveness estimates for its technology. Mercedes petitioned for 9–11 g/mi of off-cycle credit for small and midsize cars and 17–19 g/mi for large cars and trucks for start-stop technology. These compare to the EPA maximum values of 2.5 and 4.4 g/mi, respectively.

Mercedes' data on the system's real-world effectiveness were deemed insufficient, but the estimate on increased idle time was considered sufficient for EPA to provide increased interim credit. Along with the interim credit, Mercedes is required to provide more robust data for model year 2017 and later in order to use the approved method for those later model years. EPA approved Mercedes' 23% idle time estimate, based on a dataset from Progressive Insurance, although there is an unresolved question about how representative that dataset is due to self-selection bias. This is more than 50% greater than the 14% idle time assumed in the rulemaking support documents. An underlying question in the Mercedes petition is its claim that Mercedes vehicles have a higher proportion of urban driving than the industry at large. This offers a challenging proposition for Mercedes or other automakers to prove, and for EPA to verify. If such data claims could be verified, then all automakers with less-than-average idling would receive the average idling credit, and all those with more would receive their own higher credit. The net result would be overcounting fleet-average idling. An even more problematic precedent in this case is that it is based on the company's vehicles having more urban driving, and urban driving results in greater CO_2 emissions and fuel consumption than highway driving. Therefore, giving extra off-cycle credit for more urban driving is actually crediting a larger trend that is going in the opposite direction. Broader approval of applications like this would greatly increase the stop-start credits from the values presented above.

Table 3 summarizes the timeline of automaker petitions and approval decisions based on the list of applications that EPA maintains (EPA, 2018b). Several trends can be seen from this summary list. One trend is that many automakers are following the lead of other automakers' successful petitions. For example, BMW, Ford, and GM are following Chrysler's successful application for pre-2014 credits. Another key trend is toward additional credits beyond those on the predefined technology list. This trend is significant because only items on the predefined list are subject to the 10 g/mi limit for off-cycle credits. The credits requested for new technologies are for a variable crankcase suction valve for additional air-conditioning credit, initially requested by GM, and a high efficiency alternator, first requested by Ford. With the variable crankcase suction valve technology for air-conditioning compressors, BMW, Ford, and Hyundai have followed up on GM's petition with their own petitions for the same credits. Similar to Mercedes' request for additional credits for a technology already on the predefined list, Ford requested additional credits beyond the menu for glass/glazing and solar paint.

Table 3. Timeline of automaker petitions and EPA decisions for alternate methodology off-cycle credits

Company	Petition date	Petition description	Decision description	Reporting[a]
Fiat Chrysler	April 2013	2009–2013 credits for glass, high efficiency lighting, seat ventilation, and solar reflective paint	Granted on grounds of same technologies and method in original rule (2014)	Reported
Mercedes	September 2013	2012–2016 credits for high efficiency lighting, glass, and active seat ventilation; 2012-2016 credits for stop-start using alternate method with own idle data	Granted, stop-start credit approved at lower level due to data limitation (2014)	Reported
GM	December 2014	2013–2015 credits for variable crankcase suction valve for air-conditioning system compressor	Credits granted (2015)	Reported
Ford	March 2015	2012–2013 credits for high efficiency lights, glass, active seat ventilation, solar reflective paint, grill shutter, engine warm-up, transmission warm-up, engine idle start-stop,	Credits granted (2015)	Reported
Ford	January 2016	2009–2011 credits for high efficiency lights, seat ventilation, grill shutters, engine idle start-stop, engine warm-up, transmission warm-up	Credits granted (2017)	-
GM	June 2016	2010–2013 credits for high efficiency lights, grill shutters, engine idle start-stop, engine warm-up, active seat ventilation, glazing, and solar reflective coating	Credits granted (2017)	-
BMW	June 2016	2009–2013 credits for glass, active cabin ventilation, active seat ventilation, engine warm-up, high efficiency lights	Credits granted (2017)	-
Volkswagen	August 2016	2012–2013 credits for high efficiency lighting, active aerodynamics, engine start-stop, engine warm-up, transmission warm-up, glazing, paint, seat ventilation	Credits granted (2017)	-
BMW	May 2017	Credits for variable crankcase suction valve for air-conditioning system compressor	Credits granted (2017)	-
Ford	June 2017	2010–2016 credits for glass, solar paint, high efficiency alternator	Alternator credits granted; thermal control credits pending review (2017)	-
Ford	June 2017	2017 and later credits for glazing, solar paint, high efficiency alternator, and variable crankcase suction valve	Alternator and suction valve credits granted; thermal control credits pending review (2017)	-
Hyundai	June 2017	2015–2016 credits for variable crankcase suction valve compressor	Credits granted (2017)	-
GM	September 2017	2010-2016 credits for active seat ventilation	Active (2018)	-
GM	October 2017	2010-2016 credits for high efficiency alternator	Active (2018)	-
Toyota	December 2017	2013 and later credits for variable crankcase suction valve compressor	Active (2018)	-

[a] *The "-" indicates it is unclear, but it appears that the credits have not been reported in EPA data (2016a, 2018a).*

Another trend we see from this review of automaker petitions is toward automakers acquiring credits for past technology deployment. Table 4 summarizes which companies have sought off-cycle credits for earlier technology deployment. Additional information on this topic is available on the EPA website (EPA, 2018b). As previously described, the model year 2017–2025 rulemaking also included provisions for model year 2014–2016 vehicles to receive off-cycle credits. In April 2013, Fiat Chrysler was granted off-cycle credits equivalent to those on the predefined off-cycle list—not just for 2014–2016, but for 2009–2013 vehicles as well. Fiat Chrysler used the same EPA calculations that led to the development of the menu credits, and EPA granted the credits. Other automakers are similarly submitting petitions for earlier model years. Based on our review of all the automaker petitions, some of the companies are even applying for credits for model year 2009–2011 technology deployment, which is before the off-cycle credits were finalized in the 2012 adoption of the 2017–2025 regulation. This trend suggests that EPA could continue receiving many more credit applications for model years that are up to 7 years into the past. Therefore, compliance data could continue to be more substantially revised in a retrospective manner. Furthermore, these credits can continue to be used with 5-year carry-forward provisions, thus increasing the accumulation of surplus credits that reduce the amount of technology required to meet future standards.

Table 4. Off-cycle technology credit applications for pre-2012 and 2015 and later models

Off-cycle technology	Automakers seeking credit for off-cycle technology in model year 2009–2011 vehicles	Automakers with credits for model year 2015-and-later vehicles
Grill shutters	Ford, GM	BMW, Fiat Chrysler, Ford, GM, Hyundai, Jaguar Land Rover, Kia, Mercedes, Nissan, Subaru, Toyota
Ride height adjustment	-	Fiat Chrysler, Toyota
Passive cabin ventilation	-	Fiat Chrysler, Ford
Active cabin ventilation	BMW	BMW
Active seat ventilation	BMW, Fiat Chrysler, Ford, GM	BMW, Fiat Chrysler, Ford, GM, Honda, Hyundai, Jaguar Land Rover, Kia, Mercedes, Nissan, Toyota
Glass or glazing	BMW, Fiat Chrysler, Ford, GM	BMW, Fiat Chrysler, GM, Hyundai, Jaguar Land Rover, Kia, Mercedes, Toyota
Solar reflective paint or coating	Fiat Chrysler, Ford, GM	Fiat Chrysler, GM, Nissan, Toyota
Active engine warm-up	BMW, Ford, GM	BMW, Fiat Chrysler, Ford, GM, Nissan, Toyota
Active transmission warm-up	Ford	Fiat Chrysler, Ford, Honda, Hyundai, Kia, Nissan, Toyota
Engine idle stop	Ford, GM	BMW, Fiat Chrysler, Ford, GM, Honda, Hyundai, Jaguar Land Rover, Kia, Mercedes, Nissan, Toyota
High efficiency exterior lights	BMW, Ford, GM	BMW, Fiat Chrysler, Ford, GM, Honda, Hyundai, Jaguar Land Rover, Kia, Mercedes, Nissan, Subaru, Toyota
Waste heat recovery	-	-
Solar panel	-	Nissan
Electric heater circulation pump	-	GM
Variable crankcase suction compressor	-	BMW, Ford, GM, Hyundai
High efficiency alternator	Ford	Ford

DATA BASIS FOR THE OFF-CYCLE CREDITS

As part of this assessment of the use of the off-cycle crediting provisions, we sought to research and summarize the data involved in the applicable off-cycle technologies. A variety of data has been made available from the original creation of the preapproved off-cycle provisions. Through the end of 2017, these data include the more recent activities of the automakers to petition for more off-cycle credits with their support documents, as well as some additional research groups' analyses into the same technologies.

As previously introduced, the predefined off-cycle technology list emerged as part of the automaker and regulatory agencies' deliberations on 2017–2025 standards. Research by the California Air Resources Board and National Renewable Energy Laboratory (NREL) related to the California *cool cars* regulatory development (Rugh, Chaney, Lustbader, & Meyer, 2007; CARB, 2013) was the precursor to the solar and thermal control off-cycle credits (CARB, 2012). The agencies recognized that there were very limited representative real-world data and therefore used simulation and existing 5-cycle data to develop the original preapproved list of 13 technologies. As such, a combination of vehicle simulation and 5-cycle vehicle test results was relied upon for the CO_2 reduction effectiveness for the preapproved technologies. To approximate real-world conditions on a nationwide and year-round basis, EPA applied primarily meteorological data and nationwide driving activity compiled in EPA's Motor Vehicle Emission Simulator (MOVES), and data from NREL on the effectiveness of solar and thermal control technologies.

