The 2020 EPA Automotive Trends Report

Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975

United States Environmental Protection Agency

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This technical report does not necessarily represent final EPA decisions, positions, or validation of compliance data reported to EPA by manufacturers. It is intended to present technical analysis of issues using data that are currently available and that may be subject to change. The purpose of the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

These data reflect the most current available data. Historic data have been adjusted, when appropriate, to reflect the result of compliance investigations by EPA or any other corrections necessary to maintain data integrity. This edition of the report supersedes all previous versions.

The Department of Justice and EPA have reached a settlement with Mercedes based on the sale of certain diesel vehicles equipped with devices to defeat the vehicles' emission control systems. This report includes the original fuel economy and GHG certification values of these vehicles, as EPA believes this is a reasonable representation of how these vehicles were expected to perform. The affected vehicles are certain model year 2009 to 2016 diesel vehicles from Mercedes, and account for less than 1% of production in all affected years. For more information about this settlement, please see www.epa.gov/enforcement/daimler-ag-and-mercedes-benz-usa-llc-clean-air-act-civil-settlement.

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1. Introduction

This annual report is part of the U.S. Environmental Protection Agency's (EPA) commitment to provide the public with information about new light-duty vehicle greenhouse gas (GHG) emissions, fuel economy, technology data, and auto manufacturers' performance in meeting the agency's GHG emissions standards.

EPA has collected data on every new light-duty vehicle model sold in the United States since 1975, either from testing performed by EPA at the National Vehicle Fuel and Emissions Laboratory in Ann Arbor, Michigan, or directly from manufacturers using official EPA test procedures. These data are collected to support several important national programs, including EPA criteria pollutant and GHG standards, the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) Corporate Average Fuel Economy (CAFE) standards, and vehicle Fuel Economy and Environment labels. This expansive data set allows EPA to provide a uniquely comprehensive analysis of the automotive industry over the last 45 years.

A. What's New This Year

This report is updated each year to reflect the most recent data, best methodology, and any relevant regulatory changes. This version of the report contains the most up to date data available to EPA for all model years and supersedes all previous reports. The major updates for this year are as follows:

- EPA and NHTSA finalized the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule in April of 2020, which established new light-duty GHG standards for model years 2021-2026. This report includes compliance data through model year 2019 and does not generally discuss future model years. While this report has been updated to reflect regulatory changes due to the SAFE rule, the changes are minor.
- EPA also finalized technical amendments to the light-duty GHG rules that correct calculations used to determine the amount of credits created through the sale of advanced technology vehicles, such as electric vehicles. The calculations in this report reflect the methodology defined in the final technical amendment.
- Small Volume Manufacturers (SVMs) are included in discussion of the light duty GHG program (section 5), following the finalization of alternative standards for this group of manufacturers. Previous reports had omitted these manufacturers as they did not have final standards.

- This report shows projected model year 2020 data that was generally provided to EPA by manufacturers before the outbreak of COVID-19, and any associated impacts on the automobile industry. Therefore, the projected model year 2020 data may change significantly before being finalized.
- EPA has added detailed compliance data, covering all years of the light-duty GHG standards, to the EPA Automotive Trends website. We encourage readers to visit https://www.epa.gov/automotive-trends and explore the data. EPA will continue to add content and tools on the web to allow transparent access to public data.

B. Manufacturers in this Report

The underlying data for this report include every new light-duty vehicle offered for sale in the United States. These data are presented by manufacturer throughout this report, using model year 2019 manufacturer definitions determined by EPA and NHTSA for implementation of the GHG emission standards and CAFE program. For simplicity, figures and tables in the executive summary and in Sections 1-4 show only the top 14 manufacturers, by production. These manufacturers produced at least 125,000 vehicles each in the 2019 model year and accounted for approximately 98% of all production. The compliance discussion in Section 5 includes all manufacturers, regardless of production volume, and for the first time this year provides detailed data for small volume manufacturers Aston Martin, Ferrari, Lotus, and McLaren. Table 1.1 lists all manufacturers that produced vehicles in the U.S. for model year 2019, including their associated makes, and their categorization for this report. Only vehicle brands produced in model year 2019 are shown in this table; however, this report contains data on many other manufacturers and brands that have produced vehicles for sale in the U.S. since 1975.

When a manufacturer grouping changes under the GHG and CAFE programs, EPA applies the new manufacturer definitions to all prior model years for the analysis of estimated real-world CO_2 emission and fuel economy trends in Sections 1 through 4 of this report. This maintains consistent manufacturer and make definitions over time, which enables better identification of long-term trends. However, the compliance data that are discussed in Section 5 of this report maintain the previous manufacturer definitions where necessary to preserve the integrity of compliance data as accrued.

Table 1.1. Model Year 2019 Manufacturer Definitions

	Manufacturer	Makes in the U.S. Market
Large Manufacturers	BMW	BMW, Mini, Rolls Royce
	FCA	Alfa Romeo, Chrysler, Dodge, Fiat, Jeep, Maserati, Ram
	Ford	Ford, Lincoln, Roush, Shelby
	GM	Buick, Cadillac, Chevrolet, GMC
	Honda	Acura, Honda
	Hyundai	Genesis, Hyundai
	Kia	Kia
	Mazda	Mazda
	Mercedes	Maybach, Mercedes, Smart
	Nissan	Infiniti, Nissan
	Subaru	Subaru
	Tesla	Tesla
	Toyota	Lexus, Scion, Toyota
	Volkswagen	Audi, Bentley, Bugatti, Lamborghini, Porsche, Volkswagen
Other Manufacturers	Jaguar Land Rover	Jaguar, Land Rover
	Mitsubishi	Mitsubishi
	Volvo	Polestar, Volvo
	Aston Martin*	Aston Martin
	Ferrari*	Ferrari
	McLaren*	McLaren

* Small Volume Manufacturers

C. Fuel Economy and CO_2 Metrics in this Report

All data in this report for model years 1975 through 2019 are **final** and based on official data submitted to EPA and NHTSA as part of the regulatory process. In some cases, this report will show data for model year 2020, which are **preliminary** and based on data provided to EPA by automakers prior to the model year, including projected production volumes. All data in this report are based on production volumes delivered for sale in the U.S. by model year. The model year production volumes may vary from other publicized data based on calendar year sales. The report does not examine future model years, and past performance does not necessarily predict future industry trends.

The carbon dioxide (CO_2) emissions and fuel economy data in this report fall into one of two categories based on the purpose of the data and the subsequent required emissions test procedures. The first category is **compliance** data, which is measured using laboratory tests required by law for CAFE and adopted by EPA for GHG compliance. Compliance data are measured using EPA city and highway test procedures (the "2-cycle" tests), and

fleetwide averages are calculated by weighting the city and highway test results by 55% and 45%, respectively. These procedures are required for compliance; however, they no longer accurately reflect real-world driving. Compliance data may also encompass optional performance credits and adjustments that manufacturers can use towards meeting their emissions standards.

The second category is **estimated real-world** (previously called "adjusted") data, which is measured using additional laboratory tests to capture a wider range of operating conditions (including hot and cold weather, higher speeds, and faster accelerations) encountered by an average driver. This expanded set of tests is referred to as "5-cycle" testing. City and highway results are weighted 43% city and 57% highway, consistent with fleetwide driver activity data. The city and highway values are the same values found on new vehicle fuel economy labels, however the label combined value is weighted 55% city and 45% highway. Unlike compliance data, the method for calculating real-world data has evolved over time, along with technology and driving habits.

Table 1.2. Fuel Economy and CO_2 Metrics Used in this Report

CO_2 and Fuel Economy Data Category	Purpose	Current City/Highway Weighting	Current Test Basis
Compliance	Basis for manufacturer compliance with standards	55% / 45%	2-cycle
Estimated Real-World ("adjusted" in previous reports)	Best estimate of real-world performance	43% / 57%	5-cycle

This report will show estimated real-world data except for the discussion specific to the GHG regulations in Section 5 and Executive Summary Figures ES-6 through ES-8. The compliance CO_2 data must not be compared to the real-world CO_2 data presented elsewhere in this report. Appendices C and D present a more detailed discussion of the fuel economy and CO_2 data used in this report.

This report does not provide data about NHTSA's CAFE program. For more information about CAFE and manufacturer compliance with the CAFE fuel economy standards, see the CAFE Public Information Center, which can be accessed at https://one.nhtsa.gov/cafe_pic/CAFE_PIC_Home.htm.

2. Fleetwide Trends Overview

The automotive industry has made strong progress towards lower tailpipe CO_2 emissions and higher fuel economy in recent years. This section provides an update on the estimated real-world tailpipe CO_2 emissions and fuel economy for the overall fleet, and for manufacturers based on final model year 2019 data. The unique, historical data on which this report is based also provide an important backdrop for evaluating the more recent performance of the industry. Using that data, this section will also explore basic fleetwide trends in the automotive industry since EPA began collecting data in model year 1975.

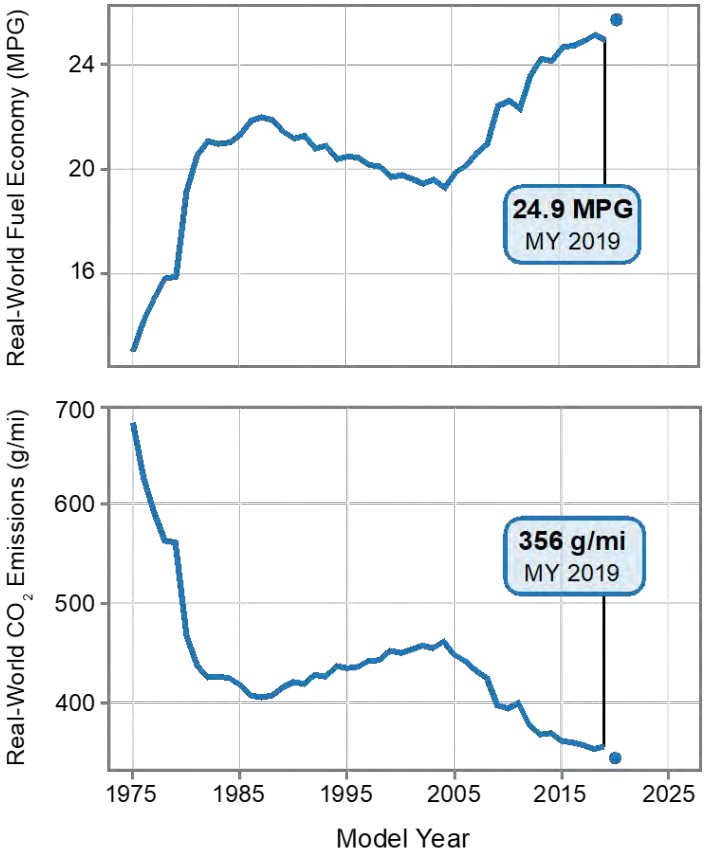
A. Overall Fuel Economy and CO_2 Trends

In model year 2019, the average estimated real-world CO_2 emission rate for all new vehicles increased slightly (less than 1%) from the record low achieved in model year 2018. The new vehicle emission rate increased 3 g/mi to 356 g/mi. Fuel economy decreased by 0.2 miles per gallon to 24.9 mpg, or slightly below the record high achieved in model year 2018[1].

Since 2004, CO_2 emissions have decreased 23%, or 105 g/mi, and fuel economy has increased 29%, or 5.6 mpg. Over that time, CO_2 emissions and fuel economy have improved in twelve out of fifteen years. The trends in CO_2 emissions and fuel economy since 1975 are shown in Figure 2.1.

Preliminary data suggest improvements in model year 2020. Average estimated real-world CO_2 emissions are projected

Figure 2.1. Estimated Real-World Fuel Economy and CO_2 Emissions

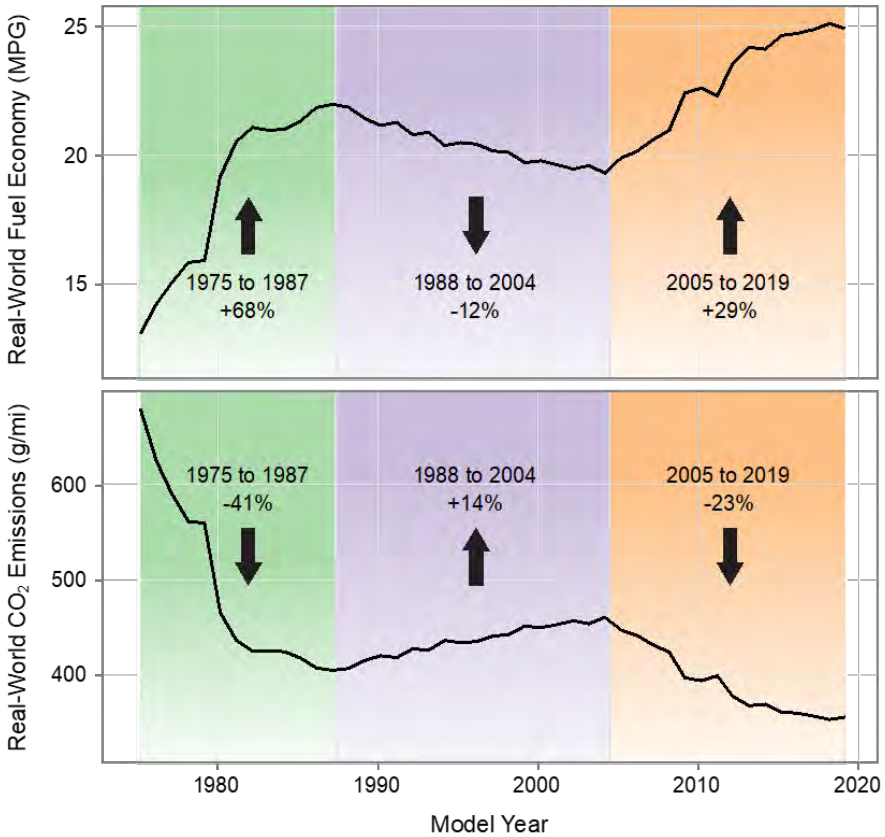


[1] EPA generally uses unrounded values to calculate values in the text, figures, and tables in this report. This approach results in the most accurate data but may lead to small apparent discrepancies due to rounding.

to fall 12 g/mi to 344 g/mi and fuel economy is projected to increase 0.8 mpg to 25.7 mpg. If achieved, these values will be record low average new vehicle CO_2 emissions and record high fuel economy. The preliminary model year 2020 data are based on production estimates provided to EPA by manufacturers months before the vehicles go on sale. The data are a useful indicator, however there is always uncertainty associated with such projections, and we caution the reader against focusing only on these data. Projected data are shown in Figure 2.1 as a dot because the values are based on manufacturer projections rather than final data.

While the most recent annual changes often receive the most public attention, the greatest value of the Trends database is to document long-term trends. The magnitude of changes in annual CO_2 emissions and fuel economy tend to be small relative to longer, multi-year trends. Figure 2.2 shows fleetwide estimated real-world CO_2 emissions and fuel economy for model years 1975–2019. Over this timeframe there have been three basic phases: 1) a rapid improvement of CO_2 emissions and fuel economy between 1975 and 1987, 2) a period of slowly increasing CO_2 emissions and decreasing fuel economy through 2004, and 3) decreasing CO_2 emissions and increasing fuel economy through the current model year.

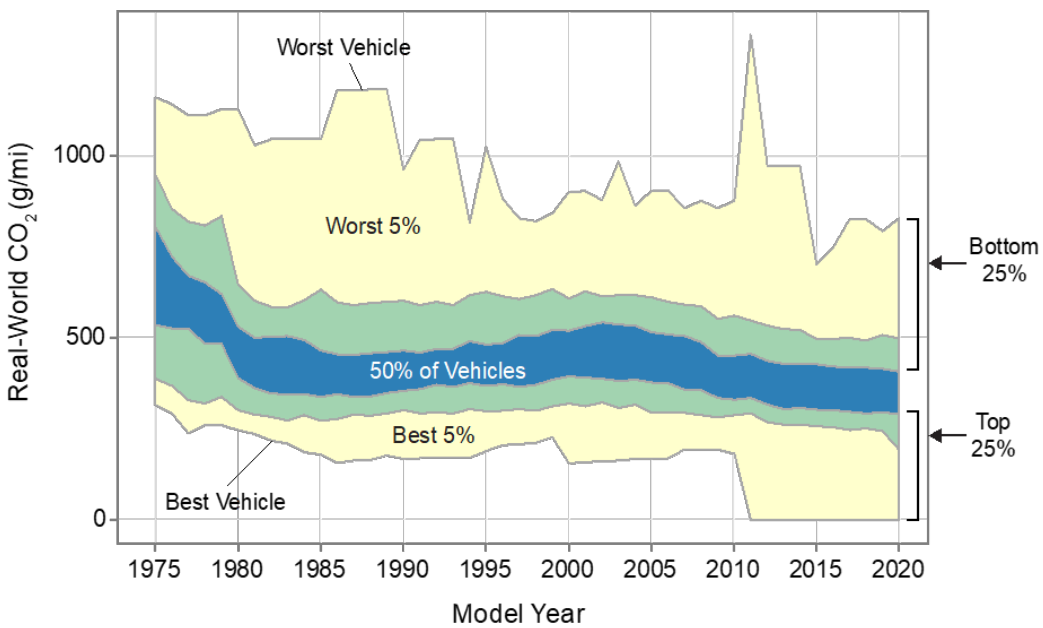
Figure 2.2. Trends in Fuel Economy and CO_2 Emissions Since Model Year 1975



Vehicle CO_2 emissions and fuel economy are inversely related for gasoline and diesel vehicles, but not for electric vehicles. Since gasoline and diesel vehicles have made up the vast majority of vehicle production since 1975, Figure 2.2 shows an inverted, but highly correlated relationship between CO_2 emissions and fuel economy. Electric vehicles, which account for a small but growing portion of vehicle production, have zero tailpipe CO_2 emissions, regardless of fuel economy (as measured in miles per gallon equivalent, or mpge). If electric vehicles continue to capture a larger market share, the overall relationship between fuel economy and tailpipe CO2 emissions will change.

Another way to look at CO_2 emissions over time is to examine how the distribution of new vehicle emission rates have changed. Figure 2.3 shows the distribution of real-world tailpipe CO_2 emissions for all vehicles produced within each model year. Half of the vehicles produced each year are clustered within a small band around the median CO_2 emission rate, as shown in blue. The remaining vehicles show a much wider spread, especially in the best and worst 5% of production each year. The lowest CO_2-emitting vehicles have all been hybrids or electric vehicles since the first hybrid was introduced in model year 2000. The highest CO_2-emitting vehicles are generally low volume performance vehicles or large trucks.

Figure 2.3. Distribution of New Vehicle CO_2 Emissions by Model Year[2]



[2] Electric vehicles prior to 2011 are not included in this figure due to limited data. However, those vehicles were available in small numbers only.

It is important to note that the methodology used in this report for calculating estimated real-world fuel economy and CO_2 emission values has changed over time to reflect changing vehicle technology and operation. For example, the estimated real-world fuel economy for a 1980s vehicle is somewhat higher than it would be if the same vehicle were being produced today. These changes are small for most vehicles, but larger for very high fuel economy vehicles. See Appendix C and D for a detailed explanation of fuel economy metrics and their changes over time.

B. Manufacturer Fuel Economy and CO_2 Emissions

Along with the overall industry, most manufacturers have improved new vehicle CO_2 emission rates and fuel economy in recent years. Manufacturer trends over the last five years are shown in Figure 2.4. This span covers the approximate length of a vehicle redesign cycle, and it is likely that most vehicles have undergone design changes in this period, resulting in a more accurate depiction of recent manufacturer trends than focusing on a single year. Changes over this time period can be attributed to both vehicle design and changing vehicle production trends.

Over the last five years, ten of the fourteen largest manufacturers selling vehicles in the U.S. decreased new vehicle estimated real-world CO_2 emission rates. Between model years 2014 and 2019, Kia achieved the largest reduction in CO_2 emissions, at 31 g/mi, followed by Honda and Hyundai. Tesla was unchanged because their all-electric fleet produces no tailpipe CO_2 emissions. Three manufacturers increased new vehicle CO_2 emission rates; Mazda had the largest increase, at 13 g/mi, followed by General Motors (GM) and Ford.

Eleven of the fourteen largest manufacturers increased fuel economy over the same period. Tesla had the largest increase in fuel economy, due mostly to the introduction of the Model 3 in model year 2017. The Model 3 is now Tesla's most efficient and highest production vehicle. Of the remaining manufacturers, Kia had the largest increase in fuel economy, again followed by Honda and Hyundai. Fuel economy did in fact increase slightly for VW, although the small increase is not visible on Figure 2.4. Fuel economy fell for three manufacturers; Mazda had the largest drop in fuel economy, followed by GM and Ford.

For model year 2019 alone, Tesla's all-electric fleet had by far the lowest tailpipe CO_2 emissions and highest fuel economy of all large manufacturers. Tesla was followed by Honda, and Hyundai. FCA had the highest new vehicle average CO_2 emissions and lowest fuel economy of the large manufacturers in model year 2019, followed by GM and Ford.

Figure 2.4. Manufacturer Estimated Real-World Fuel Economy and Tailpipe CO_2 in Model Year 2014 and 2019

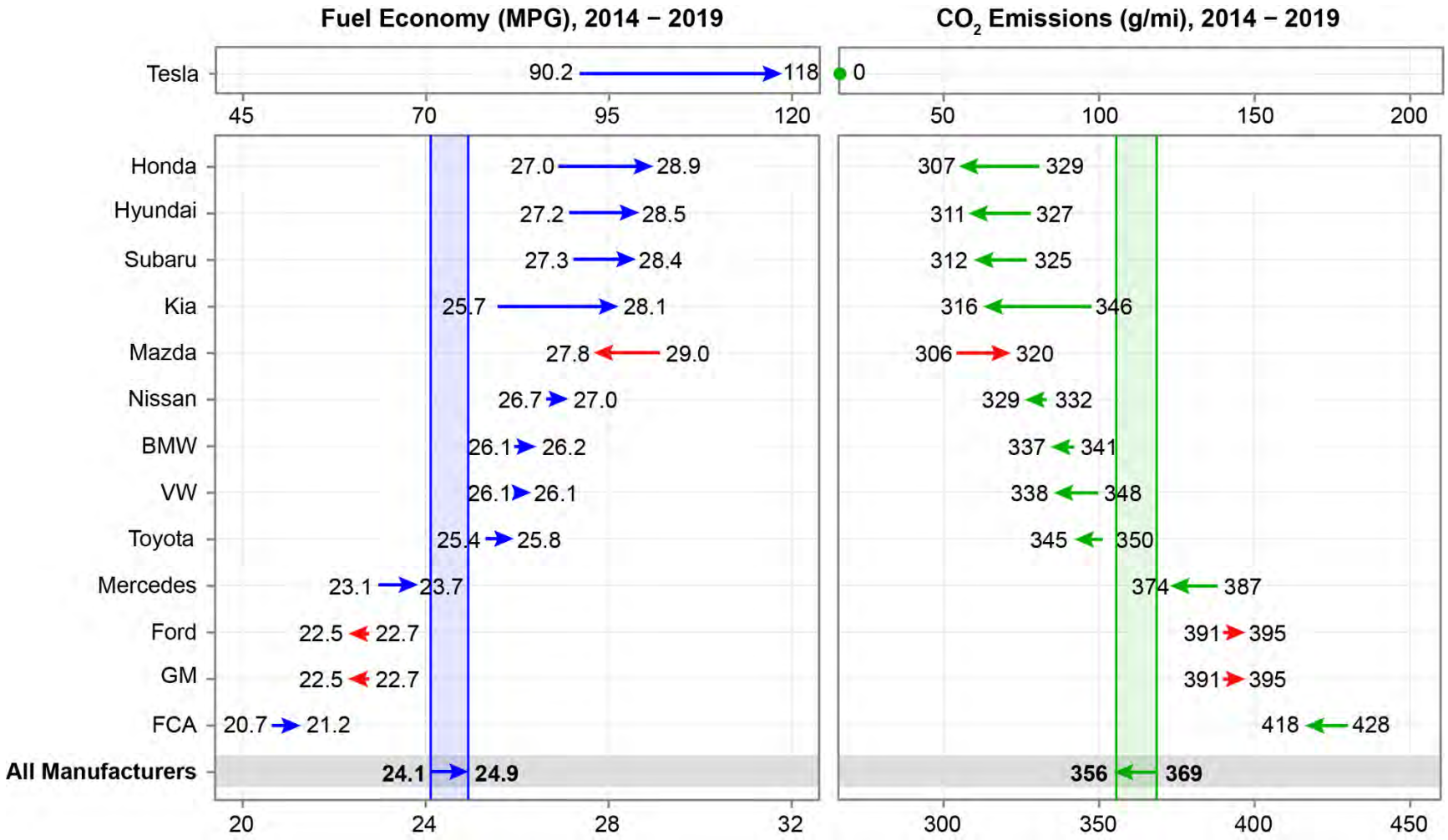


Table 2.1. Production, Estimated Real-World CO_2, and Fuel Economy for Model Year 1975–2020

Model Year	Production (000)	Real-World CO2 (g/mi)	Real-World FE (MPG)
1975	10,224	681	13.1
1976	12,334	625	14.2
1977	14,123	590	15.1
1978	14,448	562	15.8
1979	13,882	560	15.9
1980	11,306	466	19.2
1981	10,554	436	20.5
1982	9,732	425	21.1
1983	10,302	426	21.0
1984	14,020	424	21.0
1985	14,460	417	21.3
1986	15,365	407	21.8
1987	14,865	405	22.0
1988	15,295	407	21.9
1989	14,453	415	21.4
1990	12,615	420	21.2
1991	12,573	418	21.3
1992	12,172	427	20.8
1993	13,211	426	20.9
1994	14,125	436	20.4
1995	15,145	434	20.5
1996	13,144	435	20.4
1997	14,458	441	20.2
1998	14,456	442	20.1
1999	15,215	451	19.7
2000	16,571	450	19.8
2001	15,605	453	19.6
2002	16,115	457	19.5
2003	15,773	454	19.6
2004	15,709	461	19.3
2005	15,892	447	19.9
2006	15,104	442	20.1
2007	15,276	431	20.6
2008	13,898	424	21.0
2009	9,316	397	22.4
2010	11,116	394	22.6
2011	12,018	399	22.3
2012	13,449	377	23.6
2013	15,198	368	24.2
2014	15,512	369	24.1
2015	16,739	360	24.6
2016	16,278	359	24.7
2017	17,016	357	24.9
2018	16,259	353	25.1
2019	16,139	356	24.9
2020 (prelim)		*344*	*25.7*

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends.

Table 2.2. Manufacturers and Vehicles with the Highest Fuel Economy, by Year

Model Year	Manufacturer with Highest Fuel Economy[3] (mpg)	Manufacturer with Lowest Fuel Economy (mpg)	Overall Vehicle with Highest Fuel Economy[4]			Gasoline (Non-Hybrid) Vehicle with Highest Fuel Economy	
			Vehicle	Real-World FE (mpg)	Engine Type	Gasoline Vehicle	Real-World FE (mpg)
1975	Honda	Ford	Honda Civic	28.3	Gas	Honda Civic	28.3
1980	VW	Ford	VW Rabbit	40.3	Diesel	Nissan 210	36.1
1985	Honda	Mercedes	GM Sprint	49.6	Gas	GM Sprint	49.6
1990	Hyundai	Mercedes	GM Metro	53.4	Gas	GM Metro	53.4
1995	Honda	FCA	Honda Civic	47.3	Gas	Honda Civic	47.3
2000	Hyundai	FCA	Honda Insight	57.4	Hybrid	GM Metro	39.4
2005	Honda	Ford	Honda Insight	53.3	Hybrid	Honda Civic	35.1
2006	Mazda	Ford	Honda Insight	53.0	Hybrid	Toyota Corolla	32.3
2007	Toyota	Mercedes	Toyota Prius	46.2	Hybrid	Toyota Yaris	32.6
2008	Hyundai	Mercedes	Toyota Prius	46.2	Hybrid	Smart Fortwo	37.1
2009	Toyota	FCA	Toyota Prius	46.2	Hybrid	Smart Fortwo	37.1
2010	Hyundai	Mercedes	Honda FCX	60.2	FCV	Smart Fortwo	36.8
2011	Hyundai	Mercedes	BMW Active E	100.6	EV	Smart Fortwo	35.7
2012	Hyundai	FCA	Nissan-i-MiEV	109.0	EV	Toyota iQ	36.8
2013	Hyundai	FCA	Toyota IQ	117.0	EV	Toyota iQ	36.8
2014	Mazda	FCA	BMW i3	121.3	EV	Mitsubishi Mirage	39.5
2015	Mazda	FCA	BMW i3	121.3	EV	Mitsubishi Mirage	39.5
2016	Mazda	FCA	BMW i3	121.3	EV	Mazda 2	37.1
2017	Honda	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5
2018	Tesla	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5
2019	Tesla	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.6
2020 (prelim)	*Tesla*	*FCA*	*Tesla Model 3 SR+*	*138.6*	*EV*	*Mitsubishi Mirage*	*40.1*

[3] Manufacturers below the 125,000 threshold for "large" manufacturers are excluded in years they did not meet the threshold.

[4] Vehicles are shown based on estimated real-world fuel economy as calculated for this report. These values will differ from values found on the fuel economy labels at the time of sale. For more information on fuel economy metrics see Appendix C.

Table 2.3. Manufacturer Estimated Real-World Fuel Economy and CO_2 Emissions for Model Year 2018–2020

	MY 2018 Final		MY 2019 Final				*MY 2020 Preliminary*	
Manufacturer	**Real-World FE (mpg)**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**FE Change from MY 2018 (mpg)**	**Real-World CO_2 (g/mi)**	**CO_2 Change from MY 2018 (g/mi)**	***Real-World FE (mpg)***	***Real-World CO_2 (g/mi)***
BMW	26.0	339	26.2	0.2	337	-2	*25.5*	*346*
FCA	21.7	409	21.2	-0.5	418	9	*21.8*	*408*
Ford	22.4	397	22.5	0.1	395	-2	*23.3*	*381*
GM	23.0	386	22.5	-0.5	395	9	*22.8*	*391*
Honda	30.0	296	28.9	-1.1	307	12	*29.7*	*299*
Hyundai	28.6	311	28.5	0.0	311	-1	*28.9*	*306*
Kia	27.8	319	28.1	0.3	316	-4	*27.3*	*324*
Mazda	28.7	310	27.8	-0.9	320	10	*27.6*	*323*
Mercedes	23.5	377	23.7	0.2	374	-3	*23.9*	*372*
Nissan	27.1	327	27.0	-0.2	329	2	*27.4*	*323*
Subaru	28.7	310	28.4	-0.3	312	3	*28.3*	*313*
Tesla	113.7	0	118.0	4.3	0	0	*119.1*	*0*
Toyota	25.5	348	25.8	0.3	345	-3	*26.2*	*339*
VW	24.6	361	26.1	1.5	338	-23	*24.4*	*360*
All Manufacturers	**25.1**	**353**	**24.9**	**-0.2**	**356**	**3**	***25.7***	***344***

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends.

3. Vehicle Attributes

Vehicle CO_2 emissions and fuel economy are strongly influenced by vehicle design parameters, including weight, power, acceleration, and size. In general, vehicles that are larger, heavier, and more powerful typically have lower fuel economy and higher CO_2 emissions than other comparable vehicles. This section focuses on several key vehicle design attributes that impact CO_2 emissions and fuel economy and evaluates the impact of a changing automotive marketplace on overall fuel economy.

A. Vehicle Class and Type

Manufacturers offer a wide variety of light-duty vehicles in the United States. Under the CAFE and GHG regulations, new vehicles are separated into two distinct regulatory classes, cars and trucks, and each vehicle class has separate GHG and fuel economy standards. Vehicles that weigh more than 6,000 pounds gross vehicle weight[5] (GVW) or have four-wheel drive and meet various off-road requirements, such as ground clearance, qualify as trucks. Vehicles that do not meet these requirements are considered cars.

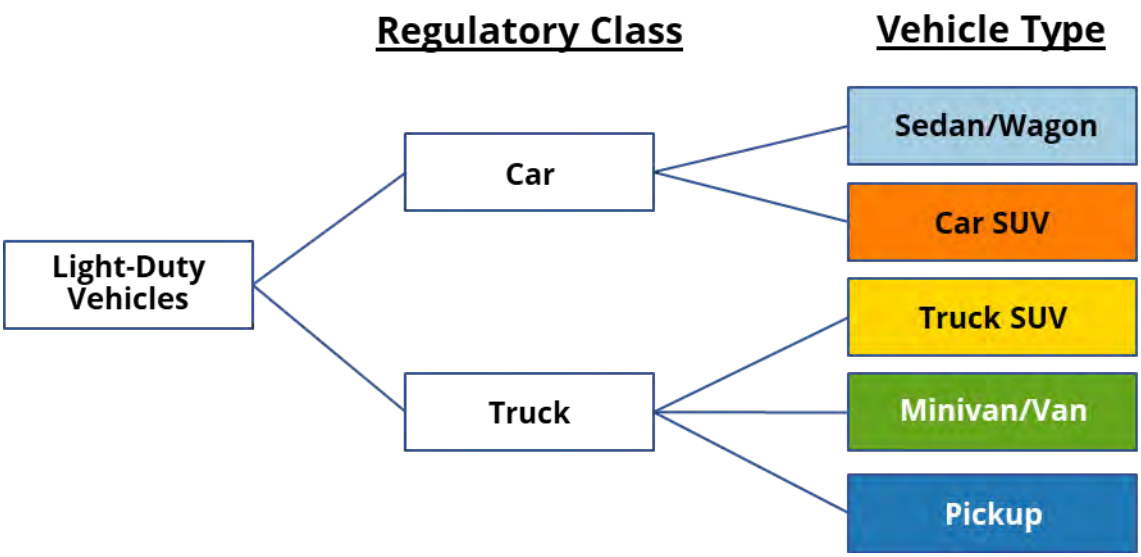
Pickup trucks, vans, and minivans are all considered trucks under the regulatory definitions, while sedans, coupes, and wagons are generally classified as cars. Sport utility vehicles (SUVs), fall into both categories. Based on the CAFE and GHG regulatory definitions, all two-wheel drive SUVs under 6,000 pounds GVW are classified as cars, while most SUVs that have four-wheel drive or are above 6,000 pounds GVW are considered trucks. SUV models that are less than 6,000 pounds GVW can have both car and truck variants, with two-wheel drive versions classified as cars and four-wheel drive versions classified as trucks. As the fleet has changed over time, the line drawn between car and truck classes has also evolved. This report uses the current regulatory car and truck definitions, and these changes have been propagated back throughout the historical data.

This report further separates the car and truck regulatory classes into five vehicle type categories based on their body style classifications under the fuel economy labeling program. The regulatory car class is divided into two vehicle types: sedan/wagon and car SUV. The sedan/wagon vehicle type includes minicompact, subcompact, compact, midsize, large, and two-seater cars, hatchbacks, and station wagons. Vehicles that are SUVs under the labeling program and cars under the CAFE and GHG regulations are classified as car SUVs in this report. The truck class is divided into three vehicle types: pickup, minivan/van,

[5] Gross vehicle weight is the combined weight of the vehicle, passengers, and cargo of a fully loaded vehicle.

and truck SUV. Vehicles that are SUVs under the labeling program and trucks under the CAFE and GHG regulations are classified as truck SUVs. Figure 3.1 shows the two regulatory classes and five vehicle types used in this report. The distinction between these five vehicle types is important because different vehicle types have different design objectives, and different challenges and opportunities for improving fuel economy and reducing CO_2 emissions.

Figure 3.1. Regulatory Classes and Vehicle Types Used in This Report



Fuel Economy and CO_2 by Vehicle Type

The production volume of the different vehicle types has changed significantly over time. Figure 3.2 shows the production shares of each of the five vehicle types since model year 1975. The overall new vehicle market continues to move away from the sedan/wagon vehicle type towards a combination of truck SUVs, car SUVs, and pickups. Sedans/wagons were the dominant vehicle type in 1975, when more than 80% of vehicles produced were sedans/wagons. Since then, their production share has generally been falling, and by model year 2019 sedans/wagons captured a record low 33% of the market, or far less than half of the market share they held in model year 1975.

Vehicles that could be classified as a car SUV or truck SUV were a very small part of the production share in 1975 but are now approaching half of the vehicle production share. By model year 2019, truck SUVs reached a record high 37% of production and car SUVs reached a record high of 12% of production. The production share of pickups has fluctuated over time, peaking at 19% in 1994 and then falling to 10% in 2012. Pickups have

increased in recent years to 16% of the market. Minivan/vans captured less than 5% of the market in 1975, increased to 11% in model year 1995 but have fallen since to 3% of vehicle production.

In model year 2019, 44% of the fleet were cars and 56% were trucks. This was the highest percentage of trucks on record and a significant change from 1975. In Figure 3.2, the dashed line between the car SUVs and truck SUVs shows the split in car and truck regulatory class.

Figure 3.2. Production Share and Estimated Real-World Fuel Economy

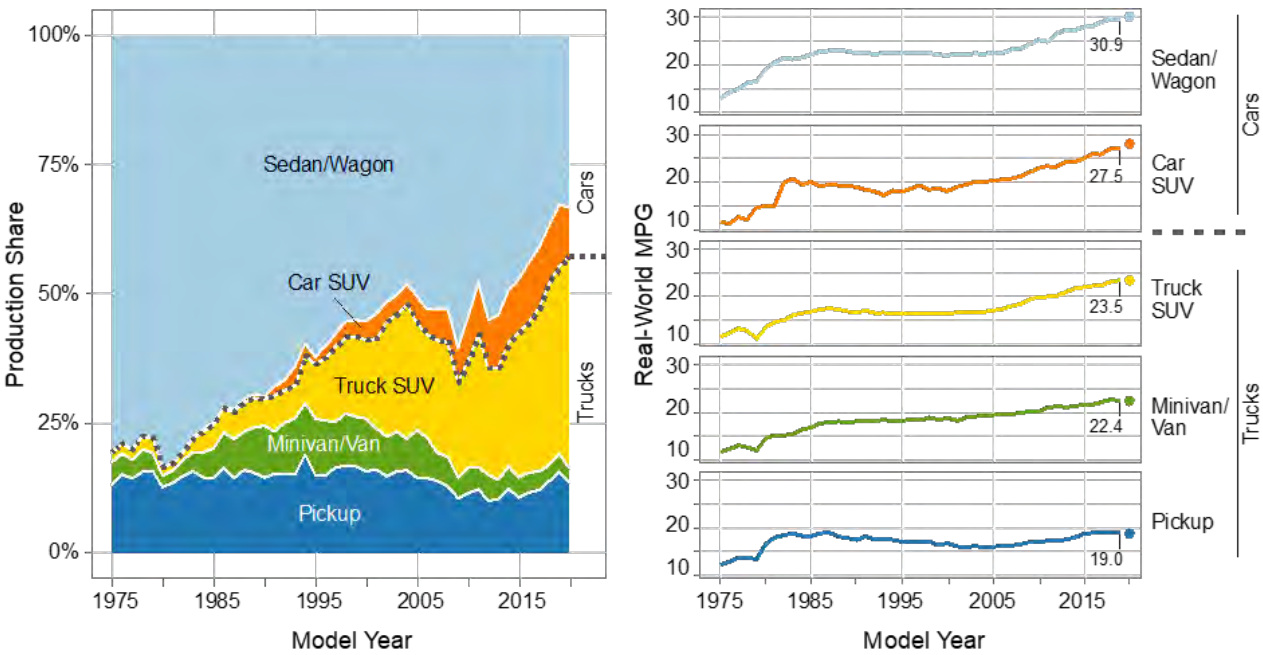


Figure 3.2 also shows estimated real-world fuel economy for each vehicle type since 1975. Three of the five vehicle types, sedan/wagons, car SUVs, and truck SUVs, are at record low CO_2 emissions and record high fuel economy. Truck SUVs had the largest year-over-year improvements in model year 2019, improving fuel economy by 0.4 mpg, followed by car SUVs (up 0.2 mpg) and sedans/wagons (up 0.1 mpg). Pickups and minivans had a small drop in fuel economy (down 0.1 mpg and 0.3 mpg, respectively), but remain close to record high fuel economy and record low CO_2 emissions set in model year 2018. All the vehicle types, except for pickups, now achieve fuel economy more than double what they achieved in 1975. In the preliminary model year 2020 data (shown as a dot on Figure 3.2), all vehicle types are expected to improve fuel economy.

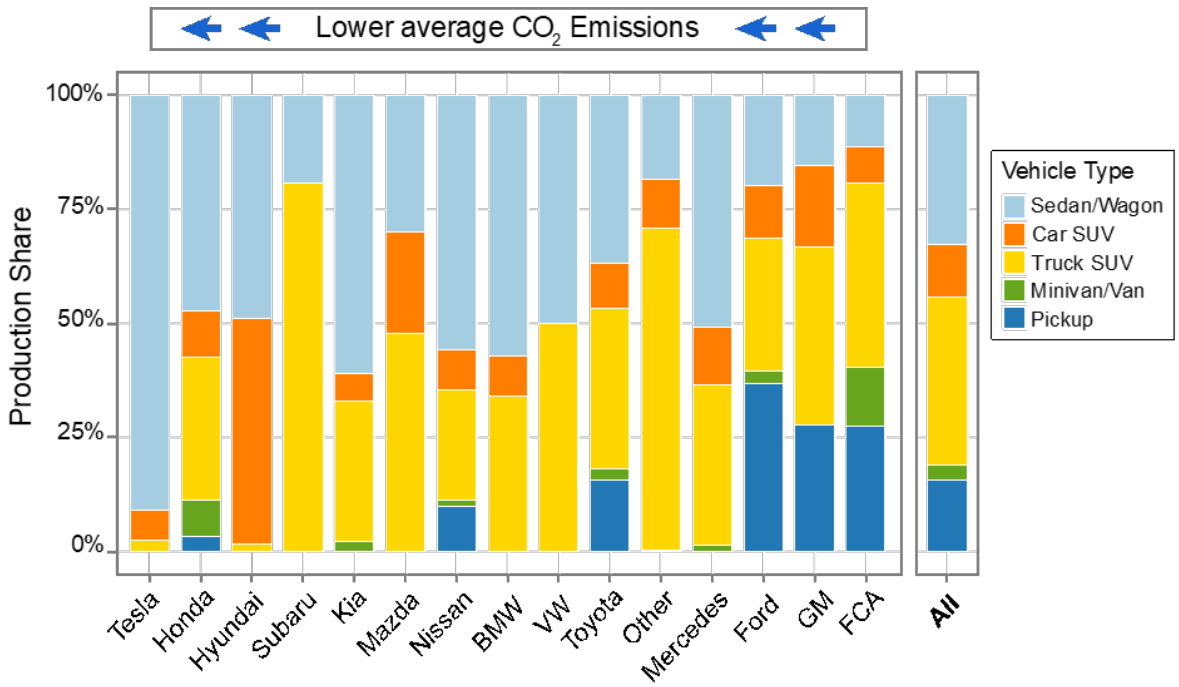
Overall fuel economy trends depend on the trends within the five vehicle types, but also on the market share of each of the vehicle types. The trend away from sedan/wagons, which remain the vehicle type with the highest fuel economy and lowest CO_2 emissions, and towards vehicle types with lower fuel economy and higher CO_2 emissions, has offset some of the fleetwide benefits that otherwise would have been achieved from the improvements within each vehicle type.

Vehicle Type by Manufacturer

The model year 2019 production breakdown by vehicle type for each manufacturer is shown in Figure 3.3. There are clear variations in production distribution by manufacturer. More than 90% of Tesla's production was sedans/wagons, which is the highest of any manufacturer. For other vehicle types, Hyundai had the highest percentage of car SUVs at 49%, Subaru had the highest percentage of truck SUVs at 81%, Ford had the highest percentage of pickups at 37%, and FCA had the highest percentage of minivan/vans at 13%.

Sedans/wagon market penetration fell 4% across the industry in model year 2019, with reductions from eleven out of fourteen manufacturers. The largest drops were from BMW at 16%, Mazda at 15%, and Hyundai at 11%, with all three companies moving their vehicle production towards car SUVs and truck SUVs.

Figure 3.3. Vehicle Type Distribution by Manufacturer for Model Year 2019



A Closer Look at SUVs

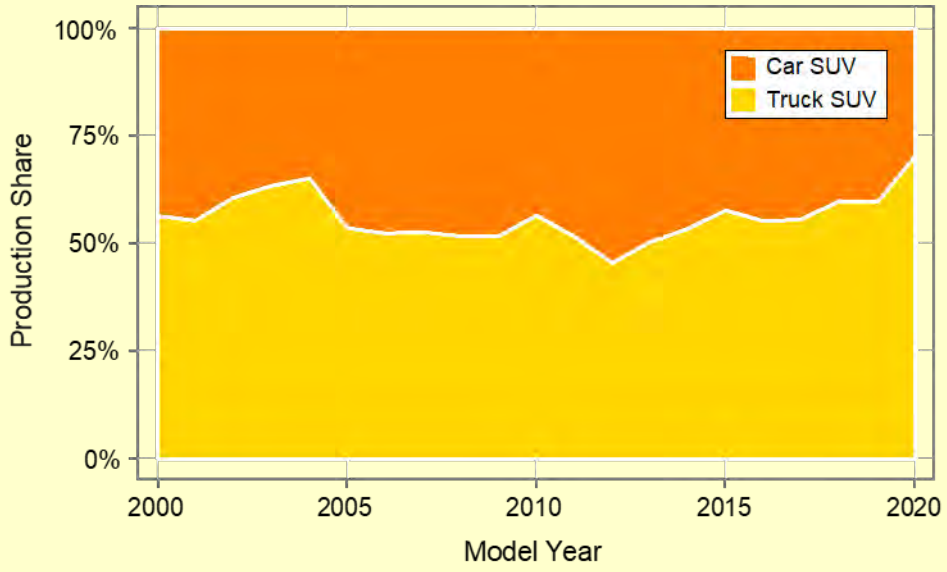
SUV Classification

Over the last 30 years, the production share of SUVs in the United States has increased in all but six years and now accounts for almost 50% of all vehicles produced (see Figure 3.2). This includes both the car and truck SUV vehicle types.

Based on the regulatory definitions of cars and trucks, SUVs that are less than 6,000 pounds GVW can be classified as either cars or trucks, depending on design requirements such as minimum angles and clearances, and whether the vehicle has 2-wheel drive or 4-wheel drive. This definition can lead to similar vehicles having different car or truck classifications, and different requirements under the GHG and CAFE regulations. One particular trend of interest is the classification of SUVs as either car SUVs or truck SUVs.

This report does not track GVW, but instead tracks weight using inertia weight classes, where inertia weight is the weight of the empty vehicle, plus 300 pounds (see weight discussion on the next page). Figure 3.4 shows the breakdown of SUVs into the car and truck categories over time for vehicles with an inertia weight of 4,000 pounds or less. Vehicles in the 4,500-pound inertia weight class and higher were excluded, as these vehicles generally exceed 6,000 pounds GVW and are classified as trucks. The relative percentage of SUVs with an inertia weight of 4,000 pounds or less that meet the current regulatory truck definition in model year 2019 is less than in model year 2000. However, since model year 2012 the percentage of truck SUVs has been increasing slowly, and the percentage of truck SUVs is projected to reach a new high in model year 2020.

Figure 3.4. Car-Truck Classification of SUVs with Inertia Weights of 4000 Pounds or Less



B. Vehicle Weight

Vehicle weight is a fundamental vehicle attribute, both because it can be related to utility functions such as vehicle size and features, and because higher weight, other things being equal, will increase CO_2 emissions and decrease fuel economy. All vehicle weight data in this report are based on inertia weight classes. Each inertia weight class represents a range of loaded vehicle weights, or vehicle curb weights[6] plus 300 pounds. Vehicle inertia weight classes are in 250-pound increments for classes below 3,000 pounds, while inertia weight classes over 3,000 pounds are divided into 500-pound increments.

Vehicle Weight by Vehicle Type

Figure 3.5 shows the average new vehicle weight from model year 1975 through 2020 for all new vehicles by vehicle type. From model year 1975 to 1981, average vehicle weight dropped 21%, from 4,060 pounds per vehicle to about 3,200 pounds; this was likely driven by both increasing fuel economy standards (which, at the time, were universal standards, and not based on any type of vehicle attribute) and higher gasoline prices.

From model year 1981 to model year 2004, the trend reversed, and average new vehicle weight began to slowly but steadily climb. By model year 2004, average new vehicle weight had increased 28% and reached 4,111 pounds per vehicle, in part because of the increasing truck share. Average vehicle weight in model year 2019 was only slightly above 2004 but has increased slowly over the last several years and is currently at the highest point on record, at 4,156 pounds. Preliminary model year 2020 data suggest that weight will continue to increase slightly.

In model year 1975, the difference between the heaviest and lightest vehicle types was about 215 pounds, or about 5% of the average new vehicle. By model year 2019, the difference between the heaviest and lightest vehicle types had increased to almost 1,600 pounds, or about 38% of the average new vehicle weight. Over that time, the weight of an average new sedan/wagon fell 13% while the weight of an average new pickup increased 27%. In 1975, the average new sedan/wagon outweighed the average new pickup by about 45 pounds, but the different weight trends over time for each of these vehicle types led to a very different result in model year 2019, with the average new pickup outweighing the average new sedan/wagon by almost 1,600 pounds. Pickups did have a large drop of over 300 pounds per average new vehicle in weight model year 2015, which is correlated with the redesign of the Ford F-150 to a largely aluminum body.

[6] Vehicle curb weight is the weight of an empty, unloaded vehicle.

Figure 3.5. Average New Vehicle Weight by Vehicle Type

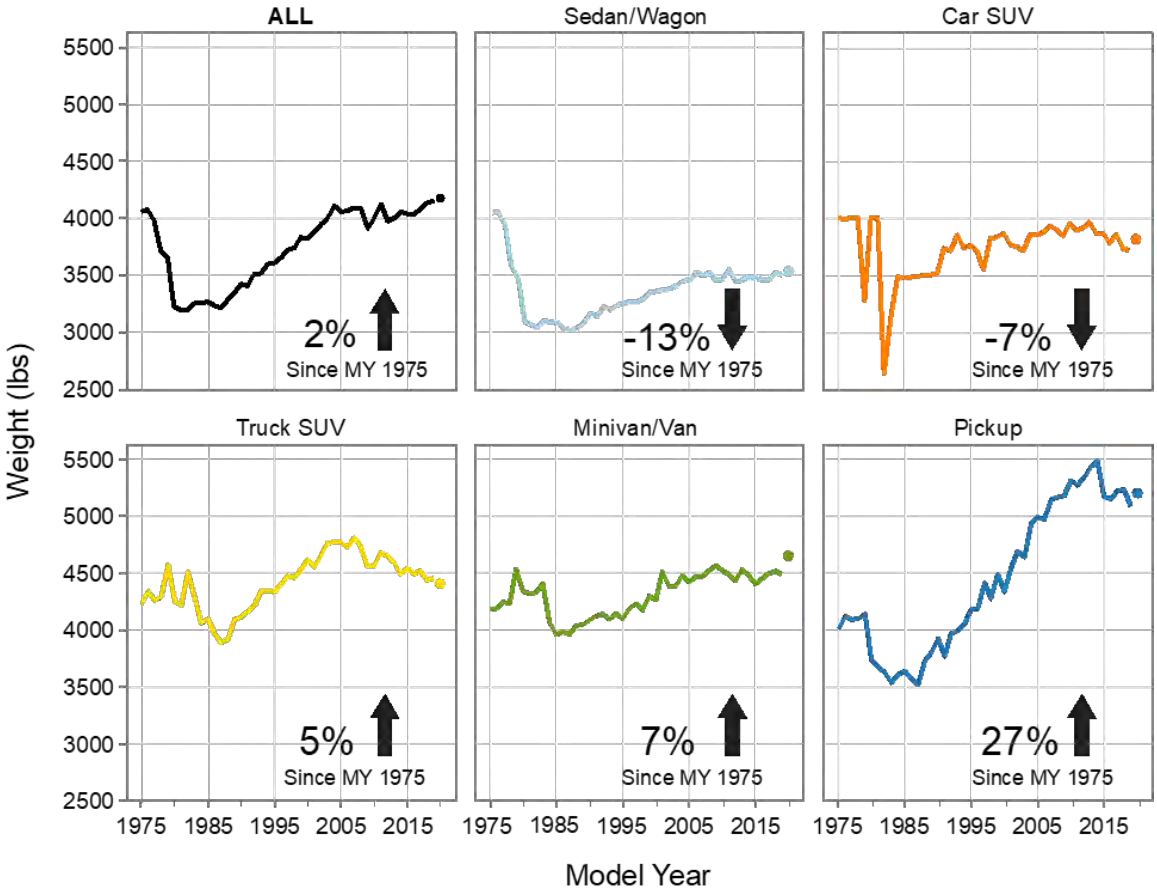
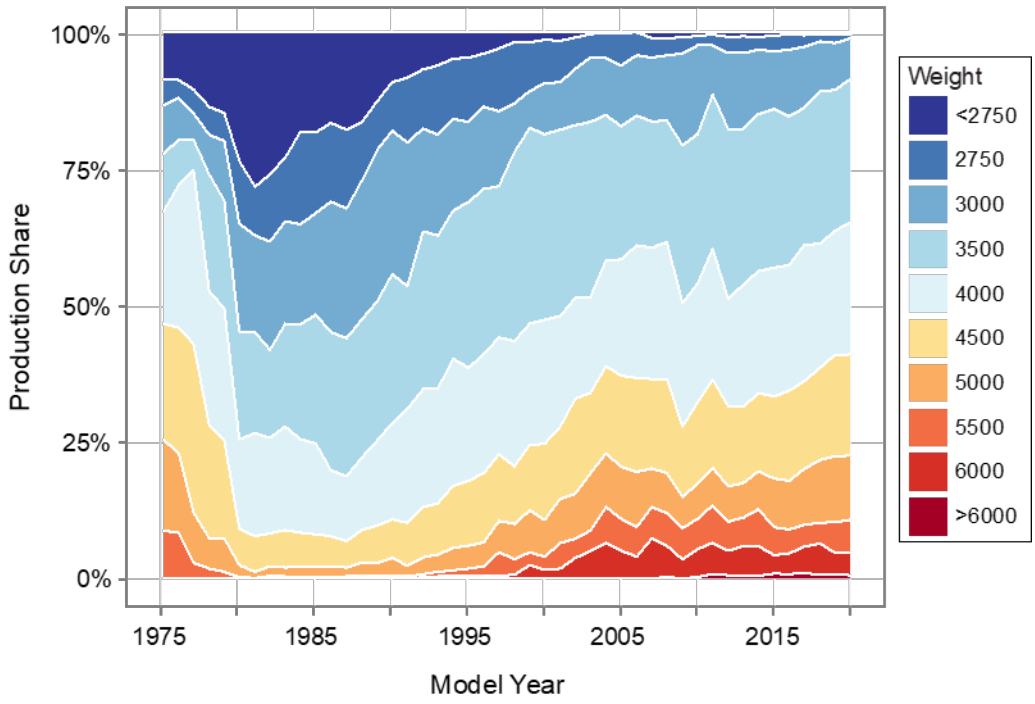


Figure 3.6 shows the annual production share of different inertia weight classes for new vehicles since model year 1975. In model year 1975 there were significant sales in all weight classes from <2,750 pounds to 5,500 pounds. In the early 1980s the largest vehicles disappeared from the market, and light cars <2,750 pounds inertia weight briefly captured more than 25% of the market. Since then, cars in the <2,750-pound inertia weight class have all but disappeared, and the market has moved towards heavier vehicles. Interestingly, the heaviest vehicles in model year 1975 were mostly large cars, whereas the heaviest vehicles today are largely trucks, with a few luxury vehicles and vans.

Figure 3.6. Inertia Weight Class Distribution by Model Year



Vehicle Weight and CO_2 Emissions

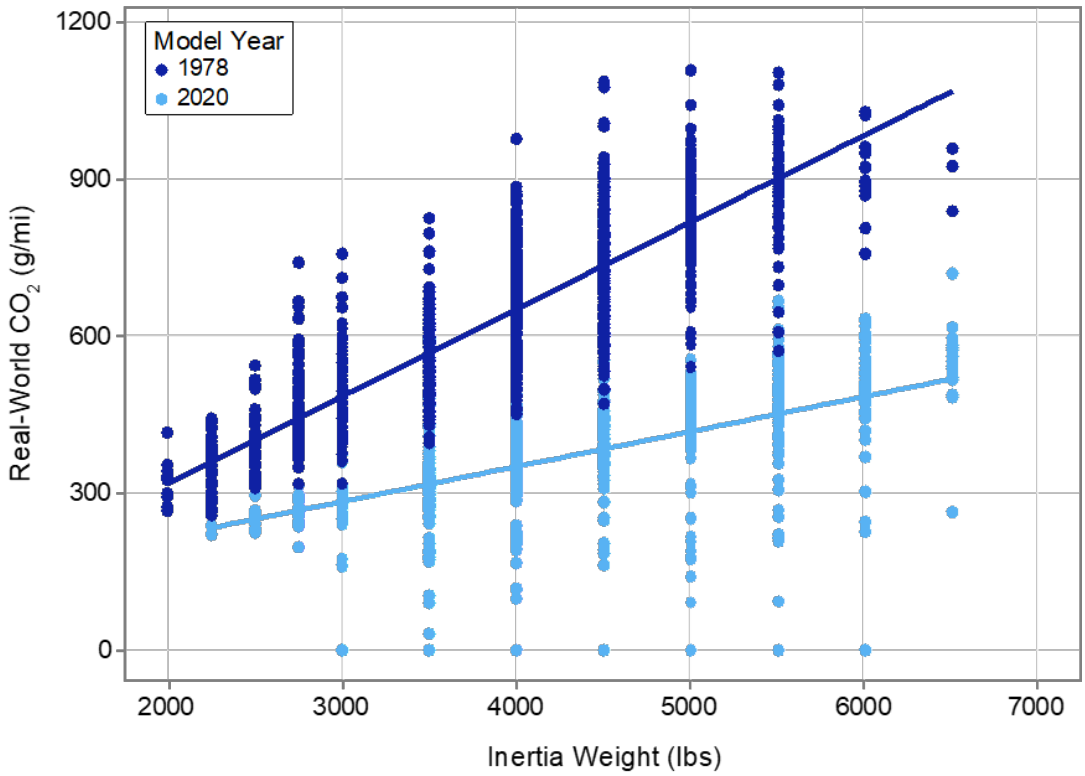
Heavier vehicles require more energy to move than lower-weight vehicles and, if all other factors are the same, will have lower fuel economy and higher CO_2 emissions. The wide array of technology available in modern vehicles complicates this comparison, but it is still useful to evaluate the relationship between vehicle weight and CO_2 emissions, and how these variables have changed over time.

Figure 3.7 shows estimated real-world CO_2 emissions as a function of vehicle inertia weight for model year 1978[7] and model year 2020. On average, CO_2 emissions increase linearly with vehicle weight for both model years, although the rate of change as vehicles get heavier is different between model year 2020 and 1978. At lower weights, vehicles from model year 2020 produce about two thirds of the CO_2 emissions of 1978 vehicles. The difference between model year 2020 and 1978 increases for heavier vehicles, as the heaviest model year 2020 vehicles produce about half of the CO_2 emissions of 1978 vehicles. Electric vehicles, which do not produce any tailpipe CO_2 emissions regardless of

[7] Model year 1978 was the first year for which complete horsepower data are available, therefore it will be used for several historical comparisons for consistency.

weight, are visible along the 0 g/mi axis of Figure 3.7. As more electric vehicles are introduced into the market, the relationship between average vehicle CO_2 emissions and inertia weight will continue to evolve.

