The 2022 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. 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.

The purpose of the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments. This edition of the report supersedes all previous versions.

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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 since 1975.

A. What's New This Year

This report is updated each year to reflect the most recent data available to EPA for all model years, relevant regulatory changes, methodology changes, and any other changes relevant to the auto industry. These changes can affect multiple model years; therefore, this version of the report supersedes all previous reports. Significant developments relevant for this edition of the report include:

- In December 2021, EPA finalized revised light-duty GHG standards for model years 2023-2026 and in March 2022 NHTSA subsequently published revised fuel economy standards for model years 2024-2026. In March 2022, EPA also restored California's waiver to enforce greenhouse gas standards for cars and light trucks. This report has been updated to reflect these changes where relevant.

- Electric vehicles continue to increase market share and are expected to continue growing in popularity. The technology, fuel economy, and emissions of electric vehicles are fundamentally different than their internal combustion counterparts. Increasing vehicle electrification may require rethinking many of the metrics and methods used in this report. While no significant changes were made this year, EPA is evaluating the best metrics and methods to explain these ongoing trends and technologies for future reports.

- This report shows projected model year 2022 data, much of which was provided to EPA by manufacturers in calendar year 2021. Given the impacts of COVID-19 and ongoing worldwide supply chain issues, and their associated impacts on the automobile industry, the projected model year 2022 data may change significantly before being finalized.
- EPA continues to update detailed data from this report, including 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 2021 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 150,000 vehicles each in the 2021 model year and accounted for more than 98% of all production. The compliance discussion in Section 5 includes all manufacturers, regardless of production volume. Table 1.1 lists all manufacturers that produced vehicles in the U.S. for model year 2021, including their associated makes, and their categorization for this report. Only vehicle brands produced in model year 2021 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 2021 Manufacturer Definitions

	Manufacturer	Makes in the U.S. Market
Large Manufacturers	BMW	BMW, Mini, Rolls Royce
	Ford	Ford, Lincoln, Roush, Shelby
	GM	Buick, Cadillac, Chevrolet, GMC
	Honda	Acura, Honda
	Hyundai	Genesis, Hyundai
	Kia	Kia
	Mazda	Mazda
	Mercedes	Maybach, Mercedes
	Nissan	Infiniti, Nissan
	Stellantis	Alfa Romeo, Chrysler, Dodge, Fiat, Jeep, Maserati, Ram
	Subaru	Subaru
	Tesla	Tesla
	Toyota	Lexus, Toyota
	Volkswagen (VW)	Audi, Bentley, Bugatti, Lamborghini, Porsche, Volkswagen
Other Manufacturers	Jaguar Land Rover	Jaguar, Land Rover
	Mitsubishi	Mitsubishi
	Volvo	Lotus, Polestar, Volvo
	Karma	Karma
	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 2021 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 2022, 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** 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	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