Since the adoption of the preapproved off-cycle credit technology list, the approved credit values and derivatives of those credit methods have essentially formed the basis for all approved credits. As previously discussed, the preapproved list accounts for more than 95% of all reported credits. The remaining credits—electric heat circulation pump and variable crankcase suction valve by GM; high efficiency alternator by Ford; and additional credit for Mercedes stop-start—apply relatively small changes from EPA calculations.

A primary question in these off-cycle applications is whether and how EPA assesses claims regarding driving behavior and driving conditions. The difficulties associated with such data vary according to the different off-cycle technology areas. For example, as previously highlighted, idle time for stop-start technology in more urban conditions is a variable for which it is difficult to capture representative nationwide data that properly account for urban, highway, and rural driving. For active aerodynamic technologies, breakdowns of data on vehicle frontal area and vehicle speed are key; however, frontal area data are not disclosed by automakers, and nationwide, year-round speed distributions are not available. For thermal control technologies, accounting for nationwide driving and year-round ambient temperature is important, and this has, to a limited extent, been analyzed as mentioned below. Collecting data to assess the accuracy of active transmission and engine warm-up technology credits relies on data including vehicle trip lengths and the number of cold starts. These examples underscore the importance and difficulty of assessing the credit value for technologies that differ according to underlying driving conditions.

Also, interactions between the off-cycle technologies further complicate how automakers petition, and agencies consider, the applicable credits to estimate their real-world benefits. For example, the extent to which a company's vehicles are driven more in urban driving with stop-start operation, as in the Mercedes petition, would also reduce their high-speed highway driving; this would suggest lower aerodynamic benefits would be available from the active aerodynamic technologies. In addition, the extent to which the stop-start technology engaged would affect the real-world operation of the engine and transmission warm-up technologies. Practically speaking, granting the off-cycle technologies absolute credits, rather than approving them on a percentage basis, overestimates the impact of each technology when off-cycle and on-cycle technologies are simultaneously applied on given vehicles. The agencies have recognized this in their vehicle simulation modeling of on-cycle efficiency technologies but have so far neglected to do so for off-cycle technologies. The errors from the absolute off-cycle technology credit get much larger as more technologies are applied.

In addition, the new credit applications have not included new physical, real-world A-to-B vehicle testing, which is to say with and without the off-cycle technology, under statistically representative driving conditions. Notably the attempt by Mercedes for more engine stop-start technology credit was not granted because of the limited A-to-B real-world testing data. Instead, a credit calculation approach that allows less credit was approved on an interim basis, and Mercedes can submit more comprehensive real-world data collected by using instrumented vehicles driven by vehicle owners over a variety of ambient and roadway conditions and types. Although physical testing is important to validate actual real-world effects, it is likely that driving conditions such as idle time, speed distributions, and ambient temperature are likely to affect the off-cycle technologies and their real-world impacts to a larger extent.

Comprehensive, statistically representative validation of the credits for the off-cycle-credit-generating technologies in the real world, such as covering representative vehicle models, nationwide vehicle use and year-round conditions, has been essentially nonexistent. However, several analyses provide new data regarding the key underlying inputs for the off-cycle credit calculations. Table 5 shows new data available from the literature and the approximate impact on the existing off-cycle technology credit values. As shown, new 2016–2017 analyses by NREL researchers help to better quantify the real-world benefits of several of the off-cycle technology areas. The NREL researchers' work on real-world vehicle efficiency is likely the most substantial public real-world data collection and analysis on this topic. NREL research from Gonder (2016) indicates that the real-world benefits from accessory load reduction, such as improved alternator efficiency, resulted in about the same benefit as seen on the established lab tests: 1.6 g/mi for real-world, versus 1.8 g/mi on 2-cycle and 1.7 g/mi on 5-cycle. Gonder (2016) also indicates that engine warm-up, if coupled with thermal retention, could result in more real-world benefit than captured by the 5-cycle test.

Table 5. Data basis for the credits offered and requested

Technology[a] (adopted regulatory credit)	New data[b]	Data basis for original credit decision[c]
Active aerodynamics-grill shutters (1.2 g/mi)	-	• Effectiveness: EPA vehicle simulation; 5-cycle and 2-cycle tests • Vehicle use: EPA MOVES • Vehicle solar and thermal load data: NREL
Active aerodynamics-ride height adjustment (0.5 g/mi)	-	
Thermal control-passive cabin ventilation (2.3 g/mi)	• Improved real-world national vehicle use data: Credit overestimated by **10 times** based on NREL (Kreutzer, Kekelia et al., 2017)	
Thermal control-active cabin ventilation (2.8 g/mi)	• Improved real-world national vehicle use data: Credit overestimated by **20 times** based on NREL (Kreutzer, Kekelia et al., 2017)	
Thermal control-active seat ventilation (1.3 g/mi)	• Improved real-world national vehicle use data: If seats are actively cooled rather than ventilated, credit could be **greater by 70%** based on NREL (Kreutzer, Rugh et al., 2017)	
Thermal control-glass or glazing (3.9 g/mi)	• Improved real-world national vehicle use data: Credit overestimated by **50%–100%** based on NREL (Kreutzer, Kekelia et al., 2017)	
Thermal control-solar reflective surface coating (0.5 g/mi)	• Improved real-world national vehicle use data: Credit underestimated **by 40%–50%** based on NREL (Kreutzer, Kekelia et al., 2017)	
Active engine warm-up (3.2 g/mi)	• Improved real-world national vehicle use data: Credit is **similar or could be greater** (up to 5.3 g/mi real world if with heat retention) (Gonder, 2016)	
Active transmission warm-up (3.2 g/mi)		
Engine idle stop (4.4 g/mi)	• Mercedes requested **3–4 times more credit** (up to 7–9 g/mi for cars and 17–19 g/mi for trucks) due to higher idle time (23% vs 13.8%) and higher technology effectiveness.	
High efficiency lights (1 g/mi)	-	
Waste heat recovery (1 g/mi)	-	
Solar panel(s) (3.3 g/mi)	-	
Electric heat circulation pump	• GM received credit for approximately **2.6 g/mi** for cars with this technology (petition/data not reported on EPA site)	• No off-cycle credit originally
Variable crankcase suction valve for air-conditioning compressor	• GM request for **1.1 g/mi** of new credits based on greater improvement than from air-conditioning credit • Hyundai request for **1.4 g/mi** of new credits based on greater improvement than offered in air-conditioning credit system	• No off-cycle credit originally (included in air-conditioning credits)
High efficiency alternator	• Ford requests up to **1.9 g/mi** in new credits for greater efficiency (from base 67% to 80%) based on handling greater electric loads • Improved real-world national vehicle use data: Credit overestimated **by 100%** (less benefit in real world than on test cycle from accessory load reduction) based on NREL (Gonder, 2016)	• No off-cycle credit originally (data deemed insufficient for predefined list)

Notes: g/mi = gram CO_2 per mile; W = watt; MOVES = Motor Vehicle Emission Simulator; NREL = National Renewable Energy Laboratory; EPA = U.S. Environmental Protection Agency.
[a]*Numbers shown for g/mi are the general upper bound and depend on technical specifications.*
[b]**Green** *suggests credits underestimate, and* **red** *suggests credits overestimate, real-world benefits.* **Blue** *indicates new or different from the menu technology credit.*
[c]*See EPA and NHTSA, 2012a; CARB, 2012.*

Two studies, also by NREL and summarized in Table 5, provide original data collection and simulation modeling to help better assess the solar and thermal control technologies. Kreutzer, Kekelia, Rugh, and Titov (2017) use new data collection and vehicle simulation modeling to analyze air-conditioning fuel use and the impact of four solar thermal control technologies that receive off-cycle credits. They find that the passive cabin ventilation credit of 2.1–2.8 g/mi is more than 10 times higher than the real-world benefit of 0.2 g/mi; the 1.7–2.3 g/mi active cabin ventilation credit is about 20 times higher than the 0.1 g/mi real-world benefit; the solar control glazing/glass credit of 2.9–3.9 g/mi is about 50%–100% higher than the 2 g/mi real-world benefit; and the solar reflective paint credit of 0.4–0.5 g/mi is about 40%–50% lower than the 0.8 g/mi real-world benefit. These indicate that much better real-world data collection and analysis is warranted—in not only these solar and thermal control areas, but also the other areas for which there has been limited actual vehicle data. Another analysis, by Kreutzer, Rugh, Titov, and Kekelia (2017), analyzes active seat ventilation based on updated data and simulation. The analysis shows that if seats are actively cooled rather than ventilated, the credit could be greater by 70%.

The exchange between the regulatory agencies and industry regarding industry requests for more off-cycle credits during the 2012 rulemaking helped further reveal the rationale for allowing and rejecting various technologies. Automakers pushed for including as many technologies as possible in the preapproved list. From the August 2011 notice of intent to the final rulemaking a year later, the list of technologies went from six to the 13 previously analyzed, and automakers requested many more. In their comments to the regulatory agencies, auto suppliers, manufacturers, and their trade groups suggested that more technologies be added to the predefined list. Suggested additions included high efficiency alternators (Alliance, Denso, Volkswagen, Porsche, Ford), electric cooling fans (Bosch), heating and air-conditioning eco-modes, transmission cooler bypass valves (Ford), navigation systems (Garmin), engine block heaters (Honda), an integral approach using a combination of technologies (Global Automakers), and congestion mitigation credits based on crash avoidance technologies (Daimler).