Figure 3.7. Relationship of Inertia Weight and CO_2 Emissions



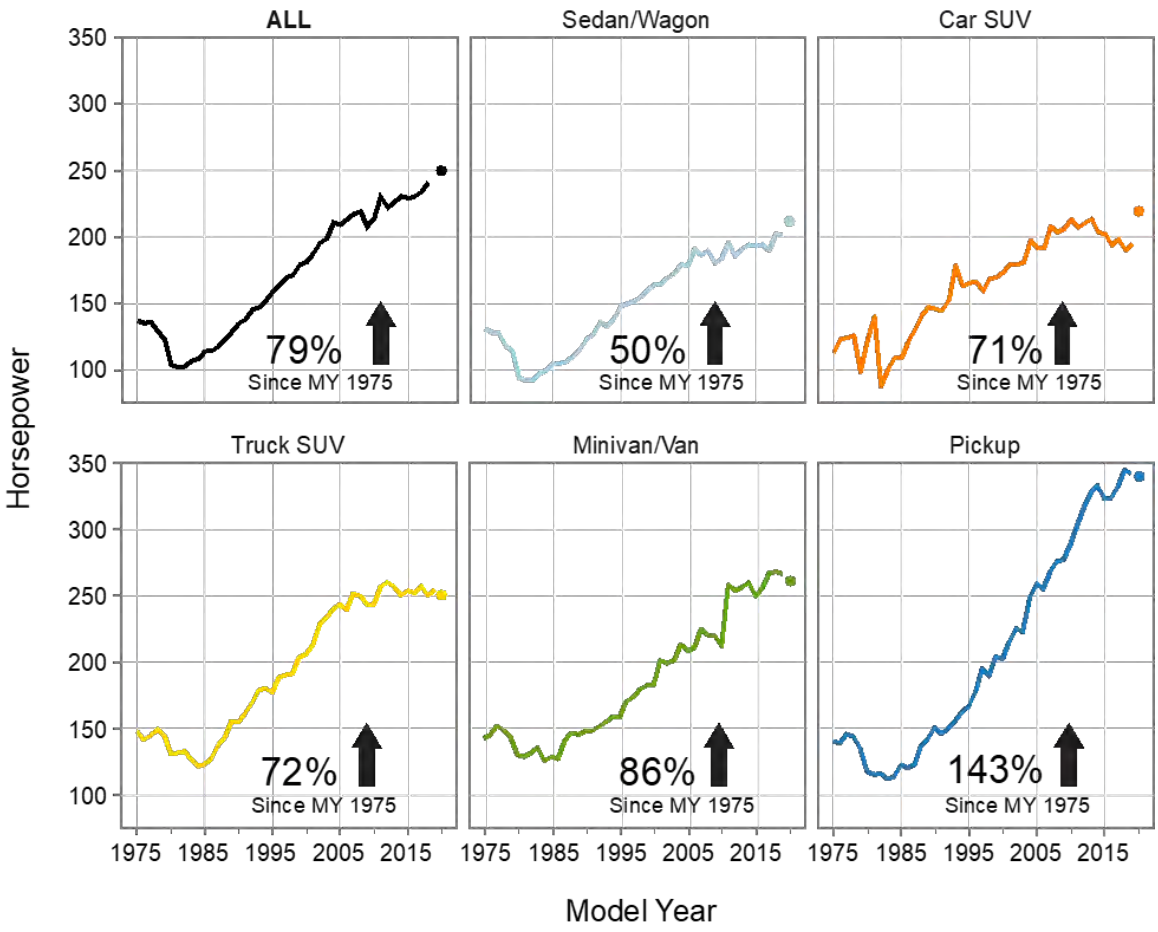
C. Vehicle Power

Vehicle power, measured in horsepower (hp), has changed dramatically since model year 1975. The average new vehicle in model year 2019 produced 75% more power than a new vehicle in model year 1975, and 140% more power than an average new vehicle in model year 1981. In the early years of this report, horsepower fell, from an average of 137 hp in model year 1975 to 102 hp in model year 1981. Since model year 1981, however, horsepower has increased 33 out of 38 years. The average new vehicle horsepower is at a record high, increasing from 241 hp in model year 2018 to 245 hp in model year 2019. The preliminary value for model year 2020 is 247 hp, which would be another record-high for horsepower.

Vehicle Power by Vehicle Type

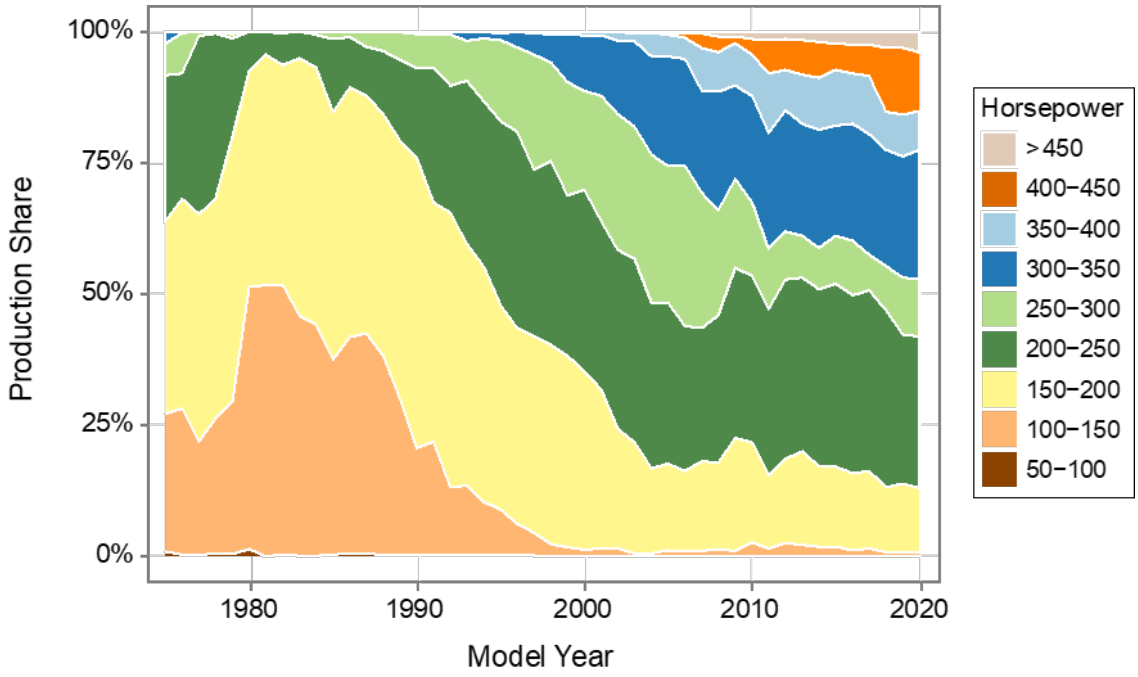
As with weight, the changes in horsepower are also quite different among vehicle types, as shown in Figure 3.8. Horsepower for sedans/wagons increased about 50% between model year 1975 and 2019, more than 70% for car SUVs and truck SUVs, 86% for minivan/vans, and 143% for pickups. Increases in horsepower have been more variable over the last decade, but the general trend continues to be increasing horsepower. The projected model year 2020 data shows another expected increase of about 2 hp.

Figure 3.8. Average New Vehicle Horsepower by Vehicle Type



The distribution of horsepower over time has shifted towards vehicles with higher horsepower, as shown in Figure 3.9. While few new vehicles in the early 1980s had greater than 200 hp, the average vehicle in model year 2020 is projected to have 247 hp. In addition, vehicles with more than 300 hp are projected to make up almost half of new vehicle production, and the maximum hp for an individual vehicle is now well over 1,000 hp.

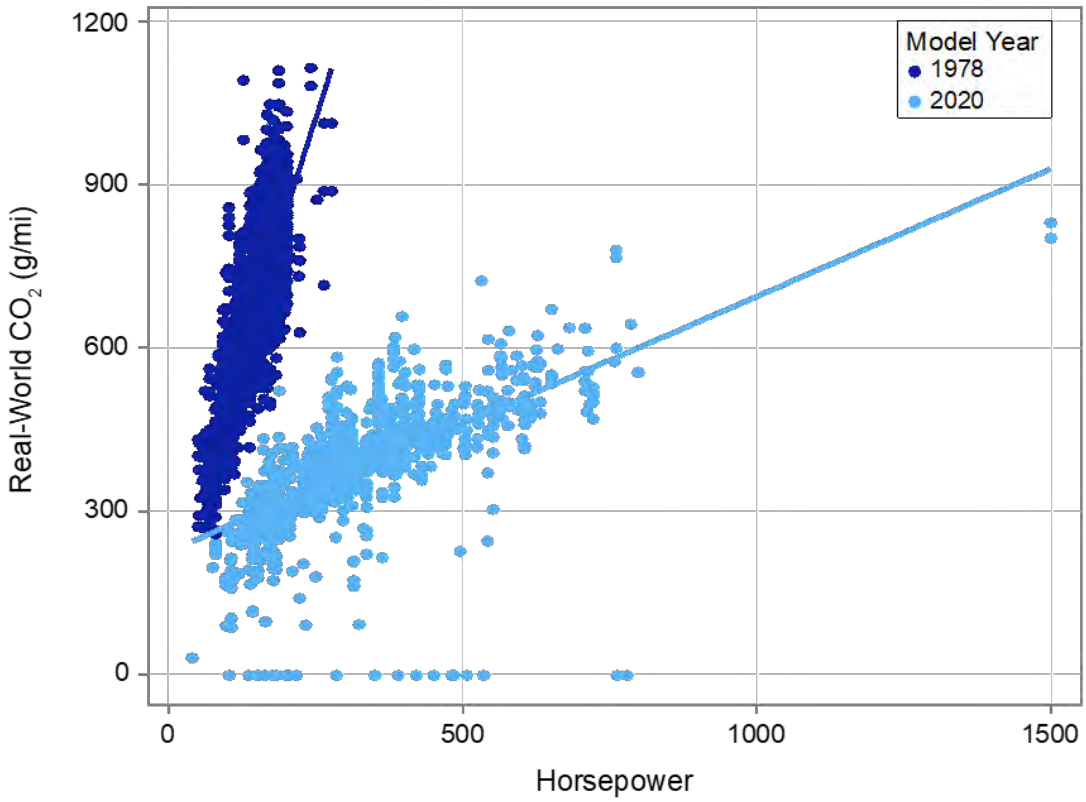
Figure 3.9. Horsepower Distribution by Model Year



Vehicle Power and CO_2 Emissions

The relationship between vehicle power, CO_2 emissions, and fuel economy has become more complex as new technology and vehicles have emerged in the marketplace. In the past, higher power generally increased CO_2 emissions and decreased fuel economy, especially when new vehicle production relied exclusively on gasoline and diesel internal combustion engines. As shown in Figure 3.10, model year 1978 vehicles with increased horsepower generally had increased CO_2 emissions. In model year 2020, CO_2 emissions are projected to increase with increased vehicle horsepower at a much lower rate than in model year 1978, such that model year 2020 vehicles will nearly all have lower CO_2 emissions than their model year 1978 counterparts with the same amount of power. Technology improvements, including turbocharged engines and hybrid packages, have reduced the incremental CO_2 emissions associated with increased power. Electric vehicles are present along the 0 g/mi line in Figure 3.10 because they produce no tailpipe CO_2 emissions, regardless of horsepower, further complicating this analysis for modern vehicles.

Figure 3.10. Relationship of Horsepower and CO_2 Emissions



Vehicle Acceleration

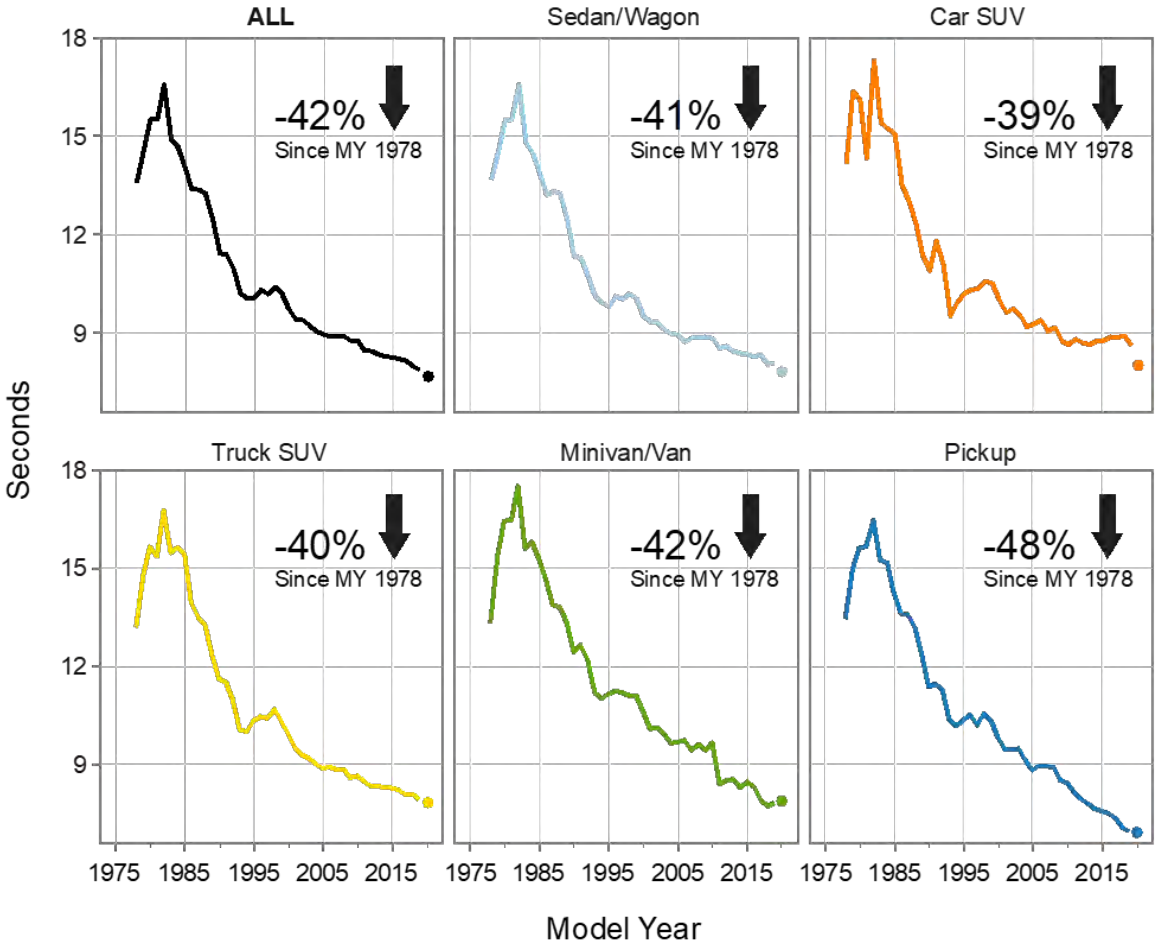
Vehicle acceleration is closely related to vehicle horsepower. As new vehicles have increased horsepower, the corresponding ability of vehicles to accelerate has also increased. The most common vehicle acceleration metric, and one of the most recognized vehicle metrics overall, is the time it takes a vehicle to accelerate from 0 to 60 miles per hour, also called the 0-to-60 time. Data on 0-to-60 times are not directly submitted to EPA but are calculated for most vehicles using vehicle attributes and calculation methods developed by MacKenzie and Heywood (2012).[8] Data are obtained from external sources for hybrids and electric vehicles.

Since the early 1980s, there has been a clear downward trend in 0-to-60 times. Figure 3.11 shows the average new vehicle 0-to-60 time from model year 1978 to model year 2019. The average new vehicle in model year 2019 has a 0-to-60 time of 7.9 seconds, which is the fastest average 0-to-60 time for any model year. It is also approaching half of the average

[8] MacKenzie, D. Heywood, J. 2012. Acceleration performance trends and the evolving relationship among power, weight, and acceleration in U.S. light-duty vehicles: A linear regression analysis. Transportation Research Board, Paper NO 12-1475, TRB 91st Annual Meeting, Washington, DC, January 2012.

0-to-60 times of the early 1980s. The calculated 0-to-60 time for model year 2020 is projected to fall further, to 7.7 seconds.

Figure 3.11. Calculated 0-to-60 Time by Vehicle Type



The long-term downward trend in 0-to-60 times is consistent across all vehicle types, though it appears to be diverging in more recent years. The average 0-to-60 time for pickups continues to decrease steadily, while times for car SUVs have begun to flatten out. The continuing decrease in pickup truck 0-to-60 times is likely due to their increasing power, as shown in Figure 3.8. While much of that power is intended to increase towing and hauling capacity, it also decreases 0-to-60 times.

D. Vehicle Footprint

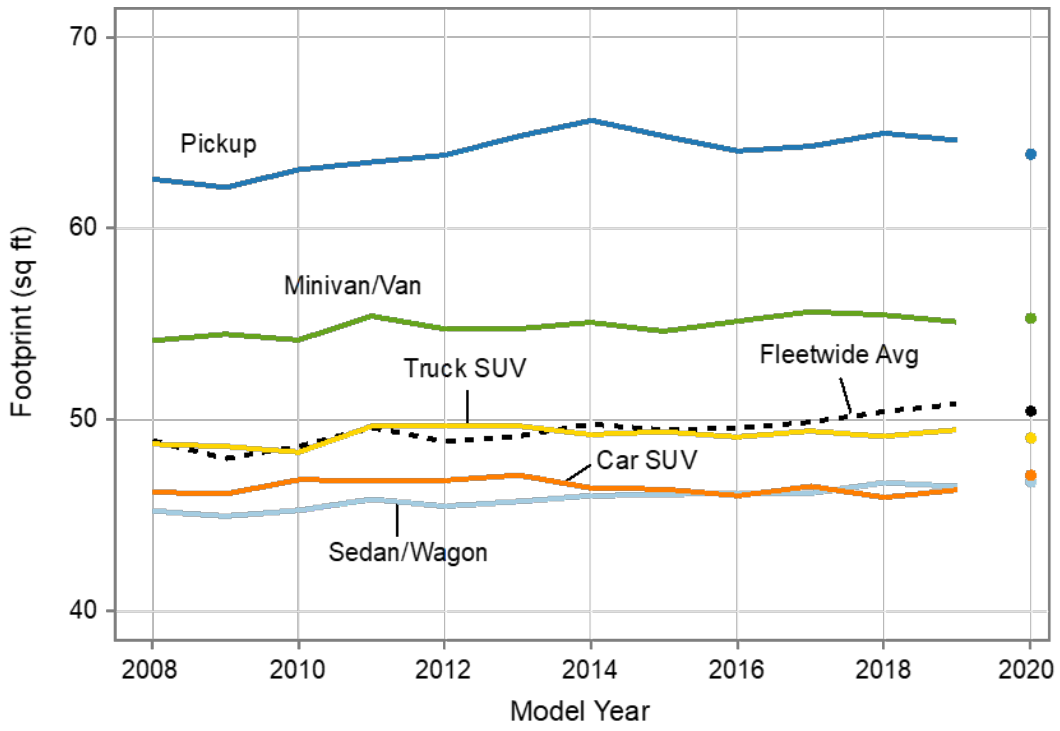
Vehicle footprint is a very important attribute since it is the basis for the current CO_2 emissions and fuel economy standards. Footprint is the product of wheelbase times average track width (the area defined by where the centers of the tires touch the ground).

This report provides footprint data beginning with model year 2008, although footprint data from model years 2008–2010 were aggregated from various sources and EPA has less confidence in the precision of these data than that of formal compliance data. Beginning in model year 2011, the first year when both car and truck CAFE standards were based on footprint, automakers began to submit reports to EPA with footprint data at the end of the model year, and these official footprint data are reflected in the final data through model year 2019. EPA projects footprint data for the preliminary model year 2020 fleet based on footprint values from the previous model year and, for new vehicle designs, publicly available data.

Vehicle Footprint by Vehicle Type

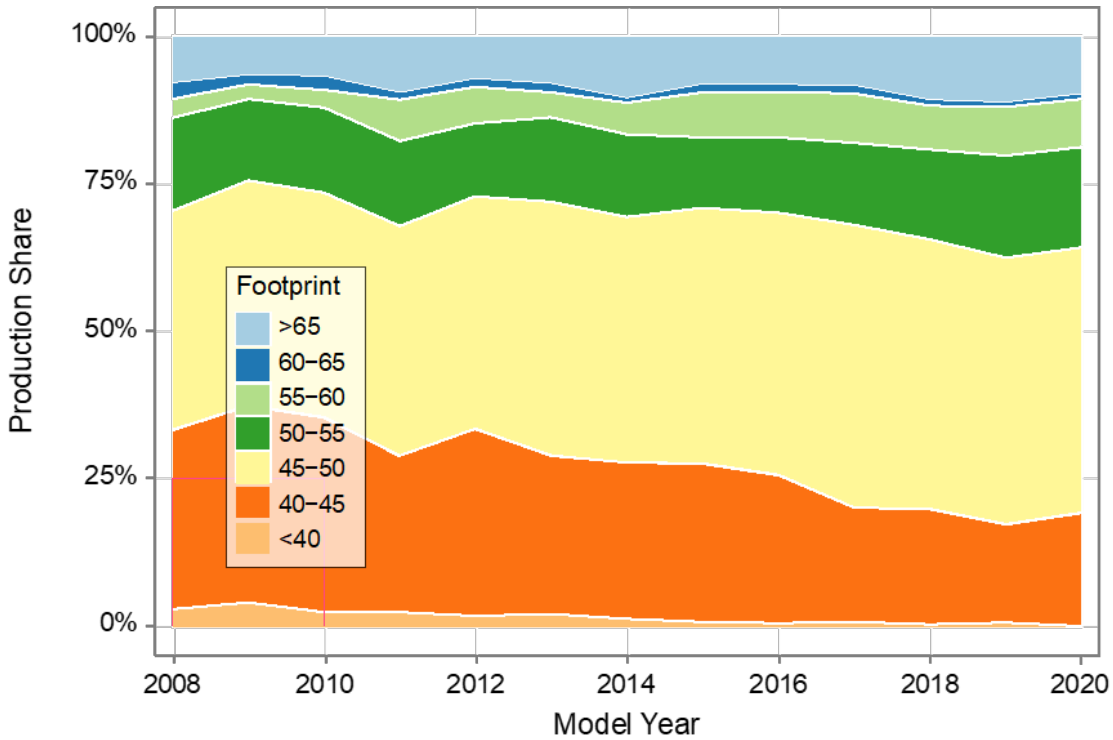
Figure 3.12 shows overall new vehicle and vehicle type footprint data since model year 2008. Between model year 2008 and 2019, the overall average footprint increased 4%, from 48.9 to 50.8 square feet. All five vehicle types have increased average footprint, ranging from a small increase for car SUVs (up 0.1 square feet or 0.3%) to a larger increase for pickup trucks (up 2.1 square feet, or 3.3%). The overall increase is larger than the individual vehicle type changes due to the changing mix of vehicles over time, as the market has shifted towards larger SUVs and away from smaller sedans/wagons.

Figure 3.12. Footprint by Vehicle Type for Model Year 2008–2020



The distribution of footprints across all new vehicles, as shown in Figure 3.13, also shows a slow reduction in the number of smaller vehicles with a footprint of less than 45 square feet. Projected data for model year 2020 suggest that overall average footprint will decrease 0.4 square feet to 50.4 square feet.

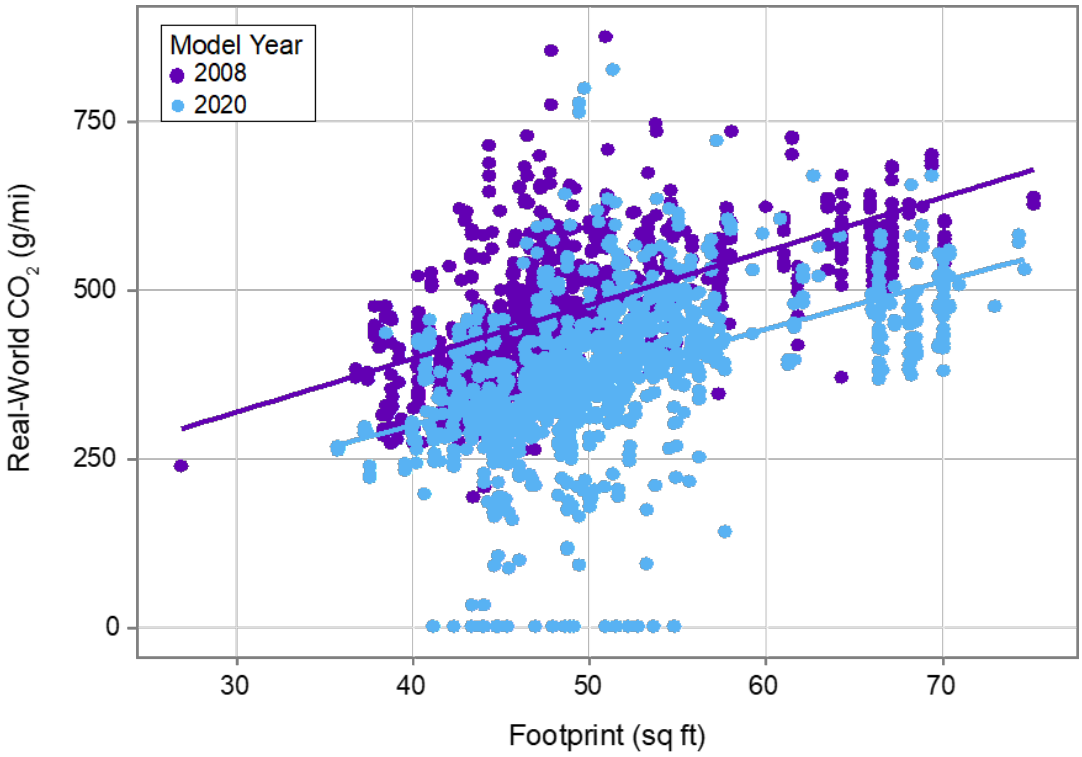
Figure 3.13. Footprint Distribution by Model Year



Vehicle Footprint and CO_2 Emissions

The relationship between vehicle footprint and CO_2 emissions is shown in Figure 3.14. Vehicles with a larger footprint are likely to weigh more and have more frontal area, which leads to increased aerodynamic resistance. Increased weight and aerodynamic resistance increase CO_2 emissions and decreases fuel economy. The general trend of increasing footprint and CO_2 emissions holds true for vehicles from model year 2008 and model year 2020, although vehicles produced in model year 2020 are projected to produce roughly 20% less CO_2 emissions than model year 2008 vehicles of a comparable footprint. Electric vehicles are shown in Figure 3.14 with zero tailpipe CO_2 emissions, regardless of footprint. As more electric vehicles enter the market, the relationship between footprint and tailpipe CO_2 emissions will become much flatter, or less sensitive to footprint.

Figure 3.14. Relationship of Footprint and CO_2 Emissions

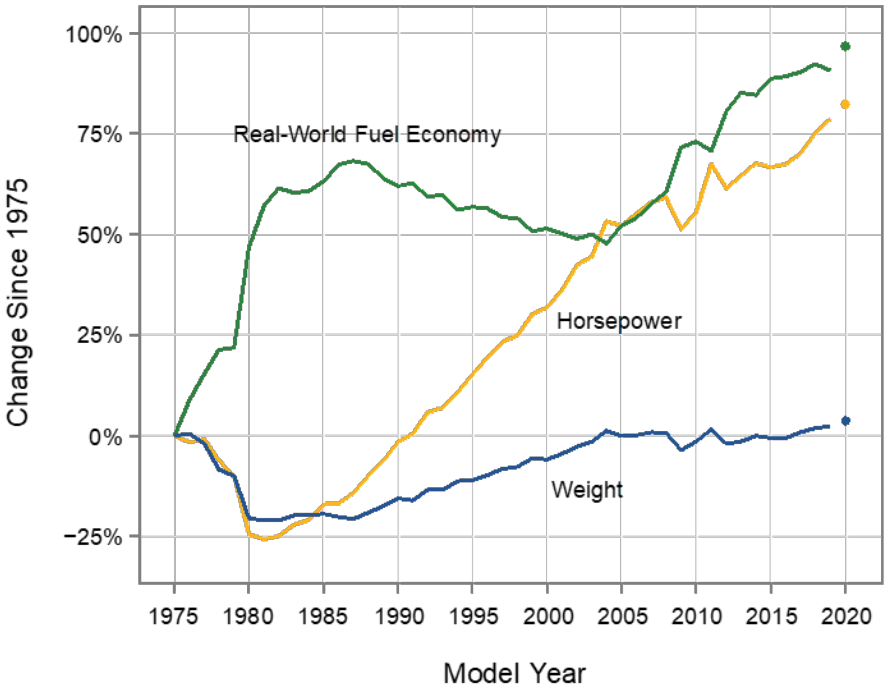


E. Summary

The past 40+ years of data show striking changes in the attributes of vehicles produced for sale in the United States. The marketplace has moved from more than 80% cars to a much more varied mix of vehicles, with recent growth in SUV sales (car SUVs and truck SUVs) resulting in SUVs capturing more than 45% of the market. The weight of an average new vehicle fell dramatically in the late 1970s, then slowly climbed for about 20 years before leveling off. Average vehicle weight in model year 2019 was only slightly above 2004 but has increased slowly over the last several years and is currently at the highest point on record.

In 2019 sedans/wagons have an average weight that is 13% below 1975, but pickups are now 27% heavier than in model year 1975. Vehicle power and acceleration have increased across all vehicle types, with overall average horsepower more than doubling the low reached in the early 1980s. Vehicle footprint has increased about 4% since this report began tracking the data in model year 2008. Figure 3.15 shows a summary of the relative changes in fuel economy, weight, horsepower, and fuel economy since 1975.

Figure 3.15. Relative Change in Fuel Economy, Weight, and Horsepower, since Model Year 1975



Over time, automotive technology innovation has been applied to vehicle design with differing emphasis between vehicle weight, power, CO_2 emissions, and fuel economy. In the two decades before model year 2004, technology innovation was generally used to increase vehicle power, and weight increased due to changing vehicle design, increased vehicle size, and increased content. During this period, average new vehicle fuel economy steadily decreased, and CO_2 emissions correspondingly increased. However, since model year 2004, technology has been used to increase fuel economy (up 29%) and power (up 16%), while reducing CO_2 emissions (down 23%). Average vehicle weight in model year 2019 was only slightly above 2004 but has increased slowly over the last several years and is currently at the highest point on record. The improvement in CO_2 emissions and fuel economy since 2004 is due to many factors, including gasoline prices, consumer preference, and increasing stringency of NHTSA light-duty car and truck CAFE standards.

Vehicle fuel economy and CO_2 emissions are clearly related to vehicle attributes investigated in this section, namely weight, horsepower, and footprint. Future trends in fuel economy and CO_2 emissions will be dependent, at least in part, by design choices related to these attributes.

Table 3.1. Vehicle Attributes by Model Year

Model Year	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Weight (lbs)	Horsepower (HP)	0 to 60 (s)	Footprint (ft^2)	Car Production Share	Truck Production Share
1975	681	13.1	4,060	137	-	-	80.7%	19.3%
1980	466	19.2	3,228	104	15.6	-	83.5%	16.5%
1985	417	21.3	3,271	114	14.1	-	75.2%	24.8%
1990	420	21.2	3,426	135	11.5	-	70.4%	29.6%
1995	434	20.5	3,613	158	10.1	-	63.5%	36.5%
2000	450	19.8	3,821	181	9.8	-	58.8%	41.2%
2001	453	19.6	3,879	187	9.5	-	58.6%	41.4%
2002	457	19.5	3,951	195	9.4	-	55.2%	44.8%
2003	454	19.6	3,999	199	9.3	-	53.9%	46.1%
2004	461	19.3	4,111	211	9.1	-	52.0%	48.0%
2005	447	19.9	4,059	209	9.0	-	55.6%	44.4%
2006	442	20.1	4,067	213	8.9	-	57.9%	42.1%
2007	431	20.6	4,093	217	8.9	-	58.9%	41.1%
2008	424	21.0	4,085	219	8.9	48.9	59.3%	40.7%
2009	397	22.4	3,914	208	8.8	47.9	67.0%	33.0%
2010	394	22.6	4,001	214	8.8	48.5	62.8%	37.2%
2011	399	22.3	4,126	230	8.5	49.5	57.8%	42.2%
2012	377	23.6	3,979	222	8.5	48.8	64.4%	35.6%
2013	368	24.2	4,003	226	8.4	49.1	64.1%	35.9%
2014	369	24.1	4,060	230	8.3	49.7	59.3%	40.7%
2015	360	24.6	4,035	229	8.3	49.4	57.4%	42.6%
2016	359	24.7	4,035	230	8.3	49.5	55.3%	44.7%
2017	357	24.9	4,093	234	8.2	49.8	52.6%	47.4%
2018	353	25.1	4,137	241	8.0	50.4	48.0%	52.0%
2019	356	24.9	4,156	245	7.9	50.8	44.4%	55.6%
2020 (prelim)	*344*	*25.7*	*4,177*	*247*	*7.7*	*50.4*	*42.8%*	*57.2%*

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends

Table 3.2. Estimated Real-World Fuel Economy and CO_2 by Vehicle Type

	Sedan/Wagon			Car SUV			Truck SUV			Minivan/Van			Pickup		
Model Year	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)
1975	80.6%	660	13.5	0.1%	799	11.1	1.7%	806	11.0	4.5%	800	11.1	13.1%	746	11.9
1980	83.5%	446	20.0	0.0%	610	14.6	1.6%	676	13.2	2.1%	629	14.1	12.7%	541	16.5
1985	74.6%	387	23.0	0.6%	443	20.1	4.5%	538	16.5	5.9%	537	16.5	14.4%	489	18.2
1990	69.8%	381	23.3	0.5%	472	18.8	5.1%	541	16.4	10.0%	498	17.8	14.5%	511	17.4
1995	62.0%	379	23.4	1.5%	499	17.8	10.5%	555	16.0	11.0%	492	18.1	15.0%	526	16.9
2000	55.1%	388	22.9	3.7%	497	17.9	15.2%	555	16.0	10.2%	478	18.6	15.8%	534	16.7
2001	53.9%	386	23.0	4.8%	472	18.8	17.3%	541	16.4	7.9%	493	18.0	16.1%	557	16.0
2002	51.5%	385	23.1	3.7%	460	19.3	22.3%	545	16.3	7.7%	475	18.7	14.8%	564	15.8
2003	50.2%	382	23.3	3.6%	446	19.9	22.6%	541	16.4	7.8%	468	19.0	15.7%	553	16.1
2004	48.0%	384	23.1	4.1%	445	20.0	25.9%	539	16.5	6.1%	464	19.2	15.9%	565	15.7
2005	50.5%	379	23.5	5.1%	440	20.2	20.6%	531	16.7	9.3%	460	19.3	14.5%	561	15.8
2006	52.9%	382	23.3	5.0%	434	20.5	19.9%	518	17.2	7.7%	455	19.5	14.5%	551	16.1
2007	52.9%	369	24.1	6.0%	431	20.6	21.7%	503	17.7	5.5%	456	19.5	13.8%	550	16.2
2008	52.7%	366	24.3	6.6%	419	21.2	22.1%	489	18.2	5.7%	448	19.8	12.9%	539	16.5
2009	60.5%	351	25.3	6.5%	403	22.0	18.4%	461	19.3	4.0%	443	20.1	10.6%	526	16.9
2010	54.5%	340	26.2	8.2%	386	23.0	20.7%	452	19.7	5.0%	442	20.1	11.5%	527	16.9
2011	47.8%	344	25.8	10.0%	378	23.5	25.5%	449	19.8	4.3%	424	20.9	12.3%	516	17.2
2012	55.0%	322	27.6	9.4%	381	23.3	20.6%	445	20.0	4.9%	418	21.3	10.1%	516	17.2
2013	54.1%	313	28.4	10.0%	365	24.3	21.8%	427	20.8	3.8%	422	21.1	10.4%	509	17.5
2014	49.2%	313	28.4	10.1%	364	24.4	23.9%	412	21.6	4.3%	418	21.3	12.4%	493	18.0
2015	47.2%	306	29.0	10.2%	353	25.1	28.1%	406	21.9	3.9%	408	21.8	10.7%	474	18.8
2016	43.8%	303	29.2	11.5%	338	26.2	29.1%	400	22.2	3.9%	410	21.7	11.7%	471	18.9
2017	41.0%	293	30.2	11.6%	339	26.1	31.7%	398	22.3	3.6%	399	22.2	12.1%	470	18.9
2018	36.7%	286	30.8	11.3%	324	27.3	35.0%	384	23.1	3.1%	389	22.8	13.9%	466	19.1
2019	32.7%	285	30.9	11.7%	323	27.5	36.5%	378	23.5	3.4%	396	22.4	15.6%	467	19.0
2020 (prelim)	*33.3%*	*272*	*32.0*	*9.5%*	*293*	*29.5*	*40.8%*	*372*	*23.9*	*2.6%*	*383*	*23.0*	*13.7%*	*460*	*19.5*

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends

Table 3.3. Model Year 2019 Vehicle Attributes by Manufacturer

Manufacturer	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Weight (lbs)	Horsepower (HP)	0 to 60 (s)	Footprint (ft^2)
BMW	337	26.2	4,248	277	6.9	49.3
FCA	418	21.2	4,631	299	7.2	54.9
Ford	395	22.5	4,482	285	7.4	55.3
GM	395	22.5	4,438	273	7.7	54.2
Honda	307	28.9	3,661	207	8.0	47.8
Hyundai	311	28.5	3,494	174	8.9	46.6
Kia	316	28.1	3,585	186	8.7	47.0
Mazda	320	27.8	3,831	191	8.9	46.3
Mercedes	374	23.7	4,390	287	6.8	49.5
Nissan	329	27.0	3,811	202	8.9	48.1
Subaru	312	28.4	3,893	186	9.4	45.9
Tesla	0	118	4,436	392	4.8	49.9
Toyota	345	25.8	4,120	233	8.0	49.5
VW	338	26.1	4,141	236	7.7	48.2
Other	351	25.2	4,202	248	8.3	48.0
All Manufacturers	**356**	**24.9**	**4,156**	**245**	**7.9**	**50.8**

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends

Table 3.4. Model Year 2019 Estimated Real-World Fuel Economy and CO_2 by Manufacturer and Vehicle Type

	Sedan/Wagon			Car SUV			Truck SUV			Minivan/Van			Pickup		
Manufacturer	**Prod Share**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**Prod Share**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**Prod Share**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**Prod Share**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**Prod Share**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**
BMW	57.3%	318	27.6	8.7%	311	28.6	33.9%	377	23.6	-	-	-	-	-	-
FCA	11.3%	400	22.2	7.9%	337	26.4	40.3%	397	22.4	13.0%	406	21.9	27.4%	487	18.3
Ford	19.8%	315	28.1	11.4%	346	25.7	29.2%	412	21.6	2.6%	384	23.1	36.9%	440	20.2
GM	15.4%	313	28.0	17.7%	314	28.3	39.2%	408	21.8	-	-	-	27.6%	475	18.7
Honda	47.2%	265	33.4	10.1%	302	29.4	31.3%	343	25.9	8.0%	383	23.2	3.3%	409	21.7
Hyundai	48.9%	274	32.3	49.4%	343	25.8	1.7%	430	20.7	-	-	-	-	-	-
Kia	61.1%	277	31.9	5.9%	337	26.4	30.7%	381	23.3	2.2%	421	21.1	-	-	-
Mazda	30.0%	291	30.5	22.0%	311	28.6	47.9%	342	26.0	-	-	-	-	-	-
Mercedes	50.8%	348	25.6	12.7%	345	25.8	35.1%	423	20.9	1.4%	406	21.9	-	-	-
Nissan	55.8%	283	31.2	8.9%	300	29.6	23.9%	381	23.4	1.5%	353	25.2	9.9%	480	18.5
Subaru	19.2%	306	29.1	-	-	-	80.8%	314	28.3	-	-	-	-	-	-
Tesla	91.0%	0	121.4	6.4%	0	91.9	2.6%	0	92.8	-	-	-	-	-	-
Toyota	36.9%	267	33.3	9.9%	316	28.1	35.1%	371	23.9	2.4%	399	22.3	15.7%	478	18.6
VW	49.9%	292	30.3	-	-	-	50.1%	384	23	-	-	-	-	-	-
Other	18.4%	290	30.6	10.7%	329	27.0	70.7%	371	23.9	0.2%	345	25.7	-	-	-
All Manufacturers	**32.7%**	**285**	**30.9**	**11.7%**	**323**	**27.5**	**36.5%**	**378**	**23.5**	**3.4%**	**396**	**22.4**	**15.6%**	**467**	**19.0**

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends

Table 3.5. Footprint by Manufacturer for Model Year 2018–2020 (ft^2)

	Final MY 2018			Final MY 2019			*Preliminary MY 2020*		
Manufacturer	**Car**	**Truck**	**All**	**Car**	**Truck**	**All**	***Car***	***Truck***	***All***
BMW	47.3	51.1	48.3	47.7	52.3	49.3	*47.8*	*51.8*	*49.3*
FCA	48.9	52.8	52.0	49.3	56.3	54.9	*48.3*	*54.1*	*53.2*
Ford	46.6	59.9	55.3	46.9	59.1	55.3	*47.8*	*56.0*	*54.0*
GM	46.4	59.2	54.4	45.9	58.3	54.2	*46.8*	*56.0*	*54.2*
Honda	46.3	49.4	47.4	45.9	50.3	47.8	*46.1*	*49.5*	*47.3*
Hyundai	46.5	49.2	46.6	46.6	49.2	46.6	*46.5*	*50.1*	*47.4*
Kia	46.2	49.5	46.9	46.0	49.1	47.0	*45.5*	*50.1*	*47.2*
Mazda	45.6	47.9	46.5	44.9	47.7	46.3	*45.7*	*47.1*	*46.4*
Mercedes	48.3	51.3	49.6	48.6	51.0	49.5	*49.0*	*52.5*	*50.8*
Nissan	46.0	51.7	47.8	46.0	52.1	48.1	*46.6*	*52.1*	*48.2*
Subaru	44.9	45.0	45.0	44.9	46.1	45.9	*44.8*	*46.2*	*45.9*
Tesla	50.3	54.8	50.4	49.8	54.8	49.9	*50.2*	*50.9*	*50.3*
Toyota	46.1	51.6	48.8	46.5	52.0	49.5	*46.1*	*52.2*	*49.2*
VW	45.9	50.5	48.4	45.3	51.2	48.2	*46.3*	*51.4*	*49.0*
Other	45.0	49.4	48.1	44.5	49.5	48.0	*45.6*	*49.0*	*48.1*
All Manufacturers	**46.5**	**53.9**	**50.4**	**46.5**	**54.2**	**50.8**	***46.8***	***53.1***	***50.4***

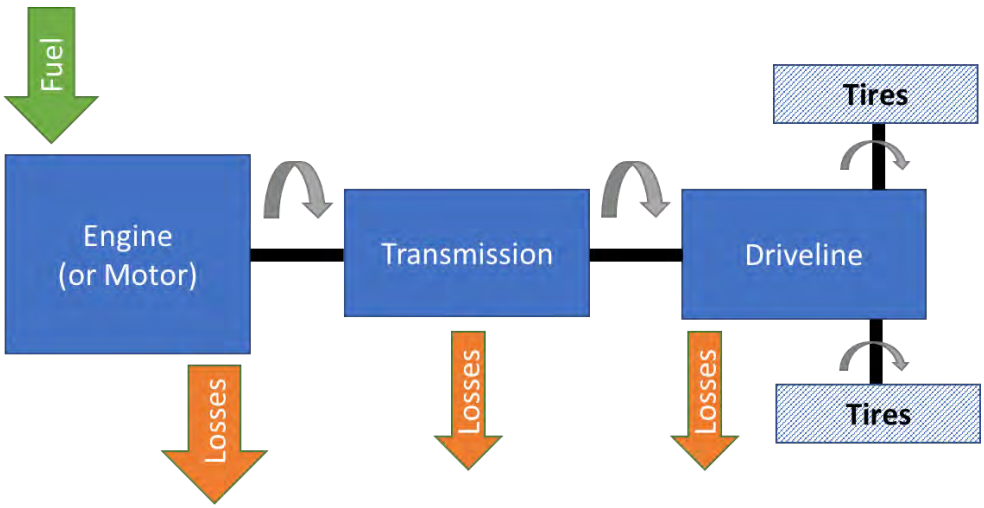
To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends

4. Vehicle Technology

Since model year 1975, the technology used in vehicles has continually evolved. Today's vehicles utilize an increasingly wide array of technological solutions developed by the automotive industry to improve vehicle attributes discussed previously in this report, including CO_2 emissions, fuel economy, vehicle power, and acceleration. Automotive engineers and designers are constantly creating and evaluating new technology and deciding how, or if, it should be applied to their vehicles.

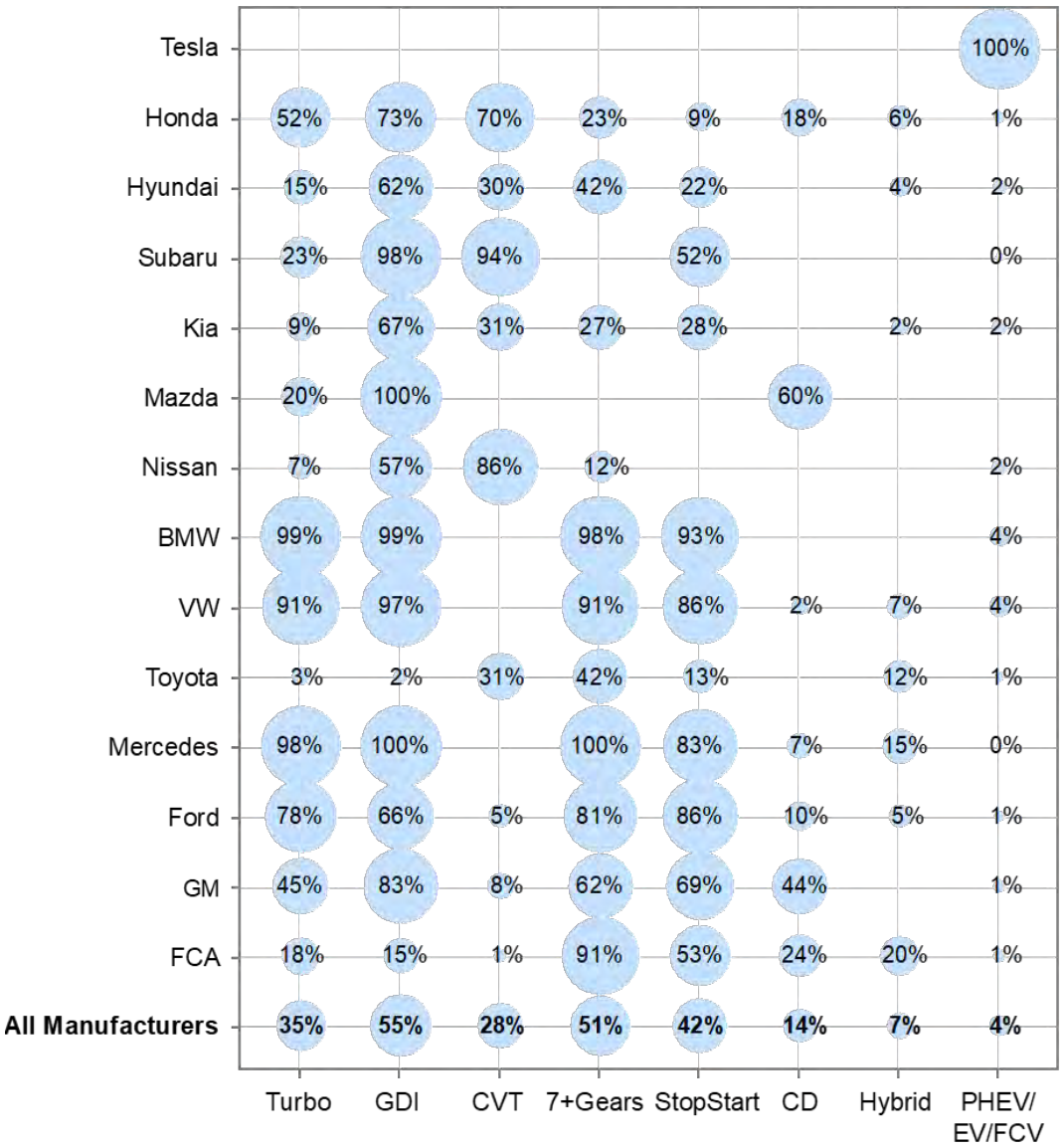
This section of the report focuses on three separate technological areas of a vehicle: the engine, transmission, and driveline. The engine (or motor) of an automobile is at the heart of any vehicle design and converts energy stored in fuel (or a battery) into rotational energy. The transmission converts the rotational energy from the relatively narrow range of speeds available at the engine to the appropriate speed required for the driving conditions. The driveline transfers the rotational energy from the transmission to the two or four wheels being used to move the vehicle. Each of these components has energy losses, or inefficiencies, which ultimately increase vehicle CO_2 emissions and decrease fuel economy. A basic illustration of the energy flow through a vehicle is shown in Figure 4.1. Hybrid vehicles, electric vehicles (EVs), and plug-in hybrid electric vehicles (PHEVs) may have somewhat different configurations than shown in Figure 4.1.

Figure 4.1. Vehicle Energy Flow



Manufacturers are adopting many new technologies to improve efficiency. Figure 4.2 illustrates projected manufacturer-specific technology adoption, with larger circles representing higher adoption rates, for model year 2020. The figure shows preliminary model year 2020 technology projections to provide insight on a quickly changing industry, even though there is some uncertainty in the preliminary data.

Figure 4.2. Manufacturer Use of Emerging Technologies for Model Year 2020



Engine technologies such as turbocharged engines (Turbo) and gasoline direct injection (GDI) allow for more efficient engine design and operation. Cylinder deactivation (CD) allows for only using part of the engine when less power is needed, and stop/start can turn off the engine entirely when the vehicle is stopped to save fuel. Hybrid vehicles use a larger

battery to recapture braking energy and provide power when necessary, allowing for a smaller, more efficiently-operated engine. Transmissions that have seven or more speeds, and continuously variable transmissions (CVTs), allow the engine to more frequently operate near its peak efficiency, providing more efficient average engine operation and a reduction in fuel usage. The technologies in Figure 4.2 are all being adopted by manufacturers to reduce CO_2 emissions and increase fuel economy. In some cases, the adoption is rapid. For example, GDI was used in fewer than 3% of vehicles as recently as model year 2008, but is projected to be in 55% of vehicles in model year 2020. Electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) are a small but growing percentage of new vehicles.

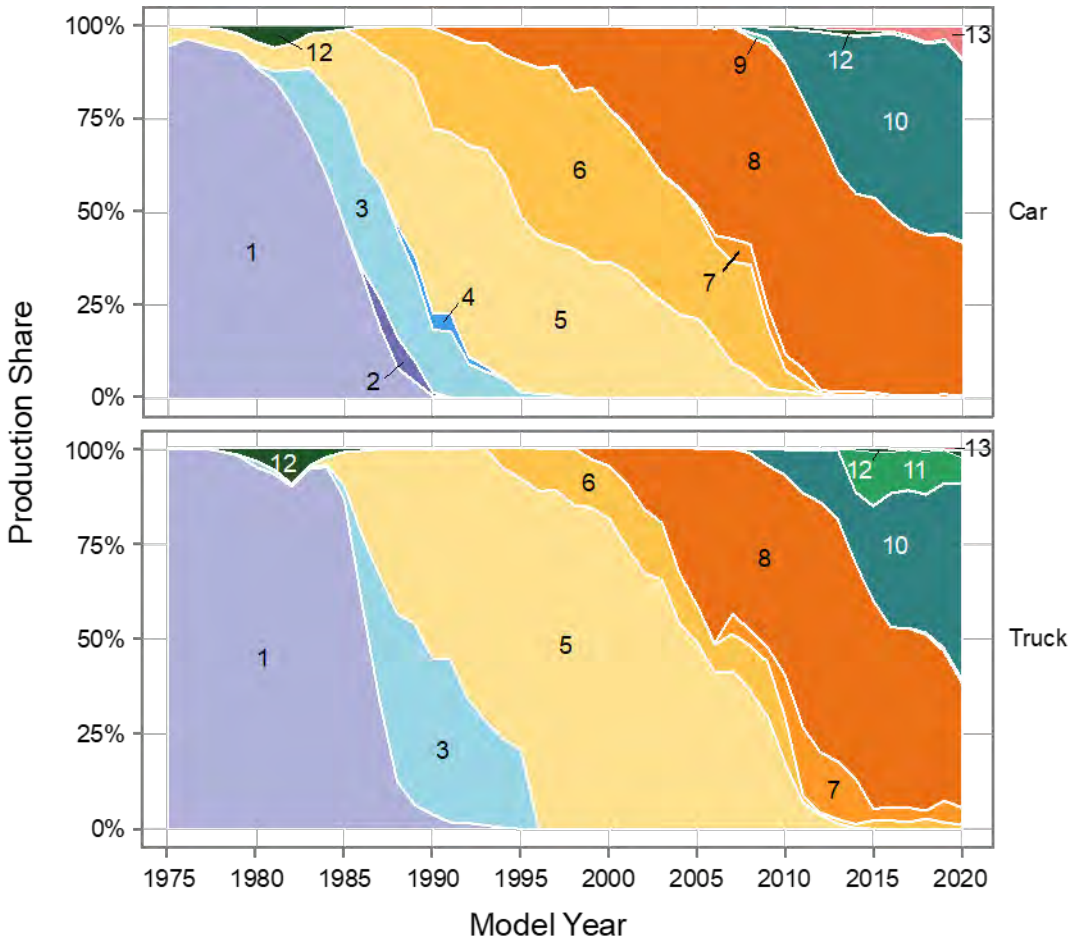
Each of the fourteen largest manufacturers have adopted several of these technologies into their vehicles, with many manufacturers achieving high penetrations of several technologies as shown in Figure 4.2. It is also clear that manufacturers' strategies to develop and adopt new technologies are unique and vary significantly. Each manufacturer is choosing technologies that best meet the design requirements of their vehicles, and in many cases, that technology is changing quickly. The rest of this section will explore how engine, transmission, and driveline technology has changed since 1975, the impact of those technology changes, and the rate at which technology is adopted by the industry.

A. Engines

Vehicle engine technology has continually evolved in the 45 years since EPA began collecting data. Over that time, engines using gasoline as a fuel have dominated the market, and the technology on those engines has changed dramatically. More recently, new engine designs such as PHEVs, EVs, and FCVs have begun to enter the market, potentially offering dramatic reductions in tailpipe CO_2 emissions and further increases in fuel economy.

The trend in engine technology since model year 1975 is shown in Figure 4.3. Vehicles that use an engine that operates exclusively on gasoline (including hybrids, but not plug-in hybrids which also use electricity) have held at least 95% of the light-duty vehicle market in almost every year. Vehicles with diesel engines briefly captured almost 6% of the market in model year 1981 but have been less than 1% of the market in most other years since 1985. PHEVs, EVs, and FCVs have added to the increasing array of technology available in the automotive marketplace and have been capturing a small but growing portion of the market. These vehicles captured 1.7% of the market in model year 2019, and are projected to grow to 4% in model year 2020.

Figure 4.3. Production Share by Engine Technology



Fuel Delivery	Valve Timing	Number of Valves	Key
Carbureted	Fixed	Two-Valve	1
		Multi-Valve	2
Throttle Body Injection	Fixed	Two-Valve	3
		Multi-Valve	4
Port Fuel Injection	Fixed	Two-Valve	5
		Multi-Valve	6
	Variable	Two-Valve	7
		Multi-Valve	8
Gasoline Direct Injection (GDI)	Fixed	Multi-Valve	9
	Variable	Multi-Valve	10
		Two-Valve	11
Diesel	—	—	12
EV/PHEV/FCV	—	—	13

Engines that use only gasoline as a fuel (including hybrids) are further divided based on three broad parameters for Figure 4.3: fuel delivery, valve timing, and number of valves per cylinder. These parameters enable better control of the combustion process, which in turn can allow for lower CO_2 emissions, increased fuel economy, and/or more power. Fuel delivery refers to the method of creating an air and fuel mixture for combustion. The technology for fuel delivery has changed over time from carburetors to fuel injection systems located in the intake system, and more recently to gasoline direct injection (GDI) systems that spray gasoline directly into the engine cylinder.

The valves on each cylinder of the engine determine the amount and timing of air entering and exhaust gases exiting the cylinder during the combustion process. Valve timing has evolved from fixed timing to variable valve timing (VVT), which can allow for much more precise control. In addition, the number of valves per cylinder has generally increased, again offering more control of air and exhaust flows. All of these changes have led to modern engines with much more precise control of the combustion process.

Figure 4.3 shows many different engine designs as they have entered, and in many cases exited, the automotive market. Some fleetwide changes occurred gradually, but in some cases (for example trucks in the late 1980s), engine technology experienced widespread change in only a few years. Evolving technology offers opportunities to improve fuel economy, CO_2 emissions, power, and other vehicle parameters. The following analysis will look at technology trends within gasoline engines (including hybrids), PHEVs and EVs, and diesel engines. Each of these categories of engine technologies has unique properties, metrics, and trends over time.

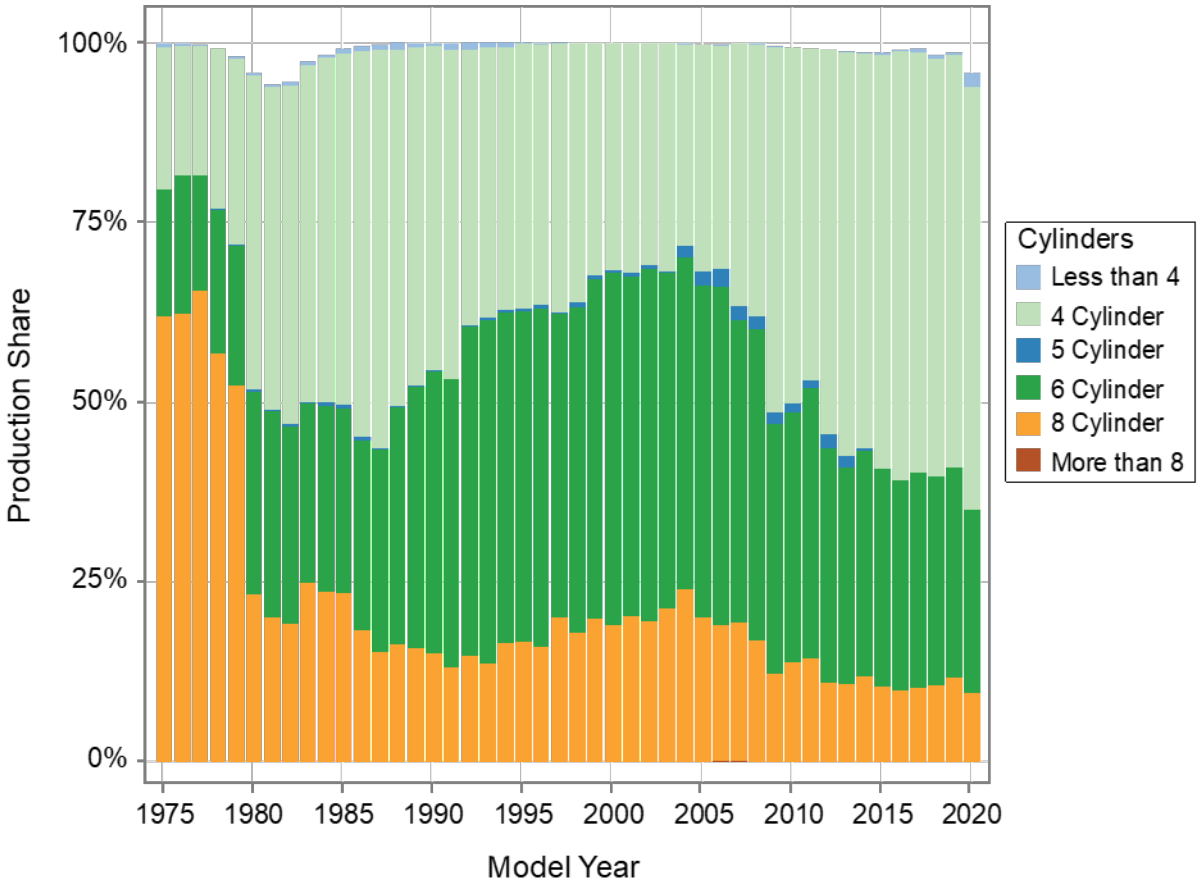
Gasoline Engines

Since EPA began tracking vehicle data in 1975, nearly 650 million vehicles have been produced for sale in the United States. For most of those years, vehicles relying on a gasoline engine as the only source of power captured more than 99% of production. The only exceptions were in the early 1980s when diesel engines peaked briefly at about 6% of the market, and more recently as electric vehicle production has increased. For the purposes of this report, hybrid vehicles are included with gasoline engines, as are “flex fuel” vehicles that are capable of operating on gasoline or a blend of 85% ethanol and 15% gasoline (E85).