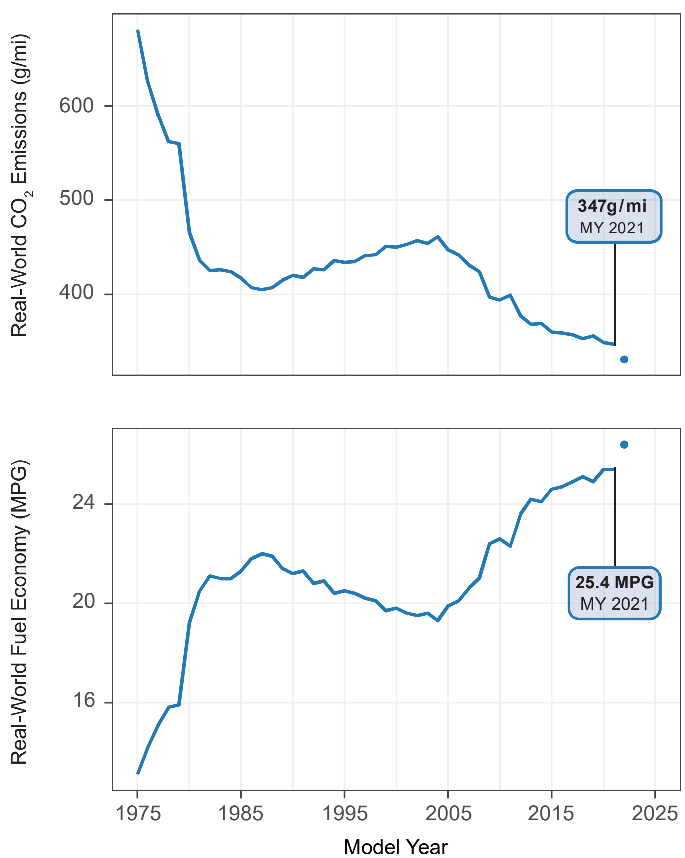
The automotive industry continues to make progress towards lower tailpipe CO_2 emissions and higher fuel economy in recent years. This section provides an update on the estimated real-world tailpipe CO_2 emissions and fuel economy for the overall fleet, and for manufacturers based on final model year 2021 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 2021, the average estimated real-world CO_2 emission rate for all new vehicles fell by 2 g/mi to 347 g/mi, the lowest ever measured. Real-world fuel economy remained at a record high 25.4 mpg.[1]

Since model year 2004, CO_2 emissions have decreased 25%, or 114 g/mi, and fuel economy has increased 32%, or 6.1 mpg. Over that time, CO_2 emissions have improved in fourteen of seventeen years. The trends in CO_2 emissions and fuel economy since 1975 are shown in Figure 2.1.

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



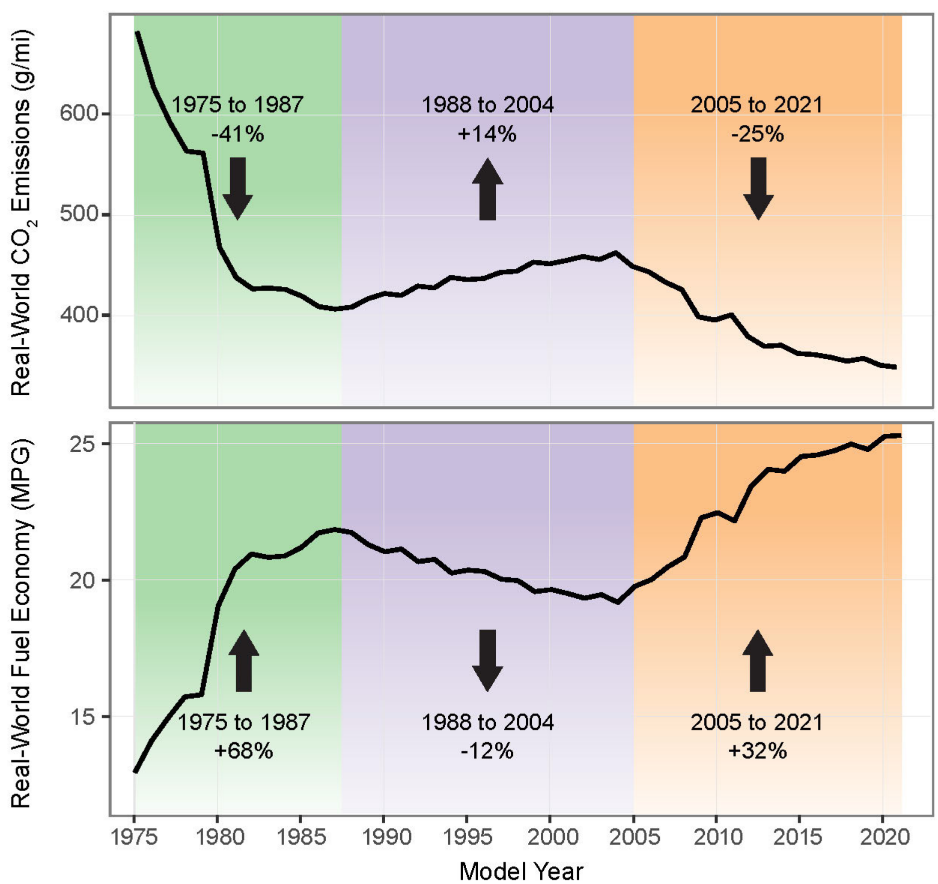
Preliminary data suggest that CO_2 emissions and fuel economy in model year 2022 will improve from the levels achieved in 2021. The preliminary model year 2022 data