To these automaker requests for more preapproved, prelisted technologies, the agencies responded: "In most cases, there was either insufficient supporting data, dependence on unique, manufacturer-specific designs or implementation, or dependence on driver interaction and usage that led to our decision not to include these technologies within the menu of off-cycle technologies" (EPA & NHTSA, 2012b). In addition to this general rationale for turning down requests, specific statements were made on other petitioned technologies. EPA would not provide passive aerodynamic improvements on the preapproved credit list or via case-by-case demonstration, because passive approaches are too difficult to define and isolate as a technology, and they also depend on the vehicle shape and vehicle brand aesthetics. Responding to the request for higher default credit values for active transmission and engine warm-up systems using a single heat-exchanging loop, the agencies indicated that manufacturers could initiate a credit request by clearly demonstrating the performance of the improved single-loop active warm-up system. Such a system would have to be at least as good as two dedicated loops for the transmission and engine to receive the total combined credit values of 3.0 g/mi for a car or 6.4 g/mi for a truck. Alternatively, automakers could seek credits above these values using the demonstration methods for technologies not on the defined technology list.

In the rulemaking discussion of air-conditioning credits, the agency response shows a different, but applicable, aspect of agency crediting provisions. While this paper has focused on the off-cycle provisions, there are more technically detailed provisions on air-conditioning credits for many specific technology improvements that increase the air-conditioning system efficiency and reduce the global warming potential and leakage of the refrigerant. The air-conditioning credits have clear constraints, summing to a maximum of 18.8 g/mi for cars and 24.4 g/mi for light trucks, likely to be similar in scale to the off-cycle provisions. Air-conditioning credits also have requirements that automakers use physical A-to-B testing, with and without the technology, for technologies beyond the air-conditioning menu credits. Demonstrating air-conditioning credit values is a more rigorous validation test than deriving a calculation from the off-cycle calculations based on EPA calculations or the 5-cycle method. This helps to explain why automakers such as BMW, Ford, GM, and Hyundai are beginning to use the off-cycle provisions, instead of the air-conditioning provisions, for more credits from air-conditioning technologies.

An additional question regarding the data basis of the off-cycle credits is related to the mathematical handling of the benefits. From the onset, the off-cycle credits have been based on an absolute g/mi basis. The engineering improvements, however, affect vehicle efficiency and CO_2 emissions on a percentage basis. This has distortionary effects on the credits in several ways, including those based on vehicle size and affected by timing. Regarding vehicle size, if credits are estimated from larger cars with larger cabin or surface area, larger accessory loads, and so on, overestimates the effect on smaller cars. Similarly, if credits are estimated based on larger light trucks, for example a Ford F150, and then used to provide credits for smaller light trucks such as the Ford Escape or Edge, the credits are likely to be similarly overestimated. The issue is even more consequential when considered over the time frame of the 2017–2025 standards.

Efficiency technologies affect vehicle fuel use and CO_2 emissions on a percentage basis, and the absolute credits will increasingly overcount improvements over time, as vehicles are made more efficient in response to the standards. The absolute off-cycle credit values were established in 2011 and 2012, looking at data from 2009–2012 and older vehicles. The average CO_2 in these years was 300 g/mi, based on 28 mpg from the test cycle and 24 mpg real world, so 10 g/mi in credits amounted to 3% of emissions. With the continuation of the off-cycle crediting provisions, the credits amount to a larger portion of vehicle emissions over time. With a 2025 average fleet CO_2 level of 173 g/mi, the same 10 g/mi in credits would be 6% of the fleet emissions. This effectively doubles the impact of the off-cycle program, as compared to the original data basis of the established preapproved credits.

AVAILABLE KNOWLEDGE ON COST-EFFECTIVENESS OF OFF-CYCLE CREDITS

The cost-effectiveness of deploying off-cycle technologies for credit, defined as the cost per g/mi benefit, is quite uncertain due to both the cost (numerator) and g/mi reduction (denominator) being so uncertain, as previously discussed. EPA only partially includes off-cycle technologies in its latest regulatory assessment. Two of the 14 off-cycle technologies are included in the regulatory assessment, simply based on the technologies already being part of test-cycle efficiency technologies. The two included individual technologies are grill shutters, providing 0.6 g/mi for cars and 1.0 g/mi for trucks as part of an aerodynamics package, and engine idle stop-start, which provides credits of 2.5 g/mi cars and 4.4 g/mi trucks. For these two individual technologies, their costs have already been included, but their full impact has not been included, because the off-cycle credit appears to have been excluded in the agencies' vehicle simulation modeling. In addition, EPA has included two generic off-cycle packages. The first package was estimated to cost $69 per vehicle and deliver 1.5 g/mi in CO_2 improvement, for a cost-effectiveness of $45 per g/mi. The second generic off-cycle package is estimated to cost $170 per vehicle and deliver 3 g/mi in CO_2 improvement, for a cost-effectiveness of $55 per g/mi.

The EPA's fleetwide assessment of compliance with the most cost-effective use of all available technologies estimated that about 2.7 g/mi of off-cycle credits would be used in model year 2025 (EPA, 2016b). Off-cycle credit technologies already have been significantly deployed, starting as early as 2009, and 2016 deployment by major automakers already has reached EPA's estimate for 2025. As a result, we find EPA's evaluation of off-cycle technologies and their costs implausible. Automakers have received many more credits and deployed far more off-cycle technologies than anticipated. Therefore, they are obviously seeing much greater value and lower cost than EPA has assessed. The only other explanation for all the off-cycle credit use that we see is that automakers were deploying the technologies anyway for reasons other than compliance with the standards.

Although estimating the absolute costs of automakers' proprietary technologies is beyond our scope, we seek to better approximate where the various off-cycle technologies fit within the sequence of compliance technology application. To do so, we look at the automaker with the highest penetration of each off-cycle technology, and then we identify conventional test-cycle efficiency technologies that the same automaker has deployed at lower rates than the off-cycle technology. This approach approximately bounds how the various off-cycle technologies' cost-to-benefit ratios are more attractive than those better-defined technologies that have clearer costs and benefits.

Table 6 shows the company with the highest penetration of each off-cycle technology, the percentage deployment of the off-cycle technology in model year 2015, and examples of test-cycle technologies for which the company had lower penetration. The table is based on two EPA reference reports on compliance (EPA 2018a, 2016c). The implication is that, for 11 of the 14 technologies, off-cycle technologies are more attractive, easier to implement, and likely more cost-effective than the various test-cycle engine and transmission technologies. For example, Fiat Chrysler has grill shutters on 60% of its new 2015 vehicles, and this represents greater penetration into its fleet than deployment of turbocharging, stop-start, cylinder deactivation, or transmissions with seven or more gears. Also shown in the table, four off-cycle technologies were already on at least 90% of one company's new vehicles in 2015—passive cabin ventilation for Ford and active cabin ventilation, glass/glazing, and high efficiency lights for BMW—showing how available these technologies are for broad deployment. Considering that the various test-cycle efficiency technologies are expected to be widely deployed by model year 2025, it would also make sense to include the off-cycle technologies in their analyses of 2025 at a lower cost-per-g/mi for reducing CO_2, or lower cost per fuel consumption reduction for fuel economy purposes, than on-cycle technologies that have yet to be applied as widely. Doing so would more accurately incorporate how automakers are likely to use off-cycle credit technology in their approaches to comply with the 2025 standards.

Table 6. Off-cycle technologies, companies with highest penetration of that off-cycle technology, and efficiency technologies with lower penetration in 2015

Off-cycle technology	Company with highest penetration	Percent of new vehicles with technology	Examples of technologies with lower penetration in 2015 than the off-cycle technology by Leading company
Grill shutters	Ford	74%	Gasoline direct injection, turbocharging, nonhybrid stop-start, cylinder deactivation, 7+ gear transmission
Ride height adjustment	Fiat Chrysler	2%	-
Passive cabin ventilation	Fiat Chrysler	92%	Gasoline direct injection, turbocharging, nonhybrid stop-start, cylinder deactivation, continuously variable transmission, 7+ gear transmission
Active cabin ventilation	BMW	91%	Nonhybrid stop-start, 7+ gear transmission
Active seat ventilation	Jaguar Land Rover	58%	(not available)
Glass or glazing	Kia, Fiat Chrysler, Jaguar Land Rover	99%+	Gasoline direct injection, turbocharging, nonhybrid stop-start, cylinder deactivation, continuously variable transmission, 7+ gear transmission
Solar reflective surface coating	GM	21%	Nonhybrid stop-start, 7+ gear transmission
Active engine warm-up	Fiat Chrysler BMW	71% 51%	Gasoline direct injection, turbocharging, nonhybrid stop-start, cylinder deactivation, continuously variable transmission, 7+ gear transmission
Active transmission warm-up	Honda	79%	Gasoline direct injection, turbocharging, nonhybrid stop-start, cylinder deactivation, continuously variable transmission, 7+ gear transmission
Engine idle stop	Jaguar Land Rover	100%	Gasoline direct injection, turbocharging, cylinder deactivation, continuously variable transmission, 7+ gear transmission
High efficiency exterior lights	Jaguar Land Rover	100%	Gasoline direct injection, turbocharging, cylinder deactivation, continuously variable transmission, 7+ gear transmission
Solar panel(s)	Nissan	<1%	-
Electric heater circulation pump	GM	3%	-
Variable crankcase suction valve	GM	50%	Turbocharging, nonhybrid stop-start, cylinder deactivation, continuously variable transmission, 7+ gear transmission

IV. ANALYSIS OF POTENTIAL OFF-CYCLE CREDIT USE THROUGH 2025

Based on the above analysis of off-cycle technology use and credit approvals, we analyze the potential expanded use of off-cycle technology through 2025. To do so, we first create a range of scenarios for off-cycle use based on the trends underway. We then use those scenarios to investigate the impacts in the fleet if a greater share of model year fleet compliance were to be achieved from off-cycle technologies.