Engine Size and Displacement

Engine size is generally described in one of two ways, either the number of cylinders or the total displacement of the engine (the total volume of the cylinders). Engine size is important because larger engines strongly correlate with higher fuel use. Figure 4.4 shows the trends in gasoline engine size over time, as measured by number of cylinders.

Figure 4.4. Gasoline Engine Production Share by Number of Cylinders



In the mid and late 1970s, the 8-cylinder engine was dominant, accounting for well over half of all new vehicle production. In model year 1980 there was a significant change in the market, as 8-cylinder engine production share dropped to about one quarter of the market and 4-cylinder production share increased to 45% of the market. Between model year 1980 and model year 1992, 4-cylinder engines were the most popular engines, although they slowly lost ground to 6-cylinder engines, and in model year 1992, 6-cylinder engines became the most popular engine option. In model year 2009, 4-cylinder engines increased 13 percentage points in a single year to again become the most popular engine option,

capturing a little over half of all production. Four-cylinder engines have remained the most popular engine option, capturing just under 60% of the market in model year 2019 and in projected model year 2020 data. Production share of 8-cylinder engines has been about 10-12% of production since model year 2012.

Overall engine size, as measured by the total volume of all the engine's cylinders, is directly related to the number of cylinders. As vehicles have moved towards engines with a lower number of cylinders, the total engine size, or displacement, is also at an all-time low. The average new vehicle in model year 1975 had a displacement of nearly 300 cubic inches, compared to an average of 174 cubic inches in model year 2019. Gasoline engine displacement per cylinder has been relatively stable over the time of this report (around 35 cubic inches per cylinder since 1980), so the reduction in overall new vehicle engine displacement is almost entirely due to the shift towards engines with fewer cylinders.

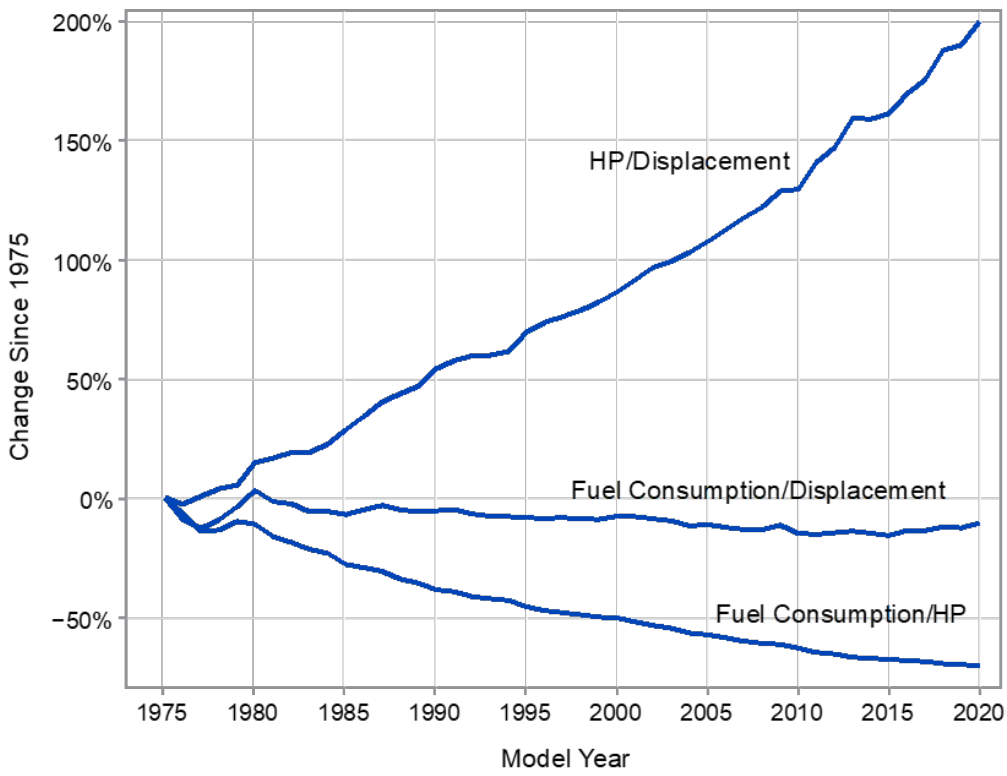
The contrasting trends in horsepower (at all-time high) and engine displacement (at an all-time low) highlight the continuing improvement in engines. These improvements are due to the development of new technologies and ongoing design improvements that allow for more efficient use of fuel or reduce internal engine friction. One additional way to examine the relationship between engine horsepower and displacement is to look at the trend in *specific* power (HP/Displacement), which is a metric to compare the power output of an engine relative to its size.

Specific power has increased nearly 200% between model year 2019 and model year 1975. The rate at which specific power has increased has been remarkably steady, as shown in Figure 4.5. The specific power of new vehicle gasoline engines has increased by about 0.02 horsepower per cubic inch every year for 40+ years. Considering the numerous and significant changes to engines over this time span, changes in consumer preferences, and the external pressures on vehicle purchases, the long-standing linearity of this trend is noteworthy. The roughly linear increase in specific power does not appear to be slowing. Turbocharged engines, direct injection, higher compression ratios, and many other engine technologies are likely to continue increasing engine specific power.

Figure 4.5 also shows two other important engine metrics, the amount of fuel consumed compared to the overall size of the engine (Fuel Consumption/Displacement), and the amount of fuel consumed relative to the amount of power produced by an engine (Fuel Consumption/HP). The amount of fuel consumed by a gasoline engine in model year 2019, relative to the total displacement, is about 13% lower than in model year 1975, although it has increased very slightly since model year 2015. Fuel consumption relative to engine horsepower has fallen almost 70% since model year 1975. Taken as a whole, the trend lines

in Figure 4.5 clearly show that gasoline engine improvements over time have been steady and continual, and have resulted in impressive improvements to internal combustion engines.

Figure 4.5. Percent Change for Specific Gasoline Engine Metrics



Fuel Delivery Systems and Valvetrains

All gasoline engines require a fuel delivery system that controls the flow of fuel delivered into the engine. The process for controlling fuel flow has changed significantly over time, allowing for much more control over the combustion process and thus more efficient engines. In the 1970s and early 1980s, nearly all gasoline engines used carburetors to meter fuel delivered to the engine. Carburetors were replaced over time with fuel injection systems; first throttle body injection (TBI) systems, then port fuel injection (PFI) systems, and more recently gasoline direct injection (GDI), as shown in Figure 4.3. TBI and PFI systems use fuel injectors to electronically deliver fuel and mix it with air outside of the engine cylinder; the resulting air and fuel mixture is then delivered to the engine cylinders for combustion. Engines that utilize GDI spray fuel directly into the air in the engine cylinder for better control of the combustion process. Engines using GDI were first introduced into the market with very limited production in model year 2007. Ten years

later, GDI engines were installed in more than 50% of model year 2019 gasoline vehicles and are projected to continue increasing.

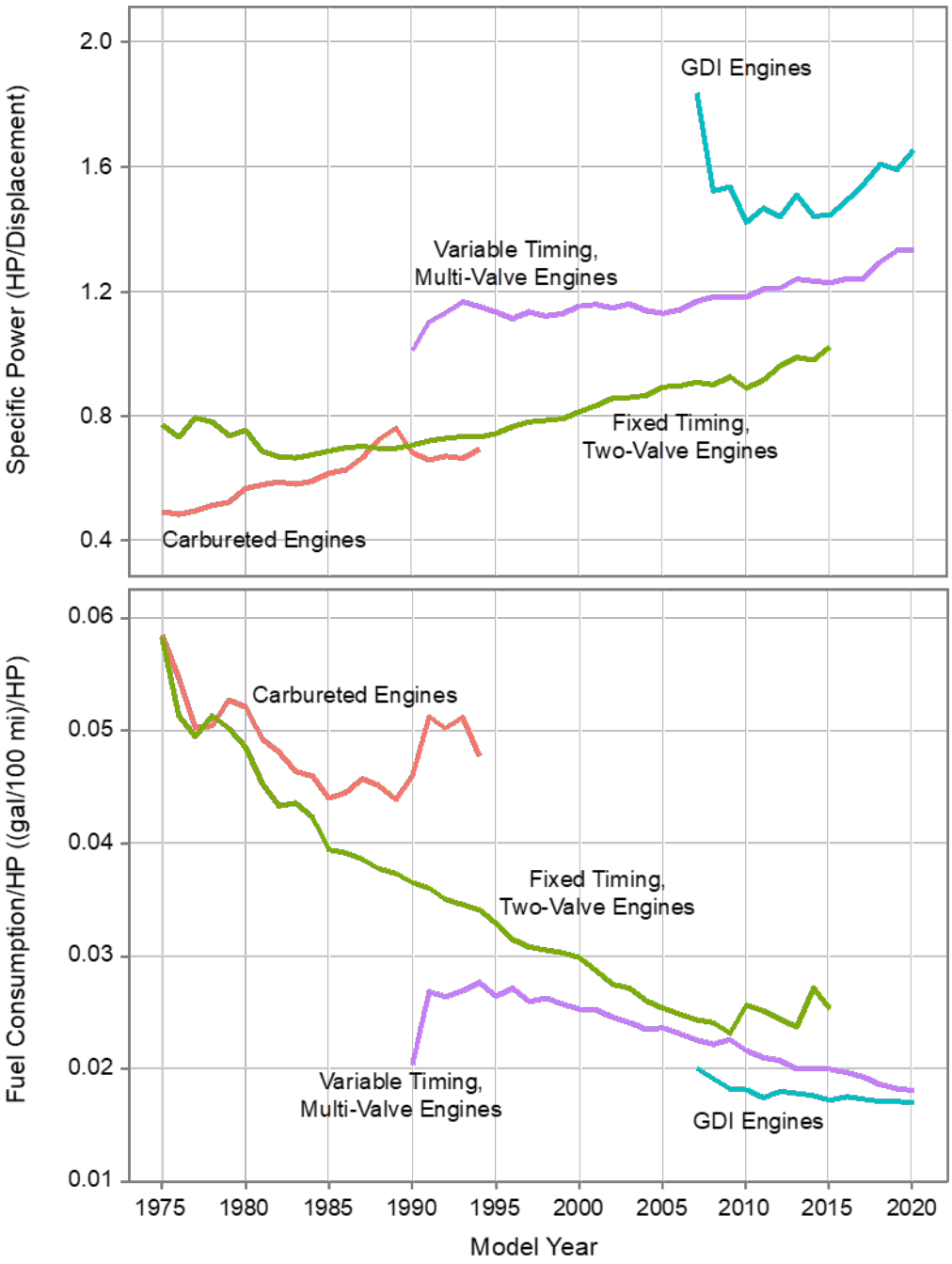
Another key aspect of engine design is the valvetrain. Each engine cylinder must have a set of valves that allow for air (or an air/fuel mixture) to flow into the engine cylinder prior to combustion and for exhaust gases to exit the cylinder after combustion. The number of valves per cylinder and the method of controlling the valves (i.e., the valvetrain) directly impacts the overall efficiency of the engine. Generally, engines with four valves per cylinder instead of two, and valvetrains that can alter valve timing during the combustion cycle can provide more engine control and increase engine power and efficiency.

This report began tracking multi-valve engines (i.e., engines with more than two valves per cylinder) for cars in model year 1986 and for trucks in model year 1994. Since that time about 90% of the fleet has converted to multi-valve design. While some three- and five-valve engines have been produced, the majority of multi-valve engines are based on four valves per cylinder. Engines with four valves generally use two valves for air intake and two valves for exhaust. In addition, this report began tracking variable valve timing (VVT) technology for cars in model year 1990 and for trucks in model year 2000, and since then nearly the entire fleet has adopted this technology. Figure 4.3 shows the evolution of engine technology, including fuel delivery method and the introduction of VVT and multi-valve engines.

As shown in Figure 4.3, fuel delivery and valvetrain technologies have often been developed simultaneously. Nearly all carbureted engines relied on fixed valve timing and had two valves per cylinder, as did early port-injected engines. Port-injected engines largely developed into engines with both multi-valve and VVT technology. Engines with GDI are almost exclusively using multi-valve and VVT technology. These four engine groupings, or packages, represent a large share of the engines produced over the timespan covered by this report.

Figure 4.6 shows the changes in specific power and fuel consumption per horsepower for each of these engine packages over time. There is a very clear increase in specific power of each engine package as engines moved from carbureted engines, to engines with two valves, fixed timing and port fuel injection, then to engines with multi-valve VVT and port fuel injection, and finally to GDI engines. Some of the increase for GDI engines may also be due to the fact that GDI engines are often paired with turbochargers to further increase power. Vehicles with fixed valve timing and two valves per cylinder have been limited in recent years and are no longer included in Figure 4.6 after model year 2015 due to very limited production.

Figure 4.6. Engine Metrics for Different Gasoline Technology Packages



Turbocharging

Turbochargers increase the power that an engine can produce by forcing more air, and thus fuel, into the engine. An engine with a turbocharger can produce more power than an identically sized engine that is naturally aspirated or does not have a turbocharger. Turbochargers are powered using the pressure of the engine exhaust as it leaves the engine. Superchargers operate the same way as turbochargers but are directly connected to the engine for power, instead of using the engine exhaust. Alternate turbocharging and supercharging methods, such as electric superchargers, are also beginning to emerge. A limited number of new vehicles utilize both a turbocharger and supercharger in one engine package.

Turbocharged engines have been increasing rapidly in the marketplace, accounting for 30% of all production in model year 2019, and projected to reach 35% in model year 2020, as shown in Figure 4.7. Many of these engines are applying turbochargers to create "turbo downsized" engine packages that can combine the improved fuel economy of smaller engines during normal operation but can provide the power of a larger engine by engaging the turbocharger when necessary. As evidence of this turbo downsizing, about 80% of gasoline turbocharged engines are 4-cylinder engines in model year 2019, with most other turbochargers being used in 6-cylinder engines. Model year 2020 is projected to be similar, with a small but growing number of vehicles equipped with 3-cylinder turbocharged engines. This is shown in Figure 4.8.

Most of the current turbocharged engines also use GDI and VVT. This allows for more efficient engine operation, helps increase the resistance to premature combustion (engine knock), and reduces turbo lag (the amount of time it takes for a turbocharger to engage). In model year 2019, almost 90% of new vehicles with gasoline turbocharged engines also used GDI.

Figure 4.9 examines the distribution of engine displacement and power of turbocharged engines over time. In model year 2011, turbochargers were used mostly in cars, and were available on engines both above and below the average engine displacement. The biggest increase in turbocharger use over the last few years has been in cars with engine displacement well below the average displacement. The distribution of horsepower for turbocharged engines is much closer to the average horsepower, even though the displacement is smaller, reflecting the higher power per displacement of turbocharged engines. This trend towards adding turbochargers to smaller, less powerful engines is consistent with the turbo downsizing trend.

Figure 4.7. Gasoline Turbo Engine Production Share by Vehicle Type

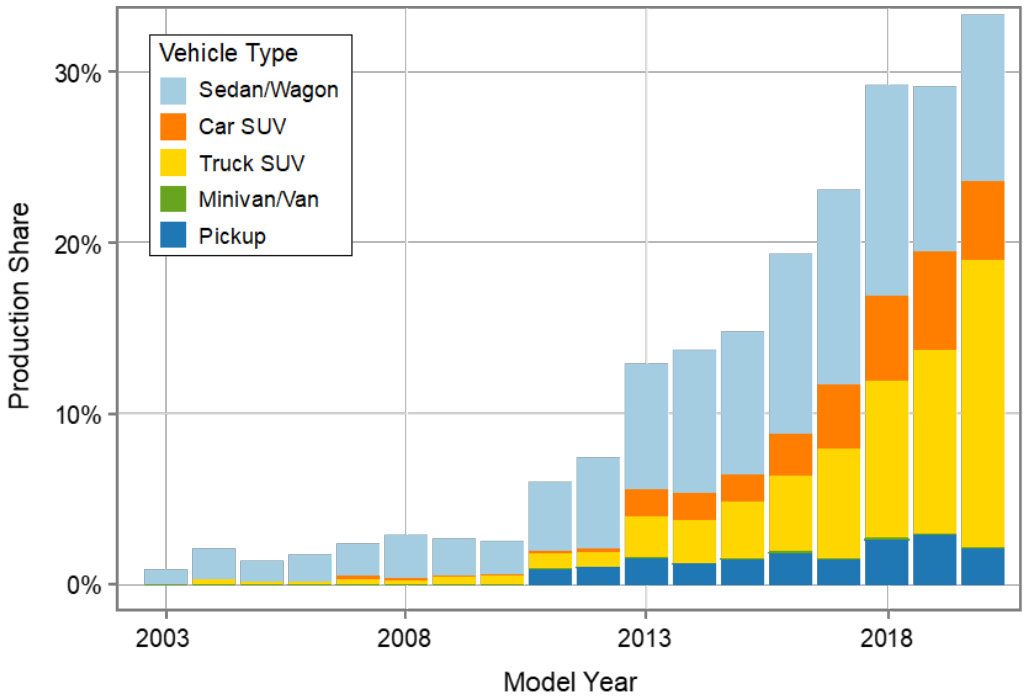


Figure 4.8. Gasoline Turbo Engine Production Share by Number of Cylinders

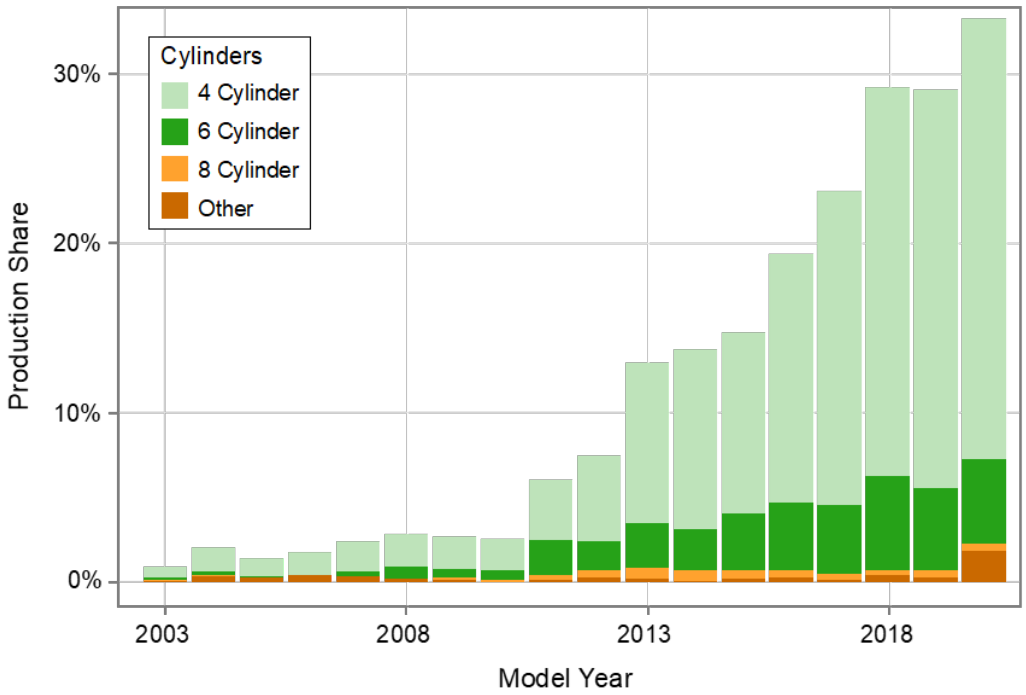
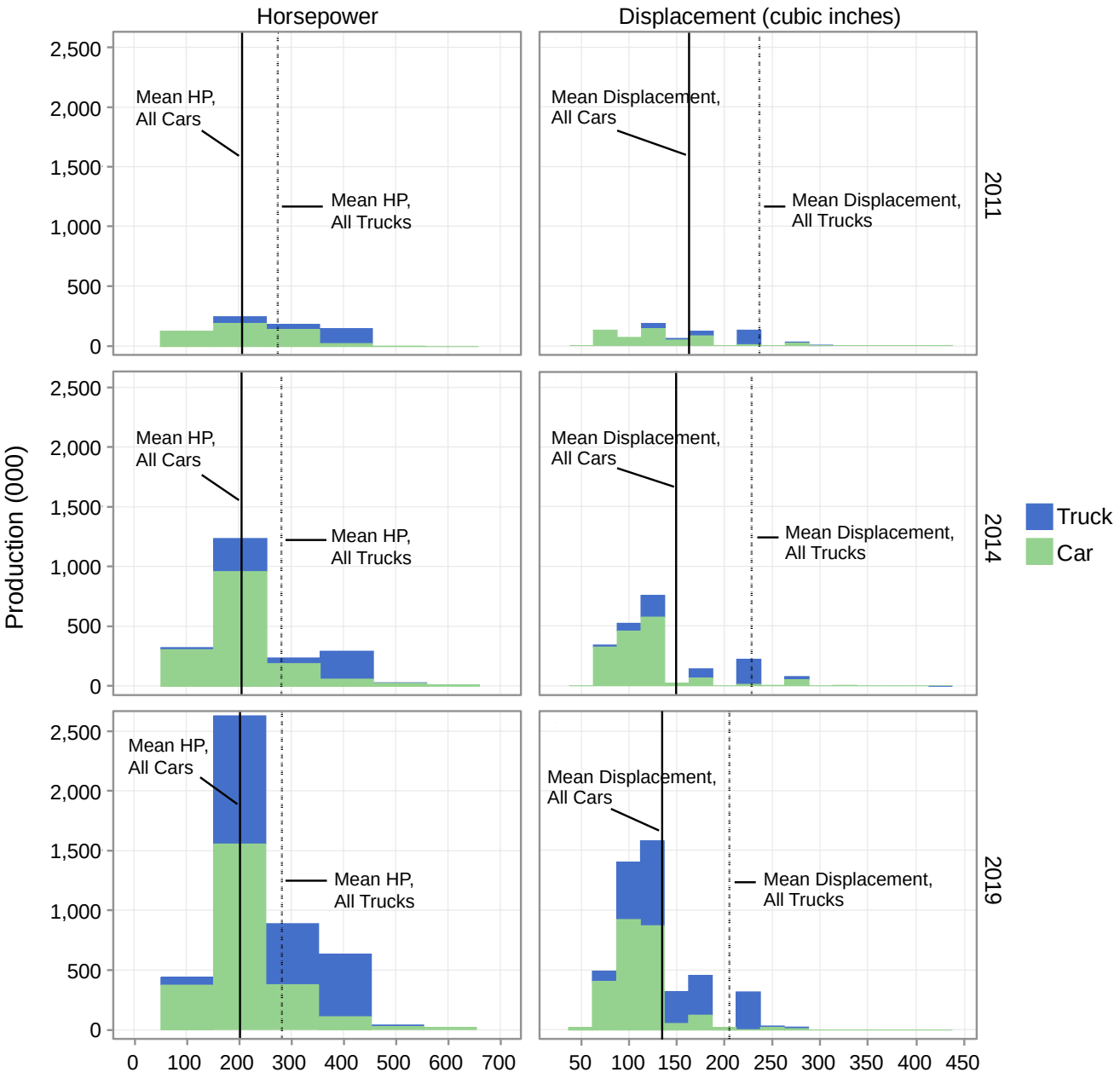


Figure 4.9. Distribution of Gasoline Turbo Vehicles by Displacement and Horsepower, Model Year 2011, 2014, and 2019



Cylinder Deactivation

Cylinder deactivation is an engine management approach that turns off the flow of fuel to one or more engine cylinders when driving conditions do not require full engine power. This effectively allows a large engine to act as a smaller engine when the additional cylinders are not needed, increasing engine efficiency and fuel economy. The use of cylinder deactivation in gasoline vehicles has been steadily climbing, and in model year 2019 gasoline engines with cylinder deactivation were almost 15% of all vehicles. This trend is expected to continue, especially as new improvements to cylinder deactivation technology, such as dynamic cylinder deactivation, reach the market.

Stop/Start

Engine stop/start technology allows the engine to be automatically turned off at idle and very quickly restarted when the driver releases the brake pedal. By turning the engine off, a vehicle can eliminate the fuel use and CO_2 emissions that would have occurred if the engine was left running. This report began tracking stop/start technology in model year 2012 at less than one percent, and already the use of stop/start has increased to almost 37% of all vehicles, with an increase to about 42% projected for model year 2020.

Hybrids

Gasoline hybrid vehicles feature a battery pack that is larger than the battery found on a typical gasoline vehicle, which allows these vehicles to store and strategically apply electrical energy to supplement the gasoline engine. The result is that the engine can be smaller than what would be needed in a non-hybrid vehicle, and the engine can be operated near its peak efficiency more often. Hybrids also utilize regenerative braking, which uses a motor/generator to capture energy from braking instead of losing that energy to friction and heat, as in traditional friction braking, and stop/start technology to turn off the engine at idle. The combination of these strategies can result in significant reductions in fuel use and CO_2 emissions.

Hybrids were first introduced in the U.S. marketplace in model year 2000 with the Honda Insight. As more models and options were introduced, hybrid production generally increased to 3.8% of all vehicles in model year 2010. Between model years 2011 and 2018, production of hybrids averaged about 2.5%, before returning to their previous peak of 3.8% in model year 2019. Hybrid production is expected to increase to a record 6.5% in model year 2020, as shown in Figure 4.10 and Figure 4.11.

Figure 4.10. Gasoline Hybrid Engine Production Share by Vehicle Type

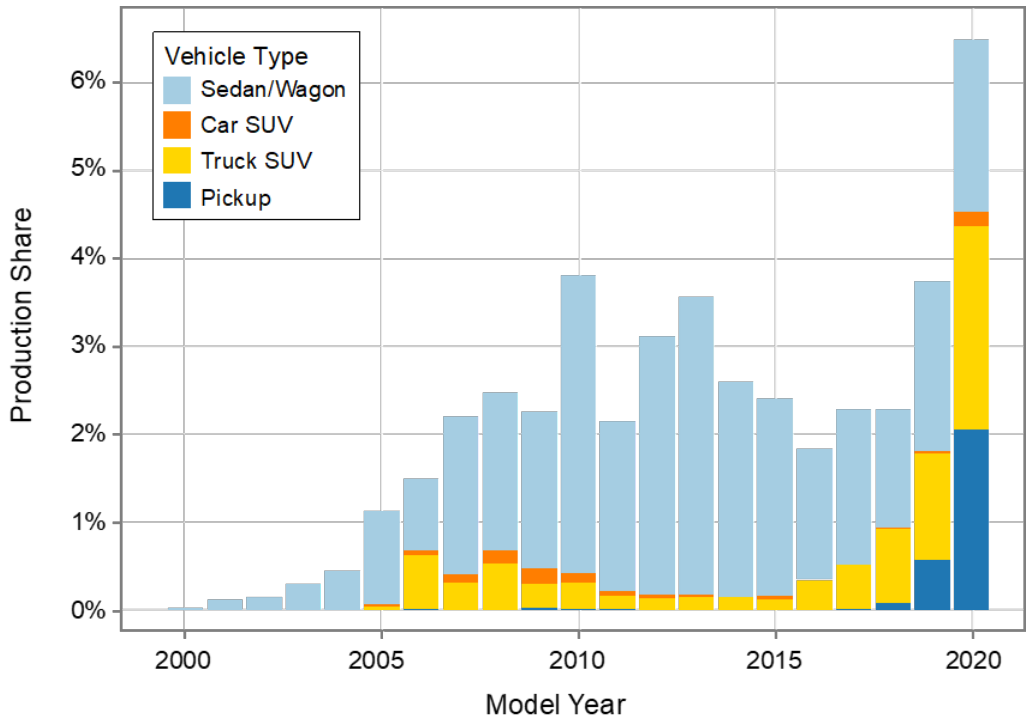
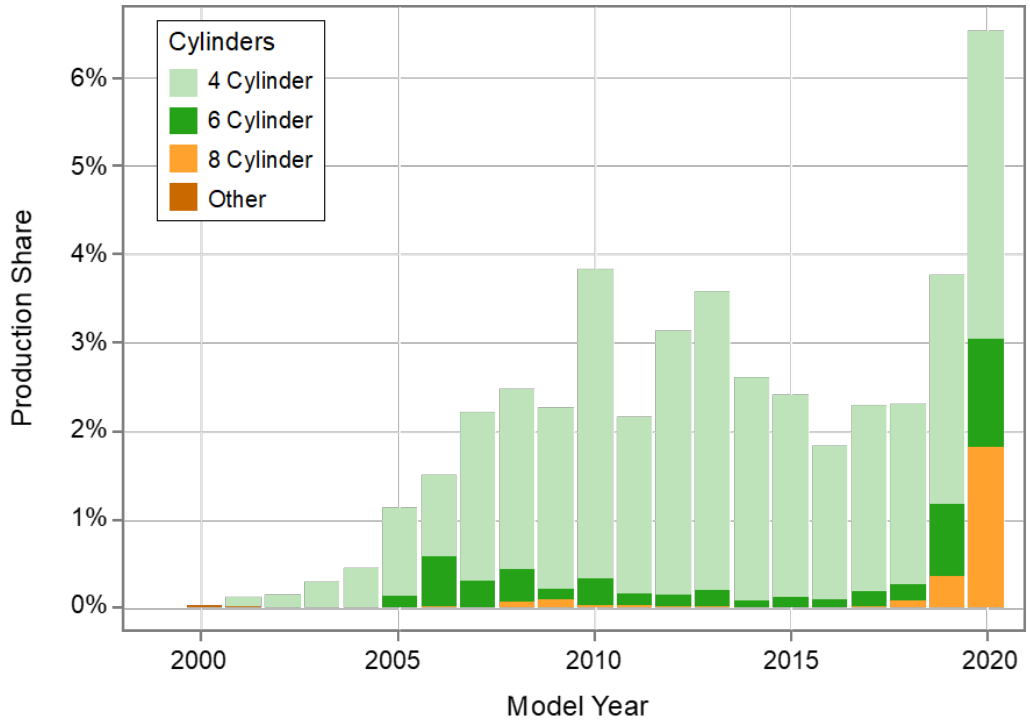


Figure 4.11. Gasoline Hybrid Engine Production Share by Number of Cylinders



Most hybrids through model year 2018 were sedan/wagons with 4-cylinder engines. However, the growth in hybrids in model year 2019 (and projected for 2020), is largely due to truck SUVs and pickup trucks along with a growing share of hybrids with 6- and 8-cylinders. The growth of hybrids in the pickup vehicle type is largely due to the introduction of "mild" hybrid systems that are capable of regenerative braking and many of the same functions as other hybrids, but utilize a smaller battery and an electrical motor that cannot directly drive the vehicle. If these types of hybrids do in fact capture a significant market share, this report may disaggregate hybrids in the future for more detailed analysis.

The production-weighted distribution of fuel economy for all hybrid cars by year is shown in Figure 4.12. Hybrid cars, on average, had fuel economy more than 40% higher than the average non-hybrid car in model year 2019. As a production weighted average, hybrid cars (including sedan/wagons and car SUVs) achieved 41.7 mpg for model year 2019, while the average non-hybrid car achieved about 29.4 mpg.

Figure 4.12. Hybrid Real-World Fuel Economy Distribution, Cars Only

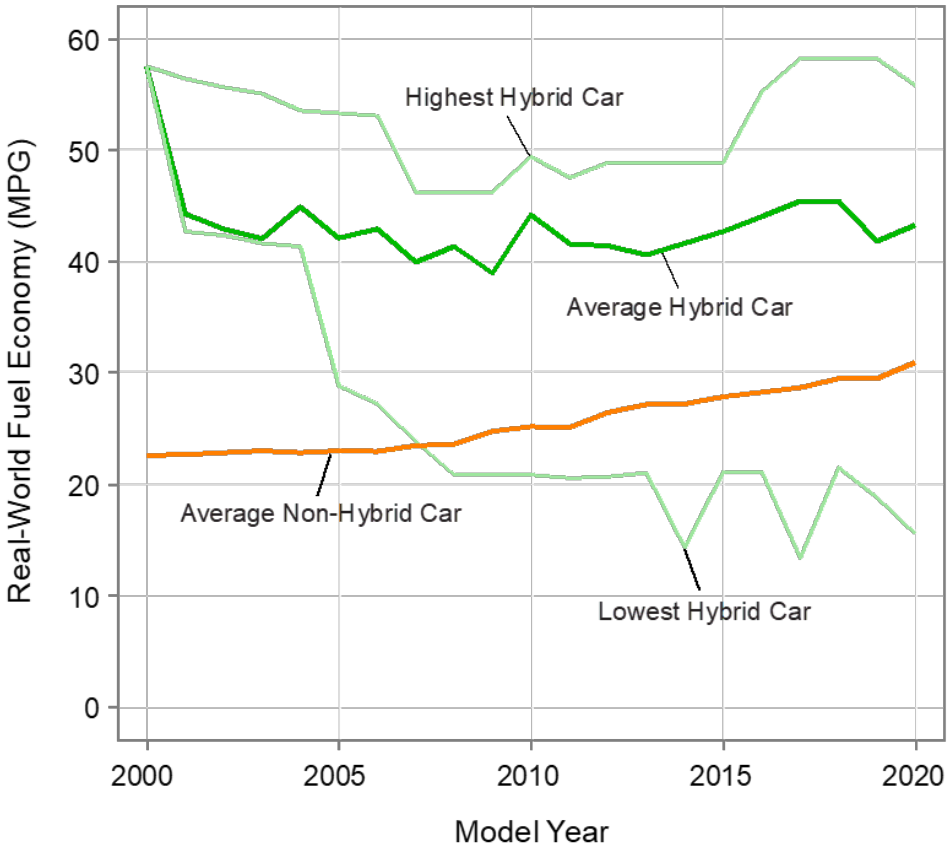


Figure 4.12 is presented only for cars since the production of hybrid trucks has been limited. While the average fuel economy of hybrid cars remains higher than the average fuel economy of non-hybrid cars, the difference has narrowed considerably. Average hybrid car fuel economy has been relatively stable since model year 2001, while the fuel economy of the average non-hybrid car has increased 30% between model years 2001 and 2019.

Plug-In Hybrid Electric, Electric, and Fuel Cell Vehicles

PHEVs and EVs are two types of vehicles that can store electricity from an external source onboard the vehicle, utilizing that stored energy to propel the vehicle. PHEVs are similar to gasoline hybrids discussed previously, but the battery packs in PHEVs can be charged from an external electricity source; this cannot be done in gasoline hybrids. EVs operate using only energy stored in a battery from external charging. Fuel cell vehicles use a fuel cell to chemically convert a fuel (usually hydrogen) into electrical energy that is then used to power the vehicle.

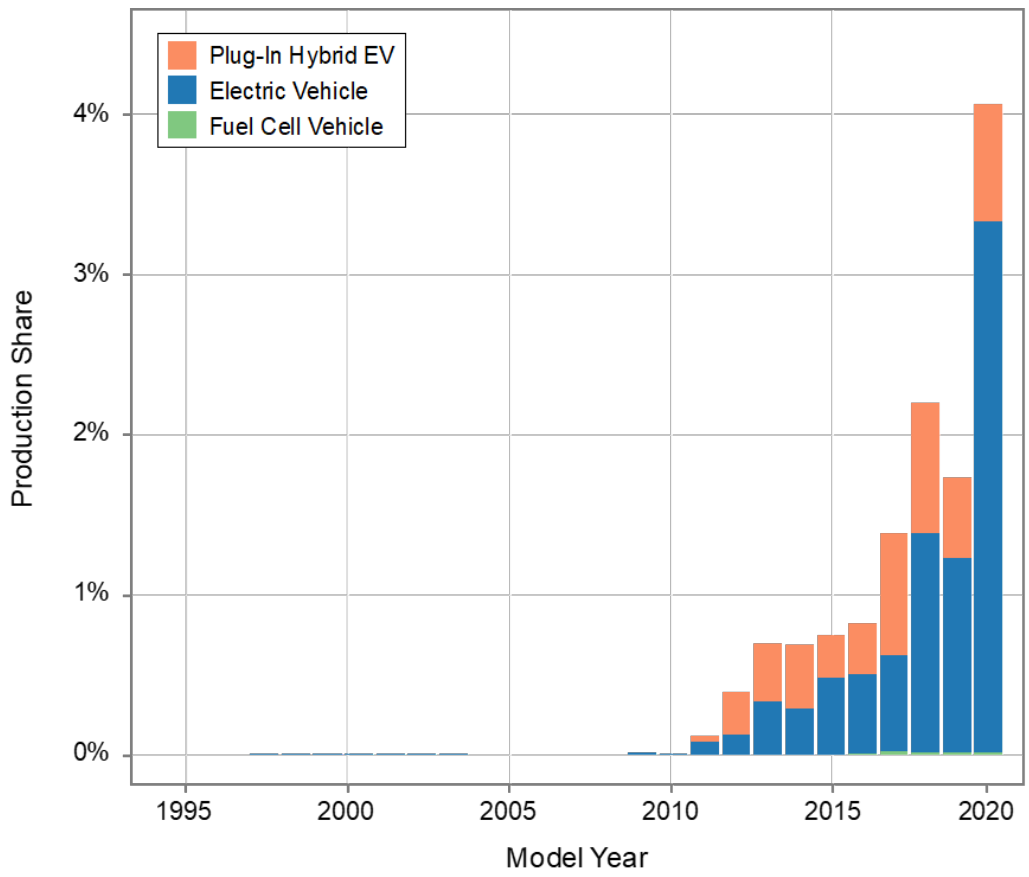
EVs do not emit tailpipe emissions at the vehicle. However, generating the electricity used to charge EVs, in most cases, creates emissions. The amount of emissions created by charging EVs varies depending on fuel source of the electricity, which can in turn vary based on location and time of day. The electric grid in the US has also been changing over time, as natural gas and renewable energy resources have been responsible for a growing portion of electricity generation across the US. Depending on the source of electricity, EVs can result in much lower CO_2 emissions over their lifetime compared to gasoline vehicles.

Since EVs do not use gasoline, the familiar metric of miles per gallon cannot be applied to EVs. Instead, EVs are rated in terms of miles per gallon-equivalent (mpge), which is the number of miles that an EV travels on an amount of electrical energy equivalent to the energy in a gallon of gasoline. This metric enables a direct comparison of energy efficiency between EVs and gasoline vehicles. EVs generally have a much higher energy efficiency than gasoline vehicles because electric motors are much more efficient than gasoline engines.

PHEVs combine the benefits of EVs with the benefits of a gasoline hybrid. These vehicles can operate either on electricity or gasoline, allowing for a wide range of engine designs and strategies for the utilization of stored electrical energy during typical driving. The use of electricity to provide some or all of the energy required for propulsion can significantly lower fuel consumption and tailpipe CO_2 emissions. For a much more detailed discussion of EV and PHEV metrics, as well as upstream emissions from electricity, see Appendix E.

The production of EVs and PHEVs has increased rapidly in recent years. Prior to model year 2011, EVs were available, but generally only in small numbers for lease in California.[9] In model year 2011 the first PHEV, the Chevrolet Volt, was introduced along with the Nissan Leaf EV. Many additional models have been introduced since, and in model year 2019 combined EV/PHEV sales were 1.7%. While this was a small reduction from the previous high of 2.2% achieved in model year 2018, combined EV and PHEV production is projected to reach a new high of 4% of all production in model year 2020. The trend in EVs, PHEVs, and FCVs are shown in Figure 4.13.

Figure 4.13. Production Share of EVs, PHEVs, and FCVs, Model Year 1995-2020[10]



[9] At least over the timeframe covered by this report. EVs were initially produced more than 100 years ago.

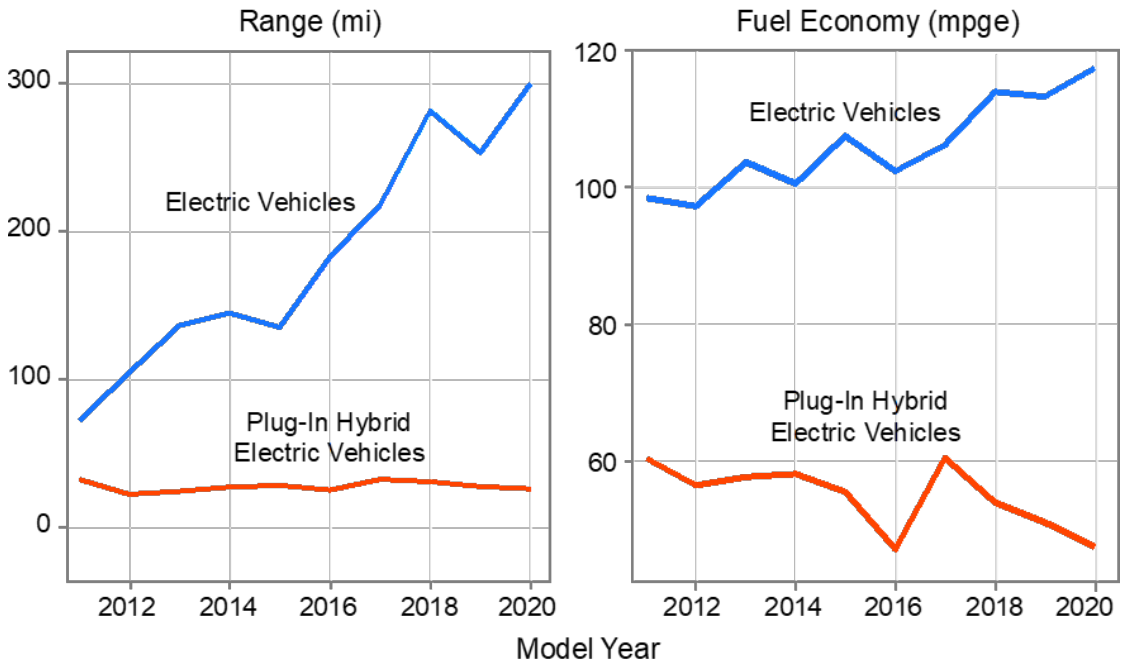
[10] EV production data were supplemented with data from Ward's and other publicly available production data for model years prior to 2011. The data only include offerings from original equipment manufacturers and does not include data on vehicles converted to alternative fuels in the aftermarket.

The inclusion of model year 2019 EV and PHEV sales reduces the overall new vehicle average CO_2 emissions by 5 g/mi, and this impact will continue to grow if EV and PHEV production increases. In model year 2019 there were three hydrogen FCVs produced, but they were only available in the state of California and Hawaii and in very small numbers. However there continues to be interest in FCVs as a future technology.

Figure 4.14 shows the range and fuel economy trends for EVs and PHEVs. The average range of new EVs has climbed substantially. In model year 2019 the average new EV is projected to have a 252-mile range, or about three and a half times the range of an average EV in 2011. This difference is largely attributable to higher production of new EVs with much longer ranges. The range values shown for PHEVs are the charge-depleting range, where the vehicle is operating on energy in the battery from an external source. This is generally the electric range of the PHEV, although some vehicles also use the gasoline engine in small amounts during charge depleting operation. The average charge depleting range for PHEVs has remained unchanged since model year 2011.

Along with improving range, the fuel economy of electric vehicles has also improved as measured in miles per gallon of gasoline equivalent (mpge). The fuel economy of electric vehicles has increased by more than 15% between model years 2011 and 2019. The combined fuel economy of PHEVs has been more variable and does not appear to have a clear trend. For more information about EV and PHEV metrics, see Appendix E.

Figure 4.14. Charge Depleting Range and Fuel Economy for EVs and PHEVs



Diesel Engines

Vehicles with diesel engines have been available in the U.S. at least as long as EPA has been collecting data. However, sales of diesel vehicles have rarely broken more than 1% of the overall market. Diesel vehicle sales peaked at 5.9% of the market in model year 1981, but quickly fell back to below 1% of production per year. While the overall percentage of diesel vehicles is low, there are still new vehicles entering the market.

Vehicles that rely on diesel fuel often achieve higher fuel economy than gasoline vehicles, largely because the energy density of diesel fuel is about 15% higher than that of gasoline. However, there is less of an advantage in terms of CO_2 emissions because diesel fuel also contains about 15% more carbon per gallon, and thus emits more CO_2 per gallon burned than gasoline.

Figure 4.15 shows the production share of diesel engines by vehicle type. Diesel engines have historically been more prevalent in the sedan/wagon vehicle type, however, since model year 2015 there have been very few sedan/wagons vehicles with diesel engines. Light-duty diesel pickup trucks re-entered the market at about the same time and are projected to increase the overall production of diesel vehicles to 1.0% of all new vehicles. If achieved, that would be only the second time since model year 1984 that diesel vehicles have accounted for at least 1.0% of all production. This report does not include the largest pickup trucks and work or vocational trucks, which have a higher penetration of diesel engines. As shown in Figure 4.16, current production of diesel engines for light-duty vehicles is limited to smaller four- and six-cylinder engines, with the growth in light-duty pickups relying almost exclusively on 6-cylinder engines.

Diesel engines, as with gasoline engines, have improved over time. Figure 4.17 shows the same metrics and trends that are explored in Figure 4.5 for gasoline engines. The specific power (HP/displacement) for diesel engines has increased about 200% since model year 1975. Fuel consumption per displacement dropped slightly in the 1980s but has increased back to about the same level as in model year 1975. Finally, fuel consumption per horsepower for diesel engines has declined about 70% since model year 1975.

Figure 4.15. Diesel Engine Production Share by Vehicle Type

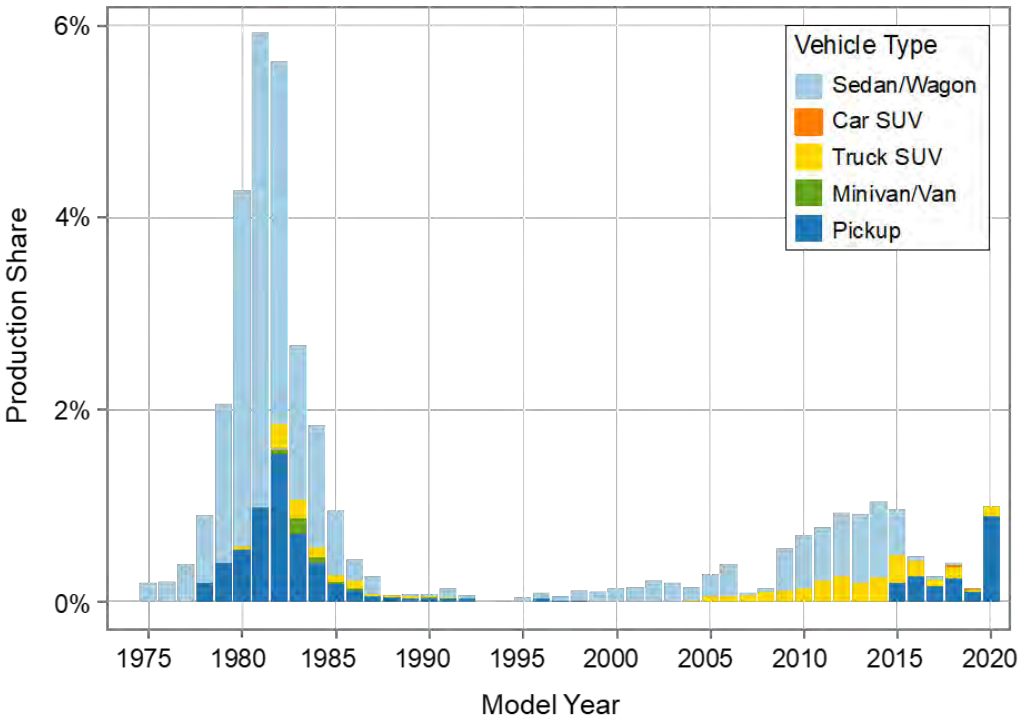


Figure 4.16. Diesel Engine Production Share by Number of Cylinders

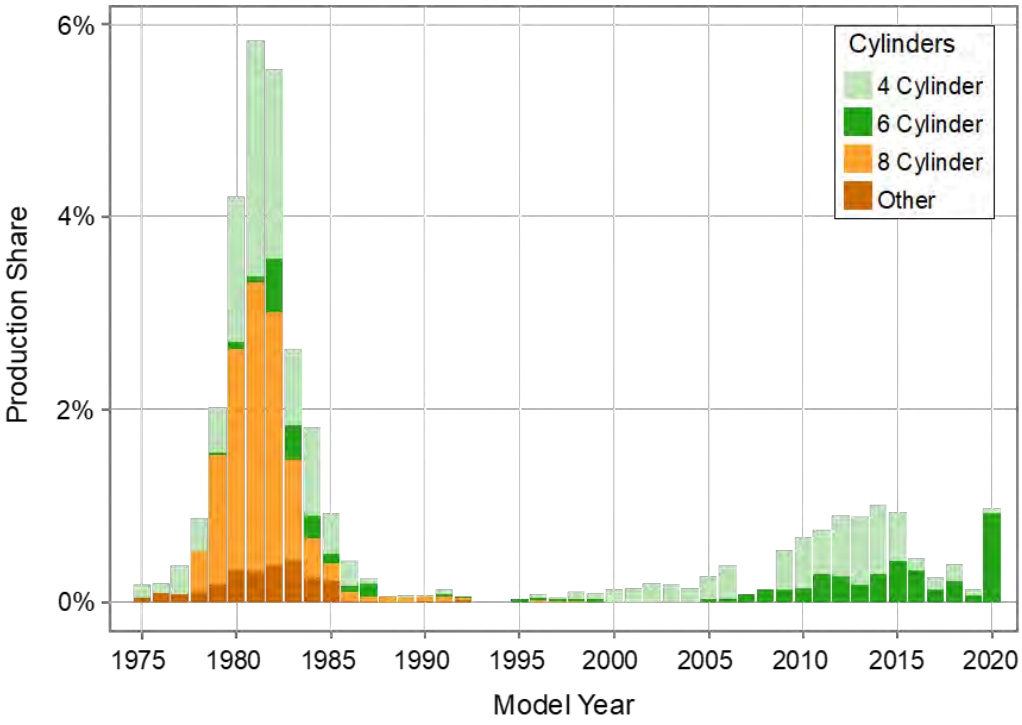
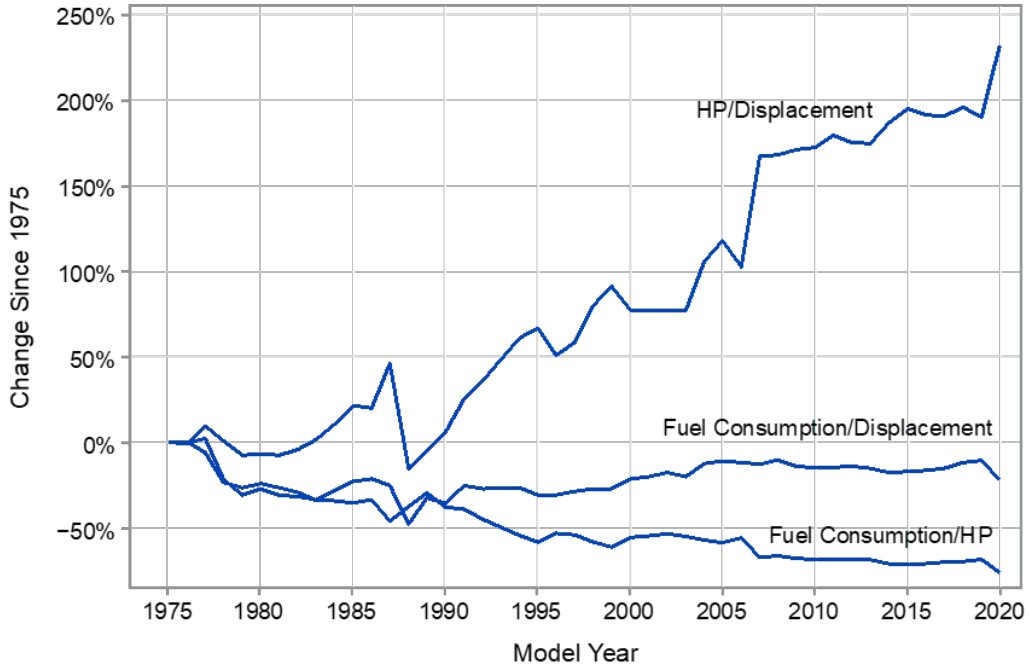


Figure 4.17. Percent Change for Specific Diesel Engine Metrics



Other Engine Technologies

In addition to the engine technologies described above, there have been a small number of other technologies available in the U.S. marketplace over the years. Vehicles that operate on compressed natural gas (CNG) are one example, but there are currently no CNG vehicles available from vehicle manufacturers (aftermarket conversions are not included here). This report will continue to track all vehicles produced for sale in the U.S., and if CNG or other technologies reach widespread availability they will be included in future versions of this report.

B. Transmission and Drive Types

The vehicle transmission and driveline connect the engine to the wheels, as shown in Figure 4.1. There are two important aspects of transmissions that impact overall vehicle efficiency and fuel economy. First, as torque (rotational force) is transferred through the transmission, a small amount is lost to friction, which reduces vehicle efficiency. Second, the design of the transmission impacts how the engine is operated, and generally transmissions with more speeds offer more opportunity to operate the engine in the most efficient way possible. For example, a vehicle with an eight-speed transmission will have more flexibility in determining engine operation than a vehicle with a five-speed transmission. This can lead to reduced fuel consumption and CO_2 emissions compared to a vehicle that is identical except for the number of transmission gears.

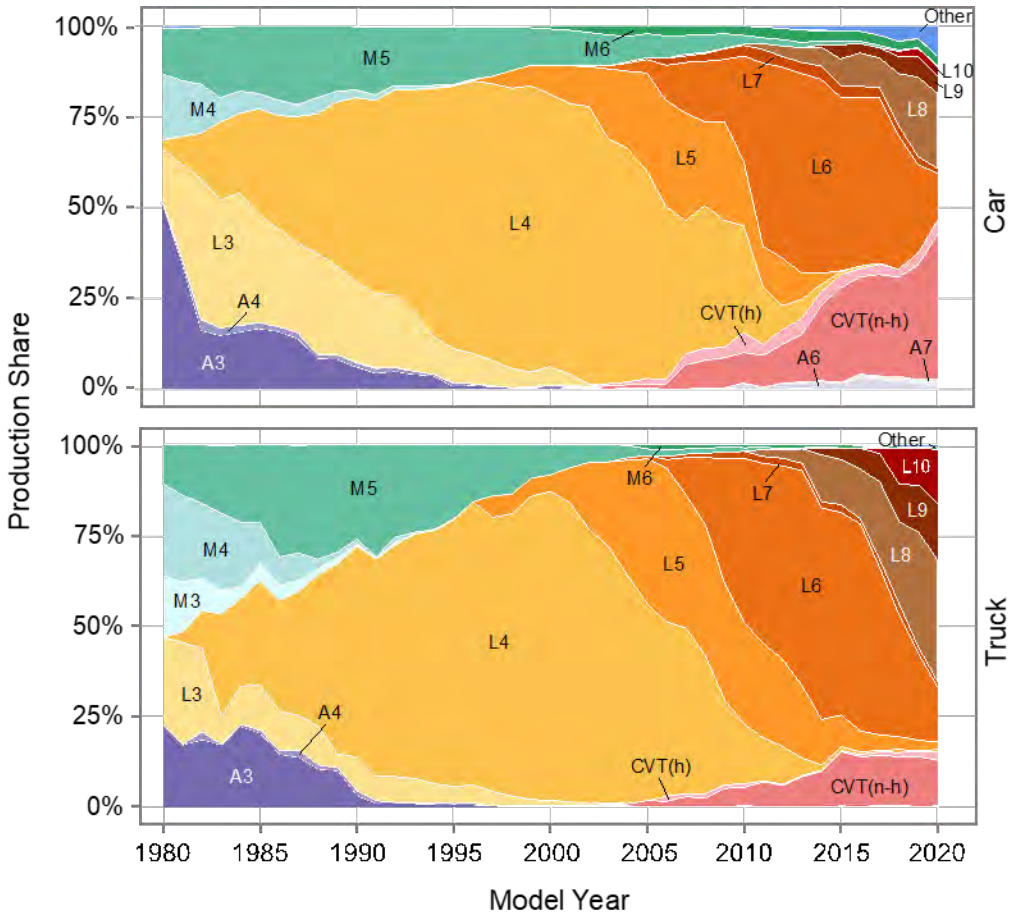
Transmissions

Transmission designs have been rapidly evolving to increase the number of gears available and allow for both better engine operation and improved efficiency. The number of gears in new vehicles continues to increase, as does the use of continuously variable transmissions (CVTs). Figure 4.18 shows the evolution of transmission production share for cars and trucks since model year 1980.[11] For this analysis, transmissions are separated into manual transmissions, CVTs, and automatic transmissions. Automatic transmissions are further separated into those with and without lockup mechanisms, which can lock up the torque converter in an automatic transmission under certain driving conditions and improve efficiency. CVTs have also been split into hybrid and non-hybrid versions to reflect the fact that hybrid CVTs are generally very different mechanically from traditional CVTs.

Dual clutch transmissions (DCTs) are essentially automatic transmissions that operate internally much more like traditional manual transmissions. The two main advantages of DCTs are that they can shift very quickly, and they can avoid some of the internal resistance of a traditional automatic transmission by eliminating the torque converter. Currently, automaker submissions to EPA do not explicitly identify DCTs as a separate transmission category. Thus, the introduction of DCTs shows up in Figure 4.18 as a slight increase in automatic transmissions without torque converters (although some DCTs may still be reported as traditional automatic transmissions).

[11] EPA has incomplete transmission data prior to model year 1980.

Figure 4.18. Transmission Production Share



Transmission	Lockup?	Number of Gears	Key
Automatic Semi-Automatic Automated Manual	No	3	A3
		4	A4
		5	A5*
		6	A6
		7	A7
		8	A8*
	Yes	2	L2*
		3	L3
		4	L4
		5	L5
		6	L6
		7	L7
		8	L8
		9	L9
		10	L10
Manual	–	3	M3
		4	M4
		5	M5
		6	M6
		7	M7*
ContinuouslyVariable (non-hybrid)	–	–	CVT(n-h)
ContinuouslyVariable (hybrid)	–	–	CVT(h)
Other	–	–	Other

*Categories A5, A8, L2, and M7 are too small to depict in the area plot.

In the early 1980s, three-speed automatic transmissions, both with and without lockup torque converters (shown as L3 and A3), were the most popular transmissions, but by model year 1985, the four-speed automatic transmission with lockup (L4) became the most popular transmission, a position it would hold for 25 years. Over 80% of all new vehicles produced in model year 1999 were equipped with an L4 transmission. After model year 1999, the production share of L4 transmissions slowly decreased as L5 and L6 transmissions were introduced into the market. Production of L5 and L6 transmissions combined passed the production of L4 transmissions in model year 2007.