[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.

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 1975–2021. 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.

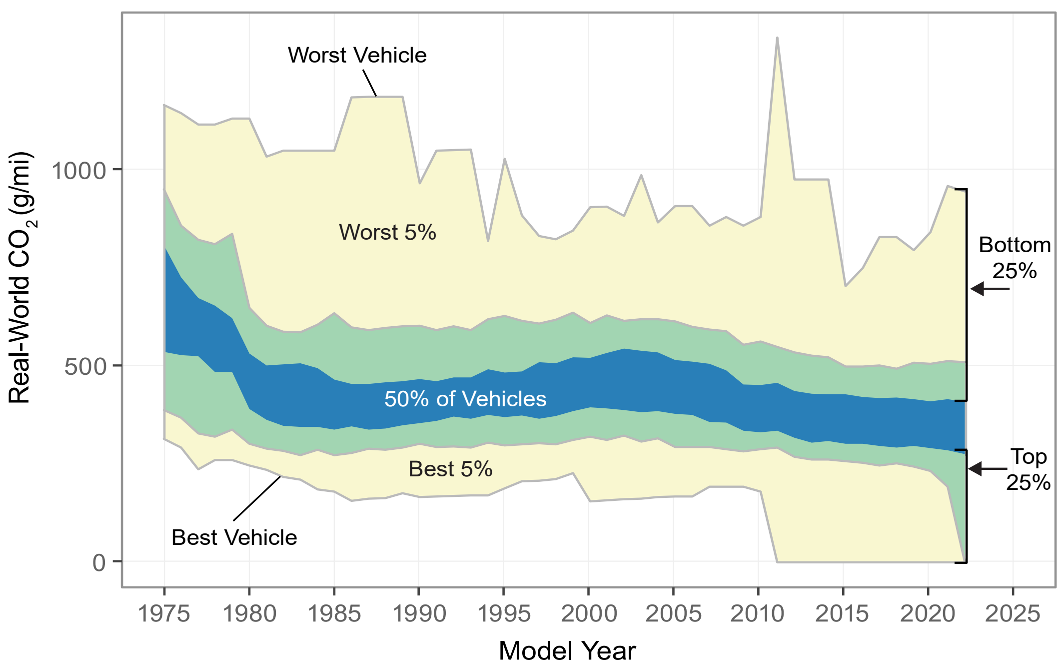
Figure 2.2. Trends in Fuel Economy and CO_2 Emissions Since Model Year 1975



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 CO_2 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 recent years as the production of electric vehicles with zero tailpipe emissions has increased. The lowest CO_2-emitting vehicles have all been hybrids or electric vehicles since the first hybrid was introduced in model year 2000, while the highest CO_2-emitting vehicles are generally 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.