SCENARIOS FOR OFF-CYCLE CREDIT USE IN 2025

As previously discussed, automakers are pursuing many opportunities for more off-cycle credits to support their compliance with the efficiency regulations. We sought to assess the potential off-cycle credits that automakers could attain as part of their compliance with the 2025 standards following from the emerging trends. In past regulatory analyses, the agencies estimated off-cycle credit use toward meeting model year 2025 standards would be less than the model year 2016 average off-cycle credit use of 3 g/mi (see EPA, 2018a). We analyze low, midrange, and high scenarios for off-cycle technology deployment that reflect the emerging trends in automaker off-cycle technology credit applications. The three credit use scenarios generally reflect both how persistent automakers are in their petitions for credits and how readily the regulatory agencies approve their submissions in the years ahead.

Low off-cycle credit use scenario. The simplest path toward off-cycle credits is to first attain the maximum amount of off-cycle credits allowed within the 13 preapproved technologies. With many available technologies already in deployment for several years by 2015, achieving the maximum available 10 g/mi from preapproved off-cycle credits is a given, even for the low scenario. This is supported by the fact that two manufacturers, Fiat Chrysler and Jaguar Land Rover, already have achieved approximately 7 g/mi credits in 2016. Based on the credit calculations and automaker trends, this would likely mean that off-cycle credits for cars are 25% lower than the fleet average, and off-cycle credits for light trucks are 25% higher. Based on being in use by at least six manufacturers in 2016, grill shutters, active seat ventilation, glass or glazing, engine idle stop, active engine warm-up, active transmission warm-up, and high efficiency exterior lights seem like the most likely credits to be most widely deployed across the fleet. As demonstrated by the many credit options available in Figure 3, there are many technology combinations that would achieve the 10 g/mi maximum for preapproved credits. In addition, based on its response to Mercedes' petition, EPA has also shown openness to providing more credits for engine stop-start based on companies reporting that their vehicle engines are idled more than EPA's default idling time, which would further ease the path for companies to get the maximum preapproved credits.

Midrange off-cycle credit use scenario. For our midrange scenario, we assume that automakers are likely to achieve at least 17.5 g/mi by model year 2025. We again begin by assuming each automaker achieves the maximum available 10 g/mi from the preapproved off-cycle technology list. Based on additional technologies being approved, and automakers' tendency to follow each other in petitioning to achieve the same credits as others, we expect automakers to pursue several technologies beyond the preapproved list. There are several ways to do so, including showing the technology has more benefits on the consumer label 5-cycle test, using a method that is a derivative of EPA's methods for calculating other approved credits, and using new approaches. GM's 1.6 g/mi credit from an electric heater circulation pump on stop-start and other electrified powertrain applications was based on the 5-cycle test method. Using an alternative methodology, based on GM's variable crankcase suction air-conditioning compressor technology petition, automakers can get off-cycle credits that go beyond the allowable preapproved air-conditioning credit limits for variable displacement compressors. Since that petition, BMW, Ford, and Hyundai have petitioned for similar credits at 1.1–1.4 g/mi. Ford's application for a higher-efficiency alternator is based on what they refer to as an alternative EPA-approved method, which would allow up to 1.9 g/mi per vehicle based on greater real-world electrical load than experienced on the 5-cycle test. In addition to credits like these, we assume many additional credits will be submitted and approved in the 9 years through the final year of the adopted standards. Considering the simple sum of maximum credits shown in Figure 3 is 25 g/mi, we conservatively assume that an additional 7 g/mi above those on the preapproved list will eventually be approved by the 5-cycle or alternative methods.

High off-cycle credit use scenario. For the high scenario, we assume that automakers have broader success in their efforts to further streamline the process for accruing more off-cycle credits. Streamlining the off-cycle approval process could occur in several different ways. First, the regulatory agencies could simply approve more of the automakers' non-preapproved credit petitions from the 5-cycle or other alternative methods. Second, the regulatory agencies could make further administrative adjustments through the ongoing midterm evaluation process. For example, the agencies could remove the 10 g/mi credit maximum for preapproved credits, or the cap on thermal and solar control technologies credit. Based on the many credit options already available, either of these approaches would easily push average automaker off-cycle credit use above 20 g/mi, or potentially as high as 30 g/mi, by model year 2025. These options are mentioned because automakers have petitioned broadly over 2015–2017 for such changes to streamline the off-cycle credit approval process and allow more and higher-value credits (Alliance of Automobile Manufacturers & Association of Global Automakers, 2016; Alliance of Automobile Manufacturers, 2017; Nevers, 2017; EPA, 2018b). Relatedly, a third way to open up the approval process for much greater off-cycle use would be for Congress to intervene with provisions to streamline off-cycle credits. For example, draft legislation would have greatly opened up the off-cycle crediting program, allowing up to 9 g/mi in CO_2 credits for autonomous and connected technologies that are entering the fleet (U.S. Congress, 2017, 2018). Our high credit use scenario therefore applies 25 g/mi in off-cycle credits toward 2025 regulatory compliance with the model year 2025 standards. This is also equivalent to the simple sum of all the best-available credits in each technology area through model year 2016, as shown in Figure 3.

Figure 4 illustrates the three 2025 off-cycle credit use scenarios, alongside the leading levels of model year 2016 off-cycle credit use for context. The 2015–2016 off-cycle credit use in the figure includes company-wide averages for Fiat Chrysler and Jaguar Land Rover, as well as the simple addition of all the leading credit values in each of the off-cycle credit technology areas based on the data shown in Figure 2 and Figure 3. The two leading automakers reported about 7 g/mi each in 2025, and combining all the best-in-category credit values sums to 25 g/mi. Automakers can pick and choose among many combinations of the preapproved technologies that were in use in 2015 and 2016 to reach a company average of 10 g/mi. The chart illustrates three 2025 scenarios: the low case with 10 g/mi to match the maximum allowed under the preapproved technology list; the midrange case with 17.5 g/mi based on conservative assumptions for automakers using available flexibilities for more credit; and the high case based on regulatory agencies approving 25 g/mi in 2025. These scenarios indicate that off-cycle credit use in 2025 is 3.7 to 9.3 times the credit use of 2.7 g/mi projected by the latest EPA regulatory analysis. For the three 2025 scenarios, the chosen credit areas are illustrative, based on popular credits in 2016; in reality, different automakers will continue to choose different off-cycle technology packages.

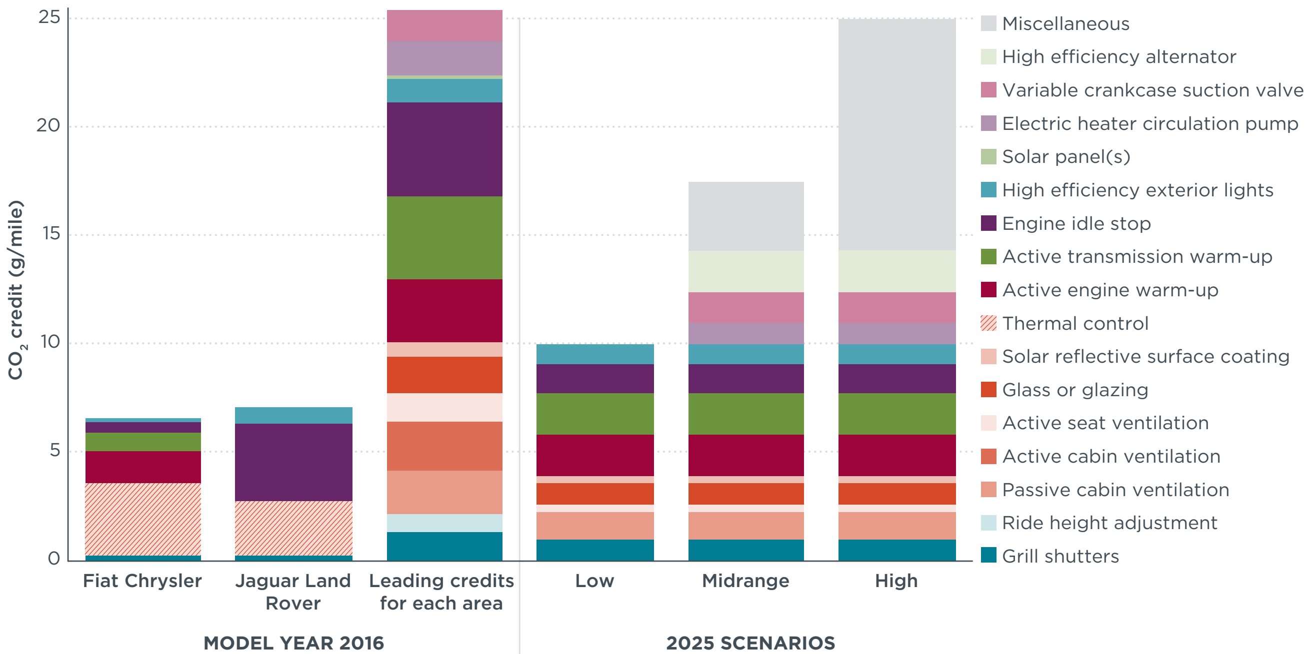

Figure 4. Leading model year 2015–2016 off-cycle credits and three scenarios for model year 2025 fleet off-cycle credit use.