Six-speed transmissions became the most popular transmission choice in model year 2010 and reached 60% of new vehicle production in model year 2013. However, the prevalence of 6-speed transmissions has since dropped quickly, to 26% in model year 2019 and to a projected 16% in model year 2020, as manufacturers have increasingly adopted transmissions with seven or more speeds and CVTs. In contrast to six-speed transmissions, the production of transmissions with seven or more speeds has increased to 47% of all vehicles in model year 2019 and is projected to grow to 51% in model year 2020, from only 2% in model year 2008. The production of CVTs (including hybrids) has also increased to almost 25% of all new vehicles, from about 8% in model year 2008. In model year 2019, eight-speed transmissions surpassed 6-speed transmission to become the most popular transmission choice. These trends are projected to continue in model year 2020, with 8-speed transmissions, CVTs, and 9 or more speed transmissions all continuing to increase market share.

Figure 4.19 shows the average number of gears in new vehicle transmissions since model year 1980 for automatic and manual transmissions. The average number of gears in new vehicles has been steadily climbing for car, trucks, automatic transmissions, and manual transmissions. In model year 1980, automatic transmissions, on average, had fewer gears than manual transmissions. However, automatic transmissions have added gears faster than manual transmissions, and now the average automatic transmission has more gears than the average manual transmission.

Figure 4.19. Average Number of Transmission Gears

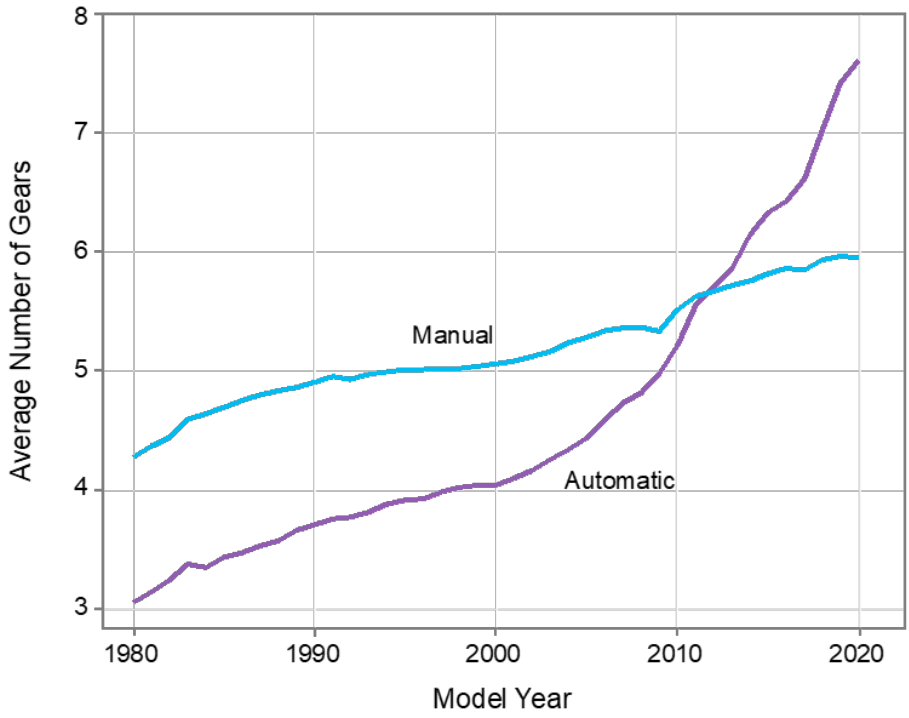
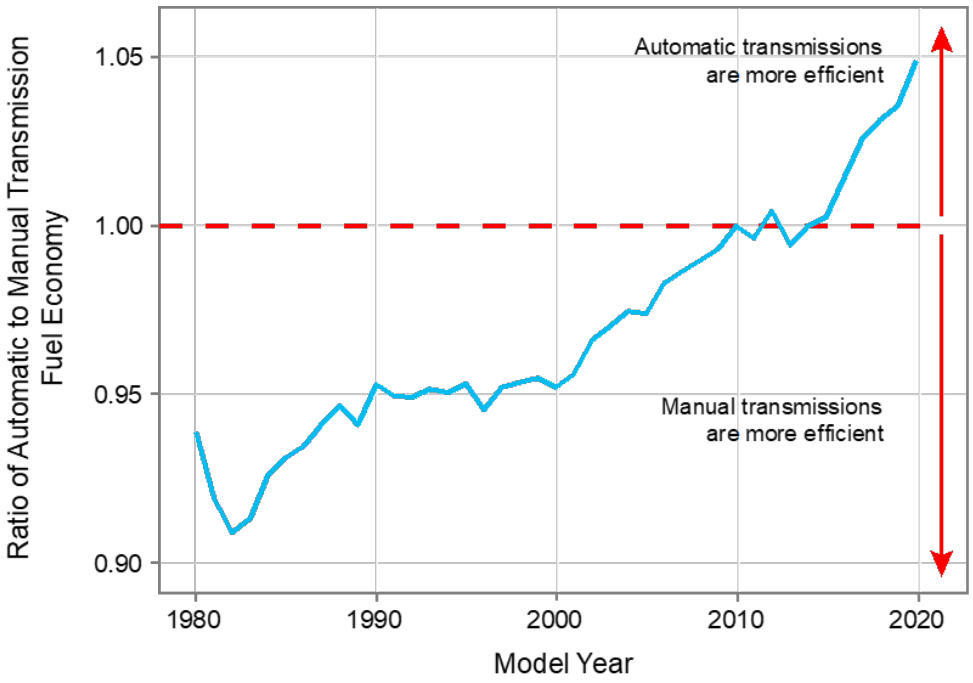


Figure 4.20. Comparison of Manual and Automatic Transmission Real-World Fuel Economy for Comparable Vehicles



In the past, automatic transmissions have generally been less efficient than manual transmissions, largely due to inefficiencies in the automatic transmission torque converter. Figure 4.20 examines this trend over time by comparing the fuel economy of automatic and manual transmission options where both transmissions were available in one model with the same engine. Vehicles with a manual transmission were more efficient than their automatic counterparts through about 2010, but modern automatic transmissions are now more efficient. Two contributing factors to this trend are that automatic transmission design has become more efficient (using earlier lockup and other strategies), and the number of gears used in automatic transmissions has increased faster than in manual transmissions.

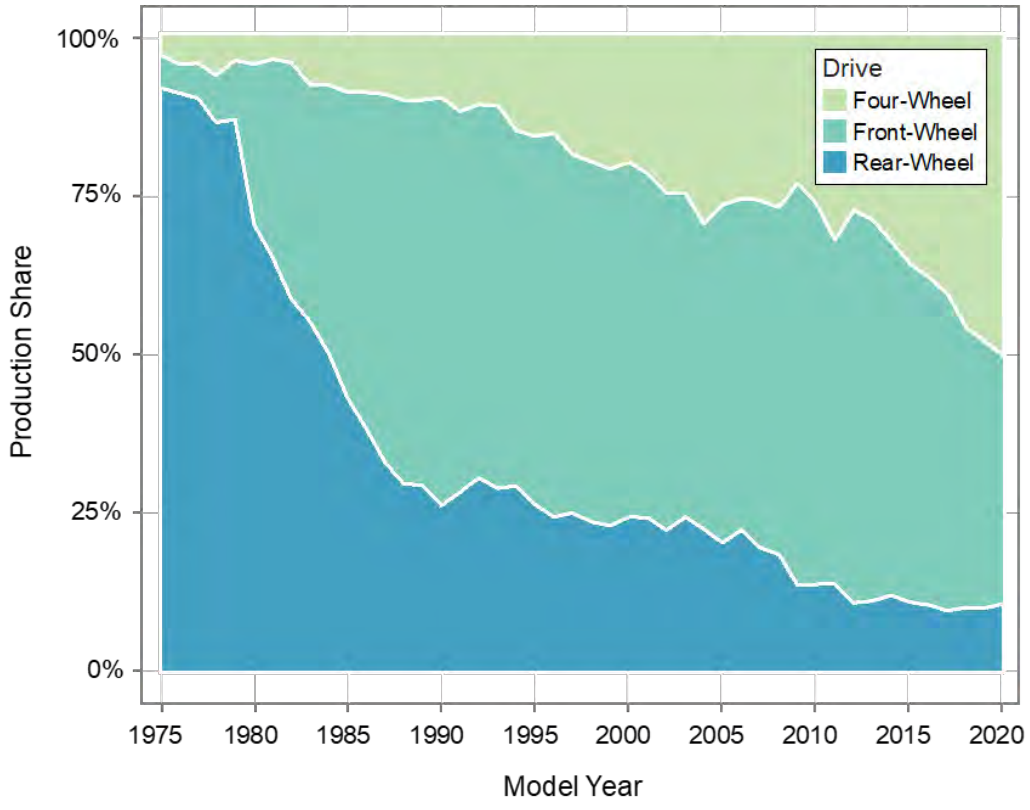
Since 1980, there has been a large shift away from manual transmissions. Manual transmission production peaked in model year 1980 at nearly 35% of production and has since fallen to an all-time low of 1.4% in model year 2019. Today, manual transmissions are available only in a limited number of small vehicles, sports cars, and a few pickups. The shrinking availability of manual transmissions does limit the relevance of analyses comparing current manual transmissions to automatic transmissions.

Drive Types

There has been a long and steady trend in new vehicle drive type away from rear-wheel drive vehicles towards front-wheel drive and four-wheel drive (including all-wheel drive) vehicles, as shown in Figure 4.21. In model year 1975, over 91% of new vehicles were produced with rear-wheel drive. Since then, production of rear-wheel drive vehicles has steadily declined to about 10% in model year 2019. Current production of rear-wheel drive vehicles is mostly limited to pickup trucks and some performance vehicles.

Production of front-wheel drive vehicles increased from 5% of new vehicle production in model year 1975 to 64% in model year 1990 and 63% in model year 2009. Since 2009 however, the production of front-wheel vehicles has also been declining, down to 42% in model year 2019. Four-wheel drive systems have steadily increased from 3.3% of new vehicle production in model year 1975 to 48% of production in model year 2019, with more than 50% of new vehicles projected to have four-wheel drive systems in model year 2020.

Figure 4.21. Front-, Rear-, and Four-Wheel Drive Production Share



C. Technology Adoption

One additional way to evaluate the evolution of technology in the automotive industry is to focus on how technology has been adopted over time. Understanding how the industry has adopted technology can lead to a better understanding of past changes in the industry, and how emerging technology may be integrated in the future. The following analysis provides more details about how manufacturers and the overall industry have adopted new technology.

Industry-Wide Technology Adoption Since 1975

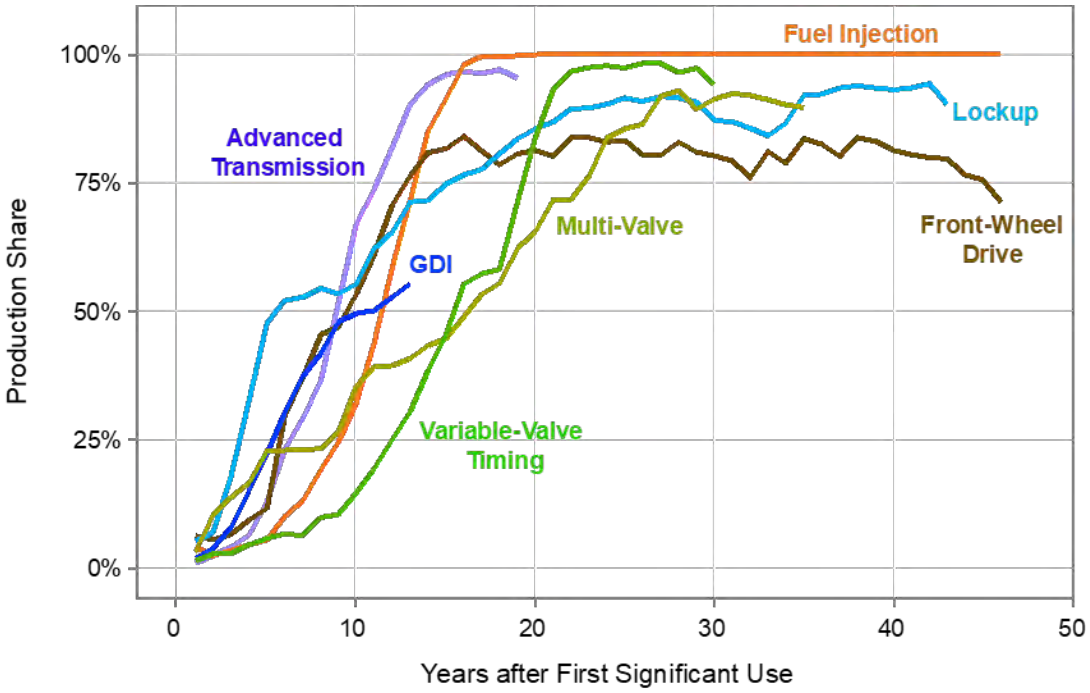
Figure 4.22 shows industry-wide adoption rates for seven technologies in passenger cars. These technologies are fuel injection (including throttle body, port, and direct injection), front-wheel drive, multi-valve engines (i.e., engines with more than two valves per cylinder), engines with variable valve timing, lockup transmissions, advanced transmissions (transmissions with six or more speeds, and CVTs), and gasoline direct injection engines. To provide a common scale, the adoption rates are plotted in terms of the number of years after the technology achieved first significant use in the industry. First significant use generally represents a production threshold of 1%, though in some cases, where full data are not available, first significant use represents a slightly higher production share.

The technology adoption pattern shown in Figure 4.22 is roughly similar for each of the seven technologies, even though they vary widely in application, complexity, and when they were initially introduced. It has taken, on average, approximately 15-20 years for new technologies to reach maximum penetration across the industry. GDI is a newer technology that has likely not reached maximum penetration across the industry but appears to be following the adoption trend of other more mature technologies. While some of these technologies may eventually be adopted in 100% of new vehicles, there may be reasons that other technologies, like front-wheel drive, will likely never be adopted in all vehicles. Adoption rates for these technologies in trucks are similar, with the exception of front-wheel drive.

The analysis for Figure 4.22 focuses on technologies that have achieved widespread use by multiple manufacturers and does not look at narrowly-adopted technologies which never achieved widespread use. One limitation to the data in this report is that EPA does not begin tracking technology production share data until after the technologies had achieved some limited market share. For example, EPA did not begin to track multi-valve engine data until model year 1986 for cars and model year 1994 for trucks, and in both cases multi-valve engines had captured about 5% market share by that time. Likewise, turbochargers

were not tracked in Trends until model year 1996 for cars and model year 2003 for trucks, and while turbochargers had less than a 1% market share in both cases at that time, it is likely that turbochargers had exceeded 1% market share in the late 1980s. Cylinder deactivation was utilized by at least one major manufacturer in the 1980s.

Figure 4.22. Industry-Wide Car Technology Penetration after First Significant Use



Technology Adoption by Manufacturers

The rate at which the overall industry adopts technology is determined by how quickly, and at what point in time, individual manufacturers adopt the technology. While it is important to understand the industry-wide adoption rates over time, the trends in Figure 4.22 mask the fact that not all manufacturers introduced these technologies at the same time, or at the same rate. The "sequencing" of manufacturers introducing new technologies is an important aspect of understanding the overall industry trend of technology adoption.

Figure 4.23 begins to disaggregate the industry-wide trends to examine how individual manufacturers have adopted new technologies.[12] For each technology, Figure 4.23 shows the amount of time it took specific manufacturers to move from initial introduction to 80% penetration for each technology, as well as the same data for the overall industry. After 80% penetration, the technology is assumed to be largely incorporated into the manufacturer's fleet, and changes between 80% and 100% are not highlighted.

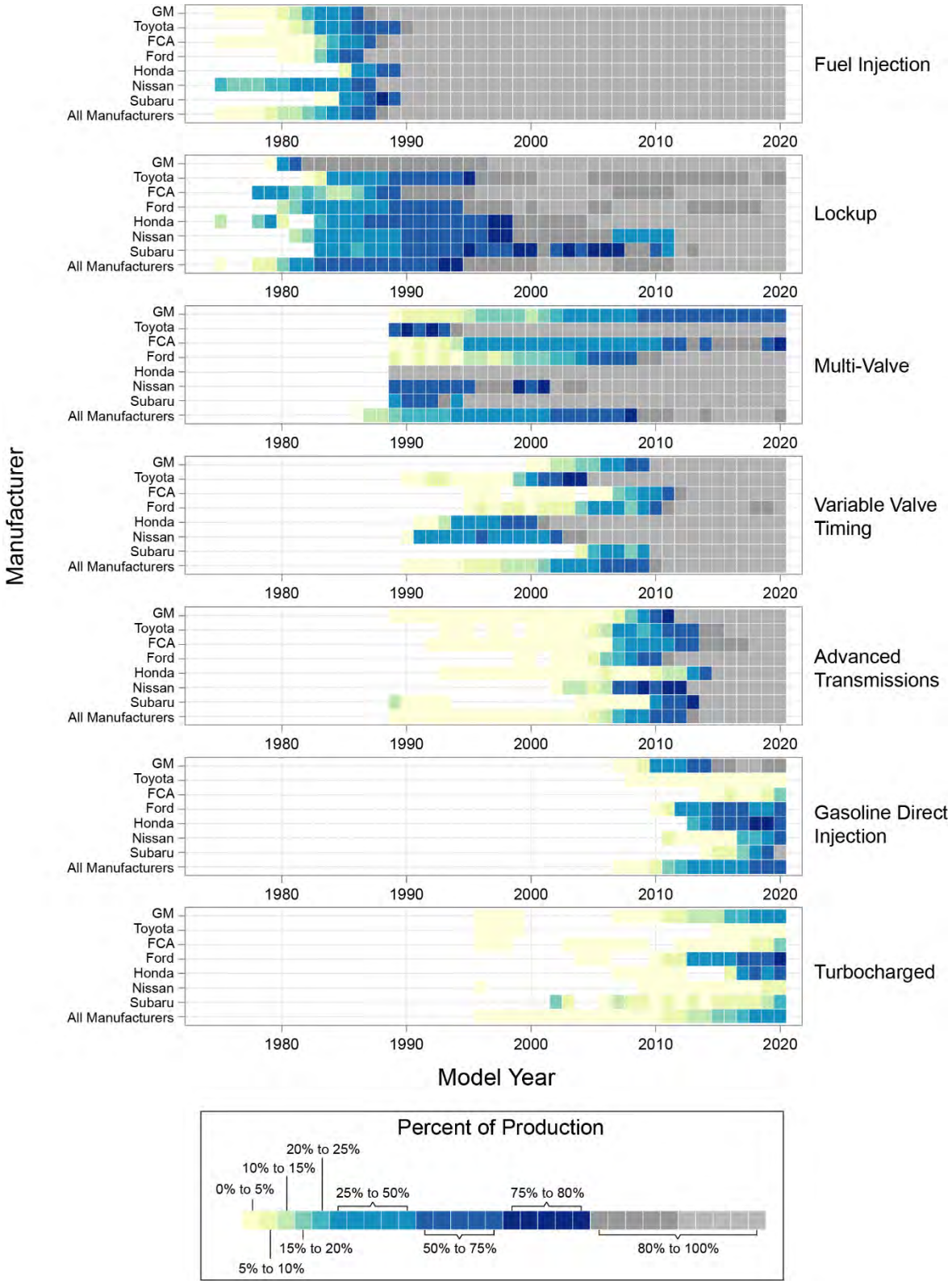
Of the seven technologies shown in Figure 4.23, five are now at or near full market penetration for the included manufacturers, and two are still in the process of adoption by manufacturers. The technologies shown in Figure 4.23 vary widely in terms of complexity, application, and when they were introduced into the market. For each technology, there are clearly variations between manufacturers, both in terms of when they began to adopt a technology, and the rate with which they adopted the technology. The degree of variation between the manufacturers also varies by technology.

The data for VVT (shown in Figure 4.22 and Figure 4.23), for example, show that several manufacturers adopted the technology much faster than the overall industry, which achieved 80% penetration in just over 20 years. It was not the rate of technology adoption alone, but rather the staggered implementation timeframes among manufacturers that resulted in the longer industry-wide average.

Fuel injection systems show the least amount of variation in initial adoption timing between manufacturers, which resulted in a faster adoption by the industry overall than technologies like VVT. One important driver for adoption of fuel injection was increasingly stringent emissions standards. Advanced transmissions, which have been available in small numbers for some time, have very rapidly increased market penetration in recent years and are now widely adopted. GDI engines appear to be following a similar path of quick uptake in recent years. Turbocharged engines have long been available, but the focus on turbo downsized engine packages is leading to much higher market penetration, although it is too early to tell what level of penetration they will ultimately achieve industry-wide.

[12] This figure is based on available data. Some technologies may have been introduced into the market before this report began tracking them. Generally, these omissions are limited, with the exception of multi-valve engine data for Honda. Honda had already achieved 70% penetration of multi-valve engines when this report began tracking them in 1986, so this figure does not illustrate Honda's prior trends.

Figure 4.23. Manufacturer Specific Technology Adoption over Time for Key Technologies

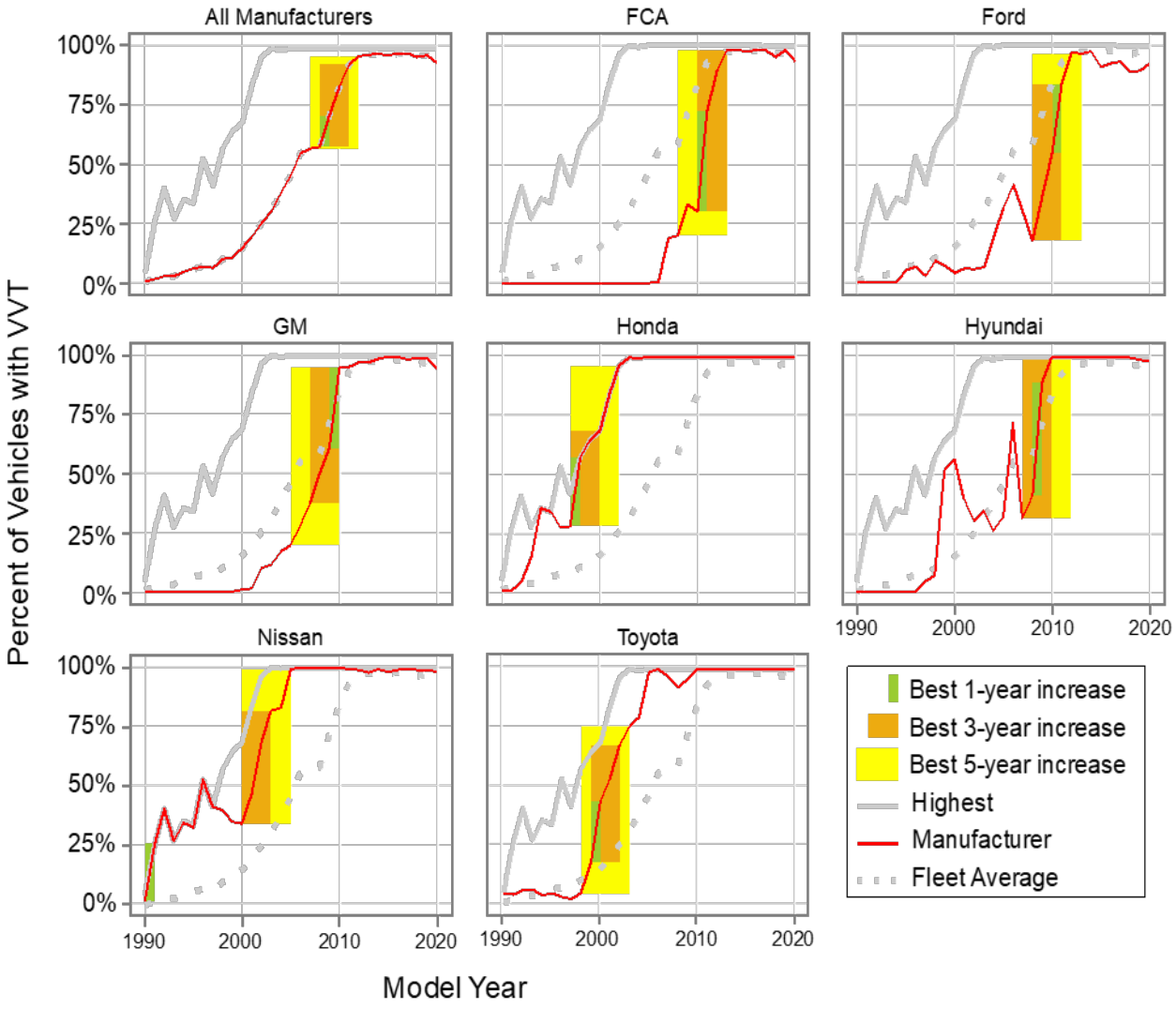


The discrepancy between manufacturer adoption rates, and the timeframe when they chose to adopt technologies, is clear in Figure 4.23 for VVT. For more detail, Figure 4.24 shows the percent penetration of VVT over time for each manufacturer (solid red line) versus the average for all manufacturers (dotted grey line) and the maximum penetration by any manufacturer (solid grey line). The largest increase in VVT penetration over any one-, three-, and five-year period for each manufacturer is shown in Figure 4.24 as green, orange, and yellow boxes.

Each manufacturer clearly followed a unique trajectory to adopt VVT. It took over 20 years for nearly all new vehicles to adopt VVT; however, it is also very clear that individual manufacturers adopted VVT across their own vehicle offerings much faster. All of the manufacturers shown in Figure 4.24 were able to adopt VVT across the vast majority of their new vehicle offerings in under 15 years, and many accomplished that feat in under ten years. As indicated by the yellow rectangles in Figure 4.24, several manufacturers increased their penetration rates of VVT by 75% or more over a five-year period. It is also important to note that every manufacturer shown adopted VVT into new vehicles at a rate faster than the overall industry-wide data would imply. The industry average represents both the rate that manufacturers adopted VVT and the effect of manufacturers adopting the technology at different times. Accordingly, the industry average shown in Figure 4.22 does not represent the average pace at which individual manufacturers adopted VVT, which is considerably faster.

VVT was first tracked in this report for cars in model year 1990 and for trucks in model year 2000. Between model year 1990 and model year 2000, there may be a small number of trucks with VVT that are not accounted for in the data. However, the first trucks with VVT produced in larger volumes (greater than 50,000 vehicles) were produced in model year 1999 and model year 2000, so the discrepancy is not enough to noticeably alter the trends in the previous figures.

Figure 4.24. VVT Adoption Details by Manufacturer

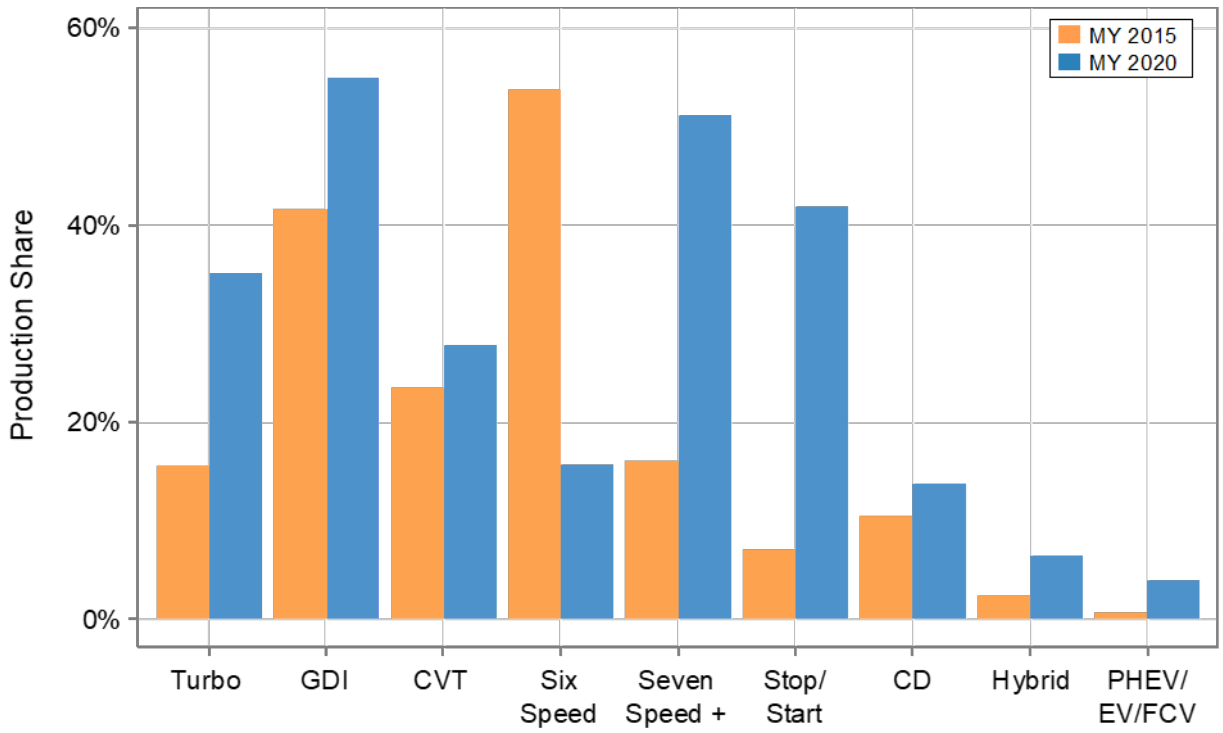


Technology Adoption in the Last Five Years

Over the last five years, engines and transmissions have continued to evolve and adopt new technologies. Figure 4.25. shows the penetration of several key technologies in model year 2015 and the projected penetration for each technology in model year 2020 vehicles. Over that five-year span, transmissions with seven or more speeds and engines with stop/start technology are both projected to increase market share by 35 percentage points, turbocharged engines are expected to increase by 20 percentage points, and vehicles with GDI engines are projected to increase by about 13 percentage points. Six speed transmissions, which were the prevalent transmission choice for many years, are projected

to lose market share by 38 percentage points between model year 2015 and 2020. These are large changes taking place across the industry over a relatively short time. As discussed in the previous section, individual manufacturers are making technology changes at even faster rates.

Figure 4.25. Five-Year Change in Light Duty Vehicle Technology Production Share



There are many factors outside the scope of this report that influence the rate and timing of when technology is adopted by individual manufacturers (e.g., price, manufacturing constraints, regulatory drivers, etc.) While no attempt is made here to identify the underlying causes, it is important to recognize that variation between manufacturers for given technologies can be masked when only the industry-wide trends are evaluated. Technology adoption by individual manufacturers is often more rapid than the overall industry trend would suggest. Manufacturers continue to adopt new technologies, and the penetration of important technologies has grown significantly over the last five years.

Table 4.1. Production Share by Engine Technologies

	Powertrain				Fuel Delivery Method													
Model Year	Gasoline	Gasoline Hybrid	Diesel	Other	Carb	GDI	Port	TBI	EV	FCV	Avg. No. of Cylinders	CID	HP	Multi-Valve	VVT	CD	Turbo	Stop/ Start
1975	99.8%	-	0.2%	-	95.7%	-	4.1%	0.0%	-	-	6.8	293	137	-	-	-	-	-
1980	95.7%	-	4.3%	-	89.7%	-	5.2%	0.8%	-	-	5.6	198	104	-	-	-	-	-
1985	99.1%	-	0.9%	-	56.1%	-	18.2%	24.8%	-	-	5.5	189	114	-	-	-	-	-
1990	99.9%	-	0.1%	-	2.1%	-	70.8%	27.0%	-	-	5.4	185	135	23.1%	-	-	-	-
1995	100.0%	-	0.0%	-	-	-	91.6%	8.4%	-	-	5.6	196	158	35.6%	-	-	-	-
2000	99.8%	0.0%	0.1%	-	-	-	99.8%	0.0%	-	-	5.7	200	181	44.8%	15.0%	-	1.3%	-
2001	99.7%	0.1%	0.1%	-	-	-	99.9%	-	-	-	5.8	201	187	49.0%	19.6%	-	2.0%	-
2002	99.6%	0.2%	0.2%	-	-	-	99.8%	-	-	-	5.8	203	195	53.3%	25.3%	-	2.2%	-
2003	99.5%	0.3%	0.2%	-	-	-	99.8%	-	-	-	5.8	204	199	55.5%	30.6%	-	1.2%	-
2004	99.4%	0.5%	0.1%	-	-	-	99.9%	-	-	-	5.9	212	211	62.3%	38.5%	-	2.3%	-
2005	98.6%	1.1%	0.3%	-	-	-	99.7%	-	-	-	5.8	205	209	65.6%	45.8%	0.8%	1.7%	-
2006	98.1%	1.5%	0.4%	-	-	-	99.6%	-	-	-	5.7	204	213	71.7%	55.4%	3.6%	2.1%	-
2007	97.7%	2.2%	0.1%	-	-	-	99.8%	-	-	-	5.6	203	217	71.7%	57.3%	7.3%	2.5%	-
2008	97.4%	2.5%	0.1%	-	-	2.3%	97.6%	-	-	-	5.6	199	219	76.4%	58.2%	6.7%	3.0%	-
2009	97.2%	2.3%	0.5%	-	-	4.2%	95.2%	-	-	-	5.2	183	208	83.8%	71.5%	7.3%	3.3%	-
2010	95.5%	3.8%	0.7%	0.0%	-	8.3%	91.0%	-	-	0.0%	5.3	188	214	85.5%	83.8%	6.4%	3.3%	-
2011	97.0%	2.2%	0.8%	0.1%	-	15.4%	83.8%	-	0.1%	0.0%	5.4	192	230	86.4%	93.1%	9.5%	6.8%	-
2012	95.5%	3.1%	0.9%	0.4%	-	22.5%	76.5%	-	0.1%	0.0%	5.1	181	222	91.8%	96.6%	8.1%	8.4%	0.6%
2013	94.8%	3.6%	0.9%	0.7%	-	30.5%	68.3%	-	0.3%	-	5.1	176	226	92.8%	97.4%	7.7%	13.9%	2.3%
2014	95.7%	2.6%	1.0%	0.7%	-	37.4%	61.3%	-	0.3%	0.0%	5.1	180	230	89.2%	97.6%	10.6%	14.8%	5.1%
2015	95.9%	2.4%	0.9%	0.7%	-	41.9%	56.7%	-	0.5%	0.0%	5.0	177	229	91.2%	97.2%	10.5%	15.7%	7.1%
2016	96.9%	1.8%	0.5%	0.8%	-	48.0%	51.0%	-	0.5%	0.0%	5.0	174	230	92.3%	98.0%	10.4%	19.9%	9.6%
2017	96.1%	2.3%	0.3%	1.4%	-	49.7%	49.4%	-	0.6%	0.0%	5.0	174	234	92.0%	98.1%	11.9%	23.4%	17.8%
2018	95.1%	2.3%	0.4%	2.2%	-	50.2%	48.0%	-	1.4%	0.0%	5.0	172	241	91.0%	96.4%	12.5%	30.0%	29.8%
2019	94.4%	3.8%	0.1%	1.7%	-	52.9%	45.7%	-	1.2%	0.0%	5.1	174	245	90.1%	97.2%	14.9%	30.0%	36.9%
2020 (prelim)	*88.5%*	*6.5%*	*1.0%*	*4.0%*	-	*55.3%*	*40.3%*	-	*3.3%*	*0.0%*	*4.9*	*168*	*247*	*89.6%*	*94.0%*	*13.8%*	*35.3%*	*42.2%*

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends.

Table 4.2. Production Share by Transmission Technologies

Model Year	Manual	Automatic with Lockup	Automatic without Lockup	CVT (Hybrid)	CVT (Non-Hybrid)	Other	4 Gears or Fewer	5 Gears	6 Gears	7 Gears	8 Gears	9+ Gears	Average No. of Gears
1975	23.0%	0.2%	76.8%	-	-	-	99.0%	1.0%	-	-	-	-	-
1980	34.6%	18.1%	46.8%	-	-	0.5%	87.9%	12.1%	-	-	-	-	3.5
1985	26.5%	54.5%	19.1%	-	-	-	80.7%	19.3%	-	-	-	-	3.8
1990	22.2%	71.2%	6.5%	-	0.0%	0.0%	79.9%	20.0%	0.1%	-	-	-	4.0
1995	17.9%	80.7%	1.4%	-	-	-	82.0%	17.7%	0.2%	-	-	-	4.1
2000	9.7%	89.5%	0.7%	-	0.0%	-	83.7%	15.8%	0.5%	-	-	-	4.1
2001	9.0%	90.3%	0.6%	0.1%	0.0%	-	80.7%	18.5%	0.7%	-	-	-	4.2
2002	8.2%	91.4%	0.3%	0.1%	0.1%	-	77.1%	21.6%	1.1%	-	-	-	4.2
2003	8.0%	90.8%	0.1%	0.3%	0.8%	-	69.2%	28.1%	1.7%	-	-	-	4.3
2004	6.8%	91.8%	0.3%	0.4%	0.7%	-	63.9%	31.8%	3.0%	0.2%	-	-	4.4
2005	6.2%	91.5%	0.1%	1.0%	1.3%	-	56.0%	37.3%	4.1%	0.2%	-	-	4.5
2006	6.5%	90.6%	0.0%	1.5%	1.4%	-	47.7%	39.2%	8.8%	1.4%	-	-	4.6
2007	5.6%	87.1%	0.0%	2.1%	5.1%	-	40.5%	36.1%	14.4%	1.5%	0.2%	-	4.8
2008	5.2%	86.8%	0.2%	2.4%	5.5%	-	38.8%	31.9%	19.4%	1.8%	0.2%	-	4.8
2009	4.8%	85.6%	0.2%	2.1%	7.3%	-	31.2%	32.2%	24.5%	2.5%	0.1%	-	5.0
2010	3.8%	84.1%	1.2%	3.8%	7.2%	-	24.6%	23.5%	38.1%	2.7%	0.2%	-	5.2
2011	3.2%	86.5%	0.3%	2.0%	8.0%	-	14.2%	18.7%	52.3%	3.1%	1.7%	-	5.5
2012	3.6%	83.4%	1.1%	2.7%	9.2%	-	8.1%	18.2%	56.3%	2.8%	2.6%	-	5.5
2013	3.5%	80.4%	1.4%	2.9%	11.8%	-	5.4%	12.8%	60.1%	2.8%	4.1%	-	5.6
2014	2.8%	76.7%	1.6%	2.3%	16.6%	-	2.2%	7.8%	58.4%	3.3%	8.4%	1.1%	5.9
2015	2.6%	72.3%	1.4%	2.2%	21.5%	-	1.5%	4.5%	54.2%	3.1%	9.5%	3.5%	5.9
2016	2.2%	72.3%	2.6%	1.7%	21.2%	-	1.1%	3.0%	54.9%	2.9%	11.2%	4.1%	6.0
2017	2.1%	71.5%	2.6%	1.9%	21.8%	-	1.0%	2.4%	49.0%	3.4%	14.6%	5.9%	6.1
2018	1.6%	72.8%	3.2%	1.7%	20.6%	-	1.9%	2.0%	37.6%	3.7%	19.0%	13.5%	6.4
2019	1.4%	72.1%	2.4%	2.2%	21.9%	-	1.5%	1.6%	26.1%	2.6%	27.5%	16.5%	6.6
2020 (prelim)	*1.5%*	*66.1%*	*4.4%*	*3.1%*	*25.0%*	-	*3.4%*	*1.3%*	*15.8%*	*2.4%*	*28.3%*	*20.7%*	*6.6*

Table 4.3. Production Share by Drive Technology

Model Year	Car			Truck			All		
	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive
1975	6.5%	93.5%	-	-	82.8%	17.2%	5.3%	91.4%	3.3%
1980	29.7%	69.4%	0.9%	1.4%	73.6%	25.0%	25.0%	70.1%	4.9%
1985	61.1%	36.8%	2.1%	7.3%	61.4%	31.3%	47.8%	42.9%	9.3%
1990	84.0%	15.0%	1.0%	15.8%	52.4%	31.8%	63.8%	26.1%	10.1%
1995	80.1%	18.8%	1.1%	18.4%	39.3%	42.3%	57.6%	26.3%	16.2%
2000	80.4%	17.7%	2.0%	20.0%	33.8%	46.3%	55.5%	24.3%	20.2%
2001	80.3%	16.7%	3.0%	16.3%	34.8%	48.8%	53.8%	24.2%	22.0%
2002	82.9%	13.5%	3.6%	15.4%	33.1%	51.6%	52.7%	22.3%	25.0%
2003	80.9%	15.9%	3.2%	15.4%	34.1%	50.4%	50.7%	24.3%	25.0%
2004	80.2%	14.5%	5.3%	12.5%	31.0%	56.5%	47.7%	22.4%	29.8%
2005	79.2%	14.2%	6.6%	20.1%	27.7%	52.2%	53.0%	20.2%	26.8%
2006	75.9%	18.0%	6.0%	18.9%	28.0%	53.1%	51.9%	22.3%	25.8%
2007	81.0%	13.4%	5.6%	16.1%	28.4%	55.5%	54.3%	19.6%	26.1%
2008	78.8%	14.1%	7.1%	18.4%	24.8%	56.8%	54.2%	18.5%	27.3%
2009	83.5%	10.2%	6.3%	21.0%	20.5%	58.5%	62.9%	13.6%	23.5%
2010	82.5%	11.2%	6.3%	20.9%	18.0%	61.0%	59.6%	13.7%	26.7%
2011	80.1%	11.3%	8.6%	17.7%	17.3%	65.0%	53.8%	13.8%	32.4%
2012	83.8%	8.8%	7.5%	20.9%	14.8%	64.3%	61.4%	10.9%	27.7%
2013	83.0%	9.3%	7.7%	18.1%	14.5%	67.5%	59.7%	11.1%	29.1%
2014	81.3%	10.6%	8.2%	17.5%	14.2%	68.3%	55.3%	12.1%	32.6%
2015	80.4%	9.7%	9.9%	16.0%	12.6%	71.4%	52.9%	10.9%	36.1%
2016	79.8%	9.1%	11.0%	15.9%	12.2%	72.0%	51.2%	10.5%	38.3%
2017	79.7%	8.3%	12.0%	16.1%	11.1%	72.8%	49.6%	9.6%	40.8%
2018	76.5%	9.4%	14.1%	13.4%	10.9%	75.6%	43.7%	10.2%	46.1%
2019	75.5%	10.1%	14.4%	14.4%	10.2%	75.4%	41.6%	10.1%	48.3%
2020 (prelim)	*71.2%*	*11.4%*	*17.4%*	*14.6%*	*10.2%*	*75.3%*	*38.8%*	*10.7%*	*50.5%*

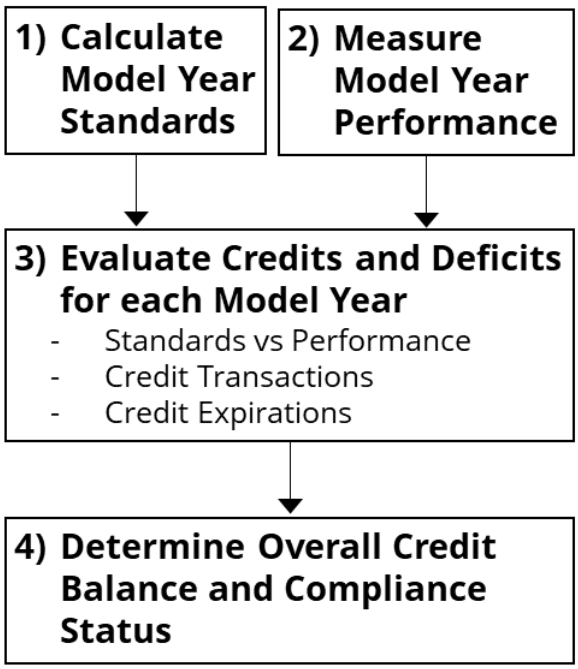
5. Manufacturer GHG Compliance

Manufacturers that produce passenger cars, light-duty trucks, and medium-duty passenger vehicles for sale in the United States are required to meet greenhouse gas (GHG) emissions and fuel economy standards. The Environmental Protection Agency (EPA) regulates greenhouse gas (GHG) emissions through the light-duty GHG program, and the National Highway Traffic Safety Administration (NHTSA) regulates fuel economy through the Corporate Average Fuel Economy (CAFE) program. The following analysis is designed to provide as much information as possible about how manufacturers are performing under EPA's GHG program, including final compliance data through model year 2019 and credit trades reported to EPA as of October 31, 2020.

This report has been updated to reflect recent regulatory changes, including the Safer Affordable Fuel-Efficient (SAFE) Vehicles rule finalized by EPA and NHTSA in April of 2020. The SAFE rule established new light-duty GHG standards for model years 2021-2026, which are generally beyond the scope of this report. Other regulatory updates include alternative standards for small volume manufacturers, and a correction to calculations to determine the amount of credits created through the sale of advanced technology vehicles.

EPA's GHG program defines standards for each manufacturer's car and truck fleets based on the average footprint of the vehicles produced for sale. Each manufacturer fleet generates credits if the fleet average emissions performance is below the standards, or deficits if it is above the standards. Credits, or deficits, that manufacturers have accrued in previous model years, credits earned as part of the early credit program, credit trades, credit forfeitures, and credit expirations are also important components in determining the final compliance status of each manufacturer. Manufacturers that maintain a positive, or zero, credit balance are considered in compliance with the GHG program. Manufacturers that end any model year with a deficit have up to three years to offset that deficit to avoid non-compliance.

Figure 5.1. The GHG Compliance Process



The general compliance process that manufacturers follow at the end of each model year is shown in Figure 5.1.

Averaging, banking, and trading (ABT) provisions have been an important part of many mobile source programs under the Clean Air Act. These provisions help manufacturers in planning and implementing a phase-in of emissions reduction technology in their production that is consistent with their unique redesign schedules. As part of the GHG program, ABT provisions allow manufacturers to average their car or truck fleet CO_2 emissions (i.e., the standards do not apply to individual vehicles), to earn and "bank" credits by reducing their car or truck fleet performance to below the applicable standards, and to trade credits between manufacturers. EPA believes the net effect of the ABT provisions is that they allow additional flexibility, encourage earlier introduction of emission reduction technologies than might otherwise occur, and do so without reducing the overall effectiveness of the program.

Manufacturer standards and model year performance are discussed in this report as per vehicle emission rates, measured in grams of CO_2 per mile (g/mi). Any discussion of manufacturer total credit balances, credit transactions, and compliance will be in terms of total mass of CO_2 emissions, measured in Megagrams of CO_2 (Mg). The use of a mass-based metric enables the banking and trading portions of the GHG program by accounting for vehicle lifetime emissions for all vehicles produced. Converting from an emission rate to total emissions is straightforward, as shown in the box on the right.

How to Calculate Total Emissions from an Emission Rate

Total emissions, or credits, are calculated by multiplying a CO_2 emission rate, the production volume of applicable vehicles, and the expected lifetime vehicle miles travelled (VMT) of those vehicles. To calculate total emissions, or credits, the following equation is used:

Credits = (CO_2 Emissions x VMT x Production) / 1,000,000

In the above equation, "Credits" are measured in megagrams (Mg) of CO_2, "CO_2 emissions" are measured in grams per mile (g/mi), and "VMT" is in miles, and specified in the regulations as 195,264 miles for cars and 225,865 for trucks. To calculate g/mi from Mg:

CO_2 Emissions = (Credits x 1,000,000) / (VMT x Production)

When using these equations to calculate values for cars and trucks in aggregate, use a production weighted average of the car and truck VMT values. For the 2019 model year, the industry wide weighted VMT is 212,269 miles.

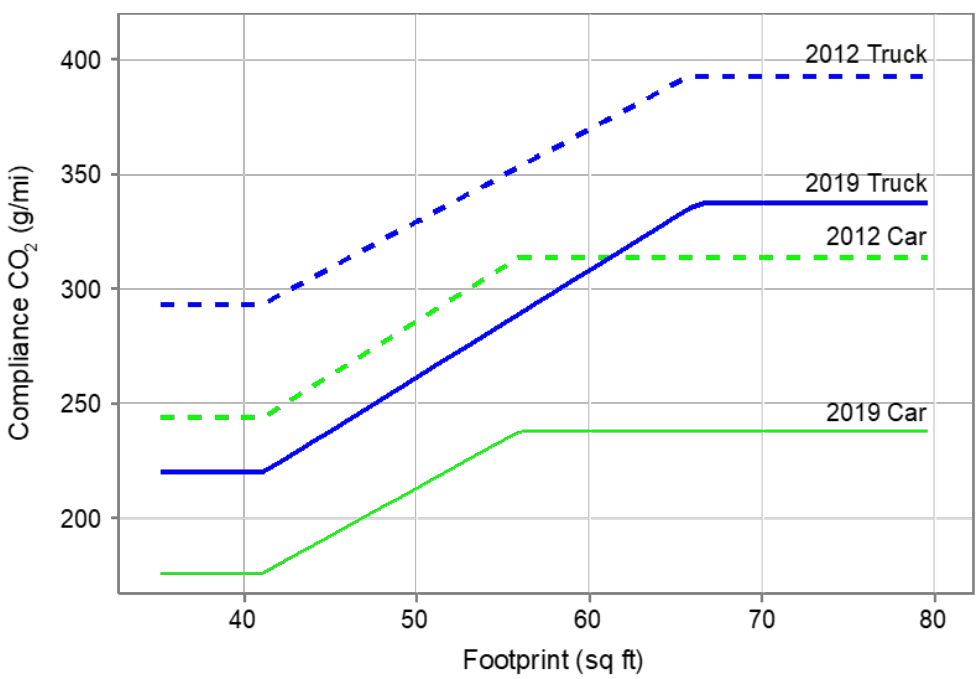
Unlike the previous sections of this report, the tailpipe CO_2 emission data presented in this section are compliance data, based on EPA's City and Highway test procedures (referred to as the "2-cycle" tests). These values should not be compared to the estimated real-world data throughout the rest of this report. For a detailed discussion of the difference between real-world and compliance data, see Appendix C. To download the data presented in this section please see the report website: https://www.epa.gov/automotive-trends.

A. Footprint-Based CO_2 Standards

At the end of each model year, manufacturers are required to calculate unique CO_2 standards for their car and truck fleets, based on the vehicles produced that model year. The GHG program uses footprint, which is the area between the four tires, as a metric for determining the specific standard for each manufacturer's car and truck and fleets. Manufacturers must calculate new standards each year as the regulations become more stringent, and as their footprint distribution and production change. See Section 3 for a discussion of footprint and vehicle production trends and the definitions of "car" and "truck" under the regulations.

The regulations define footprint "curves" that provide a CO_2 emissions target for every vehicle footprint, as shown in Figure 5.2. For example, a car with a footprint of 46.5 square feet in model year 2019 (the average car footprint) has a compliance CO_2 target of 198.1 g/mi. This is a target and not a standard, as there are no footprint-based CO_2 emissions requirements for individual vehicles at the time of certification. The unique CO_2 standards for each manufacturer's car and truck fleets are production-weighted averages of the CO_2 target values, as determined from the curves, for all the unique footprint values of the vehicles within that fleet. This is an element of the "averaging" approach of the ABT provisions. Using one production-weighted average to define a single fleet standard allows for some individual vehicles to be above that standard, while others are below.

Figure 5.2. 2012–2019 Model Year CO_2 Footprint Target Curves



The footprint curves for the 2012 and 2019 model years are shown in Figure 5.2. The targets have gradually decreased (become more stringent) from 2012 to the current 2019 levels, as defined in the regulations. Larger vehicles have higher targets, although the increases are capped beyond a certain footprint size (i.e., the curves become flat). Trucks have higher targets than cars of the same footprint in the same model year.

In addition to the footprint-based standards, EPA established several alternative standards for small to intermediate manufacturers. These provisions provide additional lead-time for manufacturers that may not be able to take full advantage of averaging or other program flexibilities due to the limited scope of the types of vehicles they sell.

The Temporary Lead-time Allowance Alternative Standards (TLAAS) provisions were available to manufacturers with production of less than 400,000 vehicles in model year 2009. This provision allowed manufacturers to place vehicles in an alternative car or truck TLAAS fleet each model year, with those vehicles subject to a less stringent standard. The standard for a TLAAS fleet was 1.25 times the standard that would have applied to that fleet based on the footprint-based approach applied to all other car and truck fleets. Each manufacturer could apply the TLAAS standards to a maximum of 100,000 vehicles, cumulative over model years 2012–2015. Mercedes, Jaguar Land Rover, Volvo, Porsche, Ferrari, Aston Martin, Lotus, and McLaren participated in the TLAAS program. The overall impact of the TLAAS program was less than 1 g/mi for all years it was available.

The intermediate volume provisions allowed intermediate volume manufacturers (those that produced less than 50,000 vehicles in the 2009 model year) to use an alternative compliance schedule in model years 2017–2020. Under these provisions, manufacturers were required to meet the model year 2016 model year standards in the model years 2017 and 2018, delay meeting the 2019–2020 standards by one model year, and finally align with the primary standards and other manufacturers in the 2021 model year. Jaguar Land Rover and Volvo are the two manufacturers utilizing these alternative compliance schedules.

Small volume manufacturers, with U.S. production of less than 5,000 vehicles per year, have additional options under the GHG program. This includes the ability to petition EPA for alternative standards for model year 2017 and later, and allowing these manufacturers to meet an established alternative model year 2017 standard in model years 2015 and 2016. Aston Martin, Ferrari, Lotus, and McLaren applied for unique alternative standards for model years 2017–2021, and EPA established alternative standards for these manufacturers in a July 2020 determination.[13] The four small volume manufacturers that

[13] 89 FR 39561, July 1, 2020.

received alternative standards in the July 2020 determination are now included in this section of the report.

Each manufacturer's standards for model year 2019 are shown in Table 5.1. In model year 2019, average car footprint was about the same as the previous year, at 46.5 square feet, and truck footprint increased from 53.9 to 54.2 square feet. The more stringent model year 2019 footprint targets, along with changes to the average truck footprint, resulted in a reduction of the car standard by 11 g/mi, from 209 g/mi to 198 g/mi, and the truck standard by 7 g/mi, from 279 g/mi to 286 g/mi. While there is no combined car and truck standard for regulatory purposes, this report will often calculate one to provide an overall view of the industry and to allow comparison across manufacturers. Overall, the effective combined car and truck standard decreased in model year 2019 by 6 g/mi, from 252 g/mi to 246 g/mi. The decrease in the overall effective standard is less than that of cars or trucks due to the market shift towards trucks, which have a higher standard.

Table 5.1. Manufacturer Footprint and Standards for Model Year 2019

	Footprint (ft^2)			Standards (g/mi)		
Manufacturer	**Car**	**Truck**	**All**	**Car**	**Truck**	**All**
Aston Martin	49.3	-	49.3	380	-	380
BMW	47.7	52.3	49.3	203	272	229
FCA	49.3	56.3	54.9	210	288	275
Ferrari	47.9	-	47.9	395	-	395
Ford	46.9	59.1	55.3	201	300	272
GM	45.9	58.3	54.2	196	295	265
Honda	45.9	50.3	47.8	196	263	227
Hyundai	46.6	49.2	46.6	199	258	200
Jaguar Land Rover	50.0	51.6	51.5	224	277	274
Kia	46.0	49.1	47.0	196	258	218
Mazda	44.9	47.7	46.3	193	251	223
McLaren	47.2	-	47.2	368	-	368
Mercedes	48.6	51.0	49.5	207	266	231
Mitsubishi	41.2	44.2	42.7	181	235	210
Nissan	46.0	52.1	48.1	196	272	225
Subaru	44.9	46.1	45.9	191	243	234
Tesla	49.8	54.8	49.9	212	284	214
Toyota	46.5	52.0	49.5	198	270	239
Volkswagen	45.3	51.2	48.2	193	267	233
Volvo	49.9	51.1	50.8	223	275	264
All Manufacturers	**46.5**	**54.2**	**50.8**	**198**	**279**	**246**

B. Model Year Performance

After determining car and truck fleet standards for the model year, manufacturers must determine the performance value for their car and truck fleets. This is the average production-weighted CO_2 tailpipe emissions of each fleet, including the impact of several optional performance credits and adjustments. These credits and adjustments allow manufacturers to benefit from technologies that reduce emissions but are not wholly captured in standard regulatory tests, provide incentives for manufacturers to adopt advanced technologies, and provide flexibility in other areas of the program. The available performance credits and adjustments include:

- Performance credits for producing alternative fuel vehicles
- Performance credits for improving air conditioning systems
- Performance credits for deploying "off-cycle" technologies that reduce emissions but are not captured on EPA's regulatory test cycles
- Adjustments for utilizing alternate methane and nitrous oxide standards

The impact of these credits and adjustments are integral to the annual model year analysis. Any performance credits generated must be included in the model year fleet calculations before a manufacturer can bank or trade credits. In addition, the performance value, including the impact of the performance credits and adjustments, is the most accurate way to compare how manufacturers' car and truck fleets are performing in comparison to the standards within a model year. The standards discussed previously were designed assuming manufacturers would use these optional provisions; therefore, any comparison that excludes them is incomplete. Manufacturer tailpipe emissions, and each of the performance credits and adjustments are examined in detail below.

Tailpipe CO_2 Emissions

The starting point for determining compliance for each manufacturer is its "2-cycle" tailpipe GHG emissions value. All manufacturers are required to test their vehicles on the Federal Test Procedure (known as the "City" test) and the Highway Fuel Economy Test (the "Highway" test). Results from these two tests are combined by weighting the City test by 55% and the Highway test by 45%, to achieve a single combined CO_2 value for each vehicle model. Manufacturers then calculate a sales-weighted average of all the combined city/highway values for each car and truck fleet. This represents the measured tailpipe CO_2 emissions of a fleet without the application of any additional performance credits. As discussed previously in this report, 2-cycle tailpipe CO_2 emissions should only be used in

the context of the compliance regulations and are not the same as and should not be compared to the estimated real-world values reported in Sections 1–4.

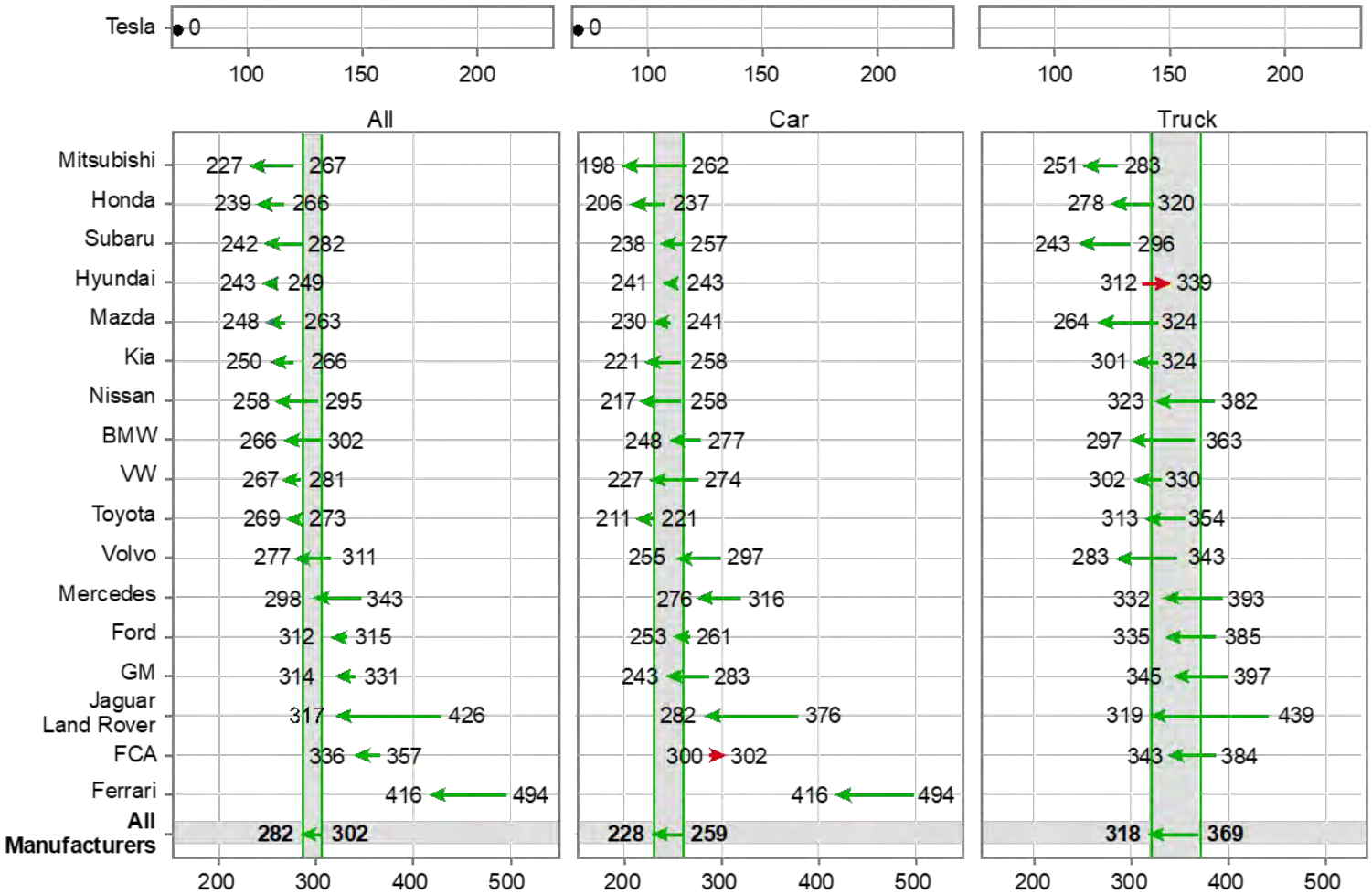
As part of the GHG program, electric vehicles and fuel cell vehicles are included in the 2-cycle tailpipe calculations with zero g/mi of tailpipe emissions. Plug-in hybrid vehicles (PHEVs) are allowed to use a zero g/mi value for the portion of operation attributed to the use of grid electricity (i.e., only emissions from the portion of operation attributed to the gasoline engine are counted). Use of the zero g/mi option was limited to the first 200,000 qualified vehicles produced by a manufacturer in the 2012–2016 model years. No manufacturer reached this limit. In the 2017–2026 model years, manufacturers may continue to use zero g/mi for these vehicles, without any limits.