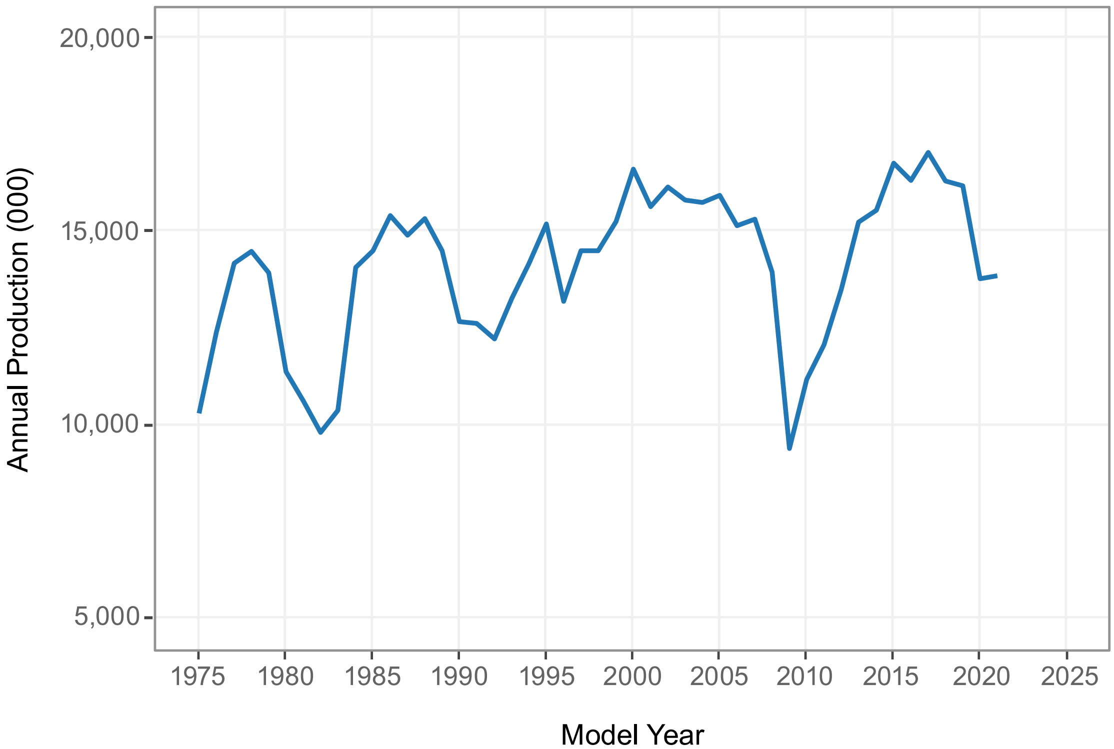
It is important to note that the methodology used in this report for calculating estimated real-world fuel economy and CO_2 emission values has changed over time to reflect changing vehicle technology and operation. For example, the estimated real-world fuel economy for a 1980s vehicle is somewhat higher 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 Appendices C and D for a detailed explanation of fuel economy metrics and their changes over time.

B. Production Trends

This report is based on the total number of vehicles produced by manufacturers for sale in the United States by model year. Model year is the manufacturer's annual production period which includes January 1 of the same calendar year. A typical model year for a vehicle begins in fall of the preceding calendar year and runs until late in the next calendar year. However, model years vary among manufacturers and can occur between Janurary 2 of the preceding calendar year and the end of the calendar year. Model year production data is the most direct way to analyze emissions, fuel economy, technology, and compliance trends because vehicle designs within a model year do not typically change. The use of model year production may lead to some short-term discrepencies with other sources, which typically report calendar year sales; however, sales based on the calendar year generally encompass more than one model year, which complicates any analysis.

Since the inception of this report, production of vehicles for sale in the United States has grown about 0.5% year over year, but there have been significant swings up or down in any given model year due to the impact of multiple market forces. For example, in model year 2009 the Great Recession resulted in the lowest model year production since the start of this report, at 9.3 million vehicles. Production rebounded over the next several model years, reaching an all-time high of more than 17 million vehicles in model year 2017. Model year 2020 production fell 15% from the previous year, as the COVID-19 pandemic had wide-ranging impacts on the economy and vehicle production. Production was up slightly in model year 2021, but the ongoing COVID-19 pandemic, as well as supply chain disruptions affecting the availability of semiconductors and other components, continue to challenge the industry. Figure 2.4 shows the production trends by model year for model years 1975 to 2021.