We note that the summary fleetwide values shown in Figure 4 are for the fleet averages. The underlying assumptions for the separate values for the two vehicle categories differ somewhat: Car credits are typically about 25% lower and light truck credits are about 25% higher. As previously discussed, the miscellaneous credits could come from existing technologies getting more credit than their 2016 values, more credit approvals from 5-cycle or alternative methods, and/or the agencies removing the 10 g/mi credit maximum for the preapproved credit list. Overall the miscellaneous credits amount to 3 g/mi for the midrange scenario and 11 g/mi for the high scenario.

ASSESSMENT OF OFF-CYCLE CREDIT USE IN 2025

Using the model year 2025 off-cycle credit scenarios, we investigate the impact on the fuel economy of the new vehicle fleet. The off-cycle technology credits are just one mechanism to help in compliance with the model year 2025 regulatory CO_2 and efficiency standards. The primary approach for compliance is to deploy more efficiency technologies that reduce each company's CO_2 emissions and fuel consumption on the 2-cycle regulatory testing procedure. These technologies include engine, transmission, hybrid electric, lightweighting, and also plug-in electric vehicle technology. Another major compliance mechanism is to apply for credits for air-conditioning systems with higher efficiency and lower refrigerant-related emissions.

To better understand the implications, we convert the impact of higher use of off-cycle credits to the consumer fuel economy impact. To translate the results from the regulatory 2-cycle test CO_2 to fuel economy, we follow EPA assumptions. First, we assume that air-conditioning system credits will be in widespread use and contribute 21.4 g/mi in fleet-average compliance credit through model year 2025, based on 18.8 g/mi for cars and 24.4 g/mi for light trucks, up from about 10 g/mi in model year 2016. Second, we assume that each gallon of gasoline on the regulatory test equates to 8,887 grams of CO_2. Third, we assume real-world consumer label fuel economy remains 23% lower than the tested 2-cycle fuel economy. A fourth assumption we adopt from EPA is its fleet mix and average footprint of cars and light trucks through model year 2025. The EPA's projected vehicle fleet trends are for the average footprints within the two categories to remain nearly identical—down 1% from 2016 to 2025 for light trucks, with no change for cars from 2016 to 2025—and the fleet balance to shift from cars toward trucks, going from 55% to 53% cars from 2016 to 2025. Further information on EPA's latest analysis with these assumptions is available in its midterm evaluation document (EPA, 2016b).

The new vehicle fleet is expected to decrease CO_2 emissions and increase fuel economy from model year 2016 to 2025 to comply with the adopted regulations. As the fleet complies with the incrementally more stringent standards, the regulatory CO_2 emissions go from 268 g/mi in 2016 to 173 g/mi in 2025. This amounts to an annual decrease in CO_2 emissions of 4.4% for those 10 years. Accounting for air-conditioning credits, converting from CO_2 to fuel use, and using the 23% test-to-consumer-label adjustment, the consumer fuel economy goes from 25 mpg in 2016 to 35 mpg in 2025. This equates to a 3.7% annual increase in fuel economy from 2016 to 2025. We illustrate the impacts of increasing off-cycle credit use on the basis of consumer fuel economy and fleetwide CO_2 in the analysis that follows.

Figure 5 quantifies the impact of off-cycle credit use on consumer fuel economy, separately analyzing the average fuel economy for passenger cars and light trucks in model year 2025. The model year 2025 scenarios include no use of off-cycle credits and the low, midrange, and high scenarios as previously described. The figure includes the latest regulatory estimates for the fleet mix, average footprint, and air-conditioning credits in 2025 (18.8 g/mi for cars and 24.4 g/mi for light trucks). The figure also includes the comparable model year 2016 consumer fuel economy values for context. We quantify the phase-in of fleet average off-cycle credits just as we do the air-conditioning credits, such that the credits do not directly result in proportional consumer label fuel economy benefits.

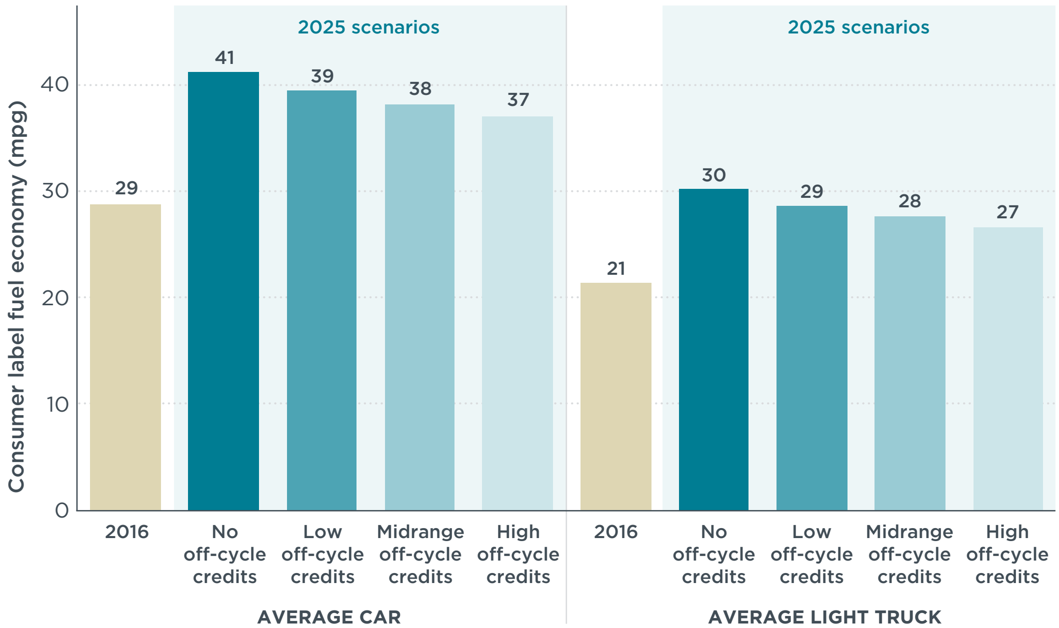

Figure 5. New vehicle consumer label fuel economy in 2016 and 2025 for average cars and light trucks, based on four scenarios with varying levels of off-cycle credit use.

As shown in Figure 5, the average car consumer label fuel economy was 29 mpg in 2016, and it would increase to 41 mpg in 2025 if there were no off-cycle credits. Under the low, midrange, and high off-cycle use cases, consumer fuel economy would reduce to 39, 38, and 37 mpg, respectively. The average light truck consumer fuel economy was 21 mpg in 2016, and it would increase to 30 mpg if there were no off-cycle credits. Under the low, midrange, and high off-cycle use cases, consumer fuel economy would reduce to 29, 28, and 27 mpg, respectively.

Figure 6 shows the increase in consumer label fuel economy from 2016 to 2025 under the same four scenarios for cars and light trucks. As shown, in a regulatory scenario without any off-cycle credits, consumer label fuel economy for cars would increase by 43%, whereas with the high off-cycle credit use, consumer label car fuel economy would increase by 29%. As a result, up to 34% of the projected increase in consumer label fuel economy for passenger cars would be lost to off-cycle credits. For light trucks, in a regulatory scenario without any off-cycle credits, consumer label fuel economy would increase by 41%, whereas with the high off-cycle credit use, consumer label car fuel economy would increase by 24%. Based on this, up to 42% of the projected increase in consumer label fuel economy for light trucks would be lost to off-cycle credits.

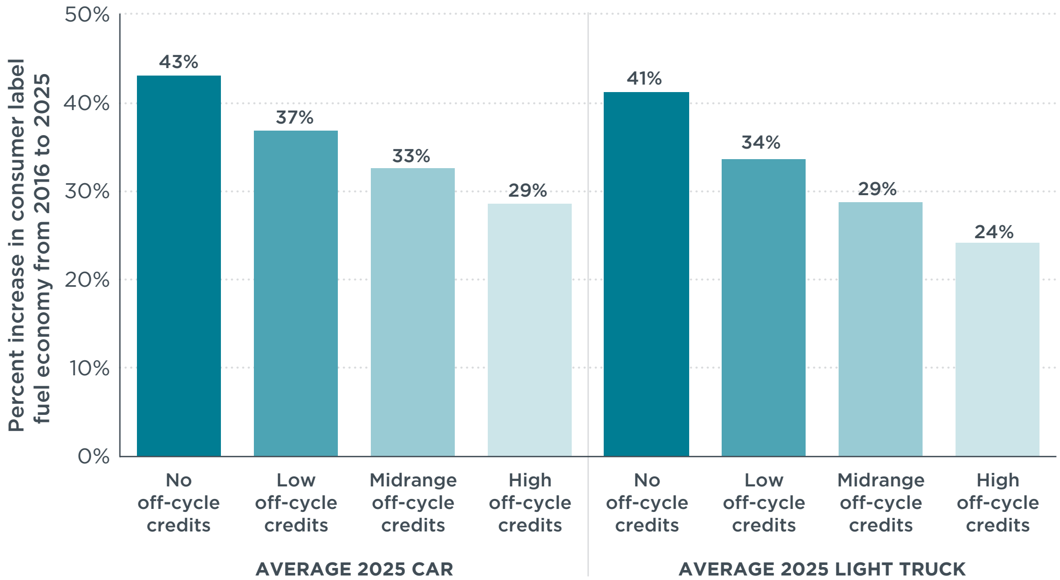

Figure 6. Increase in consumer label fuel economy for cars and trucks from 2016 to 2025, based on four scenarios with varying levels of off-cycle credits use.