Figure 5.3 shows the 2-cycle tailpipe emissions reported by each manufacturer for the 2012 and 2019 model years, for all vehicles and for car and truck fleets. Companies that produce solely electric vehicles (Tesla) are shown separately in the figure because they produce zero tailpipe emissions on the 2-cycle tests. Figure 5.3 includes all manufacturers that reported production in 2012 and 2019; there are additional manufacturers that produced vehicles in that timespan that are not shown.

Every manufacturer that has been in the U.S. market since the GHG program was implemented in 2012 has reduced fleetwide overall tailpipe GHG emissions, except for those manufacturers that only produce electric vehicles. Overall, the industry has achieved a reduction of 20 g/mi. Compliance is assessed on a fleet-specific basis, and most manufacturers have reduced emissions within their car and truck fleets, some considerably, leading to reductions of 31 and 51 g/mi in the car and truck fleets, respectively, since model year 2012. The overall reduction in tailpipe CO_2 emissions is smaller than the reduction in either the car or truck fleets because of the shifting fleet mix towards trucks.

Compared to the first year of the program, Jaguar Land Rover leads manufacturers in both the overall reduction in 2-cycle CO_2 emissions (109 g/mi) and the percentage reduction (26%). Eight manufacturers have reduced tailpipe CO_2 emissions by 10–16%, while the remainder produced single digit percentage reductions since the first year of the program. Overall, tailpipe CO_2 emissions of the entire fleet have been reduced by 20 g/mi, or about 7%, since the 2012 model year. These tailpipe values should not be directly compared to the manufacturer's standards presented in Table 5.1, as the standards were created taking into consideration the optional performance credits and adjustments available to manufacturers to reduce their performance values.

Figure 5.3. Changes in "2-Cycle" Tailpipe CO_2 Emissions, Model Year 2012 to 2019 (g/mi)



Performance Credits for Producing Alternative Fuel Vehicles

EPA's GHG program provides performance credits for dedicated and dual fuel alternative fuel vehicles. Dedicated alternative fuel vehicles run exclusively on an alternative fuel while dual fuel vehicles can run both on an alternative fuel and on conventional gasoline. This section describes two pathways for manufacturers to benefit from the production of alternative fuel vehicles. The first pathway is through a set of defined production multipliers available for certain alternative fuel vehicles. The second pathway is based on incentives for gasoline-ethanol flexible fuel vehicles (FFVs), which can run on E85 (85% ethanol and 15% gasoline), or on conventional gasoline.

Performance Credits for Advanced Technology Vehicles

The GHG program created an incentive for advanced technology vehicles through the introduction of vehicle "multipliers" for electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), fuel cell vehicles (FCVs), and compressed natural gas (CNG) vehicles. Multipliers allow manufacturers to count these vehicles as more than one vehicle in the compliance process. For example, the 2.0 multiplier for 2019 model year EVs allows a manufacturer to count every EV produced as two. The impact of the multipliers is calculated separately from the main car or truck fleet of each manufacturer, and included in this report as an advanced technology credit. The multipliers established by rulemaking are shown in Table 5.2.

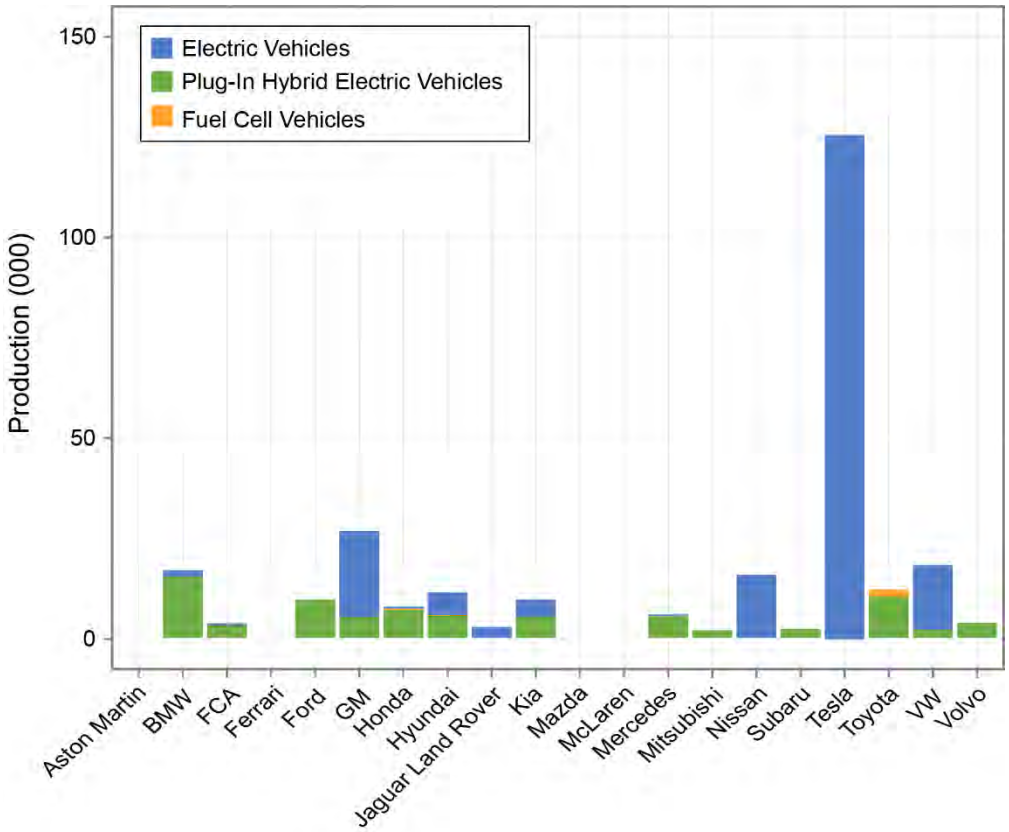
Table 5.2. Production Multipliers by Model Year

Model Year	Electric Vehicles and Fuel Cell Vehicles	Plug-In Hybrid Electric Vehicles	Dedicated and Dual-Fuel Natural Gas Vehicles
2017	2.0	1.6	1.6
2018	2.0	1.6	1.6
2019	2.0	1.6	1.6
2020	1.75	1.45	1.45
2021	1.5	1.3	1.3
2022-2026	1.0	1.0	2.0

Figure 5.4 shows the model year 2019 production volume of vehicles qualifying for multiplier incentives. More than 275,000 EVs, PHEVs, and FCVs were produced in the 2019 model year. Of those vehicles, about 70% were EVs, 29% were PHEVs, and almost 1% were FCVs. There were no CNG vehicles subject to the GHG standards in the 2019 model year,

and only a limited number of CNG vehicles in prior years. Figure 4.13 in the previous section shows the overall growth in EVs, PHEVs, and FCVs.

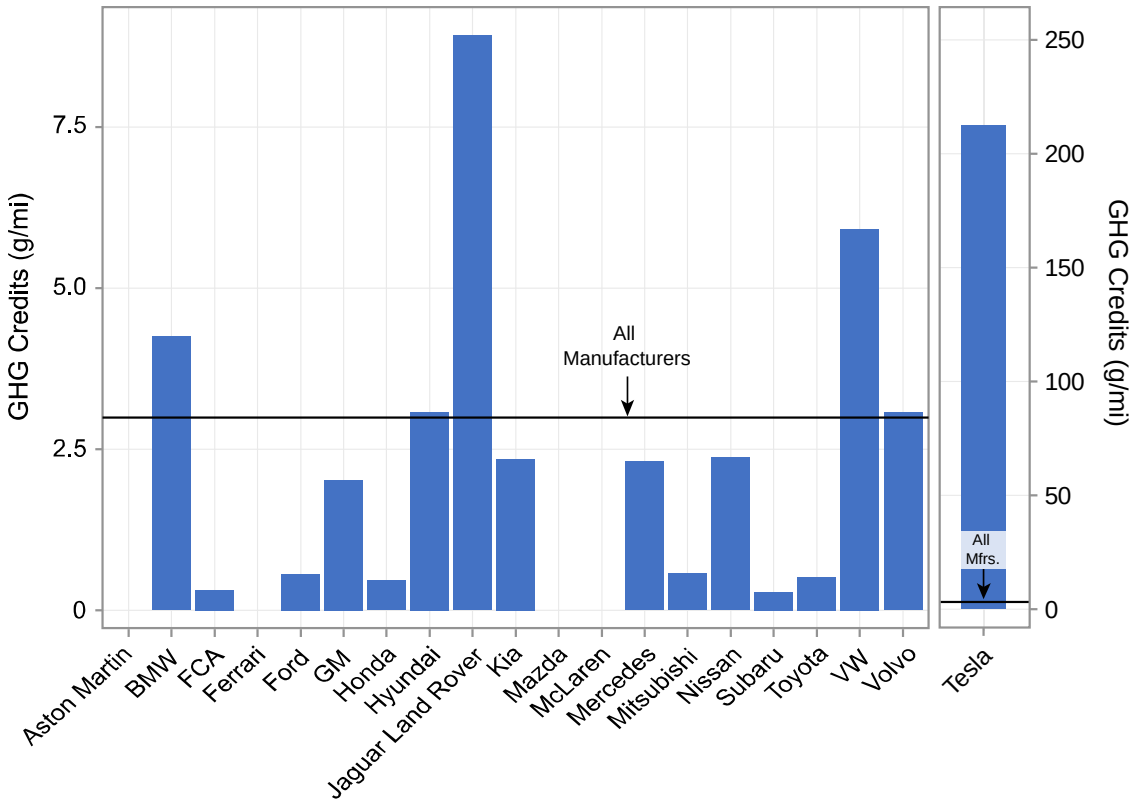
Figure 5.4. Model Year 2019 Production of EVs, PHEVs, and FCVs



The impacts of the advanced technology multiplier credit are shown in Figure 5.5. Tesla, which produces only EVs, achieved 214 g/mi of credit in model year 2019, far above any other manufacturer. The multiplier reduces Tesla's fleet performance by 214 g/mi, which in this case is the difference between their standard (214 g/mi, as shown in Table 5.1) and 2-cycle emissions (which are 0 g/mi). Tesla is shown separately in Figure 5.5 due to the scale of the credits generated by their vehicles.

After Tesla, Jaguar Land Rover had the highest g/mi effect on their fleet performance, at 8.9 g/mi. Nearly 3% of Jaguar Land Rover's production in model year 2019 was EVs, which was the highest percentage of EVs for any manufacturer other than Tesla. Volkswagen had the third highest percentage of EV production in model year 2019, at 2.1%, which reduced their fleet performance by 5.9 g/mi. BMW had the highest percentage of PHEVs, at 4.3%, resulting in a fleet performance benefit of 4.2 g/mi.

Figure 5.5. Model Year 2019 Advanced Technology Credits by Manufacturer



EPA finalized a technical amendment on March 31, 2020 that corrects the regulations pertaining to how manufacturers calculate credits for the GHG program's advanced technology incentives.[14] Manufacturers that produced vehicles eligible for these incentives have resubmitted 2-cycle data to EPA, and this report uses these updated data and calculations.

Gasoline-Ethanol Flexible Fuel Vehicles

For the 2012 to 2015 model years, FFVs could earn performance credits corresponding to the fuel economy credits under CAFE. For both programs, it was assumed that FFVs operated half of the time on each fuel. The GHG credits were based on the arithmetic average of alternative fuel and conventional fuel CO_2 emissions. Further, to fully align the GHG credit with the CAFE program, the CO_2 emissions measurement on the alternative fuel was multiplied by 0.15. The 0.15 factor was used because, under the CAFE program's implementing statutes, a gallon of alternative fuel is deemed to contain 0.15 gallons of

[14] 85 FR 22609, April 23, 2020.

gasoline fuel, and the E85 fuel economy is divided by 0.15 before being averaged with the gasoline fuel economy.

Starting in model year 2016, GHG compliance values for FFVs are based on the actual emissions performance of the FFV on each fuel, weighted by EPA's assessment of the actual use of these fuels in FFVs. In 2014, EPA issued a determination defining an "F factor" of 0.14 to use when weighting E85 and gasoline CO_2 emissions for the 2016–2018 model years FFVs; this reflects EPA's estimate that FFVs would be operating 14% of the time on E85. This approach is comparable to the "utility factor" method used to weight gasoline and electricity for PHEVs, which projects the percentage of miles that a PHEV will drive using electricity based on how many miles a fully-charged PHEV can drive using grid electricity. EPA also adopted an F-factor of 0.14 for model years 2019 and 2020, and in a separate action has recently extended the use of 0.14 to model years 2021 and later.[15] This value will continue to apply until EPA issues a new determination.

FFVs can still represent a CO_2 emissions benefit, and can help to lower the emissions of a manufacturer's fleet, but the overall impact is significantly diminished. Because the FFV values now incorporate the slightly lower CO_2 emissions when operating on E85 (typically 1–3% lower than on gasoline), and a realistic rate of E85 fuel use, the benefit from FFVs is no longer of the same magnitude that it was through the 2015 model year. Thus, we are no longer illustrating a g/mi benefit to manufacturers specific to producing FFVs. The impact of E85, a lower-GHG fuel than gasoline, is inseparable from, and built into, the 2-cycle emissions described earlier.

Most manufacturers focused their FFV production in the truck segment, with trucks making up 90% of all FFV production in the 2019 model year. FFV production continued the decline that started after model year 2014, dropping more than 20% relative to model year 2018 and reaching a low since the start of the program in model year 2012. Total FFV production in model year 2019 was down by almost 75% relative to model year 2014, the peak year for FFV production. FFV production is shown in Figure 5.6. The impact of those FFV credits is shown in Figure 5.7.

[15] "E85 Flexible Fuel Vehicle Weighting Factor for Model Years 2020 and Later Vehicles," EPA Office of Air and Radiation, CD–20–12.

Figure 5.6. Production of FFVs, Model Year 2012–2019

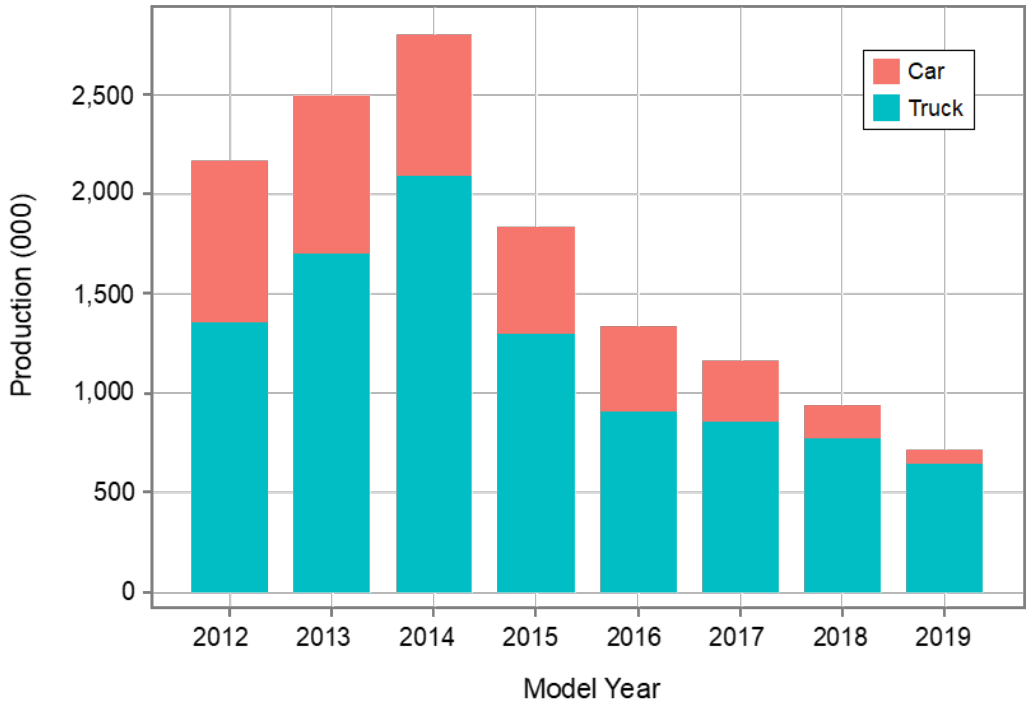
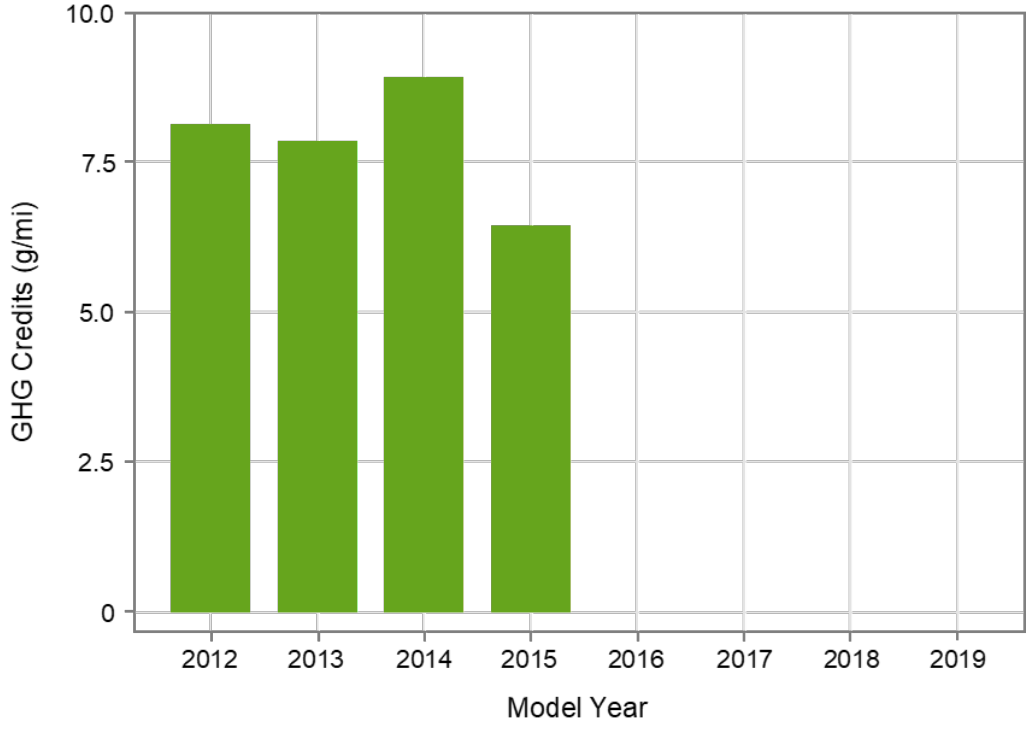


Figure 5.7. FFV Credits by Model Year



Performance Credits for Improved Air Conditioning Systems

Almost all new cars and light trucks in the United States are equipped with air conditioning (A/C) systems. There are two mechanisms by which A/C systems contribute to the emissions of greenhouse gases: through leakage of hydrofluorocarbon (HFC) refrigerants (i.e., "direct" emissions) and through the combustion of fuel to provide mechanical power to the A/C system (i.e., "indirect" emissions). The EPA 2-cycle compliance tests do not measure either A/C refrigerant leakage or the increase in tailpipe emissions attributable to the additional engine load of A/C systems. Thus, the GHG emission regulations include a provision that allows manufacturers to earn optional credits for implementing technologies that reduce either type of A/C-related emissions.

Air Conditioning Leakage Performance Credits

Refrigerants used in automotive air conditioning systems can have high global warming potentials (GWP)[16], such that leakage of a small amount of refrigerant can have a far greater impact on global warming than emissions of a similar mass of CO_2. The impacts of refrigerant leakage can be reduced significantly by using systems with leak-tight components, by using a refrigerant with a lower GWP, or by implementing both approaches.

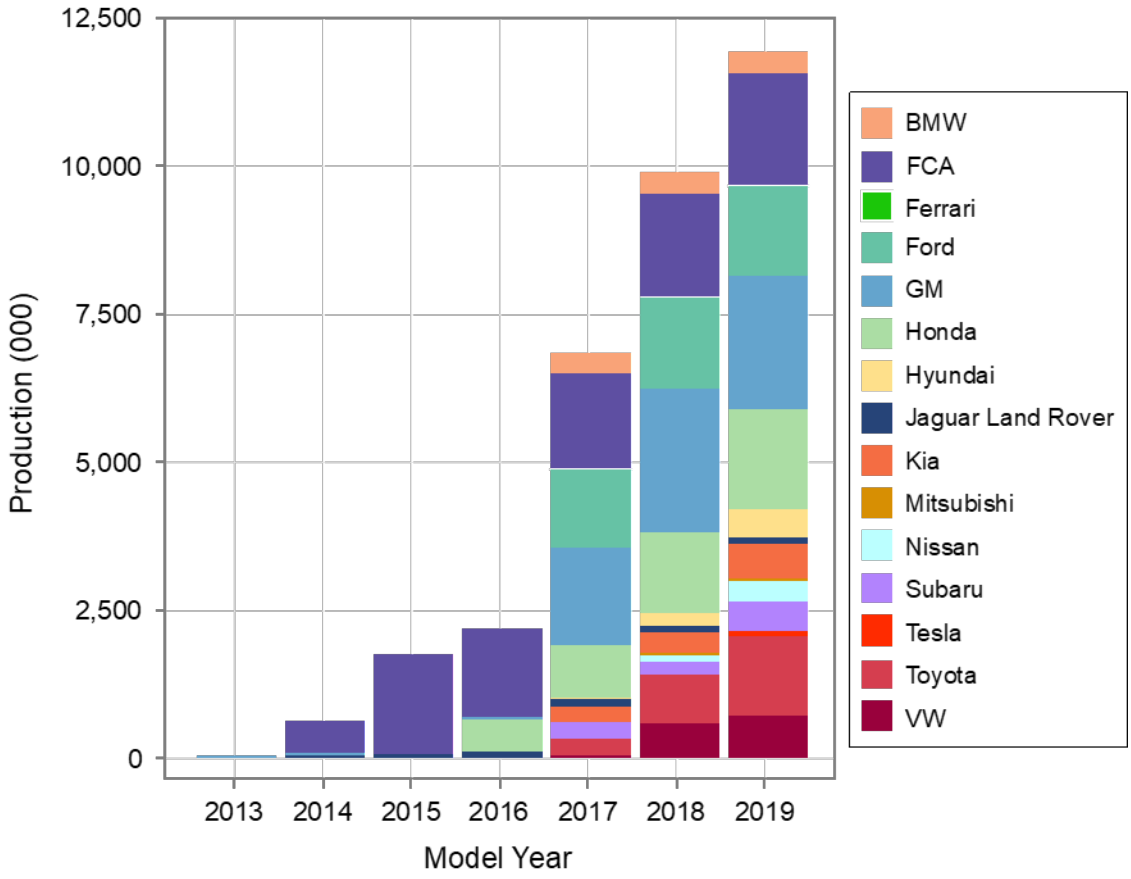
A manufacturer choosing to generate A/C leakage credits is required to calculate a leakage "score" for the specific A/C system. This score is based on the number, performance, and technology of the components, fittings, seals, and hoses of the A/C system and is calculated as refrigerant emissions in grams per year, using the procedures specified by the SAE Surface Vehicle Standard J2727. The score is then converted to a g/mi credit value based on the GWP of the refrigerant. In model year 2012, all leakage credits were based on improvements to the A/C system components (e.g., O-rings, seals, valves, and fittings).

In model year 2013, GM and Honda introduced vehicles using a refrigerant with a significantly reduced GWP. This new refrigerant, HFC-1234yf, has a GWP of 4, compared to a GWP of 1430 for the predominant refrigerant at the time, HFC-134a. In the six model years since, low GWP refrigerant use has expanded to fifteen manufacturers and more than 70% of the fleet. Five manufacturers have implemented HFO-1234yf across almost their entire fleets, with eight additional manufacturers exceeding at least 50% adoption of HFO-1234yf. The growth in usage of HFO-1234yf is illustrated in Figure 5.8. Nineteen

[16] The global warming potential (GWP) represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of CO_2. The GWP of CO_2 is 1.0.

manufacturers reported some type of A/C leakage credits in the 2019 model year, resulting in an overall performance credit of 12.7 g/mi for the industry.

Figure 5.8. HFO-1234yf Adoption by Manufacturer



Air Conditioning Efficiency Performance Credits

The A/C system also contributes to increased tailpipe CO_2 emissions through the additional work required by the engine to operate the compressor, fans, and blowers. This power demand is ultimately met by using additional fuel, which is converted into CO_2 by the engine during combustion and exhausted through the tailpipe. Increasing the overall efficiency of an A/C system reduces the additional load on the engine from A/C operation, and thereby leads to a reduction in fuel consumption and a commensurate reduction in GHG emissions.

Most of the additional load on the engine from A/C systems comes from the compressor, which pressurizes the refrigerant and pumps it around the system loop. A significant additional load may also come from electric or hydraulic fans, which move air across the

condenser, and from the electric blower, which moves air across the evaporator and into the cabin. Manufacturers have several options for improving efficiency, including more efficient compressors, fans, and motors, and system controls that avoid over-chilling the air (and subsequently re-heating it to provide the desired air temperature). For vehicles equipped with automatic climate-control systems, real-time adjustment of several aspects of the overall system can result in improved efficiency.

The regulations provide manufacturers with a "menu" of A/C system technologies and associated credit values (in g/mi of CO_2), some of which are described above. These credits are capped at 5.7 g/mi for all vehicles in the 2012–2016 model years, and at 5.0 and 7.2 g/mi for cars and trucks, respectively, in the 2017 and later model years. Seventeen manufacturers reported A/C efficiency credits in 2019, resulting in 5.2 g/mi for the industry.

Air Conditioning Performance Credit Summary

A summary of the A/C leakage and efficiency performance credits reported by the industry is shown in Figure 5.9. Leakage credits have been more prevalent than efficiency credits, but both credit types are growing in use. Figure 5.10 shows the benefit of A/C credits, for each manufacturer's fleet for the 2019 model year. Nineteen manufacturers used the A/C credit provisions—leakage reductions, efficiency improvements, or both—as part of their compliance demonstration in the 2019 model year. Jaguar Land Rover had the highest reported credit on a per vehicle g/mi basis, at 24 g/mi. Thus, A/C credits are the equivalent of about an 8% reduction from tailpipe emissions for Jaguar Land Rover. More than half of all manufacturers reported total A/C credits of 15 g/mi or more. The overall industry reported an average of 18.0 g/mi of total A/C credits.

Performance Credits for "Off-Cycle" Technology

In some cases, manufacturers employ technologies that result in CO_2 emission reductions that are not adequately captured on the 2-cycle test procedures. These benefits are acknowledged in EPA's regulations by giving manufacturers three pathways by which to accrue "off-cycle" performance credits. The first, and most widely used, pathway is a predetermined list or "menu" of credit values for specific off-cycle technologies. The second pathway is to use a broader array of emissions testing (5-cycle testing) to demonstrate the CO_2 emission reduction. The third pathway allows manufacturers to seek EPA approval to use an alternative methodology to demonstrate CO_2 emission reductions.

Figure 5.9. Fleetwide A/C Credits by Credit Type

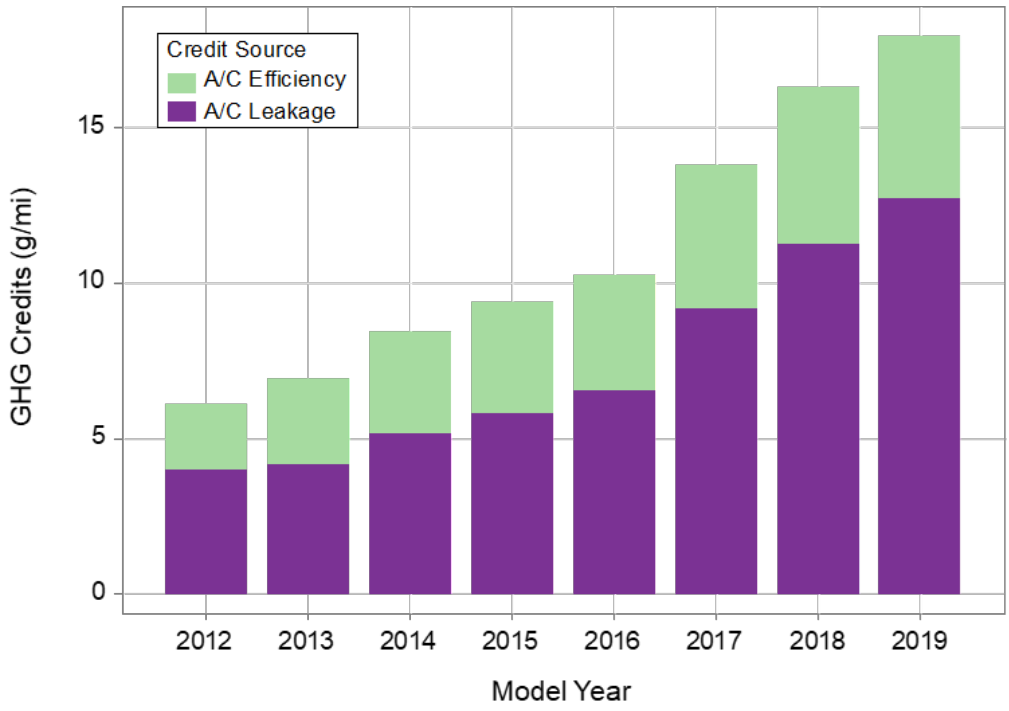
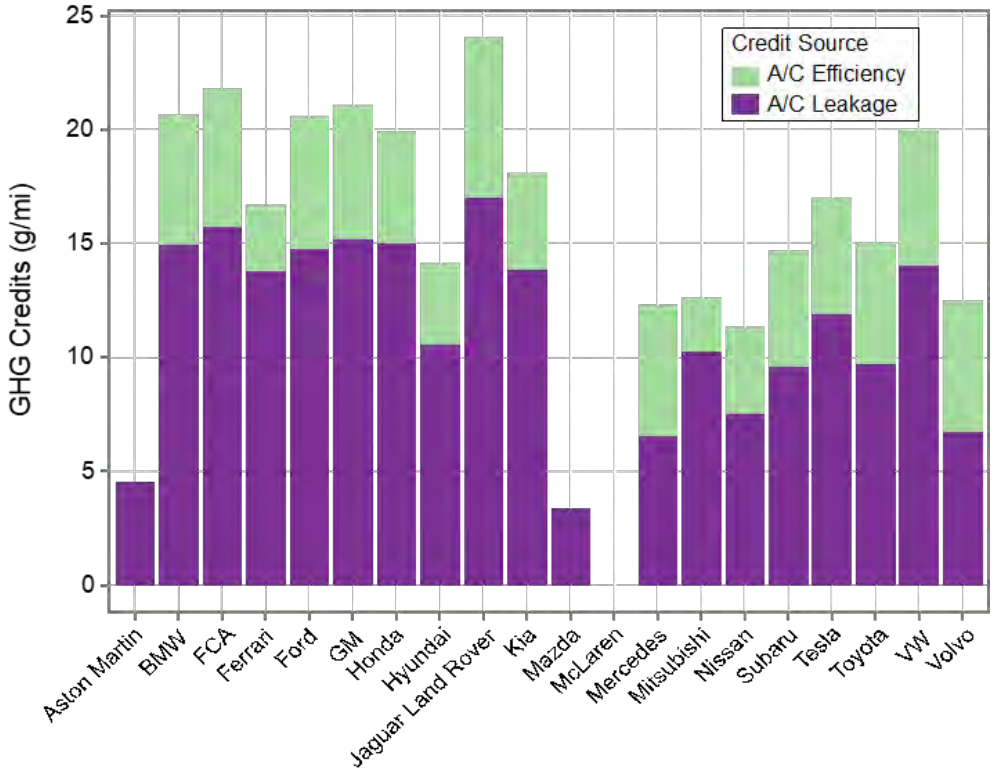


Figure 5.10. Total A/C Credits by Manufacturer for Model Year 2019



Off Cycle Performance Credits Based on the Menu

The first pathway to generating off-cycle credits is for a manufacturer to install technologies from a predetermined list or "menu" of technologies preapproved by EPA. The off-cycle credit menu provides specific credit values, or the calculation method for such values, for each technology.[17] Technologies from the menu may be used beginning in model year 2014. This pathway allows manufacturers to use conservative credit values established by EPA for a wide range of off-cycle technologies, with minimal data submittal or testing requirements.

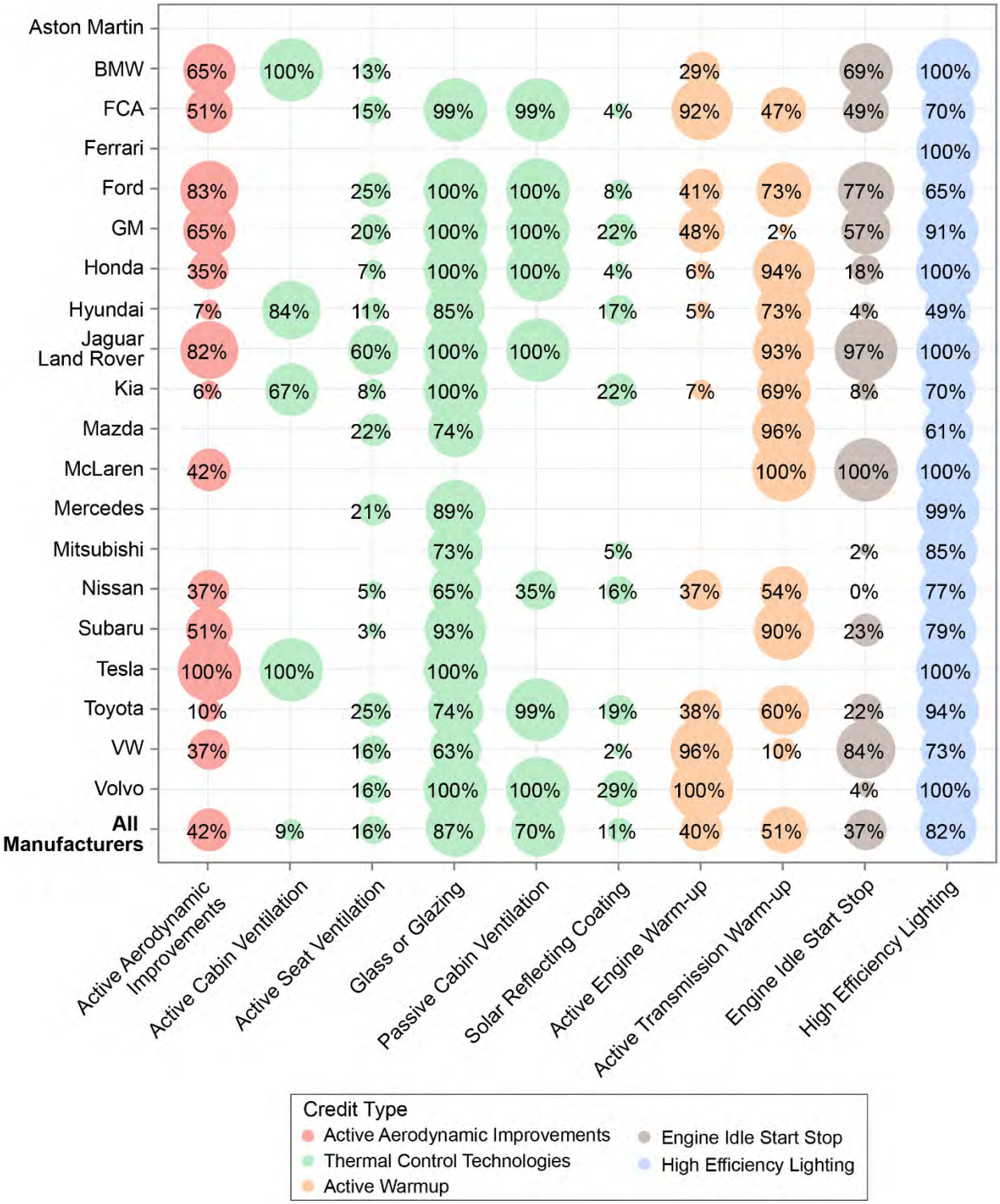
The regulations clearly define each technology and any requirements that apply for the technology to generate credits. Figure 5.11 shows the adoption of menu technologies, by manufacturer. The amount of credit awarded varies for each technology and between cars and trucks. The impact of credits from this pathway on a manufacturer's fleet is capped at 10 g/mi, meaning that any single vehicle might accumulate more than 10 g/mi, but the cumulative effect on a single manufacturer's fleet may not exceed a credit of more than 10 g/mi. Off-cycle technology credits based on the menu were widely used in model year 2019, with more than 90% of off-cycle credits generated via the menu pathway. Each of these technologies is discussed below.

Active Aerodynamics

Active aerodynamics refers to technologies which are automatically activated to improve the aerodynamics of a vehicle under certain conditions. These include grill shutters and spoilers, which allow air to flow over and around the vehicle more efficiently, and suspension systems that improve air flow at higher speeds by reducing the height of the vehicle. Credits are variable and based on the measured improvement in the coefficient of drag, a test metric that reflects the efficiency of airflow around a vehicle. Most manufacturers implemented at least some level of active aerodynamics on their model year 2019 vehicles. Tesla reported the highest implementation, at 100% of all new vehicles. Overall, 45% of new vehicles qualified for these credits, reducing overall fleet CO_2 emissions by 0.4 g/mi.

[17] See 40 CFR 86.1869-12(b).

Figure 5.11. Off-Cycle Menu Technology Adoption by Manufacturer, Model Year 2019



Thermal Control Technologies

Thermal control systems help to maintain a comfortable air temperature of the vehicle interior, without the use of the A/C system. These technologies lower the load on the A/C system and thus the amount of fuel required to run the A/C system, subsequently lowering GHG tailpipe emissions. The thermal control technologies included in the off-cycle menu are:

- Active and passive cabin ventilation – Active systems use mechanical means to vent the interior, while passive systems rely on ventilation through convective air flow. Credits available for this technology range from 1.7 to 2.8 g/mi.
- Active seat ventilation – These systems move air through the seating surface, transferring heat away from the vehicle occupants. Credits are 1.0 g/mi for cars and 1.3 g/mi for trucks.
- Glass or glazing – Credits are available for glass or glazing technologies that reduce the total solar transmittance through the glass, thus reducing the heat from the sun that reaches the occupants. The credits are calculated based on the measured solar transmittance through the glass and on the total area of glass on the vehicle.
- Solar reflective surface coating – Credits are available for solar reflective surface coating (e.g., paint) that reflects at least 65% of the infrared solar energy. Credits are 0.4 g/mi for cars and 0.5 g/mi for trucks.

Active cabin ventilation was installed on 9% of all new vehicles in model year 2019, with high rates of installation from Tesla, Hyundai, Kia, and BMW. No other manufacturers used active cabin ventilation technologies in model year 2019. Passive cabin ventilation technologies, however, were used much more widely, with seven manufacturers at or near 100% implementation, and a 70% adoption rate overall.

Active seat ventilation was used by many manufacturers and the rate of implementation remained about the same at 16% in model year 2019. Jaguar Land Rover was the leader in adopting active seat ventilation, with implementation on about 60% of their vehicles. As was the case in the previous model year, there was significant penetration of glass or glazing technology with more than 85% of the model year 2019 vehicles equipped with glass or glazing technologies. Solar reflective coatings have been used less widely, with a penetration of 11% across new vehicles in model year 2019, and no manufacturer above 30%.

Due to the likelihood of synergistic effects among the various thermal technologies, the total credit allowed from this technology group is capped at 3.0 g/mi for cars and 4.3 g/mi for trucks. Overall, about 94% of new vehicles in model year 2019 received credits from at least one of the thermal control technologies, which reduces overall fleet CO_2 emissions by 2.7 g/mi

Active Engine and Transmission Warmup

Active engine and transmission warmup systems use heat from the vehicle that would typically be wasted (exhaust heat, for example) to warm up key elements of the engine, allowing a faster transition to more efficient operation. An engine or transmission at its optimal operating temperature minimizes internal friction, and thus operates more efficiently and reduces tailpipe CO_2 emissions. Systems that use a single heat-exchanging loop that serves both transmission and engine warmup functions are eligible for either engine or transmission warmup credits, but not both. Active engine and transmission warmup technologies are each worth credit up to 1.5 g/mi for cars and 3.2 g/mi for trucks.

Most manufacturers adopted warmup technologies for their engines, transmissions, or both. Active engine warmup was installed in about 40% of all new vehicles, and active transmission warmup in 51% of the fleet, resulting in a CO_2 reduction of about 2.2 g/mi across the 2019 model year fleet. FCA, Volkswagen, and Volvo led the industry in active engine warmup, with nearly all their new vehicles employing the technology. Mazda, Honda, Subaru, Jaguar Land Rover, and McLaren led the industry in active transmission warmup technologies, with nearly all their new vehicles utilizing these technologies.

Engine Idle Stop/Start

Engine idle stop/start systems allow the engine to turn off when the vehicle is at a stop, automatically restarting the engine when the driver releases the brake and/or applies pressure to the accelerator. If equipped with a switch to disable the system, EPA must determine that the predominant operating mode of the system is the “on” setting (defaulting to “on” every time the key is turned on is one basis for such a determination). Thus, some vehicles with these systems are not eligible for credits. Credits range from 1.5 to 4.4 g/mi and depend on whether the system is equipped with an additional technology that, at low ambient temperatures, allows heat to continue to be circulated to the vehicle occupants when the engine is off during a stop-start event.

The implementation of stop/start has been increasing rapidly, as discussed in Section 4, which aggregates and reports on these systems regardless of the regulatory eligibility for credits. In model year 2019, 37% of new vehicles qualified for and claimed this credit,

resulting in a fleetwide CO_2 reduction of about 1.4 g/mi. Jaguar Land Rover and McLaren claimed start/stop credits on nearly 100% of their vehicles in model year 2019, with Volkswagen and Ford both installing stop/start systems on more than 75% of their new vehicles.

High Efficiency Exterior Lights

High efficiency lights (e.g., LEDs) reduce the total electric demand, and thus the fuel consumption and related GHG emissions, of a lighting system in comparison to conventional incandescent lighting. Credits are based on the specific lighting locations, ranging from 0.06 g/mi for turn signals and parking lights to 0.38 g/mi for low beams. The total of all lighting credits summed from all lighting locations may not exceed 1.0 g/mi.

Unlike some other off-cycle technologies, safety regulations require that all vehicles must be equipped with lights, and the popularity of high efficiency lights across manufacturers may reflect that lighting improvements are relatively straightforward to implement. All manufacturers reporting off-cycle credits indicated implementation on at least half of their fleet (except for Aston Martin), with many manufacturers at or approaching 100% implementation. More than 80% of new vehicles used high efficiency lighting in some form in model year 2019, reducing fleetwide CO_2 emissions by 0.4 g/mi.

Solar Panels

Vehicles that use batteries for propulsion, such as electric, plug-in hybrid electric, and hybrid vehicles may receive credits for solar panels that are used to charge the battery directly or to provide power directly to essential vehicle systems (e.g., heating and cooling systems). Credits are based on the rated power of the solar panels. Nissan claimed this credit in model year 2017 for a very small number of vehicles, but no manufacturer claimed use of solar panels in model year 2019.

Summary of Off-Cycle Menu-Based Performance Credits

As shown in Table 5.3, manufacturers are using a mix of off-cycle menu technologies, though each uses and benefits from the individual technologies to differing degrees. In model year 2019, the industry achieved 6.9 g/mi of credits from the menu, based on a production weighted average of credits across all manufacturers. FCA, Ford, and Jaguar Land Rover reached the 10 g/mi cap in 2019. For those manufacturers, the sum of the credits from individual technologies in Table 5.3 will exceed the total allowable credits, and only the 10 g/mi value will be used in subsequent calculations.

Table 5.3. Model Year 2019 Off-Cycle Technology Credits from the Menu, by Manufacturer and Technology (g/mi)

Manufacturer	Active Aero-dynamics	Active Engine Warmup	Active Trans Warmup	Thermal Controls	Engine Start-Stop	High Efficiency Lighting	Total Menu Credits
Aston Martin	-	-	-	-	-	-	-
BMW	1.2	0.8	-	2.5	2.0	0.9	7.4
FCA	0.4	2.7	1.5	3.8	2.1	0.2	10.0
Ferrari	-	-	-	-	-	0.7	0.7
Ford	1.1	1.1	2.1	3.3	3.1	0.2	10.0
GM	0.7	1.2	0.0	3.7	2.2	0.5	8.4
Honda	0.1	0.1	2.2	2.9	0.7	0.4	6.4
Hyundai	0.1	0.1	1.1	0.8	0.1	0.1	2.3
Jaguar Land Rover	0.6	-	2.9	3.8	4.1	0.4	10.0
Kia	0.0	0.1	1.6	1.0	0.2	0.1	3.1
Mazda	-	-	2.3	1.0	-	0.1	3.5
McLaren	0.4	-	1.5	-	1.5	0.9	4.3
Mercedes	-	-	-	1.1	-	0.9	1.9
Mitsubishi	-	-	-	0.8	0.0	0.3	1.1
Nissan	0.2	0.7	1.1	1.1	0.0	0.3	3.5
Subaru	0.2	-	2.7	1.1	0.7	0.4	5.1
Tesla	1.1	-	-	3.0	-	0.7	4.7
Toyota	0.1	0.2	1.4	3.4	0.9	0.4	6.4
VW	0.2	2.3	0.3	0.7	2.8	0.5	6.8
Volvo	-	2.8	-	3.6	0.2	1.0	7.6
All Manufacturers	**0.4**	**0.9**	**1.3**	**2.7**	**1.4**	**0.4**	**6.9**

Off-Cycle Performance Credits Based on 5-Cycle Testing

In cases where additional laboratory testing can demonstrate emission benefits, a second pathway allows manufacturers to use a broader array of emission tests (known as "5-cycle" testing because the methodology uses five different testing procedures) to demonstrate and justify off-cycle CO_2 credits.[18] The additional emission tests allow emission benefits to be demonstrated over elements of real-world driving not captured by the GHG compliance tests, including high speeds, rapid accelerations, and cold temperatures. Credits determined according to this methodology do not undergo additional public review.

GM is the only manufacturer to date to have claimed off-cycle credits based on 5-cycle testing. These credits are for an auxiliary electric pump used on certain GM gasoline-electric hybrid vehicles to keep engine coolant circulating in cold weather while the vehicle

[18] See 40 CFR 86.1869-12(c).

is stopped and the engine is off. This enables the engine stop-start system to turn off the engine more often during cold weather, while maintaining a comfortable temperature inside the vehicle. GM received off-cycle credits during the early credits program for equipping hybrid full size pick-up trucks with this technology and has since applied the technology to several other vehicles through model year 2017. They did not claim credits for this technology in model year 2019.

Off-Cycle Performance Credits Based on an Alternative Methodology

This third pathway for off-cycle technology performance credits allows manufacturers to seek EPA approval to use an alternative methodology for determining off-cycle technology CO_2 credits.[19] This option is only available if the benefit of the technology cannot be adequately demonstrated using the 5-cycle methodology. Manufacturers may also use this option for model years prior to 2014 to demonstrate CO_2 reductions for technologies that are on the off-cycle menu, or reductions that exceed those available via use of the menu. The regulations require that EPA seek public comment on and publish each manufacturer's application for credits sought using this pathway. About half of the manufacturers have petitioned for and been granted credits using this pathway in the 2019 model year.[20]

In the fall of 2013, Mercedes requested off-cycle credits for the following off-cycle technologies in use or planned for implementation in the 2012–2016 model years: stop-start systems, high-efficiency lighting, infrared glass glazing, and active seat ventilation. EPA approved methodologies for Mercedes to determine these off-cycle credits in September 2014. Subsequently, FCA, Ford, and GM requested off-cycle credits under this pathway, which EPA approved in September 2015. FCA and Ford submitted applications for off-cycle credits from high efficiency exterior lighting, solar reflective glass/glazing, solar reflective paint, and active seat ventilation. Ford's application also demonstrated off-cycle benefits from active aerodynamic improvements (grill shutters), active transmission warm-up, active engine warm-up technologies, and engine idle stop-start. GM's application described the real-world benefits of an A/C compressor made by Denso with variable crankcase suction valve technology. EPA approved the credits for FCA, Ford, and GM in September of 2015. EPA approved additional credits under this pathway for the Denso compressor in 2017 for BMW, Ford, GM, Hyundai, Toyota, and Volkswagen.

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[19] See 40 CFR 86.1869-12(d).

[20] EPA maintains a web page on which we publish the manufacturers' applications for these credits, the relevant Federal Register notices, and the EPA decision documents. See https://www.epa.gov/vehicle-and-engine-certification/compliance-information-light-duty-greenhouse-gas-ghg-standards.

In December 2016, EPA approved a methodology for determining credits from high-efficiency alternators that Ford had applied for in 2016. EPA subsequently approved high-efficiency alternator credits also for FCA, GM, and Toyota. High efficiency alternators use new technologies that reduce the overall load on the engine while continuing to meet the electrical demands of the vehicle systems, resulting in lower fuel consumption and lower CO_2 emissions.

In September of 2017 GM applied for credits under this pathway for "active climate-controlled seats," which provide cooled air directly to the occupants through the seats, thus reducing the overall load on the air conditioning system. GM reported credits for this technology in the 2018 and 2019 model year. The most recent addition to the list of technologies receiving credits through the alternative methodology pathway came in October 2019 with the approval of a pulse width modulated brushless motor power controller. This "brushless motor" technology is used to improve the efficiency of the HVAC system. Toyota applied for and received the brushless motor credit for the 2013 through 2019 model years.

Most of the approved credits have been for previous model years, and thus are not included in the detailed reporting for the 2019 model year in this section. Credit balances have been updated to include retroactive credits that have been reported to EPA, and any relevant tables that include data from previous model years will reflect the addition of these credits. Table 5.4 shows the impact of the credits submitted for brushless motors, improved air conditioning systems, high-efficiency alternators, and active climate-controlled seats. On a total fleetwide basis, the aggregated credit is 0.6 g/mi.

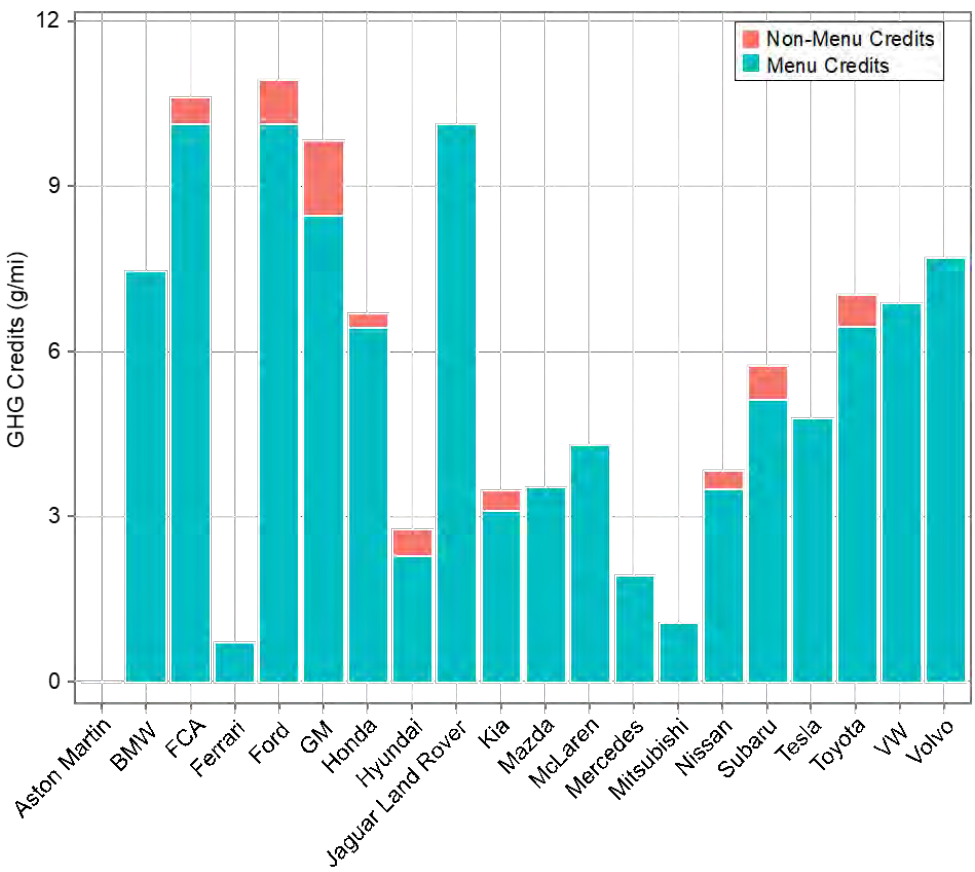
Table 5.4. Model Year 2019 Off-Cycle Technology Credits from an Alternative Methodology, by Manufacturer and Technology (g/mi)

Manufacturer	Brushless Motors	Improved A/C Systems	High-Efficiency Alternator	Active Climate Control Seats	Total Alternative Methodology Credits
FCA	-	-	0.5	-	0.5
Ford	-	0.2	0.6	-	0.8
GM	-	0.6	0.7	0.0	1.3
Honda	-	-	0.3	-	0.3
Hyundai	-	-	0.5	-	0.5
Kia	-	-	0.4	-	0.4
Nissan	-	0.1	0.2	-	0.3
Subaru	0.0	-	0.6	-	0.6
Toyota	0.1	0.1	0.3	-	0.6
All Manufacturers	**0.0**	**0.2**	**0.4**	**0.0**	**0.6**

Off-Cycle Performance Credit Summary

In total, the industry achieved 7.5 g/mi of off-cycle performance credits in model year 2019. More than 90% of those credits were claimed using technologies, and credit definitions, on the off-cycle menu. The remaining credits were due almost entirely to manufacturer submitted alternative methodologies. Figure 5.12 shows the average credit, in g/mi, that each manufacturer achieved in model year 2019. Ford led the way with the highest gram per mile benefit from off-cycle credits, followed closely by FCA, Jaguar Land Rover, and GM. Most manufacturers achieved at least some off-cycle credits; Aston Martin was the only manufacturer to not report any off-cycle credits for model year 2019.

Figure 5.12. Total Off-Cycle Credits by Manufacturer for Model Year 2019



Alternative Standards for Methane and Nitrous Oxide

As part of the GHG Program, EPA set emission standards for methane (CH_4) and nitrous oxide (N_2O) at 0.030 g/mi for CH_4 and 0.010 g/mi for N_2O. Current levels of CH_4 and N_2O emissions are generally well below these established standards, however the caps were set to prevent future increases in emissions.

There are three different ways for a manufacturer to demonstrate compliance with these standards. First, manufacturers may submit test data as they do for all other non-GHG emission standards; this option is used by most manufacturers. Because there are no credits or deficits involved with this approach, and there are no consequences with respect to the CO_2 fleet average calculation, the manufacturers are not required to submit this data as part of their GHG reporting. Hence, this GHG compliance report does not include information from manufacturers using this option.

The second option for manufacturers is to include CH_4 and N_2O, on a CO_2-equivalent basis, when calculating their fleet average performance values, in lieu of demonstrating compliance with the regulatory caps. This method directly accounts for CH_4 and N_2O, increasing the performance value of a manufacturer's fleets, while the standards remain unchanged. Analyses of emissions data have shown that use of this option may add approximately 3 g/mi to a manufacturer's fleet average. Only Subaru chose to use this approach in the 2019 model year.

The third option for complying with the CH_4 and N_2O standards allows manufacturers to propose an alternative, less stringent CH_4 and/or N_2O standard for any vehicle that may have difficulty meeting the specific standards. However, manufacturers that use this approach must also calculate the increased emissions due to the less stringent standards and the production volumes of the vehicles to which those standards apply, and then add that impact from their overall fleet performance. Nine manufacturers made use of the flexibility offered by this approach in the 2019 model year. In aggregate, the impact of this approach was an increase in the industry-wide performance of about 0.1 g/mi.[21]

Summary of Manufacturer Performance

Each of the performance credits and adjustments described here have been used by manufacturers as part of their compliance strategies under the GHG program. As described above, the availability of these provisions, and the magnitude of their impact, has varied both by manufacturer and model year. Table 5.5 through Table 5.10 below detail the impact of these provisions by manufacturer for model year 2019, and for the aggregated industry over the course of the GHG Program. The performance values in these tables can be derived by subtracting the credits and adjustment from the 2-Cycle Tailpipe value.

[21] The impact of the alternative standards for methane and nitrous oxide is based on data submitted to EPA prior to October 31, 2020. These submissions remain under review by EPA.