Figure 2.4. New Vehicle Production by Model Year



C. 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 2.5. 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. The change in production trends, and the impact on the trends shown in Figure 2.5 are discussed in more detail in the next section.

For model year 2021 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 a close grouping of Subaru, Kia, Hyundai, Nissan, and Honda. Stellantis had the highest new vehicle average CO_2 emissions and lowest fuel economy of the large manufacturers in model year 2021, followed by GM and Ford. Tesla also had the highest overall fuel economy, followed by the close group of Subaru, Kia, Nissan, Hyundai, and Honda.

Figure 2.5. Changes in Estimated Real-World Fuel Economy and CO_2 Emissions by Manufacturer

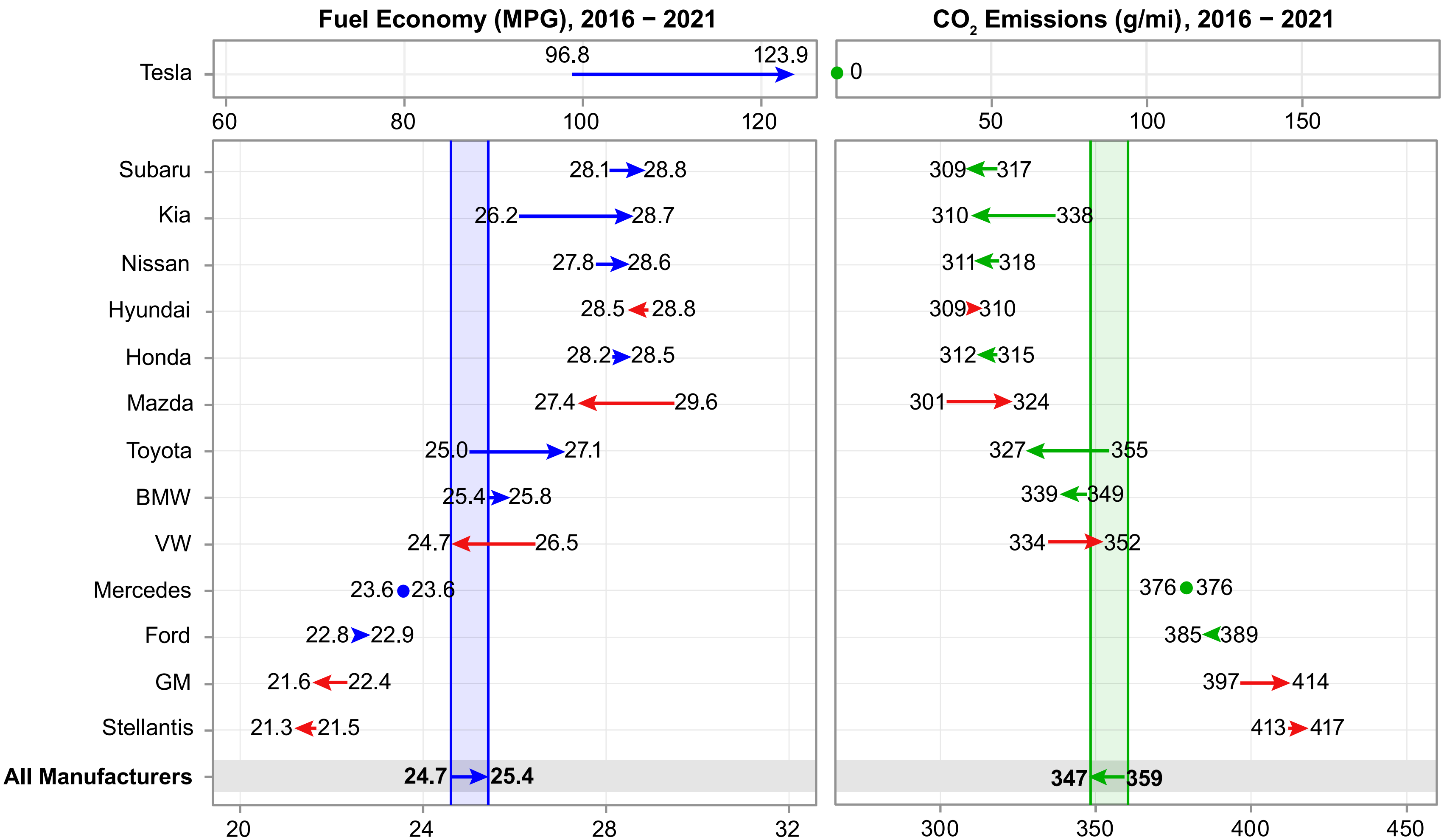


Table 2.1. Production, Estimated Real-World CO_2, and Fuel Economy for Model Year 1975–2022

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	20.1
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	13,721	349	25.4
2021	13,810	347	25.4
2022 (prelim)		*331*	*26.4*

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	Stellantis	Honda Civic	47.3	Gas	Honda Civic	47.3
2000	Hyundai	Stellantis	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	Stellantis	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	Stellantis	Nissan-i-MiEV	109.0	EV	Toyota iQ	36.8
2013	Hyundai	Stellantis	Toyota IQ	117.0	EV	Toyota iQ	36.8
2014	Mazda	Stellantis	BMW i3	121.3	EV	Mitsubishi Mirage	39.5
2015	Mazda	Stellantis	BMW i3	121.3	EV	Mitsubishi Mirage	39.5
2016	Mazda	Stellantis	BMW i3	121.3	EV	Mazda 2	37.1
2017	Honda	Stellantis	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5
2018	Tesla	Stellantis	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5
2019	Tesla	Stellantis	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.6