The assumption to exclude off-cycle credits from the fleet average consumer fuel economy label might seem somewhat controversial. This is appropriate for a variety of reasons. The intent is certainly there for off-cycle credits to translate to increased consumer fuel economy; however, based on the preceding assessment, it does not appear appropriate to count off-cycle credits as equivalent to consumer fuel economy improvement. In terms of the practical accounting for the credits, the efficiency and CO_2 benefits for the off-cycle technology are calculated separately as credits, rather than in complete fuel economy consumer label reporting as shown in EPA data (2018c). In addition, the credits are based on estimated and simulated impacts from entirely different vehicle models, and from a much smaller pool of vehicles than those that are getting the credits. Furthermore, to date, there has not been transparency on which variants of vehicle models have the off-cycle credit technologies and are receiving the credits with the purported benefits. Finally, the off-cycle technologies, as shown above, have fuel economy benefits that have not been validated for real-world benefit under comprehensive statistically representative conditions. As previously shown, some of their credits appear to be substantially under- and overcounted.

Figure 7 illustrates the impact of the off-cycle credit use scenarios previously described on all new vehicles (i.e., including cars and light trucks) for model years 2016 through 2025. In the absence of off-cycle credits, consumer fuel economy for 2016 is at 25 mpg and fuel economy increases to 35 mpg by 2025 as the fleet is assumed to remain in compliance with the adopted standards. The figure shows the impact of increased penetration of the off-cycle credit technologies incrementally over time, until they reach the maximum values shown in Figure 4, by 2025. As shown, off-cycle credits would result in reduced average consumer label new vehicle fuel economy in 2025 from 35 mpg with no credits, to 33 mpg with low off-cycle credit use of 10 g/mi, to 32 mpg with our midrange case off-cycle credit use of 17.5 g/mi, to 31 mpg with high off-cycle credit use of 25 g/mi. Relatively high levels of off-cycle credit use would be equivalent to putting off test-cycle powertrain improvements by several years. Our midrange case for off-cycle credit use is equivalent to delaying the implementation of 2023 standards to 2025, whereas the high case for off-cycle credit use is equivalent to delaying the implementation of the 2022 standards to 2025. Stating the impact another way, increased use of off-cycle credits effectively reduces the average fuel economy improvement from 4% (with no off-cycle) to 2.8% (with high off-cycle credit use) per year for 2016 through 2025 new vehicles.

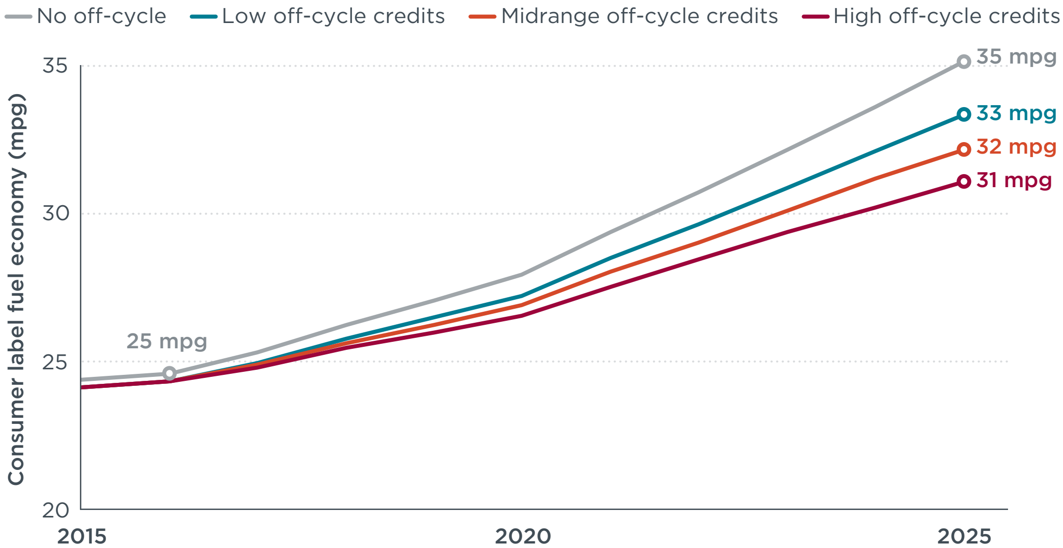

Figure 7. New vehicle consumer label fuel economy from 2015 to 2025, based on four scenarios with varying levels of off-cycle credits use.

Although we show the impact on the fuel economy standards in Figure 7, there also are impacts on the CO_2 emissions that would otherwise be required from test-cycle emission improvements. Figure 8 illustrates the projected decrease in light-duty vehicle fleet emissions from 268 g/mi in 2016 to 173 g/mi in 2025. Based on increasing use of off-cycle credits to match the scenarios previously outlined, off-cycle credits make up an increasing percentage of automakers' vehicle compliance through 2025. Off-cycle technology credits use of 3 g/mi in 2016 amounts to just 3% of the required 95 g/mi reduction for 2016–2025. Under the midrange scenario for off-cycle credit use of 17.5 g/mi, increased off-cycle credit use through 2025 amounts to 18% of regulated CO_2 reductions in model year 2025. The low (10 g/mi) and high (25 g/mi) off-cycle credit scenarios, shown in error bars, amount to 11% to 26% of the regulated emission reduction by 2025. Considering just the later regulation years that are being investigated in the midterm evaluation, 2022–2025, this increased use of off-cycle credits would amount to a much more substantial portion of the required reductions. The required CO_2 reduction from 2021 to 2025 would be 38 g/mi, which is a reduction from 211 g/mi to 173 g/mi, meaning our three scenarios for off-cycle credits would amount to 26% (low case), 48% (midrange case), and 65% (high case) of the expected CO_2 reduction that is under consideration in the midterm evaluation.

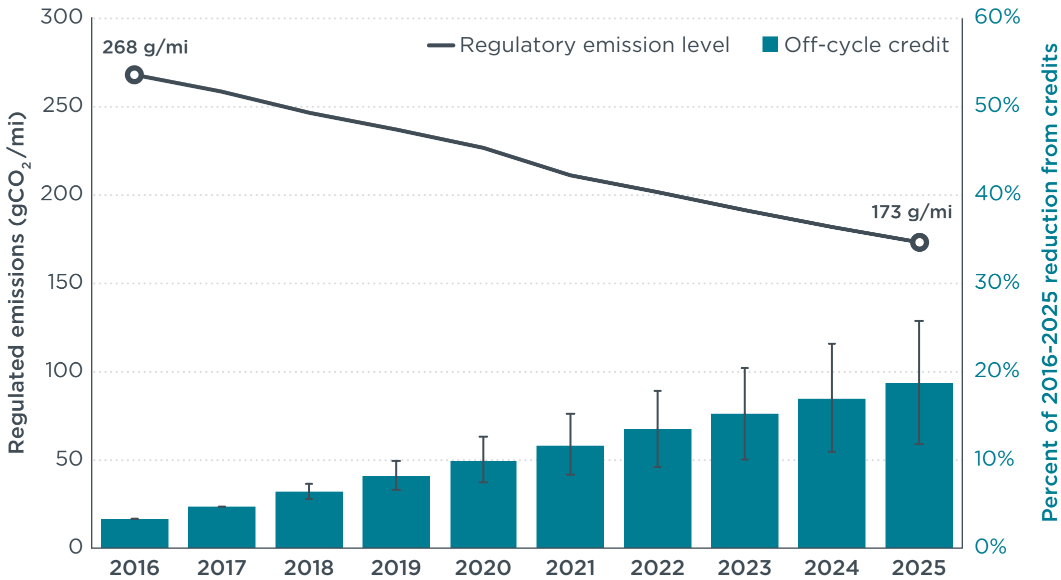

Figure 8. Increase in off-cycle credit use as percentage of regulated CO_2 reduction.

The remainder of the CO_2 reductions is expected to come from air-conditioning credits and powertrain efficiency improvements. The air-conditioning credits would amount to 23% of 2025 reductions, based on their maximum allowable usage for full deployment and as generally assumed by the regulatory agencies. Vehicle efficiency improvements that are counted over the regulated test procedure would then be expected to make up most of the remaining 50%–66% of regulated CO_2 reductions after off-cycle and air-conditioning credits, although there are also additional credit provisions, such as for nitrous oxide and methane emissions and advanced technology full-size pickups.

IMPACT ON TECHNOLOGIES ADOPTED

The use of off-cycle credits reduces the use of other planned efficiency technologies, such as engine, transmission, lightweighting, and hybridization, that would otherwise be needed to comply with efficiency standards. To better understand implications for the penetration of the test-cycle efficiency technologies, we turned to the most applicable fleet modeling available. As part of the regulatory agencies' rulemaking analysis, they model the compliance of the fleet by adding the most cost-effective technologies available until each manufacturer comes into compliance with standards through model year 2025. Within the analysis, they consider alternative scenarios, including sensitivity to more and less stringent standard levels. From EPA's analysis of alternative standards (EPA, 2012), we use the most applicable less-stringent cases and change the car-truck mix to the agencies' updated projection of 53% car and 47% light truck in 2025. Although these scenarios do not precisely match the scenarios above, they help to illustrate the impact of just a small change in off-cycle credits.