Table 5.5. Manufacturer Performance in Model Year 2019, All (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	
Aston Martin	347	-	-	4.5	-	-	342
BMW	266	4.2	-	20.6	7.4	-	234
FCA	336	0.3	-	21.8	10.5	-0.0	303
Ferrari	416	-	-	16.7	0.7	-	399
Ford	312	0.6	-	20.6	10.8	-0.3	280
GM	314	2.0	-	21.0	9.7	-0.1	282
Honda	239	0.5	-	19.9	6.6	-	212
Hyundai	243	3.1	-	14.2	2.7	-0.1	223
Jaguar Land Rover	317	8.9	-	24.0	10.0	-	274
Kia	250	2.4	-	18.1	3.4	-0.1	226
Mazda	248	-	-	3.4	3.5	-1.0	242
McLaren	393	-	-	-	4.3	-	389
Mercedes	298	2.3	-	12.3	1.9	-	282
Mitsubishi	227	0.6	-	12.6	1.1	-	212
Nissan	258	2.4	-	11.3	3.8	-0.0	241
Subaru	242	0.3	-	14.7	5.7	-	222
Tesla	0	214.0	-	17.0	4.7	-	-236
Toyota	269	0.5	-	15.1	6.9	-0.1	247
VW	267	5.9	-	20.0	6.8	-0.0	235
Volvo	277	3.1	-	12.5	7.6	-	254
All Manufacturers	**282**	**3.0**	**-**	**18.0**	**7.5**	**-0.1**	**253**

Table 5.6. Industry Performance by Model Year, All (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	
2012	302	-	8.1	6.1	1.0	-0.2	287
2013	294	-	7.8	6.9	1.1	-0.3	278
2014	294	-	8.9	8.5	3.3	-0.2	273
2015	286	-	6.4	9.4	3.4	-0.2	267
2016	285	-	-	10.3	3.6	-0.1	271
2017	284	2.2	-	13.8	5.4	-0.2	262
2018	280	3.7	-	16.3	6.8	-0.1	253
2019	282	3.0	-	18.0	7.5	-0.1	253

Table 5.7. Manufacturer Performance in Model Year 2019, Car (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	
Aston Martin	347	-	-	4.5	-		342
BMW	248	6.8	-	18.6	5.2	-	218
FCA	302	0.3	-	18.4	5.6	-0.0	278
Ferrari	416	-	-	16.7	0.7	-	399
Ford	253	2.0	-	16.5	6.3	-0.2	228
GM	243	6.8	-	15.8	6.7	-0.0	214
Honda	206	0.9	-	16.9	4.3	-	184
Hyundai	241	3.1	-	14.3	2.7	-0.1	221
Jaguar Land Rover	282	-	-	18.7	6.0	-	257
Kia	221	3.7	-	16.6	2.5	-0.2	198
Mazda	230	-	-	1.8	2.0	-0.2	226
McLaren	393	-	-	-	4.3	-	389
Mercedes	276	0.6	-	11.1	1.6	-	263
Mitsubishi	198	1.2	-	5.9	0.6	-	190
Nissan	217	3.9	-	11.6	2.7	-0.0	199
Subaru	238	-	-	5.7	2.2	-	230
Tesla	0	211.9	-	16.9	4.6	-	-233
Toyota	211	1.2	-	14.1	5.1	-0.1	191
VW	227	3.3	-	17.9	3.7	-0.0	202
Volvo	255	2.1	-	9.7	4.9	-	238
All Manufacturers	**228**	**6.3**	**-**	**14.8**	**4.3**	**-0.1**	**203**

Table 5.8. Industry Performance by Model Year, Car (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	
2012	259	-	4.0	5.4	0.6	-0.1	249
2013	251	-	4.0	6.3	0.7	-0.3	240
2014	250	-	4.6	7.5	2.2	-0.3	236
2015	243	-	3.1	8.1	2.3	-0.1	230
2016	240	-	-	8.8	2.3	-0.1	229
2017	235	4.3	-	10.2	3.4	-0.0	217
2018	228	7.6	-	13.0	4.0	-0.0	204
2019	228	6.3	-	14.8	4.3	-0.1	203

Table 5.9. Manufacturer Performance in Model Year 2019, Truck (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	
Aston Martin	-	-	-	-	-	-	-
BMW	297	-	-	24.1	11.1	-	262
FCA	343	0.3	-	22.5	11.5	-0.1	309
Ferrari	-	-	-	-	-	-	-
Ford	335	-	-	22.2	12.6	-0.4	301
GM	345	-	-	23.3	11.0	-0.1	311
Honda	278	-	-	23.5	9.4	-	245
Hyundai	339	-	-	6.9	5.8	-	326
Jaguar Land Rover	319	9.5	-	24.4	10.3	-	275
Kia	301	-	-	20.6	5.1	-	275
Mazda	264	-	-	4.8	4.9	-1.9	256
McLaren	-	-	-	-	-	-	-
Mercedes	332	4.9	-	14.2	2.4	-	310
Mitsubishi	251	-	-	18.3	1.4	-	231
Nissan	323	-	-	10.9	5.6	-	307
Subaru	243	0.4	-	16.5	6.4	-	220
Tesla	0	284.2	-	20.5	8.3	-	-313
Toyota	313	-	-	15.9	8.4	-0.1	289
VW	302	8.2	-	21.7	9.5	-0.0	263
Volvo	283	3.3	-	13.3	8.3	-	258
All Manufacturers	**318**	**0.7**	**-**	**20.2**	**9.7**	**-0.1**	**288**

Table 5.10. Industry Performance by Model Year, Truck (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	
2012	369	-	14.5	7.3	1.6	-0.3	346
2013	360	-	13.8	7.9	1.7	-0.3	337
2014	349	-	14.3	9.7	4.6	-0.1	321
2015	336	-	10.3	11.0	4.6	-0.2	310
2016	332	-	-	11.8	5.1	-0.2	316
2017	330	0.2	-	17.3	7.4	-0.3	305
2018	320	0.6	-	19.0	9.0	-0.2	292
2019	318	0.7	-	20.2	9.7	-0.1	288

C. GHG Program Credits and Deficits

The previous two sections outlined how to determine manufacturer standards and manufacturer performance values for the current model year. The next step in the compliance process it to compare the car and truck standards to the corresponding performance values to determine if each fleet was above or below the standards. This process then allows manufacturers to determine if each fleet will create GHG program credits or deficits. These program credits are the credits available to manufacturers to bank, trade, and ultimately show compliance with the overall GHG program.

Program credits are always expressed as mass-based credits in megagrams of CO_2. A mass-based credit metric captures the performance of each manufacturer's fleets relative to the standards, the total number of vehicles produced in each fleet, and the expected lifetime vehicle miles travelled for those vehicles. This conversion is necessary to enable the banking and trading of credits across manufacturer fleets, model years, and between manufacturers. To convert g/mi emission rates to total emission reductions in Mg, see the insert "How to Calculate Total Emissions from an Emission Rate" at the beginning of this section.

Manufacturers also had a limited, and voluntary, option to generate program credits in model years 2009 through 2011 from early technology adoption before the standards went into effect. Credit trades between manufacturers, credit expirations, and credit forfeitures, are also important in determining the overall program credits available to manufacturers. This section will detail these components of the GHG program, which are essential in determining manufacturer overall credit balances and manufacturer compliance with the GHG program.

Generating Credits and Deficits from Model Year Performance

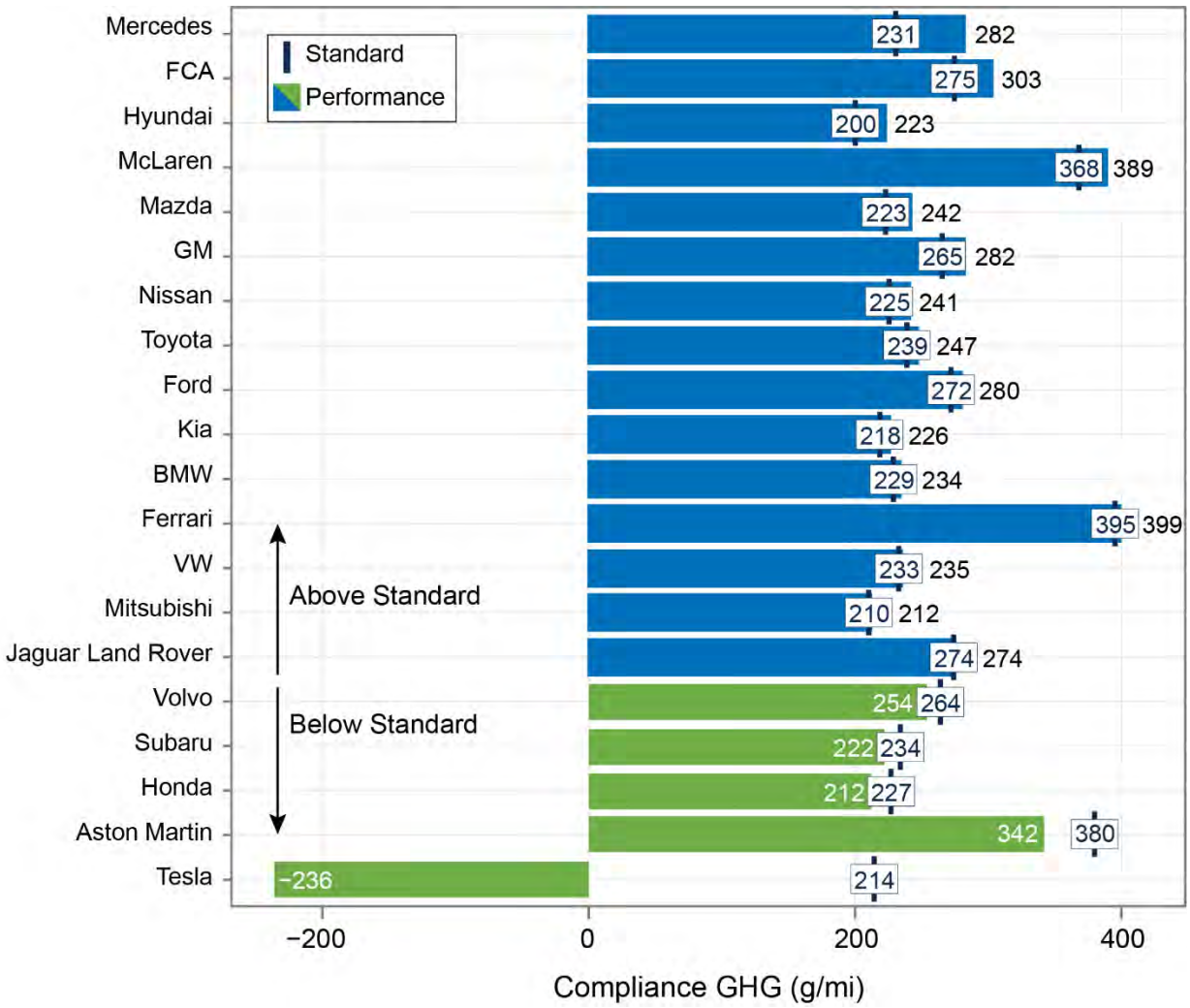
Manufacturers can calculate the credits or deficits created within a model year by comparing their car and truck fleet standards to their respective performance values and converting from a gram per mile emission rate to a mass-based total. When a car or truck fleet is below the applicable standard, that fleet generates credits for the manufacturer. Conversely, when a car or truck fleet is above the applicable standard, that fleet generates deficits.

The GHG program evaluates car and truck fleets separately, which means that there is no single, overall standard for manufacturers. However, it is possible to calculate an effective overall manufacturer standard, and performance value, from the underlying passenger car

and truck data. Figure 5.13 illustrates the performance of all manufacturers in model year 2019, compared to their effective overall standards.

Of the 20 manufacturers that produced vehicles in model year 2019, five were below their overall effective standards, and one manufacturer was even with the standards. Tesla, Honda, Subaru, Volvo, and Aston Martin were all below their standards, and generated net credits (accounting for credits and deficits from each manufacturer's car and truck fleets). Jaguar Land Rover was even with their effective overall standard but generated a small number of credits. Fourteen manufacturers were above their standards and generated net deficits in model year 2019. The fact that manufacturers were above their standards in Figure 5.13 does not mean that these manufacturers were out of compliance with the GHG program, as discussed later in this report.

Figure 5.13. Performance and Standards by Manufacturer, Model Year 2019



In model year 2019, eight manufacturers generated credits from their truck fleets, while nine generated deficits. Four manufacturers generated credits with their car fleets, compared to 16 that generated deficits. Table 5.11 through Table 5.16 provide a summary of the standards, manufacturer performance, and the credits and deficits generated by each manufacturer's car and truck fleets for model year 2019, and for the aggregated industry for model years 2009–2019 (including early credits). These tables show only credits generated within a model year, and do not account for credits used to offset deficits in other model years, credits that are traded between manufacturers, or credits that have expired or been forfeited. The tables showing combined car and truck, or overall industry values, are aggregated from the underlying car and truck data.

Table 5.11. Credits Earned by Manufacturers in Model Year 2019, All

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	342	380	-38	2,069	15,170
BMW	234	229	5	360,345	-392,573
FCA	303	275	28	2,109,158	-13,345,869
Ferrari	399	395	4	2,659	-1,853
Ford	280	272	8	1,816,423	-3,221,756
GM	282	265	17	2,554,431	-9,013,157
Honda	212	227	-15	1,730,544	5,307,829
Hyundai	223	200	23	654,883	-2,933,640
Jaguar Land Rover	274	274	0	105,504	306
Kia	226	218	8	580,746	-923,819
Mazda	242	223	19	267,020	-1,053,413
McLaren	389	368	21	1,382	-5,599
Mercedes	282	231	51	312,501	-3,304,783
Mitsubishi	212	210	2	123,924	-57,646
Nissan	241	225	16	1,366,419	-4,256,602
Subaru	222	234	-12	775,379	2,157,106
Tesla	-236	214	-450	125,538	11,070,481
Toyota	247	239	8	2,371,840	-3,799,467
VW	235	233	2	770,284	-302,728
Volvo	254	264	-10	108,275	240,374
All Manufacturers	**253**	**246**	**7**	**16,139,324**	**-23,821,639**

Table 5.12. Total Credits Earned in Model Years 2009–2019, All

Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)	Credit Expiration
2009	-	-	-	-	98,522,058	2014
2010	-	-	-	-	96,891,340	2021
2011	-	-	-	-	38,770,273	2021
2012	287	299	-12	13,446,550	33,033,097	2021
2013	278	292	-14	15,200,118	42,234,774	2021
2014	273	287	-13	15,514,338	43,292,494	2021
2015	267	274	-7	16,740,264	25,218,704	2021
2016	271	263	8	16,279,911	-27,615,344	2021
2017	262	258	5	17,015,504	-16,203,034	2022
2018	253	252	1	16,259,244	-4,168,218	2023
2019	253	246	7	16,139,324	-23,821,639	2024

Table 5.13. Credits Earned by Manufacturers in Model Year 2019, Car

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	342	380	-38	2,069	15,170
BMW	218	203	15	238,033	-674,229
FCA	278	210	68	405,487	-5,361,078
Ferrari	399	395	4	2,659	-1,853
Ford	228	201	27	568,345	-3,041,035
GM	214	196	18	847,067	-2,927,214
Honda	184	196	-12	992,811	2,328,418
Hyundai	221	199	22	643,662	-2,760,630
Jaguar Land Rover	257	224	33	7,147	-46,484
Kia	198	196	2	389,497	-175,317
Mazda	226	193	33	139,005	-903,813
McLaren	389	368	21	1,382	-5,599
Mercedes	263	207	56	198,525	-2,160,289
Mitsubishi	190	181	9	61,266	-110,428
Nissan	199	196	3	883,582	-489,564
Subaru	230	191	39	148,610	-1,135,982
Tesla	-233	212	-445	122,326	10,637,339
Toyota	191	198	-7	1,108,873	1,573,002
VW	202	193	9	384,640	-682,532
Volvo	238	223	15	25,561	-76,277
All Manufacturers	**203**	**198**	**4**	**7,170,547**	**-5,998,395**

Table 5.14. Total Credits Earned in Model Years 2009–2019, Car

Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)	Credit Expiration
2009	-	-	-	-	58,018,752	2014
2010	-	-	-	-	50,856,700	2021
2011	-	-	-	-	8,831,637	2021
2012	249	267	-18	8,657,393	30,484,967	2021
2013	240	261	-21	9,747,624	39,249,608	2021
2014	236	253	-17	9,209,352	30,407,996	2021
2015	230	241	-12	9,602,215	22,043,043	2021
2016	229	231	-2	9,012,178	3,411,251	2021
2017	217	219	-2	8,954,269	2,705,030	2022
2018	204	209	-6	7,800,108	8,396,572	2023
2019	203	198	4	7,170,547	-5,998,395	2024

Table 5.15. Credits Earned by Manufacturers in Model Year 2019, Truck

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	-	-	-	-	-
BMW	262	272	-10	122,312	281,656
FCA	309	288	21	1,703,671	-7,984,791
Ferrari	-	-	-	-	-
Ford	301	300	1	1,248,078	-180,721
GM	311	295	16	1,707,364	-6,085,943
Honda	245	263	-18	737,733	2,979,411
Hyundai	326	258	68	11,221	-173,010
Jaguar Land Rover	275	277	-2	98,357	46,790
Kia	275	258	17	191,249	-748,502
Mazda	256	251	5	128,015	-149,600
McLaren	-	-	-	-	-
Mercedes	310	266	44	113,976	-1,144,494
Mitsubishi	231	235	-4	62,658	52,782
Nissan	307	272	35	482,837	-3,767,038
Subaru	220	243	-23	626,769	3,293,088
Tesla	-313	284	-597	3,212	433,142
Toyota	289	270	19	1,262,967	-5,372,469
VW	263	267	-4	385,644	379,804
Volvo	258	275	-17	82,714	316,651
All Manufacturers	**288**	**279**	**9**	**8,968,777**	**-17,823,244**

Table 5.16. Total Credits Earned in Model Years 2009–2019, Truck

Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)	Credit Expiration
2009	-	-	-	-	40,503,306	2014
2010	-	-	-	-	46,034,640	2021
2011	-	-	-	-	29,938,636	2021
2012	346	349	-2	4,789,157	2,548,130	2021
2013	337	339	-3	5,452,494	2,985,166	2021
2014	321	330	-9	6,304,986	12,884,498	2021
2015	310	312	-2	7,138,049	3,175,661	2021
2016	316	297	19	7,267,733	-31,026,595	2021
2017	305	295	10	8,061,235	-18,908,064	2022
2018	292	286	7	8,459,136	-12,564,790	2023
2019	288	279	9	8,968,777	-17,823,244	2024

Program Credits for Early Adoption of Technology

The GHG program included an optional provision that allowed manufacturers to generate credits in the 2009–2011 model years, prior to the implementation of regulatory standards in model year 2012. This flexibility allowed manufacturers to generate credits for achieving tailpipe CO_2 emissions targets or introducing emission-reducing technology before model year 2012. Sixteen manufacturers participated in the early credits program, generating a large bank of credits for the industry before the standards took effect in model year 2012.

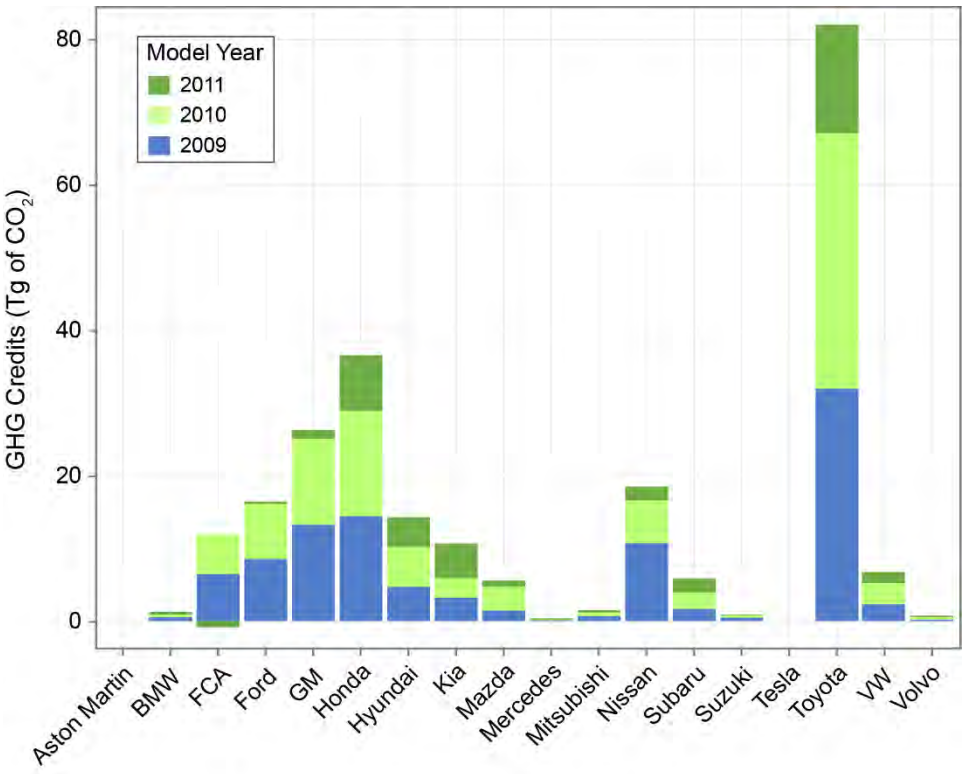
The pathways for earning credits under the early credit program mirrored those built into the annual GHG requirements, including improved tailpipe CO_2 performance and A/C systems, off-cycle credits for other technologies that reduced CO_2 emissions, and credits for manufacturing electric, plug-in hybrid, and fuel cell vehicles.

Of the 234 Tg of early credits, 85% of those credits were generated from performing better than the tailpipe CO_2 emissions targets established in the regulations. To earn credits based on tailpipe CO_2 performance, manufacturers could demonstrate tailpipe emissions levels below either California or national standards, dependent on the state the car was sold in. California developed GHG standards prior to the adoption of the EPA GHG program, and some states had adopted these standards. In all other states, CO_2 levels were calculated based on the national CAFE standards. Of the remaining early credits, about 10% were created through improving A/C system leakage, 4% were due to A/C efficiency improvements, and just over 1% were due to off-cycle credits for other technologies.

The model year 2009 credits could not be traded between companies and were limited to a 5-year credit life. Thus, all credits earned in model year 2009, or about a third of the early credits generated, expired at the end of the 2014 model year if not already used. The remaining 2010–2011 model year credits were banked and may be used until the 2021 model year. Manufacturers can no longer generate early credits. More details of the early credit program can be found in the "Early Credits Report," which was released by EPA in 2013.[22]

[22] Greenhouse Gas Emission Standards for Light-Duty Automobiles: Status of Early Credit Program for Model Years 2009-2011, Compliance Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Report No. EPA-420-R-13-005, March 2013.

Figure 5.14. Early Credits by Manufacturer



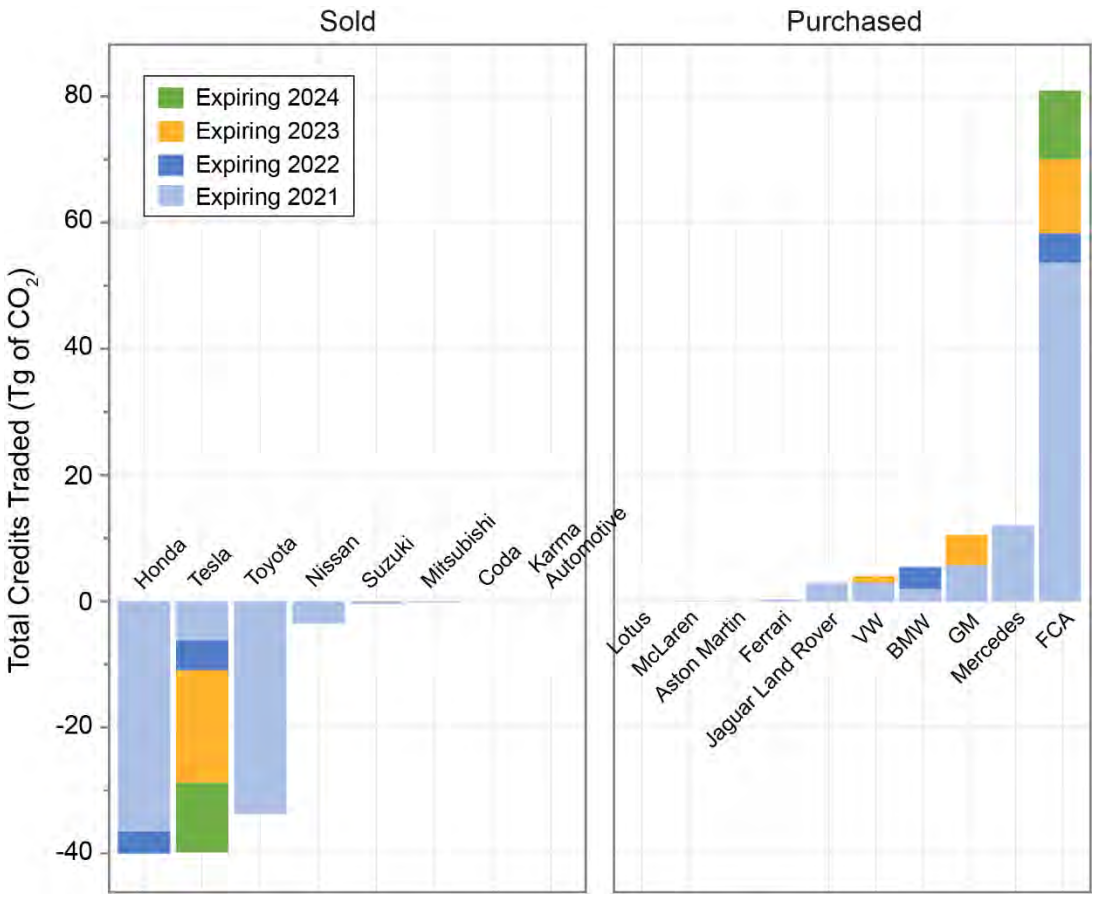
Credit Transactions

Credit trading among manufacturers has been an important part of the program for many manufacturers. An active credit market is enabling manufacturers to purchase credits to demonstrate compliance, with eight manufacturers selling credits, ten manufacturers purchasing credits, and 70 credit transactions occurring since the inception of the program. Credits may be traded among manufacturers with a great deal of flexibility, however there are several limitations, including:

1) Manufacturers must offset any existing deficits before selling credits.
2) Manufacturers may not trade credits they do not have.
3) Manufacturers are the only parties that may engage in credit transactions and hold credits (although a third party may facilitate transactions).
4) Manufacturers may not sell early credits created in model year 2009.
5) Manufacturers may not trade credits generated under an alternative standard (including TLAAS and small volume manufacturer standards).

Manufacturers can purchase or sell credits generated in any model year, if they are available, regardless of the date of the purchase. For example, many credits purchased in 2019 were generated in model years 2012 or earlier. The model year the credits were generated remains important, as those credits can be applied (and will expire) according to the model year in which they were originally created. Figure 5.15 summarizes the credit trades that have been reported to EPA as of October 31, 2020.

Figure 5.15. Total Credits Transactions through Model Year 2019



To date, about 118 Tg of credits have been traded between manufacturers since the beginning of the GHG program. In Figure 5.15, credits that have been sold are shown as negative credits, since the sale of credits will reduce the selling manufacturer's credit balance. Conversely, credits that have been purchased are shown as positive credits, since they will increase the purchasing manufacturer's credit balance. The values shown in Figure 5.15 are the total quantity of credits that have been bought or sold by a manufacturer, and likely represent multiple transactions between various manufacturers. Figure 5.15 also shows the expiration date of credits sold and acquired.

Expiration and Forfeiture of Credits

All credits earned within the GHG program have expiration dates. However, the only credits that have expired so far were credits earned under the early credit program (discussed below) from model year 2009. All credits earned from model years 2010 to 2016, which make up the majority of credits currently held by manufacturers, will expire at the end of model year 2021. Beginning in model year 2017, all credits have a 5-year lifetime; for example, credits earned in model year 2019 will expire at the end of model year 2024.

A limited number of credits have been forfeited by several manufacturers. Although forfeiture and expiration both have fundamentally the same effect – a loss or removal of credits – forfeiture is considered a different and less common mechanism, brought about by unique circumstances. Hyundai and Kia forfeited a specified quantity of 2013 model year credits after an investigation into their testing methods that concluded with a settlement announced on November 3, 2014.

Volkswagen similarly forfeited some credits, deducted from their 2017 model year balance. In the course of the investigation concerning defeat devices in Volkswagen's diesel vehicles, the EPA discovered that the company employed software to manage vehicle transmissions in gasoline vehicles. This software causes the transmission to shift gears during the EPA-prescribed emissions test in a manner that sometimes optimizes fuel economy and greenhouse gas (GHG) emissions during the test, but not under normal driving conditions. This resulted in inflated fuel economy values for some vehicles. Volkswagen forfeited credits to account for the higher CO_2 emissions of these vehicles in actual use.

Additional manufacturers forfeited credits because of their participation in the Temporary Lead Time Alternative Allowance Standards (TLAAS). Opting into these less stringent standards, which are no longer available, came with some restrictions, including the requirement that any credits accumulated by using the TLAAS standards may not be used by or transferred to a fleet meeting the primary standard. This impacted Porsche, which was bought by VW in 2012. Porsche held some credits earned against the TLAAS standards at the time they were merged with VW, and VW was not participating in the TLAAS program. Thus, those credits could not carry over to the merged company and were lost. Similarly, Mercedes and Volvo reached the end of the TLAAS program, which applied through the 2015 model year, with credits in their TLAAS bank that could not be transferred to their post-2015 bank and thus were forfeited.

D. End of Year GHG Program Credit Balances

The final GHG program credit balance at the end of each model year, and compliance status, for each manufacturer relies on all the components outlined to this point in the report. Manufacturer car and truck standards and performance within each model year, early credits, credit trades, credit forfeitures, and credit expirations are all required to determine final model year credit balances for each manufacturer. If a manufacturer ends the model year with a positive credit balance, they are in compliance with the GHG program and the accrued credits will be carried forward to the next model year. If a manufacturer ends the model year with a deficit, that manufacturer must offset the deficit within three years to avoid non-compliance. For example, a manufacturer with a deficit remaining from model year 2016 after the 2019 model year would be considered out of compliance with the 2016 standards. Manufacturers may not carry forward any credits unless all deficits have been offset.

Using Credits to Offset Deficits

If a manufacturer generates a deficit from either their car or truck fleets, that deficit must be offset from existing credits, if they are available. When applying credits, the oldest available credits are applied to the current deficit by default. Credits earned in past model years may be applied to car or truck deficits, regardless of how they were generated. Table 5.17 shows a simple example. In this case, a manufacturer generated 300,000 Mg of credits from its car fleets in model years 2017, 2018, and 2019. The manufacturer's truck fleets did not generate any credits or deficits in model years 2017 or 2018 but generated a deficit of 500,000 Mg in 2019. Because the oldest credits are applied first, credits generated in model year 2017 are the first credits applied towards the 2019 truck deficit, then 2018 and 2019 credits would be applied until the deficit is offset. After offsetting the example truck deficit in Table 5.17, this manufacturer would be left with 100,000 Mg of credits from model year 2018, and 300,000 Mg of credits from model year 2019 to bank for future use.

Table 5.17. Example of a Deficit Offset with Credits from Previous Model Years

	Model Year 2017	Model Year 2018	Model Year 2019
Generated Truck Credits	0	0	-500,000
Generated Car Credits	300,000	300,000	300,000
Applied to 2019 Deficits	-300,000	-200,000	
Remaining Credits	**0**	**100,000**	**300,000**

The complete credit and deficit accounting for each manufacturer also includes the impact of credits earned as part of the early credit program, credit trades, credit forfeitures, and credit expirations over the full span of the GHG program. The detailed deficit offset calculations for each manufacturer are not published in this report, since some of the credit trade information is considered confidential business information and is not published in detail by EPA. However, most of the underlying data for all manufacturers and model years is available on the Automotive Trends website at https://www.epa.gov/automotive-trends.

Compliance Status After the 2019 Model Year

EPA determines the compliance status of each manufacturer based on their credit balance at the end of the model year, after offsetting all deficits. Because credits may not be carried forward unless deficits from all prior model years have been resolved, a positive credit balance means compliance with the current and all previous model years of the program. If a manufacturer ends the model year with a any deficits, that manufacturer must offset the deficit within three years to avoid non-compliance. For model year 2019, deficits from model year 2016 or prior would be considered non-compliant

Figure 5.16 shows the credit balance of all manufacturers after model year 2019 including the breakdown of expiration dates, and the distribution of deficits, by age of the deficit. All manufacturers, except two, ended the 2019 model year with a positive credit balance and are thus in compliance with model year 2019 and all previous years of the GHG program. Lotus and McLaren, the two manufacturers carrying a deficit into the 2020 model year, both have deficits at the end of model year 2019, but those deficits are within the allowable time span, and will not result in non-compliance or enforcement actions from EPA. However, both manufacturers will have to offset the existing deficits in future model years either by producing efficient vehicles that exceed future standards, or by purchasing credits from other manufacturers.

The breakdown of each manufacturer's final model year 2019 credit balance, based on the source of the credits or deficits, is shown in Table 5.18. Each manufacturer has pursued a unique combination of early credits generated in model years 2009–2011, credits or deficits created in model years 2012–2019, and credit expirations, forfeitures, and trades to achieve their current credit balance. The credits earned in Table 5.18 are "net" credits, and do not account for deficits that have been offset with credits from other model years. The actual distribution of credits, by expiration date, and deficits, by the age of the deficit, are shown in Table 5.19.

Figure 5.16. Manufacturer Credit Balance After Model Year 2019

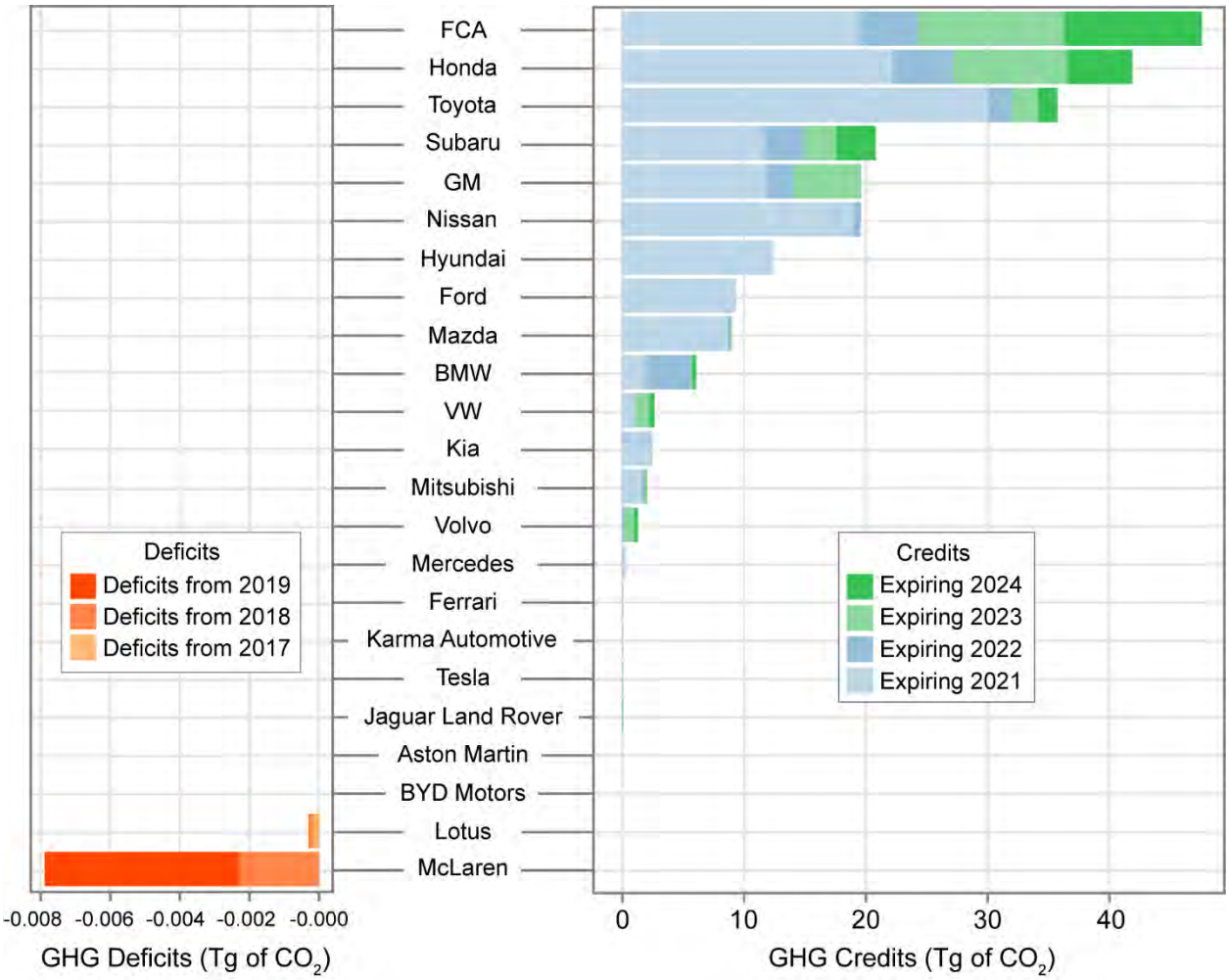


Table 5.18. Final Credit Balance by Manufacturer for Model Year 2019 (Mg)

Manufacturer	Early Credits Earned 2009-2011	Net Credits Earned 2012-2018	Net Credits Earned 2019	Credits Expired	Credits Forfeited	Credits Purchased or Sold	Final 2019 Credit Balance
Aston Martin	3,332	-37,504	15,170	-	-	35,844	16,842
BMW	1,251,522	-210,997	-392,573	-134,791	-	5,500,000	6,013,161
BYD Motors	-	5,568	-	-	-	-	5,568
Coda	-	7,251	-	-	-	-7,251	-
FCA	10,827,083	-32,540,672	-13,345,869	-	-	82,128,881	47,069,423
Ferrari	-	-151,153	-1,853	-	-	265,000	111,994
Ford	16,116,453	2,255,243	-3,221,756	-5,882,011	-	-	9,267,929
GM	25,788,547	-990,066	-9,013,157	-6,998,699	-	10,677,251	19,463,876
Honda	35,842,334	54,543,241	5,307,829	-14,133,353	-	-40,015,245	41,544,806
Hyundai	14,007,495	5,871,049	-2,933,640	-4,482,649	-169,775	-	12,292,480
Jaguar Land Rover	-	-2,874,564	306	-	-	2,922,736	48,478
Karma Automotive	-	58,852	-	-	-	-2,841	56,011
Kia	10,444,192	-4,545,523	-923,819	-2,362,882	-123,956	-	2,488,012
Lotus	-	-3,147	-	-	-	2,841	-306
Mazda	5,482,642	5,905,364	-1,053,413	-1,390,883	-	-	8,943,710
McLaren	-	-11,370	-5,599	-	-	9,079	-7,890
Mercedes	378,272	-8,968,525	-3,304,783	-	-28,416	12,227,713	304,261
Mitsubishi	1,449,336	1,430,836	-57,646	-583,146	-	-200,000	2,039,380
Nissan	18,131,200	17,312,306	-4,256,602	-8,190,124	-	-3,545,570	19,451,210
Porsche	-	426,439	-	-	-426,439	-	-
Subaru	5,755,171	13,280,987	2,157,106	-491,789	-	-	20,701,475
Suzuki	876,650	-183,097	-	-265,311	-	-428,242	-
Tesla	49,772	28,739,673	11,070,481	-	-	-39,807,765	52,161
Toyota	80,435,498	22,093,847	-3,799,467	-29,526,679	-	-33,762,431	35,440,768
VW	6,613,985	-6,019,574	-302,728	-1,442,571	-219,419	4,000,000	2,629,693
Volvo	730,187	398,009	240,374	-	-85,163	-	1,283,407
All Manufacturers	**234,183,671**	**95,792,473**	**-23,821,639**	**-75,884,888**	**-1,053,168**	**-**	**229,216,449**

Table 5.19. Distribution of Credits by Expiration Date (Mg)

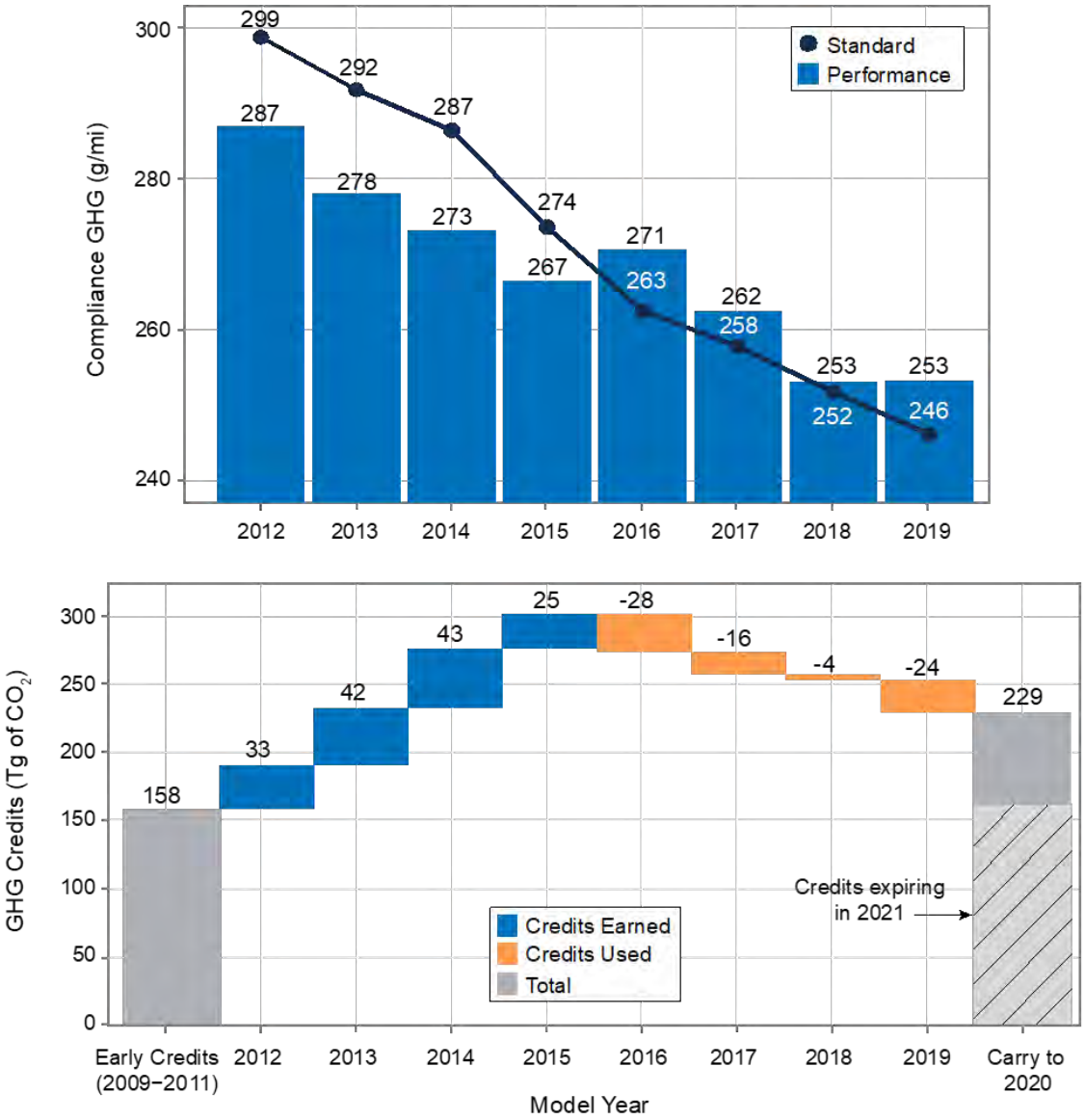
Manufacturer	Final 2019 Credit Balance	Credits Expiring in 2021	Credits Expiring in 2022	Credits Expiring in 2023	Credits Expiring in 2024	Model Year 2019 Deficits	Model Year 2018 Deficits	Model Year 2017 Deficits	Non-Compliant Deficits
Aston Martin	16,842	-	-	1,672	15,170	-	-	-	-
BMW	6,013,161	1,939,942	3,652,752	138,811	281,656	-	-	-	-
BYD Motors	5,568	4,871	529	168	-	-	-	-	-
Coda	-	-	-	-	-	-	-	-	-
FCA	47,069,423	19,348,175	4,731,544	11,915,822	11,073,882	-	-	-	-
Ferrari	111,994	99,622	8,180	4,192	-	-	-	-	-
Ford	9,267,929	9,267,929	-	-	-	-	-	-	-
GM	19,463,876	11,801,350	2,127,946	5,534,580	-	-	-	-	-
Honda	41,544,806	22,044,774	4,917,091	9,275,112	5,307,829	-	-	-	-
Hyundai	12,292,480	12,292,480	-	-	-	-	-	-	-
Jaguar Land Rover	48,478	1,688	-	-	46,790	-	-	-	-
Karma Automotive	56,011	56,011	-	-	-	-	-	-	-
Kia	2,488,012	2,488,012	-	-	-	-	-	-	-
Lotus	-306	-	-	-	-	-	-114	-192	-
Mazda	8,943,710	8,607,717	171,051	164,942	-	-	-	-	-
McLaren	-7,890	-	-	-	-	-5,599	-2,291	-	-
Mercedes	304,261	304,261	-	-	-	-	-	-	-
Mitsubishi	2,039,380	1,611,677	171,946	202,975	52,782	-	-	-	-
Nissan	19,451,210	18,799,525	651,685	-	-	-	-	-	-
Porsche	-	-	-	-	-	-	-	-	-
Subaru	20,701,475	11,593,033	3,215,610	2,599,744	3,293,088	-	-	-	-
Suzuki	-	-	-	-	-	-	-	-	-
Tesla	52,161	-	-	52,161	-	-	-	-	-
Toyota	35,440,768	29,850,127	1,911,327	2,106,312	1,573,002	-	-	-	-
VW	2,629,693	1,028,379	-	1,221,510	379,804	-	-	-	-
Volvo	1,283,407	-	188,150	778,606	316,651	-	-	-	-
All Manufacturers	**229,216,449**	**151,139,573**	**21,747,811**	**33,996,607**	**22,340,654**	**-5,599**	**-2,405**	**-192**	**0**

Figure 5.17 shows the overall industry performance, standards, and credit bank for all years of the GHG program. The industry created a large bank of credits using the early credits provision in model year 2009 through 2012. For the next four years, manufacturers continued to generate credits, as the industry GHG performance was below the industry-wide average standard. In the last four years, the industry GHG performance has been above the standard, resulting in net withdrawals from the bank of credits to maintain compliance. In model year 2019, the industry maintained overall GHG performance at 253 g/mi, while the standard fell from 252 g/mi to 246 g/mi. The gap between the standard and GHG performance grew from 1 g/mi in model year 2018 to 7 g/mi in model year 2019. To maintain compliance, the industry drew down their industry-wide total credit bank by about 24 teragrams (Tg), which was less than 10% of the total available credit balance. The overall industry emerged from model year 2019 with a bank of more than 229 Tg of GHG credits available for future use, as seen in Figure 5.17.

In addition to the balance of the industry-wide credit bank, the expiration date and distribution of credits are also important factors. Credits earned in model year 2017 or beyond have a five-year life, while all prior credits (two-thirds of the current bank) will expire at the end of model year 2021. An active credit market has resulted in approximately 70 credit trades since 2012, with eight manufacturers selling credits and ten manufacturers purchasing credits However, the availability of current or future credits is inherently uncertain.

After accounting for the use of credits, and the ability to carry forward a deficit in the case of Lotus and McLaren, the industry overall does not face any non-compliance issues as of the end of the 2019 model year.

Figure 5.17. Industry Performance and Standards, Credit Generation and Use



Appendices: Methods and Additional Data

A. Sources of Input Data

Nearly all of the data for this report are based on automakers' direct submissions to EPA. EPA has required manufacturers to provide vehicle fuel economy to consumers since 1977 and has collected data on every new light-duty vehicle model sold in the United States since 1975. The data are obtained either from testing performed by EPA at the National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan, or directly from manufacturers using official EPA test procedures.

National fuel economy standards have been in place in the United States for cars and light trucks since 1978. The Department of Transportation, through the National Highway Traffic Safety Administration (NHTSA), has the responsibility for setting and enforcing fuel economy standards through the Corporate Average Fuel Economy (CAFE) program. Since the inception of CAFE, EPA has been responsible for establishing test procedures and calculation methods, and for collecting data used to determine vehicle fuel economy levels. EPA calculates the CAFE value for each manufacturer and provides it to NHTSA. NHTSA publishes the final CAFE values in its annual "Summary of Fuel Economy Performance" reports at www.nhtsa.gov/Laws-&-Regulations/CAFE-–-Fuel-Economy. Since model year 2012, NHTSA and EPA have maintained coordinated fuel economy and greenhouse gas standards that apply to model year 2012 through model year 2026 vehicles. EPA's light-duty GHG program is described in detail in Section 5 of this report.

The data that EPA collects for this report comprise the most comprehensive database of its kind. For recent model years, the vast majority of data in this report comes from the Engines and Vehicles Compliance Information System (EV-CIS) database maintained by EPA. This database contains a broad amount of data associated with CO_2 emissions and fuel economy, vehicle and engine technology, and other vehicle performance metrics. This report extracts only a portion of the data from the EV-CIS database.

In some cases, the data submitted by automakers are supplemented by data that were obtained through independent research by EPA. For example, EPA relied on published data from external sources for certain parameters of pre-model year 2011 vehicles: (1) engines with variable valve timing (VVT), (2) engines with cylinder deactivation, and (3) vehicle footprint, as automakers did not submit this data until model year 2011. EPA projects footprint data for the preliminary model year 2020 fleet based on footprint values for existing models from previous years and footprint values for new vehicle designs available

through public sources. In addition, vehicle 0-to-60 acceleration values are not provided by automakers, but are either calculated from other Trends data, as discussed in Section 3, or taken from external sources.

The website for this report has been expanded with an emphasis on allowing users to access and evaluate more of the data behind this report. EPA plans to continue to add content and tools on the web to allow transparent access to public data. All public data available on the web can be accessed at the following links:

- Explore data with interactive figures and download data from Supplemental Data Tables supplied in previous reports here: https://www.epa.gov/automotive-trends/explore-automotive-trends-data.
- Download report tables here: https://www.epa.gov/automotive-trends/download-automotive-trends-report.

The full database used for the analysis in this report is not publicly available. The detailed production data necessary for demonstrating compliance is considered confidential business information by the manufacturers and cannot be shared by EPA. However, EPA will continue to provide as much information as possible to the public.

Preliminary vs Final Data

For each model year, automakers submit two phases of data: **preliminary data** provided to EPA for vehicle certification and labeling prior to the model year sales, and **final data** submitted after the completion of the model year for compliance with EPA's light-duty GHG regulations and NHTSA's CAFE program.

Preliminary data are collected prior to the beginning of each model year and are not used for manufacturer GHG compliance. Automakers submit "General Label" information required to support the generation of the joint EPA/NHTSA Fuel Economy and Environment Labels that appear on all new personal vehicles. As part of these submissions, automakers report pre-model year vehicle production projections for individual models and configurations to EPA.

Final data are submitted a few months after the end of each model year and include detailed final production volumes. EPA and NHTSA use this final data to determine compliance with GHG emissions and CAFE standards. These end-of-the-year submissions include detailed final production volumes. All data in this report for model years 1975 through 2019 are considered final. However, manufacturers can submit requests for

compliance credits for previous model years, so it is possible that additional credits under the GHG program could be awarded to manufacturers.

Since the preliminary fuel economy values provided by automakers are based on projected vehicle production volumes, they usually vary slightly from the final fuel economy values that reflect the actual sales at the end of the model year. With each publication of this report, the preliminary values from the previous year are updated to reflect the final values. This allows a comparison to gauge the accuracy of preliminary projections.

Table A.1 compares the preliminary and final fleetwide real-world fuel economy values for recent years (note that the differences for CO_2 emissions data would be similar, on a percentage basis). Since model year 2011, the final real-world fuel economy values have generally been close to the preliminary fuel economy values. In eight out of the last nine years, manufacturer projections have led to preliminary estimates that were higher than final data.

It is important to note that there is no perfect apples-to-apples comparison for model years 2011–2014 due to several small differences in data, such as inclusion of alternative fuel vehicle (AFV) data. The preliminary values in Table A.1 through model year 2014 did not integrate AFV data, while the final values in Table A.1 are the values reported elsewhere in this report and do include AFV data. The differences due to this would be small, on the order of 0.1 mpg or less.

Table A.1. Comparison of Preliminary and Final Real-World Fuel Economy Values (mpg)

Model Year	Preliminary Value	Final Value	Final Minus Preliminary
2011	22.8	22.3	-0.5
2012	23.8	23.6	-0.2
2013	24.0	24.2	+0.2
2014	24.2	24.1	-0.1
2015	24.7	24.6	-0.2
2016	25.6	24.7	-0.9
2017	25.2	24.9	-0.3
2018	25.4	25.1	-0.3
2019	25.5	24.9	-0.6
2020 (prelim)	*25.7*	-	-

B. Harmonic Averaging of Fuel Economy Values

Averaging multiple fuel economy values must be done harmonically in order to obtain a correct mathematical result. Since fuel economy is expressed in miles per gallon (mpg), one critical assumption with any harmonic averaging of multiple fuel economy values is whether the distance term (miles, in the numerator of mpg) is fixed or variable. This report makes the assumption that the distance term in all mpg values is fixed, i.e., that for purposes of calculating a harmonically averaged fuel economy value, it is assumed that the distance term (representing miles traveled) is equivalent across various vehicle fuel economies. This assumption is the standard practice with harmonic averaging of multiple fuel economy values (including, for example, in calculations for CAFE standards compliance), and simplifies the calculations involved.

Mathematically, when assuming a fixed distance term as discussed above, harmonic averaging of multiple fuel economy values can be defined as the inverse of the average of the reciprocals of the individual fuel economy values. It is best illustrated by a simple example.

Consider a round trip of 600 miles. For the first 300-mile leg, the driver is alone with no other passengers or cargo, and, aided by a tailwind, uses 10 gallons of gasoline, for a fuel economy of 30 mpg. On the return 300-mile trip, with several passengers, some luggage, and a headwind, the driver uses 15 gallons of gasoline, for a fuel economy of 20 mpg. Many people will assume that the average fuel economy for the entire 600-mile trip is 25 mpg, the arithmetic (or simple) average of 30 mpg and 20 mpg. But, since the driver consumed 10 + 15 = 25 gallons of fuel during the trip, the actual fuel economy is 600 miles divided by 25 gallons, or 24 mpg.

Why is the actual 24 mpg less than the simple average of 25 mpg? Because the driver used more gallons while (s)he was getting 20 mpg than when (s)he was getting 30 mpg.

This same principle is often demonstrated in elementary school mathematics when an airplane makes a round trip, with a speed of 400 mph one way and 500 mph the other way. The average speed of 444 mph is less than 450 mph because the airplane spent more time going 400 mph than it did going 500 mph.

As in both of the examples above, a harmonic average will typically yield a result that is slightly lower than the arithmetic average.

The following equation illustrates the use of harmonic averaging to obtain the correct mathematical result for the fuel economy example above:

$$\text{Average mpg} = \frac{2}{\left(\frac{1}{30} + \frac{1}{20}\right)} = 24 \text{ mpg}$$

Though the above example was for a single vehicle with two different fuel economies over two legs of a single round trip, the same mathematical principle holds for averaging the fuel economies of any number of vehicles. For example, the average fuel economy for a set of 10 vehicles, with three 30 mpg vehicles, four 25 mpg vehicles, and three 20 mpg vehicles would be (note that, in order to maintain the concept of averaging, the total number of vehicles in the numerator of the equation must equal the sum of the individual numerators in the denominator of the equation):

$$\text{Average mpg} = \frac{10}{\left(\frac{3}{30} + \frac{4}{25} + \frac{3}{20}\right)} = 24.4 \text{ mpg}$$

Arithmetic averaging, not harmonic averaging, provides the correct mathematical result for averaging fuel consumption values (in gallons per mile, the inverse of fuel economy) and CO_2 emissions (in grams per mile). In the first, round trip, example above, the first leg had a fuel consumption rate of 10 gallons over 300 miles, or 0.033 gallons per mile. The second leg had a fuel consumption of 15 gallons over 300 miles, or 0.05 gallons per mile. Arithmetically averaging the two fuel consumption values, i.e., adding them up and dividing by two, yields 0.04167 gallons per mile, and the inverse of this is the correct fuel economy average of 24 mpg. Arithmetic averaging also works for CO_2 emissions values, i.e., the average of 200 g/mi and 400 g/mi is 300 g/mi CO_2 emissions.

In summary, fuel economy values must be harmonically averaged to maintain mathematical integrity, while fuel consumption values (in gallons per mile) and CO_2 emissions values (in grams per mile) can be arithmetically averaged.

C. Fuel Economy and CO_2 Metrics

The CO_2 emissions and fuel economy data in this report fall into one of two categories: **compliance data** and **estimated real-world data**. These categories are based on the purpose of the data, and the subsequent required emissions test procedures. The following sections discuss the differences between compliance and real-world data and how they relate to raw vehicle emissions test results.

2-Cycle Test Data

In 1975 when the Corporate Average Fuel Economy (CAFE) regulation was put into place, EPA tested vehicles using two dynamometer-based test cycles, one based on city driving and one based on highway driving. CAFE was—and continues to be—required by law to use these "2-cycle tests". For consistency, EPA also adopted this approach for the GHG regulations.

Originally, the fuel economy values generated from the "2-cycle" test procedure were used both to determine compliance with CAFE requirements and to inform consumers of their expected fuel economy via the fuel economy label. Today, the raw 2-cycle test data are used primarily in a regulatory context as the basis for determining the final compliance values for CAFE and GHG regulations.

The 2-cycle testing methodology has remained largely unchanged[23] since the early 1970s. Because of this, the 2-cycle fuel economy and CO_2 values can serve as a useful comparison of long-term trends. Previous versions of this report included 2-cycle fuel economy and CO_2 data, referred to as "unadjusted" or "laboratory" values. These 2-cycle fuel economy values are still available on the report website and in Appendix D for reference. It is important to note that these 2-cycle fuel economy values do not exactly correlate to the 2-cycle tailpipe CO_2 emissions values provided in Section 5 for the GHG regulations. There are three methodological reasons for this:

[23] There were some relatively minor test procedure changes made in the late 1970s that, in the aggregate, made the city and highway tests slightly more demanding, i.e., the unadjusted fuel economy values for a given car after these test procedure changes were made are slightly lower relative to prior to the changes. EPA has long provided CAFE "test procedure adjustments" (TPAs) for passenger cars in recognition of the fact that the original CAFE standards were based on the EPA test procedures in place in 1975 (there are no TPAs for light trucks). The resulting impacts on the long-term unadjusted fuel economy trends are very small. The TPAs for cars vary but are typically in the range of 0.2–0.5 mpg for cars, or 0.1–0.3 mpg when the car TPAs are averaged over the combined car/truck fleet.

1. The GHG regulations require a car and truck weighting based on a slightly higher lifetime vehicle miles traveled (VMT) for trucks. The 2-cycle fuel economy values do not account for this difference.
2. The GHG regulations allow manufacturers to use an optional compliance approach which adds nitrous oxide and methane emissions to their 2-cycle CO_2 emissions.
3. The GHG regulations and CAFE regulations result in very slightly different annual production values. Prior to model year 2017, the 2-cycle fuel economy values rely on CAFE production values (see Appendix D).

GHG Compliance Data

Compliance data in this report are used to determine how the manufacturers are performing under EPA's GHG program. These data are reported in the Executive Summary and Section 5. The 2-cycle CO_2 test values form the basis for the compliance data, but there are some important differences due to provisions in the standards. Manufacturers' model year performance is calculated based on the measured 2-cycle CO_2 tailpipe emissions as well as optional performance credits and adjustments that manufacturers may qualify for and use.

Compliance data also includes the overall credit balances held by each manufacturer, and may incorporate credit averaging, banking, and trading by manufacturers. The compliance process is explained in detail in Section 5. Compliance CO_2 data is not comparable to estimated real-world CO_2 data, as described below.

Estimated Real-World Fuel Economy and CO_2 Data

Estimated real-world (previously called "adjusted") data is EPA's best estimate of real-world fuel economy and CO_2 emissions, as reported in Sections 1–4 of this report. The real-world values are the best data for researchers to evaluate new vehicle CO_2 and fuel economy performance. Unlike compliance data, the method for calculating real-world data has evolved over time, along with technology and driving habits. These changes in methodology are detailed in Appendix D.

Calculating estimated real-world fuel economy

Estimated real-world fuel economy data are currently measured based on the "5-cycle" test procedure that utilizes high-speed, cold start, and air conditioning tests in addition to the 2-cycle tests to provide data more representative of real-world driving. These additional laboratory tests capture a wider range of operating conditions (including hot/cold weather

and higher acceleration) that an average driver will encounter. City and highway results are weighted 43% / 57%, consistent with fleetwide driver activity data.