2020	Tesla	Stellantis	Tesla Model 3	138.6	EV	Mitsubishi Mirage	41.6
2021	Tesla	Stellantis	Tesla Model 3	139.1	EV	Mitsubishi Mirage	41.6
2022 (prelim)	*Tesla*	*Stellantis*	*Lucid Air*	*131.4*	*EV*	*Mitsubishi Mirage*	*40.1*

[3] Manufacturers below the 150,000 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 2020–2022

	MY 2020 Final		MY 2021 Final				*MY 2022 Preliminary*	
Manufacturer	**Real-World FE (mpg)**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**FE Change from MY 2020 (mpg)**	**Real-World CO_2 (g/mi)**	**CO_2 Change from MY 2020 (g/mi)**	***Real-World FE (mpg)***	***Real-World CO_2 (g/mi)***
BMW	25.5	347	25.8	0.3	339	-8	25.7	341
Ford	23.0	386	22.9	-0.1	385	-1	23.0	382
GM	23.0	386	21.6	-1.5	414	28	22.2	400
Honda	29.1	305	28.5	-0.6	312	6	28.3	315
Hyundai	28.4	312	28.5	0.1	310	-2	29.1	302
Kia	27.7	320	28.7	1.0	310	-10	28.7	305
Mazda	27.9	319	27.4	-0.5	324	6	26.5	335
Mercedes	23.4	379	23.6	0.2	376	-3	24.6	359
Nissan	27.9	317	28.6	0.6	311	-7	28.0	316
Stellantis	21.3	418	21.3	0.0	417	-1	21.6	410
Subaru	28.5	312	28.8	0.3	309	-3	28.0	317
Tesla	119.1	0	123.9	4.8	0	0	121.5	0
Toyota	27.0	329	27.1	0.1	327	-2	28.0	316
VW	24.9	354	24.7	-0.2	352	-2	27.7	306
All Manufacturers	**25.4**	**349**	**25.4**	**0.0**	**347**	**-2**	**26.4**	**331**

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, passenger cars and light trucks, and each vehicle class has separate GHG and fuel economy standards[5]. Vehicles that weigh more than 6,000 pounds gross vehicle weight[6] (GVW) or have four-wheel drive and meet various off-road requirements, such as ground clearance, qualify as light trucks. Vehicles can also qualify as light trucks based on the vehicle's functionality as defined in the regulations (for example if the vehicle can transport cargo on an open bed or the cargo carrying volume is more than the passenger carrying volume). Vehicles that do not meet these requirements are considered cars.