Figure 9 shows the impact on technology penetration for 2025 standards requiring 8 and 13 g/mi less improvement from test-cycle CO_2 improvements. As the figure shows, if an additional 8 g/mi of off-cycle credits were approved, less of the other efficiency technologies would be needed for compliance. Compared to the baseline where 54% of new vehicles were electrified (including stop-start through fully electric), only 33% of new vehicles for 2025 would be electrified if a fleet average 8 g/mi of credits were used. In the case where the 2025 standards have 13 g/mi in approved off-cycle credits, the sum of electric and hybrid technologies would be less than half, reduced to 25% of new vehicles, compared to the 54% in the no off-cycle credit case. Although the off-cycle provisions promote stop-start technology, the overall impact of allowing more off-cycle technologies is to reduce the need to deploy all the major test-cycle efficiency technologies. Although not shown, the impact is also to reduce the amount of turbocharging, cylinder deactivation, lightweighting, and advanced transmissions. This brief analysis indicates that the approval of approximately 10 g/mi of off-cycle credits amounts to trading off much of the deployment of hybrid and powertrain technologies for the off-cycle technologies whose benefits are comparatively uncertain. We note that updated analysis with the latest EPA data would likely show a similar result, with the advanced combustion technology deployment being substantially reduced, like the reductions shown in the chart for hybrid and stop-start technology.

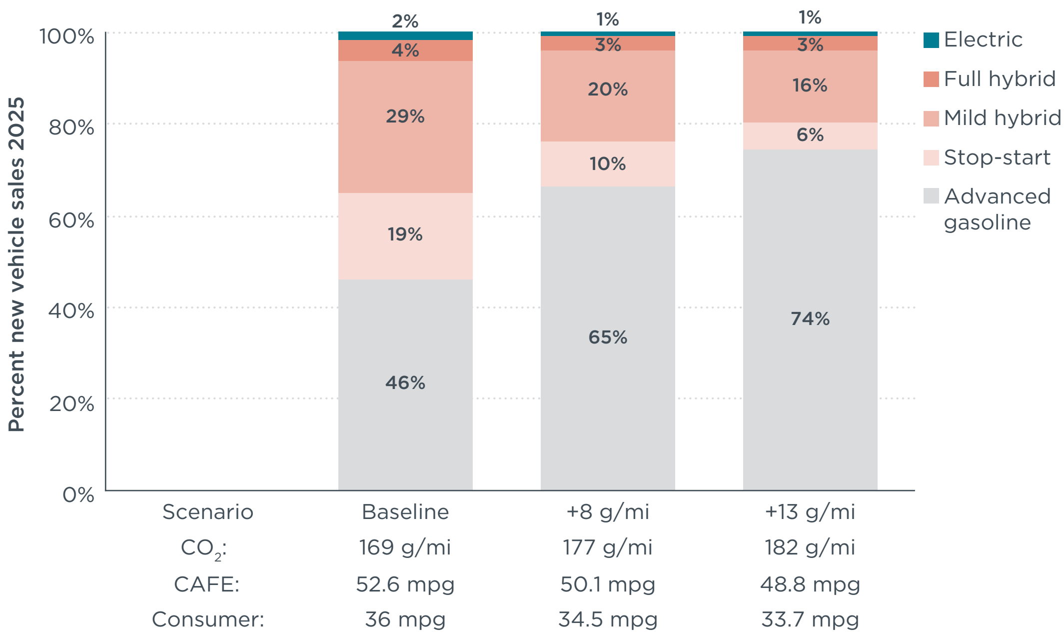

Figure 9. Technology penetration to meet baseline and 8–13 g/mi higher test-cycle CO_2 levels in new 2025 vehicles.

V. CONCLUSION

With the midterm evaluation of 2017–2025 U.S. efficiency standards underway, it is an important time to assess the approaches available to comply with the standards. Many basic details of the standards are broadly known and analyzed, including some of the finer details like how the regulations separately regulate cars and light trucks, how they are indexed to vehicle footprint, how flex-fuel vehicles receive credits, and how air-conditioning technologies also receive credit. However, the extent to which off-cycle crediting provisions could be used to ease compliance with the standards has been relatively unknown and unanalyzed.

There are several indications of just how obscured the off-cycle provisions have been. Even highly interested research experts have no way of knowing all the vehicle models receiving off-cycle credits or the sales of those models. Even the EPA, the regulatory agency that is in the position of approving the credits, is asking the automakers to more transparently report the credits (EPA, 2017b). In attempting to estimate the use of off-cycle credits in 2025, EPA evaluated a level of credit use that was about the same in 2025 as in model year 2016, even as dozens of credit requests pour in. Many of the approved credits are not yet even fully reported, and automakers aim to further open up the off-cycle approval process. For a more popular sense of how deeply shrouded the off-cycle provisions are, we note that any mention of off-cycle credits appears in only a few of the many hundreds of 2017 online news articles dealing with the U.S. corporate average fuel economy standards.

Because the off-cycle technologies have not been transparently reported and have only been minimally analyzed, even by regulatory agencies, their potential impacts to date are scarcely understood. With this paper, we analyze recent trends in off-cycle technologies and the effect they might have on the implementation of the 2025 standards. Based on the analysis, we provide a summary of findings and make several related policy recommendations.

SUMMARY OF FINDINGS

This analysis indicates that off-cycle credits could have a substantial impact on how the U.S. CO_2 and fuel economy regulations are implemented. Based on this analysis, we find that the developments and potential impact of the off-cycle credit program are far greater than generally understood by policymakers, researchers, and even the applicable regulatory agencies. We highlight the following three findings:

Off-cycle credit use. Off-cycle credit use is likely to greatly increase by 2025. Although average off-cycle credit use was just 3 g/mi in 2015, individual automakers have received credits in 12 of the 13 preapproved off-cycle technology areas and several additional technology areas. Many credit options exist, and automakers have begun to capitalize with a proliferation of credit requests. Off-cycle credit use could increase by 3 to 8 times, amounting to 10–25 g/mi of CO_2 reduction by 2025. The off-cycle credit technologies are being readily adopted, as many were already deployed within the fleet in 2009–2011, they are generally easier to implement, and they appear to be a more cost-effective option than many of the conventional test-cycle efficiency technologies.

Data rationale for off-cycle credits. Perhaps one of the more disconcerting findings is that the off-cycle credit program is based on technologies that are still largely without validated real-world benefits. From the onset, off-cycle credits were largely based on vehicle simulation and limited data. Rather than building an improved data basis as credits were approved, recent data indicate that some of the credit values are well out of line with their real-world effects. Instead, automakers are submitting derivative calculations, based on EPA's calculations for preapproved credits for off-cycle and air-conditioning credits. The new submissions tend to pick a particular input variable, such as idle time, or a particular performance variable, such as the technical efficiency of an alternator, but without analyzing the impact in a statistically comprehensive way across vehicle types, spanning real-world uses, or across different representative environmental factors such as weather, speeds, etc.

Impact on CO_2 and fuel economy standards. The increased use of off-cycle credits to 10–25 g/mi would displace 11%–26% of the CO_2 reduction otherwise needed from test-cycle improvements in the 2016–2025 regulations. Considering just the later regulation years 2022–2025 that are being investigated in the midterm evaluation, this increased use of off-cycle credits would amount to up to 26%–65% of the expected CO_2 reduction. Relatively high levels of off-cycle credit use would make the model year 2025 standards approximately equivalent to delaying the implementation of 2022–2023 standards to 2025 in terms of how much test-cycle efficiency technology would be required. Stating the impact another way, increased use of off-cycle credits could effectively reduce the average fuel economy improvement from 4% to 2.8% per year from 2016 through 2025. Our analysis also includes an assessment of the separate impacts of off-cycle credits on average car and light truck consumer label fuel economy by 2025. We find that up to 34% of the projected increase in car fuel economy, and 42% of the projected increase in light truck fuel economy, could be lost to off-cycle credit technologies.

Impact on deployment of other efficiency technologies. We were only able to partially analyze the impact of off-cycle credits on reduced penetration of particular powertrain efficiency and electric-drive technologies that would otherwise be needed to comply with efficiency standards. Even relatively small amounts of off-cycle credits greatly affect the penetration of other technologies as automakers comply with 2025 standards. Approval of off-cycle credits of 8–13 g/mi means the amount of electric-drive technology—including stop-start, mild and full hybrids, and all-electric—would drop from a baseline of 54% to just 25%–33% of new 2025 vehicles. This finding shows there is a direct and substantial trade-off between off-cycle and electric-drive technologies. As a result, a growing off-cycle program that encourages off-cycle technology adoption discourages and delays a shift to electric vehicles.

DISCUSSION AND POLICY RECOMMENDATIONS

With the large uncertainties and broad implications associated with the off-cycle program, it makes sense that there are greatly differing views on how best to proceed. From an automaker perspective, a streamlined system for credit approvals will offer greater cost-effectiveness for regulatory compliance and enable delayed deployments in advanced technologies for several years. Environmental groups are more concerned that the system lacks transparency and could detract from the regulation's energy and emissions benefits because of the prevailing uncertainties about real-world impacts. Based on the findings presented in this paper, we make the following policy recommendations.