Calculating estimated real-world CO_2 emissions

The estimated real-world CO_2 emissions shown in Sections 1–4 are not based directly on the 2-cycle tested values, but rather they are based on calculated values that convert estimated real-world fuel economy values to CO_2 using emission factors. This approach is taken because: 1) test data are not available for most historic years of data, and 2) some manufacturers choose to use an optional compliance approach which adds nitrous oxide (N_2O) and methane (CH_4) emissions to their CO_2 emissions (also referred to as Carbon Related Exhaust Emissions, or CREE), leading to slightly different test results.

The estimated real-world CO_2 emissions from gasoline vehicles are calculated by dividing 8,887 g/gal by the fuel economy of the vehicle. The 8,887 g/gal emission factor is a typical value for the grams of CO_2 per gallon of gasoline test fuel and assumes all the carbon is converted to CO_2. For example, 8,887 g/gal divided by a gasoline vehicle fuel economy of 30 mpg would yield an equivalent CO_2 emissions value of 296 grams per mile.

The estimated real-world CO_2 emissions for diesel vehicles are calculated by dividing 10,180 g/gal by the diesel vehicle fuel economy value. The 10,180 g/gal diesel emission factor is higher than for a gasoline vehicle because diesel fuel has a 14.5% higher carbon content per gallon than gasoline. Accordingly, a 30 mpg diesel vehicle would have a CO_2 equivalent value of 339 grams per mile. Emissions for vehicles other than gasoline and diesel are also calculated using appropriate emissions factors.

Example Comparison of Fuel Economy Metrics

The multiple ways of measuring fuel economy and GHG emissions can understandably lead to confusion. As an illustration to help the reader understand the various fuel economy values that can be associated with an individual vehicle, Table 1.2 shows three different fuel economy metrics for the model year 2020 Toyota Prius Eco. The 2-cycle city and highway fuel economy values are direct fuel economy measurements from the 2-cycle tests and are harmonically averaged with a 55% city / 45% highway weighting to generate a combined value. The 2-cycle laboratory tested city fuel economy of the Prius Eco is 84 mpg, the highway fuel economy is 78 mpg, and the combined 2-cycle value is 81 mpg.

Using the 5-cycle methodology, the Toyota Prius Eco has a vehicle fuel economy label value of 58 mpg city and 53 mpg highway. On the vehicle label, these values are harmonically averaged using a 55% city / 45% highway weighting to determine a combined value of 56

mpg. The estimated real-world fuel economy for the Prius Eco, which is the set of values used in calculations for this report, has the same city and highway fuel economy as the label, but the 43% city and 57% highway weighting leads to a combined value of 55 mpg, which is one mpg less than the values found on the label.

Table C.1. Fuel Economy Metrics for the Model Year 2020 Toyota Prius Eco

Fuel Economy Metric	Purpose	City/Highway Weighting	Test Basis	Fuel Economy Value (MPG)		
				Combined City/Hwy	City	Hwy
2-cycle Test (unadjusted)	Basis for manufacturer compliance with standards	55% / 45%	2-cycle	81	84	78
Label	Consumer information to compare individual vehicles	55% / 45%	5-cycle	56	58	53
Estimated Real-World	Best estimate of real-world performance	43% / 57%	5-cycle	55	58	53

Greenhouse Gases other than CO_2

In addition to tailpipe CO_2 emissions, vehicles may create greenhouse gas emissions in several other ways. The combustion process can result in emissions of N_2O, and CH_4, and leaks in vehicle air conditioning systems can release refrigerants, which are also greenhouse gases, into the environment. N_2O, CH_4, and air conditioning greenhouse gases are discussed as part of the GHG regulatory program in Section 5. Estimated real-world CO_2 emissions in Sections 1–4 only account for tailpipe CO_2 emissions.

The life cycle of the vehicle (including manufacturing and vehicle disposal) and the life cycle of the fuels (including production and distribution) can also create significant greenhouse gases. Life cycle implications of vehicles and fuels can vary widely based on the vehicle technology and fuel and are outside the scope of this report. However, there is academic research, both published and ongoing, in this area for interested readers.

D. Historical Changes in the Database and Methodology

Over the course of this report's publication, there have been some instances where relevant methodologies and definitions have been updated. Since the goal of this report is to provide the most accurate data and science available, updates are generally propagated back to through the historical database. The current version of this report supersedes all previous reports.

Changes in Estimated Real-world Fuel Economy and CO_2

The estimated real-world fuel economy values in this report are closely related to the label fuel economy values. Over the course of this report, there have been three updates to the fuel economy label methodology (for model years 1985, 2008, and 2017), and these updates were propagated through the Trends database. However, there are some important differences in how the label methodology updates have been applied in this report. This section discusses how these methodologies have been applied, partially or in full, to the appropriate model years based on the authors' technical judgement. The changes are intended to provide accurate real-world values for vehicles at the time they were produced to better reflect available technologies, changes in driving patterns, and composition of the fleet. These changes are also applicable to real-world CO_2 values, which are converted from fuel economy values using emissions factors.

Model year 1975–1985: Universal Multipliers

The first change to the label methodology occurred when EPA recognized that changing technology and driving habits led to real-world fuel economy results that over time were diverging from the fuel economy values measured using the 2-cycle tests. To address this issue, EPA introduced an alternative calculation methodology in 1985 that applied a multiplication factor to the 2-cycle test data of 0.9 for city and 0.78 for highway. The estimated real-world fuel economy values from model year 1975–1985 in this report were calculated using the same multiplication factors that were required for the model year 1985 label update. The authors believe that these correction factors were appropriate for new vehicles from model year 1975 through 1985. The combined fuel economy and CO_2 values are based on a 55% city / 45% highway weighting factor, consistent with the CAFE and label fuel economy calculations.

Model year 1986–2010: The 2006 5-cycle methodology and 43% City / 57% Highway Weighting

In 2006, EPA established a major change to the fuel economy label calculations by introducing the 5-cycle methodology[24] In addition to the city and highway tests required for 2-cycle fuel economy, the 5-cycle methodology introduces tests for high speeds (US06), air-conditioning (SC03), and a cold temperature test. It also indirectly accounts for a number of other factors that are not reflected in EPA laboratory test data (e.g., changing fuel composition, wind, road conditions) through the use of a 9.5% universal downward adjustment factor. The change from the universal adjustment factors to the 2006 5-cycle method lowered estimated real-world fuel economy values, particularly for high fuel economy vehicles. In the 2006 rulemaking, EPA projected an overall average fleetwide adjustment of 11% lower for city fuel economy and 8% lower for highway fuel economy.

For model year 1986–2004, the authors implemented the 2006 5-cycle methodology by assuming the changes in technology and driver behavior that led to lower real-world fuel economy occurred in a gradual, linear manner over 20 years. We did not attempt to perform a year-by-year analysis to determine the extent to which the many relevant factors (including higher highway speed limits, more aggressive driving, increasing vehicle horsepower-to-weight ratios, suburbanization, congestion, greater use of air conditioning, gasoline composition, etc.) that have affected real-world fuel economy since 1985 have changed over time.

Under the 5-cycle methodology, manufacturers could either: 1) perform all five tests on each vehicle (the "full 5-cycle" method), 2) use an alternative analytical "derived 5-cycle" method based on 2-cycle testing if certain conditions were met, or 3) voluntarily use lower fuel economy label estimates than those resulting from the full 5-cycle or derived 5-cycle. If manufacturers are required to perform all five tests, the results are weighted according to composite 5-cycle equations.[25] To use the derived 5-cycle method, manufacturers are required to evaluate whether fuel economy estimates using the full 5-cycle tests are comparable to results using the derived 5-cycle method. In recent years, the derived 5-cycle approach has been used to generate approximately 85% of all vehicle label fuel economy values.

For vehicles that were eligible to use the 2006 derived 5-cycle methodology, the following equations were used to convert 2-cycle city and highway fuel economy values to label

[24] See 71 Federal Register 77872, December 27, 2006.
[25] See 71 Federal Register 77883-77886, December 27, 2006.

economy values. These equations were based on the relationship between 2-cycle and 5-cycle fuel economy data for the industry as a whole.

$$\textbf{Label CITY} = \frac{1}{\left(0.003259 + \frac{1.1805}{\text{2CYCLE CITY}}\right)}$$

$$\textbf{Label HWY} = \frac{1}{\left(0.001376 + \frac{1.3466}{\text{2CYCLE HWY}}\right)}$$

Over the same timeframe, EPA phased in a change in the city and highway weightings used to determine a single combined fuel economy or CO_2 value. EPA's analysis of real-world driving activity underlying the 5-cycle fuel economy methodology assumed a "speed cutpoint" of 45 miles per hour to differentiate between (and "bin" the amount of) city and highway driving.[26] Based on this speed cutpoint, the correct weighting for correlating the new city and highway fuel economy values with real-world driving activity data from on-road vehicle studies, on a miles driven basis, is 43% city and 57% highway; this updated weighting is necessary to maintain the integrity of fleetwide fuel economy performance based on Trends data. The 55% city / 45% highway weighting is still used for both Fuel Economy and Environment Labels and the CAFE and GHG emissions compliance programs. The authors used the same gradual, linear approach to phase in the change in city and highway weightings along with the phase-in of the 2006 5-cycle methodology.

From model year 2005 to model year 2010, the 2006 5-cycle methodology and the 43% city / 57% highway weightings were used to determine the real-world fuel economy values for this report. This required using the derived 5-cycle equations and the 43% city / 57% highway weightings to recalculate real-world fuel economy values for model year 2005 to 2007, because the 2006 5-cycle methodology was not required until 2008. Model year 2008 to model year 2010 real-world fuel economy values were the same as the label fuel economy values, except for the city and highway weightings.

Model year 2011–present: Implementing the 2017 derived 5-cycle updates

In 2015, EPA released a minor update to the derived 5-cycle equations that modified the coefficients used to calculate derived 5-cycle fuel economy from 2-cycle test data.[27] This

[26] See 71 Federal Register 77904, December 27, 2006.
[27] See https://www.epa.gov/fueleconomy/basic-information-fuel-economy-labeling and http://iaspub.epa.gov/otaqpub/display_file.jsp?docid=35113&flag=1

update was required under existing regulations and applies to fuel economy label calculations for all model year 2017 and later vehicles. The following equations are used to convert 2-cycle test data values for city and highway to label fuel economy values:

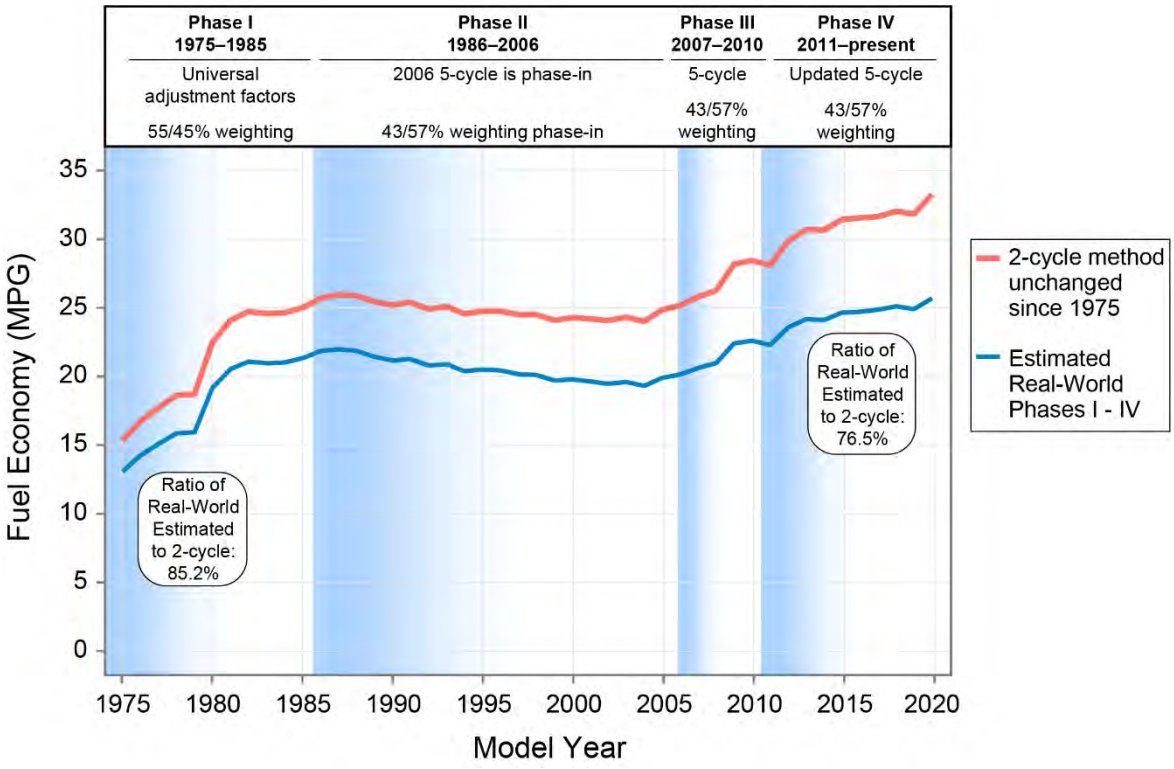
$$\textbf{Label CITY} = \frac{1}{\left(0.004091 + \frac{1.1601}{\text{2CYCLE CITY}}\right)}$$

$$\textbf{Label HWY} = \frac{1}{\left(0.003191 + \frac{1.2945}{\text{2CYCLE HWY}}\right)}$$

The updated 5-cycle calculations introduced for model year 2017 and later labels were based on test data from model year 2011 to model year 2016 vehicles. Therefore, the authors chose to retroactively apply the updated 5-cycle methodology to model years 2011 to 2016. This required recalculating the real-world fuel economy of vehicles from model year 2011 to 2016 using the new derived 5-cycle equations. Vehicles that conducted full 5-cycle testing or voluntarily lowered fuel economy values were unchanged. The 43% city / 57% highway weightings were maintained. The changes for model years 2011-2016 due to the 5-cycle update were relatively small (0.1 to 0.2 mpg overall) and did not noticeably alter the general data trends, therefore the authors determined that a phase-in period was not required for this update.

Figure D.1 below summarizes the impact of the changes in real-world data methodology relative to the 2-cycle test data, which has had a consistent methodology since 1975 (See Appendix C for more information). Over time, the estimated real-world fuel economy of new vehicles has continued to slowly diverge from 2-cycle test data, due largely to changing technology, driving patterns, and vehicle design.

Figure D.1. Estimated Real-World versus 2-Cycle Fuel Economy since Model Year 1975



Other Database Changes

Addition of Medium-Duty Passenger Vehicles

Beginning in 2011 medium-duty passenger vehicles (MDPVs), those SUVs and passenger vans (but not pickup trucks) with gross vehicle weight ratings between 8,500 and 10,000 pounds, are included in the light-duty truck category. This coincided with new regulations by NHTSA to treat these vehicles as light-duty, rather than heavy-duty, vehicles beginning in model year 2011. This represents a minor change to the database, since the number of MDPVs is much smaller than it once was (e.g., only 6,500 MDPVs were sold in model year 2012). It should be noted that this is one change to the database that has not been propagated back through the historic database, as we do not have MDPV data prior to model year 2011. Accordingly, this represents a small inflection point for the database for the overall car and truck fleet in model year 2011; the inclusion of MDPVs decreased average real-world fuel economy by 0.01 mpg and increased average real-world CO_2 emissions by 0.3 g/mi, compared to the fleet without MDPVs. The impacts on the truck fleet only were about twice as high, but still very small in absolute terms. Pickup trucks above 8,500 pounds are not included in this report.

Addition of Alternative Fuel Vehicles

Data from alternative fuel vehicles are integrated into the overall database, beginning with MY 2011 data. These vehicles include electric vehicles, plug-in hybrid vehicles, fuel cell vehicles, and compressed natural gas vehicles. CO_2 emissions from alternative fuel vehicles represent tailpipe emissions, and fuel economy for these vehicles is reported as mpge (miles per gallon of gasoline equivalent), or the miles an alternative fuel vehicle can travel on an amount of energy equivalent to that in a gallon of gasoline. Sales data prior to MY 2011 are included in some cases based on available industry reports (e.g., Ward's Automotive data).

Changes in Vehicle Classification Definitions

The car-truck classifications in this report follow the current regulatory definitions used by EPA and NHTSA for compliance with GHG emissions and CAFE standards (see definitions for passenger automobiles (cars) and non-passenger automobiles (trucks) in 49 CFR 523). These current definitions differ from those used in the 2010 and older versions of the *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends* report, and reflect a decision by NHTSA to reclassify many small, 2-wheel drive sport utility vehicles (SUVs) from the truck category to the car category, beginning with model year 2011. When this re-classification was initiated in the 2011 report, the absolute truck share decreased by approximately 10%.

The current car-truck definitions have been propagated back throughout the entire historical Trends database to maintain the integrity of long-term trends of car and truck production share. Since the authors did not have all of the requisite technical information on which to make retroactive car-truck classifications, we used engineering judgment to classify past models.

This report previously presented data on more vehicle types, but recent vehicle design has led to far less distinction between vehicle types and reporting on more disaggregated vehicle types was no longer useful.

Manufacturer Definitions

When a manufacturer grouping changes under the GHG and CAFE programs, the current manufacturer definitions are generally applied to all prior model years. This maintains consistent manufacturer and make definitions over time, which enables better identification of long-term trends. However, some of the compliance data maintain the

previous manufacturer definitions where necessary to preserve the integrity of compliance data as they were accrued.

Differences in Production Data Between CAFE and GHG Regulations

The data used to discuss real-world trends in Sections 1 through 4 of this report are based on production volumes reported under CAFE prior to model year 2017, not the GHG standards. The production volume levels automakers provide in their final CAFE reports may differ slightly from their final GHG reports (typically less than 0.1%) because of different reporting requirements. The EPA regulations require emission compliance in the 50 states, the District of Columbia, Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands, whereas the CAFE program requires data from the 50 states, the District of Columbia, and Puerto Rico only. All compliance data detailed in Section 5, for all years, are based on production volumes reported under the GHG standards. Starting with model year 2017 and forward, the real-world data are also based on production volumes reported under EPA' s GHG standards. As described above, the difference in production volumes is very small and does not impact the long-term trends or analysis.

E. Electric Vehicle and Plug-In Hybrid Metrics

Electric Vehicles (EVs) and Plug-in Hybrid Vehicles (PHEVs) have continued to gain market share. While overall market penetration of these vehicles is still low, their production share is projected to reach 4% in model year 2020. This section addresses some of the technical metrics used both to quantify EV and PHEV operation and to integrate data from these vehicles with gasoline and diesel vehicle data.

EVs operate using only energy stored in a battery from external charging. PHEVs blend EV technology with more familiar powertrain technology from petroleum-fueled vehicles. Current PHEVs feature both an electric drive system designed to be charged from an electricity source external to the vehicle (like an EV) and a gasoline internal combustion engine. There are generally three ways that a PHEV can operate:

- Charge-depleting electric-only mode – In electric-only mode the vehicle operates like an EV, using only energy stored in the battery to propel the vehicle.
- Charge-depleting blended mode – In blended mode the vehicle uses both energy stored in the battery and energy from the gasoline tank to propel the vehicle. Depending on the vehicle design and driving conditions, blended operation can include substantial all-electric driving.
- Charge-sustaining mode – In charge-sustaining mode, the PHEV has exhausted the external energy from the electric grid that is stored in the battery and relies on the gasoline internal combustion engine. In charge-sustaining mode, the vehicle will operate much like a traditional hybrid.

The presence of both electric drive and an internal combustion engine results in a complex system that can be used in many different combinations, and manufacturers are choosing to operate PHEV systems in different ways. This complicates direct comparisons among PHEV models.

This section discusses EV and PHEV metrics for several example model year 2020 vehicles. For consistency and clarity for the reader, the data for specific vehicles discussed in this section reflect values from the EPA/DOT Fuel Economy and Environment Labels, which use a 55% city / 45% highway weighting for combined fuel economy and CO_2 values. When data for these vehicles are integrated into the data for the rest of the report, the real-world highway and city values are combined using a 43% city / 57% highway weighting. Additionally, some PHEV calculations are also adjusted, as explained at the end of this section.

Table E.1 shows the label driving range for several EVs and PHEVs when operating only on electricity, as well as the total electricity plus gasoline range for PHEVs. The average range of new EVs is increasing, as shown in Section 4, and many EVs are approaching the range of an average gasoline vehicle. [28] PHEVs generally have a much smaller all electric range, however the combined electric and gasoline range for PHEVs often exceeds gasoline-only vehicles. Several PHEVs now exceed 500 miles of total range.

Table E.1. Model Year 2020 Example EV and PHEV Powertrain and Range

Manufacturer	Model	Fuel or Powertrain	Electric Range (miles)	Total Range (miles)	Utility Factor
GM	Bolt	EV	259	259	-
Nissan	Leaf 62 kWh	EV	226	226	-
Tesla	Model 3 LR	EV	330	330	-
FCA	Pacifica	PHEV	32	520	0.61
Ford	Escape	PHEV	37	530	0.66
Honda	Clarity	PHEV	48	340	0.73
Toyota	Prius Prime	PHEV	25	640	0.53
Volvo	XC90	PHEV	18	520	0.43

Determining the electric range of PHEVs is complicated if the vehicle can operate in blended modes. For PHEVs like the Ford Escape, which cannot operate in blended mode, the electric range represents the estimated range operating in electric only mode. However, for PHEVs that operate in a blended mode, the electric range represents the estimated range of the vehicle operating in either electric only *or* blended mode, due to the design of the vehicle. For example, the Volvo XC90 uses electricity stored in its battery and a small amount of gasoline to achieve an alternative fuel range of 18 miles. Some PHEVs did not use any gasoline to achieve their electric range value on EPA test cycles; however, certain driving conditions (e.g., more aggressive accelerations, higher speeds, and air conditioning or heater operation) would likely cause these vehicles to operate in a blended mode instead of an all-electric mode.

Table E.1 also introduces the concept of a utility factor. The utility factor is directly related to the electric range for PHEVs, and is a projection, on average, of the percentage of miles that will be driven using electricity (in electric-only and blended modes) by an average

[28] In addition to growing EV range, the number of public electric vehicle charging stations is growing rapidly. For more information, see the U.S. Department of Energy's Alternative Fuels Data Center at https://www.afdc.energy.gov/.

driver. The model year 2020 Escape, for example, has a utility factor of 0.66, i.e., it is expected that, on average, the Escape will operate 66% of the time on electricity and 34% of the time on gasoline. Utility factor calculations are based on an SAE methodology that EPA has adopted for regulatory compliance (SAE 2010).

Table E.2 shows five energy-related metrics for model year 2020 example EVs and PHEVs that are included on the EPA/NHTSA Fuel Economy and Environment labels. Comparing the energy or fuel efficiency performance from alternative fuel vehicles raises complex issues of how to compare different fuels. Consumers and OEMs are familiar and comfortable with evaluating gasoline and diesel vehicle fuel economy in terms of miles per gallon, and it is the primary efficiency metric in this report. To enable this comparison for alternative fuel vehicles, the overall energy efficiency of vehicles operating on electricity, hydrogen, and CNG are evaluated in terms of miles per gallon of gasoline equivalent (an energy metric described in more detail below).

Table E.2. Model Year 2020 Example EV and PHEV Fuel Economy Label Metrics

			Charge Depleting			Charge Sustaining	Overall
Manufacturer	**Model**	**Fuel or Power -train**	**Electricity (kW-hrs/ 100 miles)**	**Gasoline (gallons/ 100 miles)**	**Fuel Economy (mpge)**	**Fuel Economy (mpg)**	**Fuel Economy (mpge)**
GM	Bolt	EV	29	-	118	N/A	118
Nissan	Leaf 62 kWh	EV	31	-	108	N/A	108
Tesla	Model 3 LR	EV	26	-	130	N/A	130
FCA	Pacifica	PHEV	41	0.0	82	30	48
Ford	Escape	PHEV	33	0.0	102	41	66
Honda	Clarity	PHEV	31	0.0	110	42	76
Toyota	Prius Prime	PHEV	25	0.0	133	54	78
Volvo	XC90	PHEV	58	0.1	55	27	34

The fourth column in Table E.2 gives electricity consumption rates for EVs and PHEVs during charge depleting operation in units of kilowatt-hours per 100 miles (kW-hrs/100 miles). As shown on the vehicle label, the electricity consumption rate is based on the amount of electricity required from an electric outlet to charge the vehicle and includes wall-to-vehicle charging losses. The values for all of the EVs and PHEVs reflect the electricity consumption rate required to operate the vehicle in either electric-only or blended mode operation. PHEVs that are capable of operating in a blended mode may also consume some gasoline in addition to electricity. Any additional gasoline used is shown in the fifth column. For example, the Volvo XC90 PHEV consumes 58 kW-hrs and 0.1 gallons of gasoline per 100 miles during this combination of electric-only and blended modes.

The sixth column converts the electricity consumption data in the fourth column and the gasoline consumption data in the fifth column into a combined miles per gallon of gasoline-equivalent (mpge) metric. The mpge metric is a measure of the miles the vehicle can travel on an amount of energy that is equal to the amount of energy stored in a gallon of gasoline. For a vehicle operating on electricity, mpge is calculated as 33.705 kW-hrs/gallon divided by the vehicle electricity consumption in kW-hrs/mile. For example, for the Leaf, 33.705 kW-hrs/gallon divided by 0.31 kW-hrs/mile (equivalent to 31 kW-hrs/100 miles) is 108 mpge.[29] Because the Volvo XC90 consumes both electricity and gasoline over the alternative fuel range of 18 miles, the charge depleting fuel economy of 55 mpge includes both the electricity and gasoline consumption, at a rate of 58 kW-hrs/100 miles of electricity and 0.1 gal/100 miles of gasoline.

The seventh column gives label fuel economy values for vehicles operating on gasoline only, which is relevant here only for the PHEVs operating in charge sustaining mode. For PHEVs, the EPA/NHTSA label shows both electricity consumption in kW-hrs/100 miles and mpge, when the vehicle operates exclusively on electricity or in a blended mode, and gasoline fuel economy in mpg, when the vehicle operates exclusively on gasoline.

The final column gives the overall mpge values reflecting the overall energy efficiency of the vehicle for all of the fuels on which the vehicle can operate, and provide a common metric to compare vehicles that operate on different fuels. In addition to the energy metrics in the previous columns, the one key additional parameter necessary to calculate a combined electricity/gasoline mpge value for a PHEV is the utility factor that was introduced in Table E.1. For EVs the overall fuel economy in the last column is equal to the charge depleting fuel economy, as EVs can only operate in a charge depleting mode.

Table E.3 gives vehicle tailpipe CO_2 emissions values that are included on the EPA/DOT Fuel Economy and Environment labels (and reflected in the label's Greenhouse Gas Rating). These label values reflect EPA's best estimate of the CO_2 tailpipe emissions that these vehicles will produce, on average, in real-world city and highway operation. EVs, of course, have no tailpipe emissions. For the PHEVs, the label CO_2 emissions values utilize the same utility factors discussed above to weight the CO_2 emissions on electric and gasoline operation.

[29] The actual calculations were done with unrounded numbers. Using the rounded numbers provided here may result in a slightly different number due to rounding error.

Table E.3. Model Year 2020 Example EV and PHEV Label Tailpipe CO_2 Emissions Metrics

Manufacturer	Model	Fuel or Powertrain	Tailpipe CO_2 (g/mile)
GM	Bolt	EV	0
Nissan	Leaf 62 kWh	EV	0
Tesla	Model 3 LR	EV	0
FCA	Pacifica	PHEV	119
Ford	Escape	PHEV	77
Honda	Clarity	PHEV	57
Toyota	Prius Prime	PHEV	78
Volvo	XC90	PHEV	197

Table E.4 accounts for the "upstream" CO_2 emissions associated with the production and distribution of electricity used in EVs and PHEVs. Gasoline and diesel fuels also have CO_2 emissions associated with their production and distribution, but these upstream emissions are not reflected in the tailpipe CO_2 emissions values discussed elsewhere in this report. Combining vehicle tailpipe and fuel production/distribution sources, gasoline vehicles emit about 80 percent of total CO_2 emissions at the vehicle tailpipe with the remaining 20 percent of total CO_2 emissions associated with upstream fuel production and distribution. Diesel fuel has a similar approximate relationship between tailpipe and upstream CO_2 emissions. On the other hand, vehicles powered by grid electricity emit no CO_2 (or other emissions) at the vehicle tailpipe; therefore, all CO_2 emissions associated with an EV are due to fuel production and distribution. Depending on how the electricity is produced, these fuels can have very high fuel production/distribution CO_2 emissions (for example, if coal is used with no CO_2 emissions control) or very low CO_2 emissions (for example, if renewable processes with minimal fossil energy inputs are used).

Electricity production in the United States varies significantly from region to region and has been changing over time. Hydroelectric plants provide a large percentage of electricity in the Northwest, while coal-fired power plants produce the majority of electricity in the Midwest. Natural gas, wind, and solar have increased their electricity market share in many regions of the country. Nuclear power plants make up most of the balance of U.S. electricity production. In order to bracket the possible GHG emissions impact, Table E.4 provides ranges with the low end of the range corresponding to the California power plant GHG emissions factor, the middle of the range represented by the national average power

plant GHG emissions factor, and the upper end of the range corresponding to the power plant GHG emissions factor for part of the Midwest (Illinois and Missouri).

Table E.4. Model Year 2020 Example EV and PHEV Upstream CO_2 Emission Metrics (g/mi)

Manufacturer	Model	Fuel or Powertrain	Tailpipe + Total Upstream CO_2			Tailpipe + Net Upstream CO_2		
			Low	Avg	High	Low	Avg	High
GM	Bolt	EV	73	136	232	20	82	179
Nissan	Leaf 62 kWh	EV	80	148	254	23	91	197
Tesla	Model 3 LR	EV	66	122	210	4	60	148
FCA	Pacifica	PHEV	213	267	351	128	182	267
Ford	Escape	PHEV	152	199	273	94	142	215
Honda	Clarity	PHEV	129	178	255	72	120	197
Toyota	Prius Prime	PHEV	131	160	205	82	111	155
Volvo	XC90	PHEV	305	359	444	221	275	359
Average Sedan/Wagon			**346**	**346**	**346**	**277**	**277**	**277**

Based on data from EPA's eGRID power plant database,[30] and accounting for additional greenhouse gas emissions impacts for feedstock processing upstream of the power plant,[31] EPA estimates that the electricity CO_2 emission factors for various regions of the country vary from 256 g CO_2/kW-hr in California to 811 g CO_2/kW-hr in the Midwest, with a national average of 473 g CO_2/kW-hr. Emission rates for small regions in upstate New York and Alaska have lower electricity upstream CO_2 emission rates than California. However, California is a good surrogate for the "low" end of the range because California is a leading market for current EVs and PHEVs. Initial sales of electric vehicles have been largely, though not exclusively, focused in regions of the country with power plant CO_2 emissions factors lower than the national average, such as California, New York, and other coastal areas. Accordingly, in terms of CO_2 emissions, EPA believes that the current "sales-weighted average" vehicle operating on electricity in the near term will likely fall somewhere between the low end of this range and the national average.[32]

[30] Abt Associates 2020. The emissions & generation resource integrated database technical support document for eGRID 2018, prepared for the U.S. Environmental Protection Agency, January 2020.
[31] Argonne National Laboratory 2019. GREET_1_2019 Model. greet.es.anl.gov.
[32] To estimate the upstream greenhouse gas emissions associated with operating an EV or PHEV in a specific geographical area, use the emissions calculator at www.fueleconomy.gov/feg/Find.do?action=bt2.

The fourth through sixth columns in Table E.4 provide the range of tailpipe plus *total* upstream CO_2 emissions for EVs and PHEVs based on regional electricity emission rates. For comparison, the average model year 2020 car is also included in the last row of Table E.4. The methodology used to calculate the range of tailpipe plus total upstream CO_2 emissions for EVs is shown in the following example for the model year 2020 Nissan Leaf (62 kWh battery):

- Start with the label (5-cycle values weighted 55% city / 45% highway) vehicle electricity consumption in kW-hr/mile, which for the Leaf is 31 kW-hr/100 miles, or 0.31 kW-hr/mile
- Determine the regional powerplant emission rate, regional losses during electricity distribution, and the additional regional emissions due to fuel production upstream of the powerplant (for California, these numbers are 225 g/kW-hr, 4.8%, and 8.3%, respectively).
- Determine the regional upstream emission factor (for California 225 g/kW-hr / (1–0.048) * (1+0.083) = 256 g CO_2/kW-hr)[33]
- Multiply by the range of Low (California = 256g CO_2/kW-hr), Average (National Average = 473 g CO_2/kW-hr), and High (Midwest = 811 g CO_2/kW-hr) electricity upstream CO_2 emission rates, which yields a range for the Leaf of 80-254 grams CO_2/mile.

The tailpipe plus total upstream CO_2 emissions values for PHEVs include the upstream CO_2 emissions due to electricity operation and both the tailpipe and upstream CO_2 emissions due to gasoline operation, using the utility factor discussed above to weight the values for electricity and gasoline operation. The tailpipe plus total upstream CO_2 emissions values for the average car are the average real-world model year 2018 car tailpipe CO_2 emissions multiplied by 1.25 to account for upstream emissions due to gasoline production.

The values in columns four through six are tailpipe plus *total* upstream CO_2 emissions. As mentioned, all of the gasoline and diesel vehicle CO_2 emissions data in the rest of this report refer only to tailpipe emissions and do not reflect the upstream emissions associated with gasoline or diesel production and distribution. Accordingly, in order to equitably compare the overall relative impact of EVs and PHEVs with tailpipe emissions of petroleum-fueled vehicles, EPA uses the metric "tailpipe plus *net* upstream emissions" for EVs and PHEVs. The net upstream emissions for an EV is equal to the total upstream

[33] The actual calculations were done with unrounded numbers. Using the rounded numbers provided here may result in a slightly different number due to rounding error.

emissions for the EV minus the upstream emissions that would be expected from a comparably sized gasoline vehicle; size is a good first-order measure for utility, and footprint is the size-based metric used for standards compliance. The net upstream emissions for PHEVs are equal to the net upstream emissions of the PHEV due to electricity consumption in electric or blended mode multiplied by the utility factor. The net upstream emissions for a gasoline vehicle are zero. This approach was adopted for EV and PHEV regulatory compliance with the 2012–2016 light-duty vehicle GHG emissions standards for the production of EVs and PHEVs beyond a threshold; however, those thresholds were never exceeded.

For each EV or PHEV, the upstream emissions for a comparable gasoline vehicle are determined by first using the footprint-based compliance curves to determine the CO_2 compliance target for a vehicle with the same footprint. Since upstream emissions account for approximately 20% of total CO_2 emissions for gasoline vehicles, the upstream emissions for the comparable gasoline vehicle are equal to one-fourth of the tailpipe-only compliance target.

The final three columns of Table E.4 give the tailpipe plus net upstream CO_2 values for EVs and PHEVs using the same Low, Average, and High electricity upstream CO_2 emissions rates discussed above. These values bracket the possible real-world net CO_2 emissions that would be associated with consumer use of these vehicles. For the Leaf, these values are simply the values in columns four through six minus the upstream GHG emissions of a comparably sized gasoline vehicle. Based on the model year 2020 CO_2 footprint curve, the 5-cycle tailpipe GHG emissions for a Leaf-sized gasoline vehicle meeting its compliance target would be close to 226 grams/mi, with upstream emissions of one-fourth of this value, or 57 g/mi. The net upstream emision for a Leaf (with the 62 kWh battery) are determined by subtracting this value, 57 g/mi, from the total (tailpipe + total upstream). The result is a range for the tailpipe plus net upstream value of 23–197 g/mile as shown in Table E.4, with a more likely sales-weighted value in the 23–91 g/mi range.

For PHEVs, the tailpipe plus net upstream emissions values use the utility factor values discussed above to weight the individual values for electric operation and gasoline operation.

Alternative Metrics for EVs and PHEVs

Determining metrics for EVs and PHEVs that are meaningful and accurate is challenging. In particular, vehicles capable of using dual fuels, such as PHEVs, can have complicated modes of operation that make it difficult to determine meaningful metrics. Here we've

discussed several metrics that are used on the EPA/DOT Fuel Economy and Environment Labels and in a regulatory context, namely mpge, tailpipe CO_2 emissions, and net upstream GHG emissions. There are, however, other ways that alternative fuel vehicle operation can be quantified.

Other energy metric options that could be considered include: (1) mpge plus net fuel life cycle energy, which would also reflect differences in upstream energy consumption in producing the alternative fuel relative to gasoline-from-oil; and (2) miles per gallon of gasoline, which would only count gasoline use and not other forms of energy. Compared to mpge, using the mpge plus net fuel life-cycle energy metric would generally result in lower fuel economy values, and using the miles per gallon of gasoline metric would yield higher fuel economy values.

Additional Note on PHEV Calculations

Calculating fuel economy and CO_2 emission values for PHEVs is a complicated process, as discussed in this section. The examples given for individual vehicles were based on calculations behind the EPA/DOT Fuel Economy and Environment Labels. In addition to the approach used for the labels, there are multiple methods for determining utility factors depending on the intended use of the value. The standardized utility factor calculations are defined in the Society of Automobile Engineers (SAE) document SAE J2841.

The utility factors that are used for fleetwide calculations are somewhat different than those used to create label values. For label values, multi-day individual utility factors (MDIUF) are used to incorporate "a driver's day to day variation into the utility calculation." For fleetwide calculations, fleet utility factors (FUF) are applied to "calculate the expected fuel and electric consumption of an entire fleet of vehicles." Since the Trends report is generally a fleetwide analysis, the FUF utility factors were applied, instead of the MDIUF utility factors, when the data were integrated with the rest of the fleet data. Additionally, since Trends uses a 43% city / 57% highway weighting for combining real-world fuel economy and CO_2 data, the FUF utility factors created for Trends were based on that weighting, not on 55% city / 45% highway weighting used on the fuel economy label.

F. Authors and Acknowledgments

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Table 2.1
Production, Estimated Real-World CO2, and Fuel Economy for Model Year 1975–2020

Model Year	Production (000)	Real-World CO_2 (g/mi)	Real-World FE (mpg)
1975	10,224	681	13.1
1976	12,334	625	14.2
1977	14,123	590	15.1
1978	14,448	562	15.8
1979	13,882	560	15.9
1980	11,306	466	19.2
1981	10,554	436	20.5
1982	9,732	425	21.1
1983	10,302	426	21.0
1984	14,020	424	21.0
1985	14,460	417	21.3
1986	15,365	407	21.8
1987	14,865	405	22.0
1988	15,295	407	21.9
1989	14,453	415	21.4
1990	12,615	420	21.2
1991	12,573	418	21.3
1992	12,172	427	20.8
1993	13,211	426	20.9
1994	14,125	436	20.4
1995	15,145	434	20.5
1996	13,144	435	20.4
1997	14,458	441	20.2
1998	14,456	442	20.1
1999	15,215	451	19.7
2000	16,571	450	19.8
2001	15,605	453	19.6
2002	16,115	457	19.5
2003	15,773	454	19.6
2004	15,709	461	19.3
2005	15,892	447	19.9
2006	15,104	442	20.1
2007	15,276	431	20.6
2008	13,898	424	21.0
2009	9,316	397	22.4
2010	11,116	394	22.6
2011	12,018	399	22.3
2012	13,449	377	23.6
2013	15,198	368	24.2
2014	15,512	369	24.1
2015	16,739	360	24.6
2016	16,278	359	24.7
2017	17,016	357	24.9
2018	16,259	353	25.1
2019	16,139	356	24.9
2020 (prelim)	-	*344*	*25.7*

Table 2.2
Manufacturers and Vehicles with the Highest Fuel Economy, by Year

			Overall Vehicle with Highest Fuel Economy**			Gasoline (Non-Hybrid) Vehicle with Highest Fuel Economy (mpg)	
Model Year	Manufacturer with Highest Fuel Economy* (mpg)	Manufacturer with Lowest Fuel Economy (mpg)	Vehicle	Real-World FE (mpg)	Engine Type	Gasoline Vehicle	Real-World FE (mpg)
1975	Honda	Ford	Honda Civic	28.3	Gas	Honda Civic	28.3
1976	Honda	Ford	Honda Civic	30.5	Gas	Honda Civic	30.5
1977	Honda	FCA	Honda Civic	37.6	Gas	Honda Civic	37.6
1978	Mazda	Ford	VW Rabbit	37.5	Diesel	Nissan B-210	34.3
1979	Honda	Ford	VW Rabbit	39.1	Diesel	Nissan 210	33.6
1980	VW	Ford	VW Rabbit	40.3	Diesel	Nissan 210	36.1
1981	VW	Ford	VW Rabbit	40.9	Diesel	Toyota Starlet	37.9
1982	Honda	Ford	VW Rabbit	42.7	Diesel	Nissan Sentra	41.0
1983	Honda	Ford	Nissan Sentra	45.3	Diesel	Honda Civic	42.4
1984	Honda	Ford	Honda Civic	48.0	Gas	Honda Civic	48.0
1985	Honda	Mercedes	GM Sprint	49.6	Gas	GM Sprint	49.6
1986	Hyundai	Mercedes	GM Sprint	56.8	Gas	GM Sprint	56.8
1987	Hyundai	Mercedes	GM Sprint	54.8	Gas	GM Sprint	54.8
1988	Hyundai	Mercedes	GM Metro	54.4	Gas	GM Metro	54.4
1989	Hyundai	Mercedes	Honda Civic	50.6	Gas	Honda Civic	50.6
1990	Hyundai	Mercedes	GM Metro	53.4	Gas	GM Metro	53.4
1991	Hyundai	Mercedes	GM Metro	53.0	Gas	GM Metro	53.0
1992	Hyundai	Mercedes	GM Metro	52.6	Gas	GM Metro	52.6
1993	Honda	Mercedes	GM Metro	52.2	Gas	GM Metro	52.2
1994	Kia	FCA	GM Metro	52.2	Gas	GM Metro	52.2
1995	Honda	FCA	Honda Civic	47.3	Gas	Honda Civic	47.3
1996	Hyundai	FCA	Suzuki Swift	43.3	Gas	Suzuki Swift	43.3
1997	Hyundai	FCA	GM Metro	42.8	Gas	GM Metro	42.8
1998	Honda	FCA	GM Metro	42.0	Gas	GM Metro	42.0
1999	Hyundai	FCA	VW Jetta	41.0	Diesel	GM Metro	39.3
2000	Hyundai	FCA	Honda Insight	57.4	Hybrid	GM Metro	39.4
2001	Hyundai	FCA	Honda Insight	56.3	Hybrid	Honda Civic	37.3
2002	Honda	FCA	Honda Insight	55.6	Hybrid	Honda Civic	35.9
2003	Honda	Ford	Honda Insight	55.0	Hybrid	Honda Civic	35.5
2004	Honda	Ford	Honda Insight	53.5	Hybrid	Honda Civic	35.3
2005	Honda	Ford	Honda Insight	53.3	Hybrid	Honda Civic	35.1
2006	Mazda	Ford	Honda Insight	53.0	Hybrid	Toyota Corolla	32.3
2007	Toyota	Mercedes	Toyota Prius	46.2	Hybrid	Toyota Yaris	32.6
2008	Hyundai	Mercedes	Toyota Prius	46.2	Hybrid	Smart Fortwo	37.1
2009	Toyota	FCA	Toyota Prius	46.2	Hybrid	Smart Fortwo	37.1
2010	Hyundai	Mercedes	Honda FCX	60.2	FCV	Smart Fortwo	36.8
2011	Hyundai	Mercedes	BMW Active E	100.6	EV	Smart Fortwo	35.7
2012	Hyundai	FCA	Nissan i-MiEV	109.0	EV	Toyota iQ	36.8
2013	Hyundai	FCA	Toyota IQ	117.0	EV	Toyota iQ	36.8
2014	Mazda	FCA	BMW i3	121.3	EV	Mitsubishi Mirage	39.5
2015	Mazda	FCA	BMW i3	121.3	EV	Mitsubishi Mirage	39.5
2016	Mazda	FCA	BMW i3	121.3	EV	Mazda 2	37.1
2017	Honda	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5
2018	Tesla	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5

Table 2.2
Manufacturers and Vehicles with the Highest Fuel Economy, by Year

			Overall Vehicle with Highest Fuel Economy**			Gasoline (Non-Hybrid) Vehicle with Highest Fuel Economy (mpg)	
Model Year	Manufacturer with Highest Fuel Economy* (mpg)	Manufacturer with Lowest Fuel Economy (mpg)	Vehicle	Real-World FE (mpg)	Engine Type	Gasoline Vehicle	Real-World FE (mpg)
2019	Tesla	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.6
2020 (prelim)	*Tesla*	*FCA*	*Tesla Model 3 SR+*	*138.6*	*EV*	*Mitsubishi Mirage*	*40.1*

* Manufacturers below the 125,000 threshold for “large” manufacturers are excluded in years they did not meet the threshold.

** Vehicles are shown based on estimated real-world fuel economy as calculated for this report. These values will differ from values found on the fuel economy labels at the time of sale. For more information on fuel economy metrics see Appendix C.

Table 2.3
Manufacturer Estimated Real-World Fuel Economy and CO_2 Emissions for Model Year 2018 - 2020

	MY 2018 Final		MY 2019 Final				*MY 2020 Preliminary*	
Manufacturer	**Real-World FE (mpg)**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**FE Change from MY 2018 (mpg)**	**Real-World CO_2 (g/mi)**	**CO_2 Change from MY 2018 (g/mi)**	***Real-World FE (mpg)***	***Real-World CO_2 (g/mi)***
BMW	26.0	339	26.2	0.2	337	-2	*25.5*	*346*
FCA	21.7	409	21.2	-0.5	418	9	*21.8*	*408*
Ford	22.4	397	22.5	0.1	395	-2	*23.3*	*381*
GM	23.0	386	22.5	-0.5	395	9	*22.8*	*391*
Honda	30.0	296	28.9	-1.1	307	12	*29.7*	*299*
Hyundai	28.6	311	28.5	0.0	311	-1	*28.9*	*306*
Kia	27.8	319	28.1	0.3	316	-4	*27.3*	*324*
Mazda	28.7	310	27.8	-0.9	320	10	*27.6*	*323*
Mercedes	23.5	377	23.7	0.2	374	-3	*23.9*	*372*
Nissan	27.1	327	27.0	-0.2	329	2	*27.4*	*323*
Subaru	28.7	310	28.4	-0.3	312	3	*28.3*	*313*
Tesla	113.7	0	118.0	4.3	0	0	*119.1*	*0*
Toyota	25.5	348	25.8	0.3	345	-3	*26.2*	*339*
VW	24.6	361	26.1	1.5	338	-23	*24.4*	*360*
All Manufacturers	**25.1**	**353**	**24.9**	**-0.2**	**356**	**3**	***25.7***	***344***

Table 3.1
Vehicle Attributes by Model Year

Model Year	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Weight (lbs)	Horsepower (HP)	0 to 60 (s)	Footprint (ft^2)	Car Production Share	Truck Production Share
1975	681	13.1	4,060	137	-	-	80.7%	19.3%
1976	625	14.2	4,079	135	-	-	78.9%	21.1%
1977	590	15.1	3,982	136	-	-	80.1%	19.9%
1978	562	15.8	3,715	129	13.6	-	77.5%	22.5%
1979	560	15.9	3,655	124	14.6	-	77.9%	22.1%
1980	466	19.2	3,228	104	15.6	-	83.5%	16.5%
1981	436	20.5	3,202	102	15.6	-	82.8%	17.2%
1982	425	21.1	3,202	103	16.6	-	80.5%	19.5%
1983	426	21.0	3,257	107	14.9	-	78.0%	22.0%
1984	424	21.0	3,262	109	14.7	-	76.5%	23.5%
1985	417	21.3	3,271	114	14.1	-	75.2%	24.8%
1986	407	21.8	3,238	114	13.4	-	72.1%	27.9%
1987	405	22.0	3,221	118	13.4	-	72.8%	27.2%
1988	407	21.9	3,283	123	13.3	-	70.9%	29.1%
1989	415	21.4	3,351	129	12.5	-	70.1%	29.9%
1990	420	21.2	3,426	135	11.5	-	70.4%	29.6%
1991	418	21.3	3,410	138	11.5	-	69.6%	30.4%
1992	427	20.8	3,512	145	11.0	-	68.6%	31.4%
1993	426	20.9	3,519	147	10.3	-	67.6%	32.4%
1994	436	20.4	3,603	152	10.1	-	61.9%	38.1%
1995	434	20.5	3,613	158	10.1	-	63.5%	36.5%
1996	435	20.4	3,659	164	10.4	-	62.2%	37.8%
1997	441	20.1	3,727	169	10.2	-	60.1%	39.9%
1998	442	20.1	3,744	171	10.4	-	58.3%	41.7%
1999	451	19.7	3,835	179	10.3	-	58.3%	41.7%
2000	450	19.8	3,821	181	9.8	-	58.8%	41.2%
2001	453	19.6	3,879	187	9.5	-	58.6%	41.4%
2002	457	19.5	3,951	195	9.4	-	55.2%	44.8%
2003	454	19.6	3,999	199	9.3	-	53.9%	46.1%
2004	461	19.3	4,111	211	9.1	-	52.0%	48.0%
2005	447	19.9	4,059	209	9.0	-	55.6%	44.4%
2006	442	20.1	4,067	213	8.9	-	57.9%	42.1%
2007	431	20.6	4,093	217	8.9	-	58.9%	41.1%
2008	424	21.0	4,085	219	8.9	48.9	59.3%	40.7%
2009	397	22.4	3,914	208	8.8	47.9	67.0%	33.0%
2010	394	22.6	4,001	214	8.8	48.5	62.8%	37.2%
2011	399	22.3	4,126	230	8.5	49.5	57.8%	42.2%
2012	377	23.6	3,979	222	8.5	48.8	64.4%	35.6%
2013	368	24.2	4,003	226	8.4	49.1	64.1%	35.9%
2014	369	24.1	4,060	230	8.3	49.7	59.3%	40.7%
2015	360	24.6	4,035	229	8.3	49.4	57.4%	42.6%
2016	359	24.7	4,035	230	8.3	49.5	55.3%	44.7%
2017	357	24.9	4,093	234	8.2	49.8	52.6%	47.4%
2018	353	25.1	4,137	241	8.0	50.4	48.0%	52.0%
2019	356	24.9	4,156	245	7.9	50.8	44.4%	55.6%
2020 (prelim)	*344*	*25.7*	*4,177*	*247*	*7.7*	*50.4*	*42.8%*	*57.2%*

Table 3.2
Estimated Real-World Fuel Economy and CO_2 by Vehicle Type

	Sedan/Wagon			Car SUV			Truck SUV			Minivan/Van			Pickup		
Model Year	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)
1975	80.6%	660	13.5	0.1%	799	11.1	1.7%	806	11.0	4.5%	800	11.1	13.1%	746	11.9
1976	78.8%	598	14.9	0.1%	840	10.6	1.9%	755	11.8	4.1%	754	11.8	15.1%	714	12.4
1977	80.0%	570	15.6	0.1%	731	12.2	1.9%	692	12.8	3.6%	710	12.5	14.3%	656	13.6
1978	77.3%	525	16.9	0.1%	768	11.6	2.5%	723	12.3	4.3%	736	12.1	15.7%	668	13.3
1979	77.8%	517	17.2	0.1%	623	14.3	2.8%	844	10.5	3.5%	774	11.5	15.9%	674	13.2
1980	83.5%	446	20.0	0.0%	610	14.6	1.6%	676	13.2	2.1%	629	14.1	12.7%	541	16.5
1981	82.7%	418	21.4	0.0%	605	14.7	1.3%	621	14.3	2.3%	599	14.8	13.6%	500	17.9
1982	80.3%	402	22.2	0.1%	450	19.8	1.5%	616	14.7	3.2%	605	14.7	14.8%	486	18.5
1983	77.7%	403	22.1	0.3%	430	20.7	2.5%	568	15.8	3.7%	593	15.1	15.8%	473	18.9
1984	76.1%	397	22.4	0.4%	461	19.3	4.1%	551	16.2	4.8%	552	16.1	14.6%	488	18.3
1985	74.6%	387	23.0	0.6%	443	20.1	4.5%	538	16.5	5.9%	537	16.5	14.4%	489	18.2
1986	71.7%	375	23.7	0.4%	470	18.9	4.6%	523	17.0	6.8%	509	17.5	16.5%	471	18.9
1987	72.2%	373	23.8	0.6%	458	19.4	5.2%	515	17.3	7.5%	503	17.7	14.4%	467	19.0
1988	70.2%	368	24.1	0.7%	462	19.2	5.6%	522	17.0	7.4%	497	17.9	16.1%	490	18.1
1989	69.3%	375	23.7	0.7%	465	19.1	5.7%	537	16.6	8.8%	499	17.8	15.4%	499	17.8
1990	69.8%	381	23.3	0.5%	472	18.8	5.1%	541	16.4	10.0%	498	17.8	14.5%	511	17.4
1991	67.8%	379	23.4	1.8%	488	18.2	6.9%	531	16.7	8.2%	496	17.9	15.3%	489	18.2
1992	66.6%	385	23.1	2.0%	498	17.8	6.2%	548	16.2	10.0%	496	17.9	15.1%	508	17.5
1993	64.0%	379	23.5	3.6%	522	17.0	6.3%	546	16.3	10.9%	488	18.2	15.2%	505	17.6
1994	59.6%	382	23.3	2.3%	493	18.0	9.1%	555	16.0	10.0%	498	17.8	18.9%	510	17.4
1995	62.0%	379	23.4	1.5%	499	17.8	10.5%	555	16.0	11.0%	492	18.1	15.0%	526	16.9
1996	60.0%	381	23.3	2.2%	482	18.4	12.2%	548	16.2	10.7%	485	18.3	14.9%	518	17.1
1997	57.6%	380	23.4	2.5%	462	19.2	14.5%	551	16.1	8.8%	489	18.2	16.7%	528	16.8
1998	55.1%	380	23.4	3.1%	487	18.2	14.7%	550	16.2	10.3%	475	18.7	16.7%	523	17.0
1999	55.1%	386	23.0	3.2%	480	18.5	15.4%	553	16.1	9.6%	486	18.3	16.7%	546	16.3
2000	55.1%	388	22.9	3.7%	497	17.9	15.2%	555	16.0	10.2%	478	18.6	15.8%	534	16.7
2001	53.9%	386	23.0	4.8%	472	18.8	17.3%	541	16.4	7.9%	493	18.0	16.1%	557	16.0
2002	51.5%	385	23.1	3.7%	460	19.3	22.3%	545	16.3	7.7%	475	18.7	14.8%	564	15.8
2003	50.2%	382	23.3	3.6%	446	19.9	22.6%	541	16.4	7.8%	468	19.0	15.7%	553	16.1
2004	48.0%	384	23.1	4.1%	445	20.0	25.9%	539	16.5	6.1%	464	19.2	15.9%	565	15.7
2005	50.5%	379	23.5	5.1%	440	20.2	20.6%	531	16.7	9.3%	460	19.3	14.5%	561	15.8
2006	52.9%	382	23.3	5.0%	434	20.5	19.9%	518	17.2	7.7%	455	19.5	14.5%	551	16.1
2007	52.9%	369	24.1	6.0%	431	20.6	21.7%	503	17.7	5.5%	456	19.5	13.8%	550	16.2
2008	52.7%	366	24.3	6.6%	419	21.2	22.1%	489	18.2	5.7%	448	19.8	12.9%	539	16.5
2009	60.5%	351	25.3	6.5%	403	22.0	18.4%	461	19.3	4.0%	443	20.1	10.6%	526	16.9
2010	54.5%	340	26.2	8.2%	386	23.0	20.7%	452	19.7	5.0%	442	20.1	11.5%	527	16.9
2011	47.8%	344	25.8	10.0%	378	23.5	25.5%	449	19.8	4.3%	424	20.9	12.3%	516	17.2
2012	55.0%	322	27.6	9.4%	381	23.3	20.6%	445	20.0	4.9%	418	21.3	10.1%	516	17.2
2013	54.1%	313	28.4	10.0%	365	24.3	21.8%	427	20.8	3.8%	422	21.1	10.4%	509	17.5
2014	49.2%	313	28.4	10.1%	364	24.4	23.9%	412	21.6	4.3%	418	21.3	12.4%	493	18.0
2015	47.2%	306	29.0	10.2%	353	25.1	28.1%	406	21.9	3.9%	408	21.8	10.7%	474	18.8
2016	43.8%	303	29.2	11.5%	338	26.2	29.1%	400	22.2	3.9%	410	21.7	11.7%	471	18.9
2017	41.0%	293	30.2	11.6%	339	26.1	31.7%	398	22.3	3.6%	399	22.2	12.1%	470	18.9
2018	36.7%	286	30.8	11.3%	324	27.3	35.0%	384	23.1	3.1%	389	22.8	13.9%	466	19.1
2019	*32.7%*	*285*	*30.9*	*11.7%*	*323*	*27.5*	*36.5%*	*378*	*23.5*	*3.4%*	*396*	*22.4*	*15.6%*	*467*	*19.0*
2020 (prelim)	*33.3%*	*272*	*32.0*	*9.5%*	*293*	*29.5*	*40.8%*	*372*	*23.9*	*2.6%*	*383*	*23.0*	*13.7%*	*460*	*19.5*

Table 3.3
Model Year 2019 Vehicle Attributes by Manufacturer

Manufacturer	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Weight (lbs)	Horsepower (HP)	0 to 60 (s)	Footprint (ft^2)
BMW	337	26.2	4,248	277	6.9	49.3
FCA	418	21.2	4,631	299	7.2	54.9
Ford	395	22.5	4,482	285	7.4	55.3
GM	395	22.5	4,438	273	7.7	54.2
Honda	307	28.9	3,661	207	8.0	47.8
Hyundai	311	28.5	3,494	174	8.9	46.6
Kia	316	28.1	3,585	186	8.7	47.0
Mazda	320	27.8	3,831	191	8.9	46.3
Mercedes	374	23.7	4,390	287	6.8	49.5
Nissan	329	27.0	3,811	202	8.9	48.1
Subaru	312	28.4	3,893	186	9.4	45.9
Tesla	0	118.0	4,436	392	4.8	49.9
Toyota	345	25.8	4,120	233	8.0	49.5
VW	338	26.1	4,141	236	7.7	48.2
Other	351	25.2	4,202	248	8.3	48.0
All Manufacturers	**356**	**24.9**	**4,156**	**245**	**7.9**	**50.8**

Table 3.4
Model Year 2019 Estimated Real-World Fuel Economy and CO_2 by Manufacturer and Vehicle Type

	Sedan/Wagon			Car SUV			Truck SUV			Minivan/Van			Pickup		
Manufacturer	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)
BMW	57.3%	318	27.6	0.087	311	28.6	33.9%	377	23.6	-	-	-	-	-	-
FCA	11.3%	400	22.2	7.9%	337	26.4	40.3%	397	22.4	13.0%	406	21.9	27.4%	487	18.3
Ford	19.8%	315	28.1	11.4%	346	25.7	29.2%	412	21.6	2.6%	384	23.1	36.9%	440	20.2
GM	15.4%	313	28.0	17.7%	314	28.3	39.2%	408	21.8	-	-	-	27.6%	475	18.7
Honda	47.2%	265	33.4	10.1%	302	29.4	31.3%	343	25.9	8.0%	383	23.2	3.3%	409	21.7
Hyundai	48.9%	274	32.3	49.4%	343	25.8	1.7%	430	20.7	-	-	-	-	-	-
Kia	61.1%	277	31.9	5.9%	337	26.4	30.7%	381	23.3	2.2%	421	21.1	-	-	-
Mazda	30.0%	291	30.5	22.0%	311	28.6	47.9%	342	26.0	-	-	-	-	-	-
Mercedes	50.8%	348	25.6	12.7%	345	25.8	35.1%	423	20.9	1.4%	406	21.9	-	-	-
Nissan	55.8%	283	31.2	8.9%	300	29.6	23.9%	381	23.4	1.5%	353	25.2	9.9%	480	18.5
Subaru	19.2%	306	29.1	-	-	-	80.8%	314	28.3	-	-	-	-	-	-
Tesla	91.0%	0	121.4	6.4%	0	91.9	2.6%	0	92.8	-	-	-	-	-	-
Toyota	36.9%	267	33.3	9.9%	316	28.1	35.1%	371	23.9	2.4%	399	22.3	15.7%	478	18.6
VW	49.9%	292	30.3	-	-	-	50.1%	384	23.0	-	-	-	-	-	-
Other	18.4%	290	30.6	10.7%	329	27.0	70.7%	371	23.9	0.2%	345	25.7	-	-	-
All Manufacturers	**32.7%**	**285**	**30.9**	**11.7%**	**323**	**27.5**	**36.5%**	**378**	**23.5**	**3.4%**	**396**	**22.4**	**15.6%**	**467**	**19.0**