Transparency. In the near term, a more transparent off-cycle program would lead to much greater credibility. Without transparently sharing information about the exact models with the off-cycle technologies and applicable off-cycle credits, it creates the appearance that automakers and regulatory agencies lack confidence in their real-world benefits. In one credit approval document, the approving agency—EPA—states, "lack of reporting of approved credits undermines the transparency of EPA's program. EPA does find it problematic that previously approved off-cycle credits, some of which were approved by EPA more than two years ago, remain unreported" (EPA, 2017b). We recommend full reporting of the off-cycle credit values in g/mi and megagrams of CO_2 by vehicle make and model. This would be a minimally appropriate addition for such a key regulatory provision with so much at stake in reducing the overall compliance burden and technology investments by the auto industry.

Clearer constraints and principles for approvals. A system with clearer constraints would also lead to improved credibility for the off-cycle program. Without a clear statement of principles and constraints on credits, the recent trends suggest that agency approvals and rationale will continue to meander as new credit requests are submitted. One possible criterion for the agencies to more clearly define is *additionality*. This is perhaps the single most common international criterion in evaluating the merits of climate change mitigation policies, as it asks whether the program provokes new additional action or not. This is perhaps similar and relevant to how EPA has referred to the importance of "new and innovative" technologies in its off-cycle program. Many automakers are submitting credit requests for technologies they had in the market in 2009–2011, which was before preapproved credits were determined, and other technologies that already deliver test-cycle benefits, such as with stop-start and alternator efficiency. A key question regarding all requests for off-cycle credits is whether they are changing automaker investment and deployment actions, or, whether they are simply providing additional credit for existing or already planned actions. Also, relatedly, clarification about the principles and constraints for air-conditioning credits is important. Considering how air-conditioning and off-cycle credit programs have similar frameworks, using menu-based credits and options for additional data-demonstrated credits, the agencies should clarify when and why automakers can bypass the air-conditioning program's testing requirements by applying for more air-conditioning credits in the off-cycle program.

Data requirements. Related to the data within credit applications, the agencies ideally would better define principles for their approvals of off-cycle credits. For example, beyond the preapproved list, EPA indicates, "The demonstration program must be robust, verifiable, and capable of demonstrating the real-world emissions benefit of the technology with strong statistical significance." This original principle does not appear to be applied, for example, with new consideration of off-menu technologies, for example in GM and others' submissions for variable crankcase suction valve for air-conditioning compressor, Mercedes' submission for more idle stop-start credit, or Ford's submission for a high efficiency alternator. Instead, EPA's approvals of credits for millions of vehicles are predicated upon derivative credit calculations from simulation modeling or anecdotal data from a few technologies assessed within a few vehicle models. Principles for standardized statistical sampling of data would lead to a fair and unbiased off-cycle program. As part of these data requirements, ideally the submissions would explicitly indicate which vehicle models the credits apply to and from which vehicle models real-world data were collected.

New emerging autonomous and connected vehicle technologies. There is considerable discussion at technical conferences and in research literature on inclusion of autonomous vehicle technologies in the off-cycle program. For example, Mersky and Samaras (2016) suggest efficiency benefits up to 10%, or efficiency losses of up to 3%, could result from autonomous features, depending on how vehicles' autonomous algorithms are designed. An auto industry trade group mentions the autonomous feature benefits of mitigating congestion, accident avoidance, and ridesharing in discussions about opening up off-cycle credits in the midterm evaluation of the 2025 standards (Nevers, 2017). There was even draft Congressional legislation related to opening up the off-cycle program by 9 g/mi for technologies like adaptive cruise control, autonomous braking, and vehicle connectivity (U.S. Congress, 2016). With additional such technologies entering the market, independent of the efficiency standards, this could become much more important over time. Regulatory language indicates that system-level impacts, like those resulting from ridesharing and congestion mitigation, as well as technologies for crash-avoidance or safety critical systems, are not eligible for off-cycle credits. With the CO_2 and fuel economy programs under review, and with previously noted trends showing several issues with an expanding off-cycle credit program, it is important for the agencies to clarify that these types of technologies are still, presumably, not eligible for credits.

Inclusion of off-cycle credit technology in regulatory analysis. Another recommendation that can be implemented in the near term is to include off-cycle credit use in all regulatory analyses related to the 2017–2025 midterm evaluation and potential new standards. Most off-cycle technologies involve relatively minimal equipment to implement, have been adopted sooner and at higher penetration levels than many test-cycle technologies, and are likely much more cost-effective than many test-cycle efficiency technologies. Noting that the off-cycle technologies are proving to be more attractive for automakers, the regulatory agencies ideally would include them within their regulatory scenarios. Even if this means approximating the off-cycle technology cost effectiveness for comparison to other technologies with lower penetration in 2016, this would be a major improvement over the very limited inclusion in their past analyses. Doing so would more accurately incorporate how automakers are using off-cycle credits in their approaches to comply with the standards, and compliance costs through 2025 are likely to be much lower as a result.

More accurate percentage-based credits. From the beginning of the off-cycle program, the credits have been based on an absolute g/mi basis. Because efficiency technologies affect vehicle fuel use and CO_2 emissions on a percentage basis, using absolute credits increasingly overcounts improvements in a distortionary way. The absolute off-cycle credit values were established in 2011 and 2012, looking at data from 2009–2012 and older vehicles. The average CO_2 emission level in these years was around 300 g/mi (28 mpg test cycle, 24 mpg real world); 10 g/mi in credits amounted to 3% of emissions. With the continuation of the off-cycle crediting provisions, the credits amount to a larger portion of vehicle emissions over time. With a 2025 average fleet CO_2 level of 173 g/mi, 10 g/mi would be 6% of the fleet emissions. This effectively doubles the impact of the off-cycle program, compared to the original data basis of the established preapproved credits. Especially considering the continued petitions that could go well beyond the 10 g/mi threshold, this problem will become more serious in the years ahead. A simple remedy to this is that the 10 g/mi threshold for off-cycle technology credits could be converted to a maximum percentage improvement of CO_2 emission levels that matches the original data basis. Based on this math and the uncertainty regarding the off-cycle program's real-world benefits and lack of data validation, a reasonable constraint would be to limit the program's impact to 3% of the regulated CO_2 emission target. This would be in line with the original 10 g/mi limit on preapproved credits based on simulated and tested vehicles when the new fleet averaged 300 g/mi. Such a limit would be reasonable through 2025, while longer-term issues described below are addressed with the collection of more data. Changing the off-cycle program to account for credits in percentage terms, rather than absolute g/mi, would be an even more appropriate mathematical adjustment.

Structural test procedure improvements. Over the longer term, there is a bigger issue whereby real-world efficiency and CO_2 benefits are delivering less-than-projected regulatory benefits. We already see this looming issue where the divergence between tested and consumer fuel economy is growing (see Figure 1 and Tietge, Diaz et al., 2017). The complete U.S. model-by-model database shows higher-mpg vehicles are receiving a greater shortfall in their real-world efficiency than lower-mpg vehicles. The U.S. off-cycle program is helping to seek out technologies that are real-world efficiency winners, but it ignores that vast amount of data that shows the general trend in the other direction.

This general trend and the off-cycle program's reliance on the 5-cycle testing procedure provide a shaky basis for a robust off-cycle program that is meant to bring real-world benefits. The off-cycle program selectively identifies technologies in a one-sided manner. While the majority of technologies show more benefit on the regulatory test than in the real world, automakers are selecting the minority of technologies with the opposite result to request credit. As long as automakers hold nearly all the real-world data, they will, regardless of the trend, continue to selectively submit data that proves their case. If automakers and regulators were serious about improving the real-world efficiency benefits, they would begin to address the majority of technologies that have real-world performance issues. To move toward a more coherent off-cycle program, the automakers and EPA would acknowledge this troubling trend and transparently present data that demonstrate they are shrinking the test-to-real-world gap before considering any regulatory provisions that allow more credits.

Broad consortium with comprehensive data collection. A robust long-term off-cycle program would demonstrate a clear commitment to comprehensive real-world data validation and fidelity between the off-cycle program and real-world results. The current off-cycle system is primarily based on a negotiated list of technologies, automakers' continued petitions for more credits, lack of transparency, a one-sided system that ignores cycle-beating technologies, submission of selectively chosen data, and increasing automaker pressure to make a more streamlined system for greater credits. Based on this, it is worth wondering if the use of off-cycle credits, based on default values and limited data, was premature and needs much better vetting to become a reliable program with any environmental benefits.

However, it is possible to overcome all these issues. In addition to the program improvements suggested above, a broad consortium would likely be needed to sift through the more complex issues. A multistakeholder program to collect valid, nationwide, year-round data on driving behavior and conditions would be a core component. The consortium ideally would include representatives from independent research groups and national laboratories as well as from technical teams in industry and regulatory agencies. A new program like this could help standardize off-cycle credits, use statistically representative sampling of data, transparently share data, ensure consistent calculations of their benefits, lead to better credit certainty and quick approvals to manufacturers, and ensure the credits are appropriate. Without such structural changes in the test and off-cycle procedures, the U.S. CO_2 program runs the risk of a much greater issue—that an official change to a new regulatory test cycle is the only viable correction to the continued divergence between the regulatory goals and real-world outcomes.

Although this study is focused on the U.S. situation, the topic of off-cycle credits is pertinent around the world. Efficiency and emission standards are critical tools to steer the fleet toward more advanced technologies, and to help achieve national and local climate change and air quality goals. As real-world vehicle emission performance continues to lag expected regulatory benefits, opaque and poorly understood regulatory provisions like the U.S. off-cycle program exacerbate such concerns and accelerate the call to shift to an all-electric fleet. Other regulatory agencies around the world would be wise to take the uncertain U.S. off-cycle program as an example of a path to avoid until full transparency, clear principles and constraints, and rigorous real-world data validation are assured.

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