Table 3.5
Footprint by Manufacturer for Model Year 2018 - 2020 (ft^2)

Manufacturer	Final MY 2018			Final MY 2019			*Preliminary MY 2020*		
	Car	Truck	All	Car	Truck	All	*Car*	*Truck*	*All*
BMW	47.3	51.1	48.3	47.7	52.3	49.3	*47.8*	*51.8*	*49.3*
FCA	48.9	52.8	52.0	49.3	56.3	54.9	*48.3*	*54.1*	*53.2*
Ford	46.6	59.9	55.3	46.9	59.1	55.3	*47.8*	*56.0*	*54.0*
GM	46.4	59.2	54.4	45.9	58.3	54.2	*46.8*	*56.0*	*54.2*
Honda	46.3	49.4	47.4	45.9	50.3	47.8	*46.1*	*49.5*	*47.3*
Hyundai	46.5	49.2	46.6	46.6	49.2	46.6	*46.5*	*50.1*	*47.4*
Kia	46.2	49.5	46.9	46.0	49.1	47.0	*45.5*	*50.1*	*47.2*
Mazda	45.6	47.9	46.5	44.9	47.7	46.3	*45.7*	*47.1*	*46.4*
Mercedes	48.3	51.3	49.6	48.6	51.0	49.5	*49.0*	*52.5*	*50.8*
Nissan	46.0	51.7	47.8	46.0	52.1	48.1	*46.6*	*52.1*	*48.2*
Subaru	44.9	45.0	45.0	44.9	46.1	45.9	*44.8*	*46.2*	*45.9*
Tesla	50.3	54.8	50.4	49.8	54.8	49.9	*50.2*	*50.9*	*50.3*
Toyota	46.1	51.6	48.8	46.5	52.0	49.5	*46.1*	*52.2*	*49.2*
VW	45.9	50.5	48.4	45.3	51.2	48.2	*46.3*	*51.4*	*49.0*
Other	45.0	49.4	48.1	44.5	49.5	48.0	*45.6*	*49.0*	*48.1*
All Manufacturers	**46.5**	**53.9**	**50.4**	**46.5**	**54.2**	**50.8**	***46.8***	***53.1***	***50.4***

Table 4.1
Production Share by Engine Technologies

	Powertrain				Fuel Delivery Method													
Model Year	Gasoline	Gasoline Hybrid	Diesel	Other	Carb	GDI	Port	TBI	EV	FCV	Avg. No. of Cylinders	CID	HP	Multi-Valve	VVT	CD	Turbo	Stop/ Start
1975	99.8%		0.2%		95.7%	-	4.1%	0.0%	-	-	6.8	293	137	-	-	-	-	-
1976	99.8%		0.2%		97.3%	-	2.5%	0.0%	-	-	6.9	294	135	-	-	-	-	-
1977	99.6%		0.4%		96.2%	-	3.4%	0.0%	-	-	6.9	287	136	-	-	-	-	-
1978	99.1%		0.9%		95.2%	-	3.9%	0.0%	-	-	6.7	266	129	-	-	-	-	-
1979	98.0%		2.0%		94.2%	-	3.7%	0.1%	-	-	6.5	252	124	-	-	-	-	-
1980	95.7%		4.3%		89.7%	-	5.2%	0.8%	-	-	5.6	198	104	-	-	-	-	-
1981	94.1%		5.9%		86.7%	-	5.1%	2.4%	-	-	5.5	193	102	-	-	-	-	-
1982	94.4%		5.6%		80.6%	-	5.8%	8.0%	-	-	5.4	188	103	-	-	-	-	-
1983	97.3%		2.7%		75.2%	-	7.3%	14.8%	-	-	5.5	193	107	-	-	-	-	-
1984	98.2%		1.8%		67.6%	-	11.9%	18.7%	-	-	5.5	190	109	-	-	-	-	-
1985	99.1%		0.9%		56.1%	-	18.2%	24.8%	-	-	5.5	189	114	-	-	-	-	-
1986	99.6%		0.4%		41.4%	-	32.5%	25.7%	-	-	5.3	180	114	3.4%	-	-	-	-
1987	99.7%		0.3%		28.4%	-	39.9%	31.4%	-	-	5.2	175	118	10.6%	-	-	-	-
1988	99.9%		0.1%		15.0%	-	50.6%	34.3%	-	-	5.3	180	123	14.0%	-	-	-	-
1989	99.9%		0.1%		8.7%	-	57.3%	33.9%	-	-	5.4	185	129	16.9%	-	-	-	-
1990	99.9%		0.1%		2.1%	-	70.8%	27.0%	-	-	5.4	185	135	23.1%	-	-	-	-
1991	99.9%		0.1%		0.6%	-	70.6%	28.7%	-	-	5.3	184	138	23.1%	-	-	-	-
1992	99.9%		0.1%		0.5%	-	81.6%	17.8%	-	-	5.5	191	145	23.3%	-	-	-	-
1993	100.0%				0.3%	-	85.0%	14.6%	-	-	5.5	191	147	23.5%	-	-	-	-
1994	100.0%		0.0%		0.1%	-	87.7%	12.1%	-	-	5.6	197	152	26.7%	-	-	-	-
1995	100.0%		0.0%		-	-	91.6%	8.4%	-	-	5.6	196	158	35.6%	-	-	-	-
1996	99.9%		0.1%		-	-	99.3%	0.7%	-	-	5.6	197	164	39.3%	-	-	0.2%	-
1997	99.9%		0.1%		-	-	99.5%	0.5%	-	-	5.7	199	169	39.6%	-	-	0.4%	-
1998	99.9%		0.1%		-	-	99.8%	0.1%	-	-	5.6	199	171	40.9%	-	-	0.8%	-
1999	99.9%		0.1%		-	-	99.9%	0.1%	-	-	5.8	203	179	43.4%	-	-	1.4%	-
2000	99.8%	0.0%	0.1%		-	-	99.8%	0.0%	-	-	5.7	200	181	44.8%	15.0%	-	1.3%	-
2001	99.7%	0.1%	0.1%		-	-	99.9%	-	-	-	5.8	201	187	49.0%	19.6%	-	2.0%	-
2002	99.6%	0.2%	0.2%		-	-	99.8%	-	-	-	5.8	203	195	53.3%	25.3%	-	2.2%	-
2003	99.5%	0.3%	0.2%		-	-	99.8%	-	-	-	5.8	204	199	55.5%	30.6%	-	1.2%	-
2004	99.4%	0.5%	0.1%		-	-	99.9%	-	-	-	5.9	212	211	62.3%	38.5%	-	2.3%	-
2005	98.6%	1.1%	0.3%		-	-	99.7%	-	-	-	5.8	205	209	65.6%	45.8%	0.8%	1.7%	-
2006	98.1%	1.5%	0.4%		-	-	99.6%	-	-	-	5.7	204	213	71.7%	55.4%	3.6%	2.1%	-
2007	97.7%	2.2%	0.1%		-	-	99.8%	-	-	-	5.6	203	217	71.7%	57.3%	7.3%	2.5%	-
2008	97.4%	2.5%	0.1%		-	2.3%	97.6%	-	-	-	5.6	199	219	76.4%	58.2%	6.7%	3.0%	-
2009	97.2%	2.3%	0.5%		-	4.2%	95.2%	-	-	-	5.2	183	208	83.8%	71.5%	7.3%	3.3%	-
2010	95.5%	3.8%	0.7%	0.0%	-	8.3%	91.0%	-	-	0.0%	5.3	188	214	85.5%	83.8%	6.4%	3.3%	-
2011	97.0%	2.2%	0.8%	0.1%	-	15.4%	83.8%	-	0.1%	0.0%	5.4	192	230	86.4%	93.1%	9.5%	6.8%	-
2012	95.5%	3.1%	0.9%	0.4%	-	22.5%	76.5%	-	0.1%	0.0%	5.1	181	222	91.8%	96.6%	8.1%	8.4%	0.6%
2013	94.8%	3.6%	0.9%	0.7%	-	30.5%	68.3%	-	0.3%	-	5.1	176	226	92.8%	97.4%	7.7%	13.9%	2.3%
2014	95.7%	2.6%	1.0%	0.7%	-	37.4%	61.3%	-	0.3%	0.0%	5.1	180	230	89.2%	97.6%	10.6%	14.8%	5.1%
2015	95.9%	2.4%	0.9%	0.7%	-	41.9%	56.7%	-	0.5%	0.0%	5.0	177	229	91.2%	97.2%	10.5%	15.7%	7.1%
2016	96.9%	1.8%	0.5%	0.8%	-	48.0%	51.0%	-	0.5%	0.0%	5.0	174	230	92.3%	98.0%	10.4%	19.9%	9.6%
2017	96.1%	2.3%	0.3%	1.4%	-	49.7%	49.4%	-	0.6%	0.0%	5.0	174	234	92.0%	98.1%	11.9%	23.4%	17.8%
2018	95.1%	2.3%	0.4%	2.2%	-	50.2%	48.0%	-	1.4%	0.0%	5.0	172	241	91.0%	96.4%	12.5%	30.0%	29.8%
2019	94.4%	3.8%	0.1%	1.7%	-	52.9%	45.7%	-	1.2%	0.0%	5.1	174	245	90.1%	97.2%	14.9%	30.0%	36.9%
2020 (prelim)	*88.5%*	*6.5%*	*1.0%*	*4.0%*	*-*	*55.3%*	*40.3%*	*-*	*3.3%*	*0.0%*	*4.9*	*168*	*247*	*89.6%*	*94.0%*	*13.8%*	*35.3%*	*42.2%*

Table 4.2
Production Share by Transmission Technologies

Model Year	Manual	Automatic with Lockup	Automatic without Lockup	CVT (Hybrid)	CVT (Non-Hybrid)	Other	4 Gears or Fewer	5 Gears	6 Gears	7 Gears	8 Gears	9+ Gears	Avg. No. of Gears
1975	23.0%	0.2%	76.8%	-	-	-	99.0%	1.0%	-	-	-	-	-
1976	20.9%	-	79.1%	-	-	-	100.0%	-	-	-	-	-	-
1977	19.8%	-	80.2%	-	-	-	100.0%	-	-	-	-	-	-
1978	22.7%	5.5%	71.9%	-	-	-	92.7%	7.3%	-	-	-	-	-
1979	24.2%	7.3%	68.1%	-	-	0.4%	93.8%	6.2%	-	-	-	-	3.3
1980	34.6%	18.1%	46.8%	-	-	0.5%	87.9%	12.1%	-	-	-	-	3.5
1981	33.6%	33.0%	32.9%	-	-	0.5%	85.6%	14.4%	-	-	-	-	3.5
1982	32.4%	47.8%	19.4%	-	-	0.4%	84.4%	15.6%	-	-	-	-	3.6
1983	30.5%	52.1%	17.0%	-	-	0.4%	80.9%	19.1%	-	-	-	-	3.7
1984	28.4%	52.8%	18.8%	-	-	0.0%	81.3%	18.7%	-	-	-	-	3.7
1985	26.5%	54.5%	19.1%	-	-	-	80.7%	19.3%	-	-	-	-	3.8
1986	29.8%	53.5%	16.7%	-	-	-	76.8%	23.2%	-	-	-	-	3.8
1987	29.1%	55.4%	15.5%	-	-	0.0%	76.2%	23.8%	-	-	-	-	3.9
1988	27.6%	62.2%	10.2%	-	-	-	76.8%	23.2%	-	-	-	-	3.9
1989	24.6%	65.5%	9.9%	-	0.1%	0.0%	78.5%	21.4%	0.0%	-	-	-	3.9
1990	22.2%	71.2%	6.5%	-	0.0%	0.0%	79.9%	20.0%	0.1%	-	-	-	4.0
1991	23.9%	71.6%	4.5%	-	0.0%	-	77.3%	22.6%	0.0%	-	-	-	4.0
1992	20.7%	74.8%	4.5%	-	0.0%	-	80.8%	19.2%	0.1%	-	-	-	4.0
1993	19.8%	76.5%	3.7%	-	0.0%	-	80.9%	19.0%	0.1%	-	-	-	4.0
1994	19.5%	77.6%	3.0%	-	-	-	80.8%	19.0%	0.2%	-	-	-	4.1
1995	17.9%	80.7%	1.4%	-	-	-	82.0%	17.7%	0.2%	-	-	-	4.1
1996	15.2%	83.5%	1.3%	-	0.0%	0.0%	84.7%	15.1%	0.2%	-	-	-	4.1
1997	14.0%	85.5%	0.5%	-	0.0%	-	82.4%	17.3%	0.2%	-	-	-	4.1
1998	12.8%	86.7%	0.5%	-	0.0%	-	82.1%	17.7%	0.2%	-	-	-	4.1
1999	10.1%	89.4%	0.5%	-	0.0%	-	84.4%	15.3%	0.3%	-	-	-	4.1
2000	9.7%	89.5%	0.7%	-	0.0%	-	83.7%	15.8%	0.5%	-	-	-	4.1
2001	9.0%	90.3%	0.6%	0.1%	0.0%	-	80.7%	18.5%	0.7%	-	-	-	4.2
2002	8.2%	91.4%	0.3%	0.1%	0.1%	-	77.1%	21.6%	1.1%	-	-	-	4.2
2003	8.0%	90.8%	0.1%	0.3%	0.8%	-	69.2%	28.1%	1.7%	-	-	-	4.3
2004	6.8%	91.8%	0.3%	0.4%	0.7%	-	63.9%	31.8%	3.0%	0.2%	-	-	4.4
2005	6.2%	91.5%	0.1%	1.0%	1.3%	-	56.0%	37.3%	4.1%	0.2%	-	-	4.5
2006	6.5%	90.6%	0.0%	1.5%	1.4%	-	47.7%	39.2%	8.8%	1.4%	-	-	4.6
2007	5.6%	87.1%	0.0%	2.1%	5.1%	-	40.5%	36.1%	14.4%	1.5%	0.2%	-	4.8
2008	5.2%	86.8%	0.2%	2.4%	5.5%	-	38.8%	31.9%	19.4%	1.8%	0.2%	-	4.8
2009	4.8%	85.6%	0.2%	2.1%	7.3%	-	31.2%	32.2%	24.5%	2.5%	0.1%	-	5.0
2010	3.8%	84.1%	1.2%	3.8%	7.2%	-	24.6%	23.5%	38.1%	2.7%	0.2%	-	5.2
2011	3.2%	86.5%	0.3%	2.0%	8.0%	-	14.2%	18.7%	52.3%	3.1%	1.7%	-	5.5
2012	3.6%	83.4%	1.1%	2.7%	9.2%	-	8.1%	18.2%	56.3%	2.8%	2.6%	-	5.5
2013	3.5%	80.4%	1.4%	2.9%	11.8%	-	5.4%	12.8%	60.1%	2.8%	4.1%	-	5.6
2014	2.8%	76.7%	1.6%	2.3%	16.6%	-	2.2%	7.8%	58.4%	3.3%	8.4%	1.1%	5.9
2015	2.6%	72.3%	1.4%	2.2%	21.5%	-	1.5%	4.5%	54.2%	3.1%	9.5%	3.5%	5.9
2016	2.2%	72.3%	2.6%	1.7%	21.2%	-	1.1%	3.0%	54.9%	2.9%	11.2%	4.1%	6.0
2017	2.1%	71.5%	2.6%	1.9%	21.8%	-	1.0%	2.4%	49.0%	3.4%	14.6%	5.9%	6.1
2018	1.6%	72.8%	3.2%	1.7%	20.6%	-	1.9%	2.0%	37.6%	3.7%	19.0%	13.5%	6.4
2019	1.4%	72.1%	2.4%	2.2%	21.9%	-	1.5%	1.6%	26.1%	2.6%	27.5%	16.5%	6.6
2020 (prelim)	*1.5%*	*66.1%*	*4.4%*	*3.1%*	*25.0%*	-	*3.4%*	*1.3%*	*15.8%*	*2.4%*	*28.3%*	*20.7%*	*6.6*

Table 4.3
Production Share by Drive Technology

	Car			Truck			All		
Model Year	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive
1975	6.5%	93.5%	-	-	82.8%	17.2%	5.3%	91.4%	3.3%
1976	5.8%	94.2%	-	-	77.0%	23.0%	4.6%	90.6%	4.8%
1977	6.8%	93.2%	-	-	76.2%	23.8%	5.5%	89.8%	4.7%
1978	9.6%	90.4%	-	-	70.9%	29.1%	7.4%	86.0%	6.6%
1979	11.9%	87.8%	0.3%	-	81.9%	18.1%	9.2%	86.5%	4.3%
1980	29.7%	69.4%	0.9%	1.4%	73.6%	25.0%	25.0%	70.1%	4.9%
1981	37.0%	62.2%	0.7%	1.9%	78.0%	20.1%	31.0%	65.0%	4.0%
1982	45.6%	53.6%	0.8%	1.7%	78.1%	20.2%	37.0%	58.4%	4.6%
1983	47.1%	49.9%	3.1%	1.4%	72.5%	26.1%	37.0%	54.8%	8.1%
1984	53.5%	45.5%	1.0%	5.0%	63.5%	31.5%	42.1%	49.8%	8.2%
1985	61.1%	36.8%	2.1%	7.3%	61.4%	31.3%	47.8%	42.9%	9.3%
1986	70.7%	28.2%	1.0%	5.9%	63.4%	30.7%	52.6%	38.0%	9.3%
1987	76.4%	22.6%	1.1%	7.6%	60.2%	32.2%	57.7%	32.8%	9.6%
1988	80.9%	18.3%	0.8%	9.2%	56.7%	34.1%	60.0%	29.5%	10.5%
1989	81.6%	17.4%	1.0%	10.1%	57.1%	32.8%	60.2%	29.3%	10.5%
1990	84.0%	15.0%	1.0%	15.8%	52.4%	31.8%	63.8%	26.1%	10.1%
1991	81.1%	17.5%	1.3%	10.3%	52.3%	37.3%	59.6%	28.1%	12.3%
1992	78.4%	20.5%	1.1%	14.5%	52.1%	33.4%	58.4%	30.4%	11.2%
1993	80.6%	18.3%	1.1%	16.8%	50.6%	32.7%	59.9%	28.8%	11.3%
1994	81.3%	18.3%	0.4%	13.8%	47.0%	39.2%	55.6%	29.2%	15.2%
1995	80.1%	18.8%	1.1%	18.4%	39.3%	42.3%	57.6%	26.3%	16.2%
1996	83.7%	14.8%	1.4%	20.9%	39.8%	39.2%	60.0%	24.3%	15.7%
1997	83.8%	14.5%	1.7%	14.2%	40.6%	45.2%	56.1%	24.9%	19.0%
1998	82.9%	15.0%	2.1%	19.3%	35.5%	45.1%	56.4%	23.5%	20.1%
1999	83.2%	14.7%	2.1%	17.5%	34.4%	48.1%	55.8%	22.9%	21.3%
2000	80.4%	17.7%	2.0%	20.0%	33.8%	46.3%	55.5%	24.3%	20.2%
2001	80.3%	16.7%	3.0%	16.3%	34.8%	48.8%	53.8%	24.2%	22.0%
2002	82.9%	13.5%	3.6%	15.4%	33.1%	51.6%	52.7%	22.3%	25.0%
2003	80.9%	15.9%	3.2%	15.4%	34.1%	50.4%	50.7%	24.3%	25.0%
2004	80.2%	14.5%	5.3%	12.5%	31.0%	56.5%	47.7%	22.4%	29.8%
2005	79.2%	14.2%	6.6%	20.1%	27.7%	52.2%	53.0%	20.2%	26.8%
2006	75.9%	18.0%	6.0%	18.9%	28.0%	53.1%	51.9%	22.3%	25.8%
2007	81.0%	13.4%	5.6%	16.1%	28.4%	55.5%	54.3%	19.6%	26.1%
2008	78.8%	14.1%	7.1%	18.4%	24.8%	56.8%	54.2%	18.5%	27.3%
2009	83.5%	10.2%	6.3%	21.0%	20.5%	58.5%	62.9%	13.6%	23.5%
2010	82.5%	11.2%	6.3%	20.9%	18.0%	61.0%	59.6%	13.7%	26.7%
2011	80.1%	11.3%	8.6%	17.7%	17.3%	65.0%	53.8%	13.8%	32.4%
2012	83.8%	8.8%	7.5%	20.9%	14.8%	64.3%	61.4%	10.9%	27.7%
2013	83.0%	9.3%	7.7%	18.1%	14.5%	67.5%	59.7%	11.1%	29.1%
2014	81.3%	10.6%	8.2%	17.5%	14.2%	68.3%	55.3%	12.1%	32.6%
2015	80.4%	9.7%	9.9%	16.0%	12.6%	71.4%	52.9%	10.9%	36.1%

Table 4.3
Production Share by Drive Technology

Model Year	Car			Truck			All		
	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive
2016	79.8%	9.1%	11.0%	15.9%	12.2%	72.0%	51.2%	10.5%	38.3%
2017	79.7%	8.3%	12.0%	16.1%	11.1%	72.8%	49.6%	9.6%	40.8%
2018	76.5%	9.4%	14.1%	13.4%	10.9%	75.6%	43.7%	10.2%	46.1%
2019	75.5%	10.1%	14.4%	14.4%	10.2%	75.4%	41.6%	10.1%	48.3%
2020 (prelim)	*71.2%*	*11.4%*	*17.4%*	*14.6%*	*10.2%*	*75.3%*	*38.8%*	*10.7%*	*50.5%*

Figure 5.3
Changes in "2-Cycle" Tailpipe CO_2 Emissions, Model Year 2012 to 2019 (g/mi)

	Model Year 2012			Model Year 2019		
Manufacturer	**Car**	**Truck**	**All**	**Car**	**Truck**	**All**
BMW	277	363	302	248	297	266
FCA	300	384	357	302	343	336
Ferrari	494	-	494	416	-	416
Ford	261	385	315	253	335	312
GM	283	397	331	243	345	314
Honda	237	320	266	206	278	239
Hyundai	243	312	249	241	339	243
Jaguar Land Rover	376	439	426	282	319	317
Kia	258	324	266	221	301	250
Mazda	241	324	263	230	264	248
Mercedes	316	393	343	276	332	298
Mitsubishi	262	283	267	198	251	227
Nissan	258	382	295	217	323	258
Subaru	257	296	282	238	243	242
Tesla	0	-	0	0	0	0
Toyota	221	354	273	211	313	269
VW	274	330	281	227	302	267
Volvo	297	343	311	255	283	277
All Manufacturers	**259**	**369**	**302**	**228**	**318**	**282**

Figure 5.4
Model Year 2019 Production of EVs, PHEVs, and FCVs

Manufacturer	Production of EV	Production of PHEV	Production of FCV
Aston Martin	-	-	-
BMW	1,557	15,571	-
FCA	434	3,484	-
Ferrari	-	-	-
Ford	-	9,846	-
GM	21,361	5,516	-
Honda	522	7,221	337
Hyundai	5,629	5,781	224
Jaguar Land Rover	3,004	34	-
Kia	4,267	5,573	-
Mazda	-	-	-
McLaren	-	-	-
Mercedes	394	5,712	-
Mitsubishi	-	2,185	-
Nissan	16,035	-	-
Subaru	-	2,547	-
Tesla	125,538	-	-
Toyota	-	10,628	1,711
VW	15,968	2,405	-
Volvo	-	4,049	-
All Manufacturers	**194,709**	**80,552**	**2,272**

Figure 5.5
Model Year 2019 Advanced Technology Credits by Manufacturer

Manufacturer	Total (g/mi)
Aston Martin	-
BMW	4.2
FCA	0.3
Ferrari	-
Ford	0.6
GM	2.0
Honda	0.5
Hyundai	3.1
Jaguar Land Rover	8.9
Kia	2.4
Mazda	-
McLaren	-
Mercedes	2.3
Mitsubishi	0.6
Nissan	2.4
Subaru	0.3
Tesla	214.0
Toyota	0.5
VW	5.9
Volvo	3.1
All Manufacturers	**3.0**

Figure 5.6
Production of FFVs, Model Year 2012-2019

Model Year	Car	Truck
2012	815,440	1,352,258
2013	791,660	1,701,209
2014	709,192	2,091,685
2015	538,648	1,300,077
2016	429,195	910,075
2017	307,116	859,376
2018	164,578	772,181
2019	71,622	644,494

Figure 5.7
FFV Credits by
Model Year (g/mi)

Model Year	GHG Credits
2012	8.1
2013	7.8
2014	8.9
2015	6.4
2016	-
2017	-
2018	-
2019	-

Figure 5.8
HFO-1234yf Adoption by Manufacturer (Production Volume)

	Model Year						
Manufacturer	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
BMW	-	-	-	-	334,633	367,072	358,787
FCA	-	540,098	1,683,956	1,504,046	1,633,139	1,750,652	1,906,228
Ferrari	-	-	-	-	1,886	2,559	2,659
Ford	-	-	-	-	1,326,663	1,530,469	1,512,981
GM	41,913	30,652	16,298	32,775	1,632,981	2,433,265	2,242,408
Honda	471	599	-	541,393	897,751	1,368,127	1,698,515
Hyundai	-	-	-	-	14,663	211,969	481,403
Jaguar Land Rover	-	56,604	62,316	114,580	122,586	110,615	105,504
Kia	-	-	-	-	264,353	336,262	580,596
Mazda	-	-	-	-	-	-	-
Mercedes	-	-	-	-	-	-	-
Mitsubishi	-	-	-	-	-	58,968	55,880
Nissan	-	-	-	-	-	94,474	338,942
Subaru	-	-	-	-	292,788	228,363	488,650
Tesla	-	-	-	-	-	-	96,459
Toyota	-	-	-	-	277,645	819,578	1,345,131
VW	-	-	-	-	50,884	588,122	714,364
Volvo	-	-	-	-	-	-	-
All Manufacturers	**42,384**	**627,953**	**1,762,570**	**2,192,794**	**6,849,972**	**9,900,495**	**11,928,507**

Figure 5.9
Fleetwide A/C Credits by Credit Type

Model Year	A/C Leakage Credits (g/mi)	A/C Efficiency Credits (g/mi)
2012	4.0	2.1
2013	4.2	2.8
2014	5.2	3.3
2015	5.9	3.6
2016	6.6	3.7
2017	9.2	4.6
2018	11.3	5.0
2019	12.7	5.2

Figure 5.10
Total A/C Credits by Manufacturer for Model Year 2019

Manufacturer	A/C Leakage Credits (g/mi)	A/C Efficiency Credits (g/mi)
Aston Martin	4.5	-
BMW	14.9	5.7
FCA	15.7	6.1
Ferrari	13.8	2.9
Ford	14.7	5.8
GM	15.2	5.8
Honda	15.0	4.9
Hyundai	10.6	3.6
Jaguar Land Rover	17.0	7.0
Kia	13.8	4.3
Mazda	3.4	-
McLaren	-	-
Mercedes	6.5	5.8
Mitsubishi	10.3	2.4
Nissan	7.5	3.8
Subaru	9.6	5.1
Tesla	11.9	5.1
Toyota	9.7	5.4
VW	14.0	5.9
Volvo	6.7	5.8

Figure 5.11

Off-Cycle Menu Technology Adoption by Manufacturer, Model Year 2019

Manufacturer	Active Aerodynamic Improvements	Active Cabin Ventilation	Active Seat Ventilation	Glass Or Glazing	Passive Cabin Ventilation	Solar Reflective Coating	Active Engine Warmup	Active Transmission Warmup	Engine Idle Start Stop	High Efficiency Lighting
Aston Martin	-	-	-	-	-	-	-	-	-	-
BMW	65%	100%	13%	-	-	-	29%	-	69%	100%
FCA	51%	-	15%	99%	99%	4%	92%	47%	49%	70%
Ferrari	-	-	-	-	-	-	-	-	-	100%
Ford	83%	-	25%	100%	100%	8%	41%	73%	77%	65%
GM	65%	-	20%	100%	100%	22%	48%	2%	57%	91%
Honda	35%	-	7%	100%	100%	4%	6%	94%	18%	100%
Hyundai	7%	84%	11%	85%	-	17%	5%	73%	4%	49%
Jaguar Land Rover	82%	-	60%	100%	100%	-	-	93%	97%	100%
Kia	6%	67%	8%	100%	-	22%	7%	69%	8%	70%
Mazda	-	-	22%	74%	-	-	-	96%	-	61%
McLaren	42%	-	-	-	-	-	-	100%	100%	100%
Mercedes	-	-	21%	89%	-	-	-	-	-	99%
Mitsubishi	-	-	-	73%	-	5%	-	-	2%	85%
Nissan	37%	-	5%	65%	35%	16%	37%	54%	0%	77%
Subaru	51%	-	3%	93%	-	-	-	90%	23%	79%
Tesla	100%	100%	-	100%	-	-	-	-	-	100%
Toyota	10%	-	25%	74%	99%	19%	38%	60%	22%	94%
VW	37%	-	16%	63%	-	2%	96%	10%	84%	73%
Volvo	-	-	16%	100%	100%	29%	100%	-	4%	100%
All Manufacturers	**42%**	**9%**	**16%**	**87%**	**70%**	**11%**	**40%**	**51%**	**37%**	**82%**

Figure 5.12

Total Off-Cycle Credits by Manufacturer for Model Year 2019

Manufacturer	Menu Credits (g/mi)	Non-Menu Credits (g/mi)
Aston Martin	-	-
BMW	7.4	-
FCA	10.0	0.5
Ferrari	0.7	-
Ford	10.0	0.8
GM	8.4	1.3
Honda	6.4	0.3
Hyundai	2.3	0.5
Jaguar Land Rover	10.0	-
Kia	3.1	0.4
Mazda	3.5	-
McLaren	4.3	-
Mercedes	1.9	-
Mitsubishi	1.1	-
Nissan	3.5	0.3
Subaru	5.1	0.6
Tesla	4.7	-
Toyota	6.4	0.6
Volvo	7.6	-
VW	6.8	-

Figure 5.13

Performance and Standards by Manufacturer, 2019 Model Year

Manufacturer	Performance (g/mi)	Standard (g/mi)
Aston Martin	342	380
BMW	234	229
FCA	303	275
Ferrari	399	395
Ford	280	272
GM	282	265
Honda	212	227
Hyundai	223	200
Jaguar Land Rover	274	274
Kia	226	218
Mazda	242	223
McLaren	389	368
Mercedes	282	231
Mitsubishi	212	210
Nissan	241	225
Subaru	222	234
Tesla	-236	214
Toyota	247	239
Volvo	254	264
VW	235	233

Figure 5.14
Early Credits by Manufacturer

Manufacturer	MY 2009 Credits (Tg of CO2)	MY 2010 Credits (Tg of CO2)	MY 2011 Credits (Tg of CO2)
Aston Martin	0.0	0.0	0.0
BMW	0.5	0.4	0.4
FCA	6.3	5.4	-0.9
Ferrari	-	-	-
Ford	8.4	7.4	0.3
GM	13.0	11.6	1.2
Honda	14.1	14.2	7.5
Hyundai	4.6	5.4	4.0
Jaguar Land Rover	-	-	-
Kia	3.1	2.7	4.7
Mazda	1.4	3.2	0.9
McLaren	-	-	-
Mercedes	0.1	0.1	0.2
Mitsubishi	0.6	0.5	0.3
Nissan	10.5	5.8	1.9
Subaru	1.6	2.2	1.9
Suzuki	0.4	0.3	0.1
Tesla	-	0.0	0.0
Toyota	31.3	34.5	14.7
VW	2.2	2.9	1.5
Volvo	0.2	0.4	0.2

Figure 5.15
Total Credits Transactions Through Model Year 2019

Manufacturer	Expires 2021	Expires 2022	Expires 2023	Expires 2024
Aston Martin	0.0	-	-	-
BMW	2.0	3.5	-	-
Coda	0.0	-	-	-
FCA	54.4	4.7	11.9	11.1
Ferrari	0.3	-	-	-
GM	5.8	-	4.9	-
Honda	-36.5	-3.5	-	-
Jaguar Land Rover	2.9	-	-	-
Karma Automotive	0.0	-	-	-
Lotus	0.0	-	-	-
McLaren	0.0	0.0	-	-
Mercedes	12.2	-	-	-
Mitsubishi	-0.2	-	-	-
Nissan	-3.5	-	-	-
Suzuki	-0.4	-	-	-
Tesla	-6.2	-4.7	-17.8	-11.1
Toyota	-33.8	-	-	-
VW	3.0	-	1.0	-

Figure 5.16
Manufacturer Credit Balance
After Model Year 2019

Please see Tab T.5.19 for this data

Figure 5.17
Industry Performance and Standards, Credit Generation and Use

Model Year	Performance (g/mi)	Standard (g/mi)
2012	287	299
2013	278	292
2014	273	287
2015	267	274
2016	271	263
2017	262	258
2018	253	252
2019	253	246

Model Year	Credits (Mg)	Credits (Tg)
Early Credits (2009-2011)	158,298,783	158
2012	32,834,749	33
2013	41,712,952	42
2014	43,264,078	43
2015	25,133,541	25
2016	-27,615,344	-28
2017	-16,422,453	-16
2018	-4,168,218	-4
2019	-23,821,639	-24
carry to 2020	229,216,449	229

Table 5.1
Manufacturer Footprint and Standards for Model Year 2019

Manufacturer	Footprint (ft^2)			Standards (g/mi)		
	Car	Truck	All	Car	Truck	All
Aston Martin	49.3	-	49.3	380	-	380
BMW	47.7	52.3	49.3	203	272	229
FCA	49.3	56.3	54.9	210	288	275
Ferrari	47.9	-	47.9	395	-	395
Ford	46.9	59.1	55.3	201	300	272
GM	45.9	58.3	54.2	196	295	265
Honda	45.9	50.3	47.8	196	263	227
Hyundai	46.6	49.2	46.6	199	258	200
Jaguar Land Rover	50.0	51.6	51.5	224	277	274
Kia	46.0	49.1	47.0	196	258	218
Mazda	44.9	47.7	46.3	193	251	223
McLaren	47.2	-	47.2	368	-	368
Mercedes	48.6	51.0	49.5	207	266	231
Mitsubishi	41.2	44.2	42.7	181	235	210
Nissan	46.0	52.1	48.1	196	272	225
Subaru	44.9	46.1	45.9	191	243	234
Tesla	49.8	54.8	49.9	212	284	214
Toyota	46.5	52.0	49.5	198	270	239
Volkswagen	45.3	51.2	48.2	193	267	233
Volvo	49.9	51.1	50.8	223	275	264
All Manufacturers	**46.5**	**54.2**	**50.8**	**198**	**279**	**246**

Table 5.2
Production Multipliers by Model Year

Model Year	Electric Vehicles and Fuel Cell Vehicles	Plug-In Hybrid Electric Vehicles	Dedicated and Dual-Fuel Natural Gas Vehicles
2017	2.0	1.6	1.6
2018	2.0	1.6	1.6
2019	2.0	1.6	1.6
2020	1.75	1.45	1.45
2021	1.5	1.3	1.3
2022-2026	1.0	1.0	2.0

Table 5.3
Model Year 2019 Off-Cycle Technology Credits from the Menu, by Manufacturer and Technology (g/mi)

Manufacturer	Active Aero-dynamics	Active Engine Warmup	Active Trans Warmup	Thermal Controls	Engine Start-Stop	High Efficiency Lighting	Total Menu Credits
Aston Martin	-	-	-	-	-	-	-
BMW	1.2	0.8	-	2.5	2.0	0.9	7.4
FCA	0.4	2.7	1.5	3.8	2.1	0.2	10.0
Ferrari	-	-	-	-	-	0.7	0.7
Ford	1.1	1.1	2.1	3.3	3.1	0.2	10.0
GM	0.7	1.2	0.0	3.7	2.2	0.5	8.4
Honda	0.1	0.1	2.2	2.9	0.7	0.4	6.4
Hyundai	0.1	0.1	1.1	0.8	0.1	0.1	2.3
Jaguar Land Rover	0.6	-	2.9	3.8	4.1	0.4	10.0
Kia	0.0	0.1	1.6	1.0	0.2	0.1	3.1
Mazda	-	-	2.3	1.0	-	0.1	3.5
McLaren	0.4	-	1.5	-	1.5	0.9	4.3
Mercedes	-	-	-	1.1	-	0.9	1.9
Mitsubishi	-	-	-	0.8	0.0	0.3	1.1
Nissan	0.2	0.7	1.1	1.1	0.0	0.3	3.5
Subaru	0.2	-	2.7	1.1	0.7	0.4	5.1
Tesla	1.1	-	-	3.0	-	0.7	4.7
Toyota	0.1	0.2	1.4	3.4	0.9	0.4	6.4
VW	0.2	2.3	0.3	0.7	2.8	0.5	6.8
Volvo	-	2.8	-	3.6	0.2	1	7.6
All Manufacturers	**0.4**	**0.9**	**1.3**	**2.7**	**1.4**	**0.4**	**6.9**

Table 5.4
Model Year 2019 Off-Cycle Technology Credits from an Alternative Methodology, by Manufacturer and Technology (g/mi)

Manufacturer	Brushless Motors	Improved A/C Systems	High-Efficiency Alternator	Active Climate Control Seats	Total Alternative Methodology Credits
FCA	-	-	0.5	-	0.5
Ford	-	0.2	0.6	-	0.8
GM	-	0.6	0.7	0.0	1.3
Honda	-	-	0.3	-	0.3
Hyundai	-	-	0.5	-	0.5
Kia	-	-	0.4	-	0.4
Nissan	-	0.1	0.2	-	0.3
Subaru	0.0	-	0.6	-	0.6
Toyota	0.1	0.1	0.3	-	0.6
All Manufacturers	**0.0**	**0.2**	**0.4**	**0.0**	**0.6**

Table 5.5
Manufacturer Performance in Model Year 2019, All (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH4 & N2O	
Aston Martin	347	-	-	4.5	-	-	342
BMW	266	4.2	-	20.6	7.4	-	234
FCA	336	0.3	-	21.8	10.5	-0.0	303
Ferrari	416	-	-	16.7	0.7	-	399
Ford	312	0.6	-	20.6	10.8	-0.3	280
GM	314	2.0	-	21.0	9.7	-0.1	282
Honda	239	0.5	-	19.9	6.6	-	212
Hyundai	243	3.1	-	14.2	2.7	-0.1	223
Jaguar Land Rover	317	8.9	-	24.0	10.0	-	274
Kia	250	2.4	-	18.1	3.4	-0.1	226
Mazda	248	-	-	3.4	3.5	-1.0	242
McLaren	393	-	-	-	4.3	-	389
Mercedes	298	2.3	-	12.3	1.9	-	282
Mitsubishi	227	0.6	-	12.6	1.1	-	212
Nissan	258	2.4	-	11.3	3.8	0.0	241
Subaru	242	0.3	-	14.7	5.7	-	222
Tesla	0	214.0	-	17.0	4.7	-	-236
Toyota	269	0.5	-	15.1	6.9	-0.1	247
VW	267	5.9	-	20.0	6.8	-0.0	235
Volvo	277	3.1	-	12.5	7.6	-	254
All Manufacturers	**282**	**3.0**	**-**	**18.0**	**7.5**	**-0.1**	**253**

Table 5.6
Industry Performance by Model Year, All (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH4 & N2O	
2012	302	-	8.1	6.1	1.0	-0.2	287
2013	294	-	7.8	6.9	1.1	-0.3	278
2014	294	-	8.9	8.5	3.3	-0.2	273
2015	286	-	6.4	9.4	3.4	-0.2	267
2016	285	-	-	10.3	3.6	-0.1	271
2017	284	2.2	-	13.8	5.4	-0.2	262
2018	280	3.7	-	16.3	6.8	-0.1	253
2019	282	3.0	-	18.0	7.5	-0.1	253

Table 5.7
Manufacturer Performance in Model Year 2019, Car (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH4 & N2O	
Aston Martin	347	-	-	4.5	-	-	342
BMW	248	6.8	-	18.6	5.2	-	218
FCA	302	0.3	-	18.4	5.6	-0.0	278
Ferrari	416	-	-	16.7	0.7	-	399
Ford	253	2.0	-	16.5	6.3	-0.2	228
GM	243	6.8	-	15.8	6.7	-0.0	214
Honda	206	0.9	-	16.9	4.3	-	184
Hyundai	241	3.1	-	14.3	2.7	-0.1	221
Jaguar Land Rover	282	-	-	18.7	6.0	-	257
Kia	221	3.7	-	16.6	2.5	-0.2	198
Mazda	230	-	-	1.8	2.0	-0.2	226
McLaren	393	-	-	-	4.3	-	389
Mercedes	276	0.6	-	11.1	1.6	-	263
Mitsubishi	198	1.2	-	5.9	0.6	-	190
Nissan	217	3.9	-	11.6	2.7	-0.0	199
Subaru	238	-	-	5.7	2.2	-	230
Tesla	0	211.9	-	16.9	4.6	-	-233
Toyota	211	1.2	-	14.1	5.1	-0.1	191
VW	227	3.3	-	17.9	3.7	-0.0	202
Volvo	255	2.1	-	9.7	4.9	-	238
All Manufacturers	**228**	**6.3**	**-**	**14.8**	**4.3**	**-0.1**	**203**

Table 5.8
Industry Performance by Model Year, Car (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH4 & N2O	
2012	259	-	4.0	5.4	0.6	-0.1	249
2013	251	-	4.0	6.3	0.7	-0.3	240
2014	250	-	4.6	7.5	2.2	-0.3	236
2015	243	-	3.1	8.1	2.3	-0.1	230
2016	240	-	-	8.8	2.3	-0.1	229
2017	235	4.3	-	10.2	3.4	-0.0	217
2018	228	7.6	-	13.0	4.0	-0.0	204
2019	228	6.3	-	14.8	4.3	-0.1	203

Table 5.9
Manufacturer Performance in Model Year 2019, Truck (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH4 & N2O	
Aston Martin	-	-	-	-	-	-	-
BMW	297	-	-	24.1	11.1	-	262
FCA	343	0.3	-	22.5	11.5	-0.1	309
Ferrari	-	-	-	-	-	-	-
Ford	335	-	-	22.2	12.6	-0.4	301
GM	345	-	-	23.3	11.0	-0.1	311
Honda	278	-	-	23.5	9.4	-	245
Hyundai	339	-	-	6.9	5.8	-	326
Jaguar Land Rover	319	9.5	-	24.4	10.3	-	275
Kia	301	-	-	20.6	5.1	-	275
Mazda	264	-	-	4.8	4.9	-1.9	256
McLaren	-	-	-	-	-	-	-
Mercedes	332	4.9	-	14.2	2.4	-	310
Mitsubishi	251	-	-	18.3	1.4	-	231
Nissan	323	-	-	10.9	5.6	-	307
Subaru	243	0.4	-	16.5	6.4	-	220
Tesla	0	284.2	-	20.5	8.3	-	-313
Toyota	313	-	-	15.9	8.4	-0.1	289
VW	302	8.2	-	21.7	9.5	-0.0	263
Volvo	283	3.3	-	13.3	8.3	-	258
All Manufacturers	**318**	**0.7**	**-**	**20.2**	**9.7**	**-0.1**	**288**

Table 5.10
Industry Performance by Model Year, Truck (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH4 & N2O	
2012	369	-	14.5	7.3	1.6	-0.3	346
2013	360	-	13.8	7.9	1.7	-0.3	337
2014	349	-	14.3	9.7	4.6	-0.1	321
2015	336	-	10.3	11.0	4.6	-0.2	310
2016	332	-	-	11.8	5.1	-0.2	316
2017	330	0.2	-	17.3	7.4	-0.3	305
2018	320	0.6	-	19.0	9.0	-0.2	292
2019	318	0.7	-	20.2	9.7	-0.1	288

Table 5.11
Credits Earned by Manufacturers in Model Year 2019, All

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	342	380	-38	2,069	15,170
BMW	234	229	5	360,345	-392,573
FCA	303	275	28	2,109,158	-13,345,869
Ferrari	399	395	4	2,659	-1,853
Ford	280	272	8	1,816,423	-3,221,756
GM	282	265	17	2,554,431	-9,013,157
Honda	212	227	-15	1,730,544	5,307,829
Hyundai	223	200	23	654,883	-2,933,640
Jaguar Land Rover	274	274	0	105,504	306
Kia	226	218	8	580,746	-923,819
Mazda	242	223	19	267,020	-1,053,413
McLaren	389	368	21	1,382	-5,599
Mercedes	282	231	51	312,501	-3,304,783
Mitsubishi	212	210	2	123,924	-57,646
Nissan	241	225	16	1,366,419	-4,256,602
Subaru	222	234	-12	775,379	2,157,106
Tesla	-236	214	-450	125,538	11,070,481
Toyota	247	239	8	2,371,840	-3,799,467
VW	235	233	2	770,284	-302,728
Volvo	254	264	-10	108,275	240,374
All Manufacturers	**253**	**246**	**7**	**16,139,324**	**-23,821,639**

Table 5.12
Total Credits Earned in Model Years 2009-2019, All

Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Generated Credits (Mg)	Credit Expiration
2009	-	-	-	-	98,522,058	2014
2010	-	-	-	-	96,891,340	2021
2011	-	-	-	-	38,770,273	2021
2012	287	299	-12	13,446,550	33,033,097	2021
2013	278	292	-14	15,200,118	42,234,774	2021
2014	273	287	-13	15,514,338	43,292,494	2021
2015	267	274	-7	16,740,264	25,218,704	2021
2016	271	263	8	16,279,911	-27,615,344	2021
2017	262	258	5	17,015,504	-16,203,034	2022
2018	253	252	1	16,259,244	-4,168,218	2023
2019	253	246	7	16,139,324	-23,821,639	2024

Table 5.13
Credits Earned by Manufacturers in Model Year 2019, Car

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	342	380	-38	2,069	15,170
BMW	218	203	15	238,033	-674,229
FCA	278	210	68	405,487	-5,361,078
Ferrari	399	395	4	2,659	-1,853
Ford	228	201	27	568,345	-3,041,035
GM	214	196	18	847,067	-2,927,214
Honda	184	196	-12	992,811	2,328,418
Hyundai	221	199	22	643,662	-2,760,630
Jaguar Land Rover	257	224	33	7,147	-46,484
Kia	198	196	2	389,497	-175,317
Mazda	226	193	33	139,005	-903,813
McLaren	389	368	21	1,382	-5,599
Mercedes	263	207	56	198,525	-2,160,289
Mitsubishi	190	181	9	61,266	-110,428
Nissan	199	196	3	883,582	-489,564
Subaru	230	191	39	148,610	-1,135,982
Tesla	-233	212	-445	122,326	10,637,339
Toyota	191	198	-7	1,108,873	1,573,002
VW	202	193	9	384,640	-682,532
Volvo	238	223	15	25,561	-76,277
All Manufacturers	**203**	**198**	**4**	**7,170,547**	**-5,998,395**

Table 5.14
Total Credits Earned in Model Years 2009-2019, Car

Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Generated Credits (Mg)	Credit Expiration
2009	-	-	-	-	58,018,752	2014
2010	-	-	-	-	50,856,700	2021
2011	-	-	-	-	8,831,637	2021
2012	249	267	-18	8,657,393	30,484,967	2021
2013	240	261	-21	9,747,624	39,249,608	2021
2014	236	253	-17	9,209,352	30,407,996	2021
2015	230	241	-12	9,602,215	22,043,043	2021
2016	229	231	-2	9,012,178	3,411,251	2021
2017	217	219	-2	8,954,269	2,705,030	2022
2018	204	209	-6	7,800,108	8,396,572	2023
2019	203	198	4	7,170,547	-5,998,395	2024

Table 5.15
Credits Earned by Manufacturers in Model Year 2019, Truck

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	-	-	-	-	-
BMW	262	272	-10	122,312	281,656
FCA	309	288	21	1,703,671	-7,984,791
Ferrari	-	-	-	-	-
Ford	301	300	1	1,248,078	-180,721
GM	311	295	16	1,707,364	-6,085,943
Honda	245	263	-18	737,733	2,979,411
Hyundai	326	258	68	11,221	-173,010
Jaguar Land Rover	275	277	-2	98,357	46,790
Kia	275	258	17	191,249	-748,502
Mazda	256	251	5	128,015	-149,600
McLaren	-	-	-	-	-
Mercedes	310	266	44	113,976	-1,144,494
Mitsubishi	231	235	-4	62,658	52,782
Nissan	307	272	35	482,837	-3,767,038
Subaru	220	243	-23	626,769	3,293,088
Tesla	-313	284	-597	3,212	433,142
Toyota	289	270	19	1,262,967	-5,372,469
VW	263	267	-4	385,644	379,804
Volvo	258	275	-17	82,714	316,651
All Manufacturers	**288**	**279**	**9**	**8,968,777**	**-17,823,244**

Table 5.16
Total Credits Earned in Model Years 2009-2019, Truck

Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Generated Credits (Mg)	Credit Expiration
2009	-	-	-	-	40,503,306	2014
2010	-	-	-	-	46,034,640	2021
2011	-	-	-	-	29,938,636	2021
2012	346	349	-2	4,789,157	2,548,130	2021
2013	337	339	-3	5,452,494	2,985,166	2021
2014	321	330	-9	6,304,986	12,884,498	2021
2015	310	312	-2	7,138,049	3,175,661	2021
2016	316	297	19	7,267,733	-31,026,595	2021
2017	305	295	10	8,061,235	-18,908,064	2022
2018	292	286	7	8,459,136	-12,564,790	2023
2019	288	279	9	8,968,777	-17,823,244	2024

Table 5.18
Final Credit Balance by Manufacturer for Model Year 2019 (Mg)

Manufacturer	Early Credits Earned 2009-2011	Net Credits Earned 2012-2018	Net Credits Earned 2019	Credits Expired	Credits Forfeited	Credits Purchased or Sold	Final 2019 Credit Balance
Aston Martin	3,332	-37,504	15,170	-	-	35,844	16,842
BMW	1,251,522	-210,997	-392,573	-134,791	-	5,500,000	6,013,161
BYD Motors	-	5,568	-	-	-	-	5,568
Coda	-	7,251	-	-	-	-7,251	-
FCA	10,827,083	-32,540,672	-13,345,869	-	-	82,128,881	47,069,423
Ferrari	-	-151,153	-1,853	-	-	265,000	111,994
Ford	16,116,453	2,255,243	-3,221,756	-5,882,011	-	-	9,267,929
GM	25,788,547	-990,066	-9,013,157	-6,998,699	-	10,677,251	19,463,876
Honda	35,842,334	54,543,241	5,307,829	-14,133,353	-	-40,015,245	41,544,806
Hyundai	14,007,495	5,871,049	-2,933,640	-4,482,649	-169,775	-	12,292,480
Jaguar Land Rover	-	-2,874,564	306	-	-	2,922,736	48,478
Karma Automotive	-	58,852	-	-	-	-2,841	56,011
Kia	10,444,192	-4,545,523	-923,819	-2,362,882	-123,956	-	2,488,012
Lotus	-	-3,147	-	-	-	2,841	-306
Mazda	5,482,642	5,905,364	-1,053,413	-1,390,883	-	-	8,943,710
McLaren	-	-11,370	-5,599	-	-	9,079	-7,890
Mercedes	378,272	-8,968,525	-3,304,783	-	-28,416	12,227,713	304,261
Mitsubishi	1,449,336	1,430,836	-57,646	-583,146	-	-200,000	2,039,380
Nissan	18,131,200	17,312,306	-4,256,602	-8,190,124	-	-3,545,570	19,451,210
Porsche	-	426,439	-	-	-426,439	-	-
Subaru	5,755,171	13,280,987	2,157,106	-491,789	-	-	20,701,475
Suzuki	876,650	-183,097	-	-265,311	-	-428,242	-
Tesla	49,772	28,739,673	11,070,481	-	-	-39,807,765	52,161
Toyota	80,435,498	22,093,847	-3,799,467	-29,526,679	-	-33,762,431	35,440,768
VW	6,613,985	-6,019,574	-302,728	-1,442,571	-219,419	4,000,000	2,629,693
Volvo	730,187	398,009	240,374	-	-85,163	-	1,283,407
All Manufacturers	**234,183,671**	**95,792,473**	**-23,821,639**	**-75,884,888**	**-1,053,168**	**-**	**229,216,449**

Table 5.19
Distribution of Credits by Expiration Date (Mg)

Manufacturer	Final 2019 Credit Balance	Credits Expiring in 2021	Credits Expiring in 2022	Credits Expiring in 2023	Credits Expiring in 2024	Model Year 2019 Deficits	Model Year 2018 Deficits	Model Year 2017 Deficits	Non-Compliant Deficits
Aston Martin	16,842	-	-	1,672	15,170	-	-	-	-
BMW	6,013,161	1,939,942	3,652,752	138,811	281,656	-	-	-	-
BYD Motors	5,568	4,871	529	168	-	-	-	-	-
Coda	-	-	-	-	-	-	-	-	-
FCA	47,069,423	19,348,175	4,731,544	11,915,822	11,073,882	-	-	-	-
Ferrari	111,994	99,622	8,180	4,192	-	-	-	-	-
Ford	9,267,929	9,267,929	-	-	-	-	-	-	-
GM	19,463,876	11,801,350	2,127,946	5,534,580	-	-	-	-	-
Honda	41,544,806	22,044,774	4,917,091	9,275,112	5,307,829	-	-	-	-
Hyundai	12,292,480	12,292,480	-	-	-	-	-	-	-
Jaguar Land Rover	48,478	1,688	-	-	46,790	-	-	-	-
Karma Automotive	56,011	56,011	-	-	-	-	-	-	-
Kia	2,488,012	2,488,012	-	-	-	-	-	-	-
Lotus	-306	-	-	-	-	-	-114	-192	-
Mazda	8,943,710	8,607,717	171,051	164,942	-	-	-	-	-
McLaren	-7,890	-	-	-	-	-5,599	-2,291	-	-
Mercedes	304,261	304,261	-	-	-	-	-	-	-
Mitsubishi	2,039,380	1,611,677	171,946	202,975	52,782	-	-	-	-
Nissan	19,451,210	18,799,525	651,685	-	-	-	-	-	-
Porsche	-	-	-	-	-	-	-	-	-
Subaru	20,701,475	11,593,033	3,215,610	2,599,744	3,293,088	-	-	-	-
Suzuki	-	-	-	-	-	-	-	-	-
Tesla	52,161	-	-	52,161	-	-	-	-	-
Toyota	35,440,768	29,850,127	1,911,327	2,106,312	1,573,002	-	-	-	-
VW	2,629,693	1,028,379	-	1,221,510	379,804	-	-	-	-
Volvo	1,283,407	-	188,150	778,606	316,651	-	-	-	-
All Manufacturers	**229,216,449**	**151,139,573**	**21,747,811**	**33,996,607**	**22,340,654**	**-5,599**	**-2,405**	**-192**	**0**

Appendix Table A.1

Comparison of Preliminary and Final Real-World Fuel Economy Values (mpg)

Model Year	Preliminary Value	Final Value	Final Minus Preliminary
2011	22.8	22.3	-0.5
2012	23.8	23.6	-0.2
2013	24.0	24.2	0.2
2014	24.2	24.1	-0.1
2015	24.7	24.6	-0.2
2016	25.6	24.7	-0.9
2017	25.2	24.9	-0.3
2018	25.4	25.1	-0.3
2019	25.5	24.9	-0.6
2020 (prelim)	*25.7*	-	-

Appendix Table C.1
Fuel Economy Metrics for the Model Year 2020 Toyota Prius Eco

Fuel Economy Metric	Purpose	City/Highway Weighting	Test Basis	Fuel Economy Value (MPG)		
				City/Hwy	City	Hwy
2-cycle Test (unadjusted)	Basis for manufacturer compliance with standards	55%/45%	2-cycle	81	84	78
Label	Consumer information to compare individual vehicles	55%/45%	5-cycle	56	58	53
Estimated Real-World	Best estimate of real-world performance	43%/57%	5-cycle	55	58	53

Appendix Table E.1
Model Year 2020 Example EV and PHEV Powertrain and Range

Manufacturer	Model	Fuel or Powertrain	Alternative Fuel Range (miles)*	Total Range (miles)	Utility Factor
GM	Bolt	EV	259	259	-
Nissan	Leaf 62 kWh	EV	226	226	-
Tesla	Model 3 LR	EV	330	330	-
FCA	Pacifica	PHEV	32	520	0.61
Ford	Escape	PHEV	37	530	0.66
Honda	Clarity	PHEV	48	340	0.73
Toyota	Prius Prime	PHEV	25	640	0.53
Volvo	XC90	PHEV	18	520	0.43

Appendix Table E.2
Model Year 2020 Example EV and PHEV Fuel Economy Label Metrics

			Charge Depleting			Charge Sustaining	
Manufacturer	**Model**	**Fuel or Powertrain**	**Electricity (kW-hrs/ 100 miles)**	**Gasoline (gallons/ 100 miles)**	**Fuel Economy (mpge)**	**Fuel Economy (mpg)**	**Overall Fuel Economy (mpge)**
GM	Bolt	EV	29	-	118	N/A	118
Nissan	Leaf 62 kWh	EV	31	-	108	N/A	108
Tesla	Model 3 LR	EV	26	-	130	N/A	130
FCA	Pacifica	PHEV	41	0	82	30	48
Ford	Escape	PHEV	33	0	102	41	66
Honda	Clarity	PHEV	31	0	110	42	76
Toyota	Prius Prime	PHEV	25	0	133	54	78
Volvo	XC90	PHEV	58	0.1	55	27	34

Appendix Table E.3

Model Year 2020 Example EV and PHEV Label Tailpipe CO2 Emissions Metrics

Manufacturer	Model	Fuel or Powertrain	Tailpipe CO_2 (g/mile)
GM	Bolt	EV	0
Nissan	Leaf 62 kWh	EV	0
Tesla	Model 3 LR	EV	0
FCA	Pacifica	PHEV	119
Ford	Escape	PHEV	77
Honda	Clarity	PHEV	57
Toyota	Prius Prime	PHEV	78
Volvo	XC90	PHEV	197

Appendix Table E.4

Model Year 2020 EV and PHEV Upstream CO_2 Emission Metrics Metrics (g/mi)

			Tailpipe & Total Upstream CO_2			Tailpipe & Net Upstream CO_2		
Manufacturer	**Model**	**Fuel or Powertrain**	**Low (g/mile)**	**Avg (g/mile)**	**High (g/mile)**	**Low (g/mile)**	**Avg (g/mile)**	**High (g/mile)**
GM	Bolt	EV	73	136	232	20	82	179
Nissan	Leaf 62 kWh	EV	80	148	254	23	91	197
Tesla	Model 3 LR	EV	66	122	210	4	60	148
FCA	Pacifica	PHEV	213	267	351	128	182	267
Ford	Escape	PHEV	152	199	273	94	142	215
Honda	Clarity	PHEV	129	178	255	72	120	197
Toyota	Prius Prime	PHEV	131	160	205	82	111	155
Volvo	XC90	PHEV	305	359	444	221	275	359
Average Sedan/Wagon			**346**	**346**	**346**	**277**	**277**	**277**