Pickup trucks, vans, and minivans are classified as light trucks under NHTSA's regulatory definitions, while sedans, coupes, and wagons are generally classified as cars. Sport utility vehicles (SUVs) can fall into either category depending on the relevant attributes of the specific vehicle. Based on the CAFE and GHG regulatory definitions, most 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.

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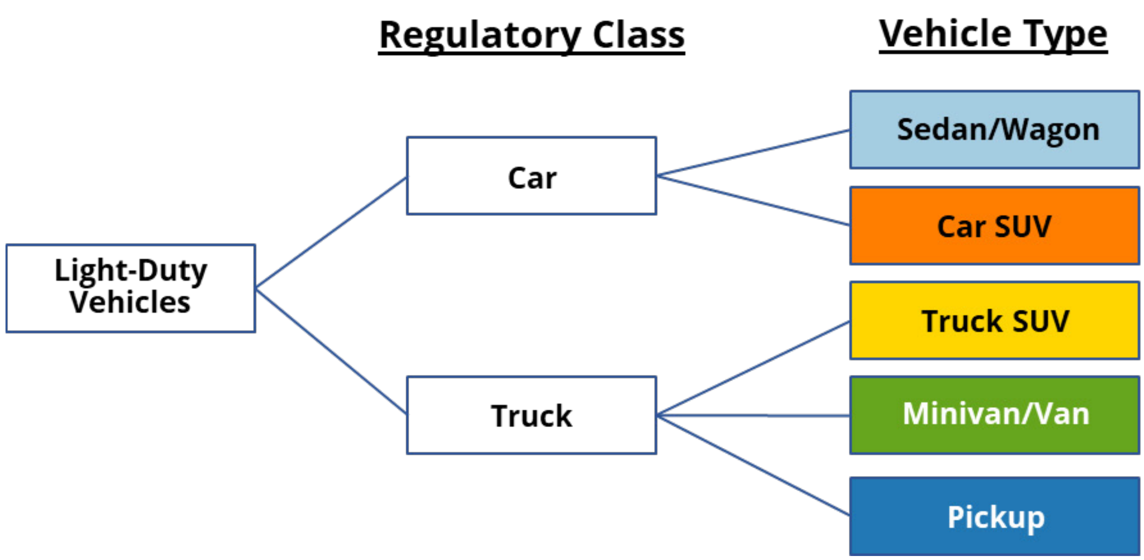
[5] Passenger vehicles (cars) and light trucks (trucks) are defined by regulation in EPA's 40 CFR 86.1818-12 which references the Department of Transportation's 49 CFR 523.4-523.5.

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

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, 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. Sedan/wagons were the dominant vehicle type in 1975, when more than 80% of vehicles produced were sedan/wagons. Since then, their production share has generally been falling, reaching a new low in model year 2021 at only 26% of all production, 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 now account for more than half of all new vehicles produced. In model year 2021, truck SUVs reached a record high 45% of production. Car SUVs reached a record high of 13% of production in model year 2020 and account for 11% of production in model year 2021. The production share of pickups has fluctuated over time, peaking at 19% in 1994 and then falling to 10% in 2012. Pickups have generally increased in recent years and accounted for 16% of the market in model year 2021. Minivan/vans captured less than 5% of the market in 1975, increased to 11% in model year 1995 but have fallen since to 2% of vehicle production in model year 2021. The projected 2022 data shows a vehicle type distribution that is similar to model year 2021.

In model year 2021, the regulatory truck class reached the highest percentage of production on record, at 63%, and experienced the largest shift towards trucks observed since 1975. Trucks increased from 56% to 63% of production in model year 2021. 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

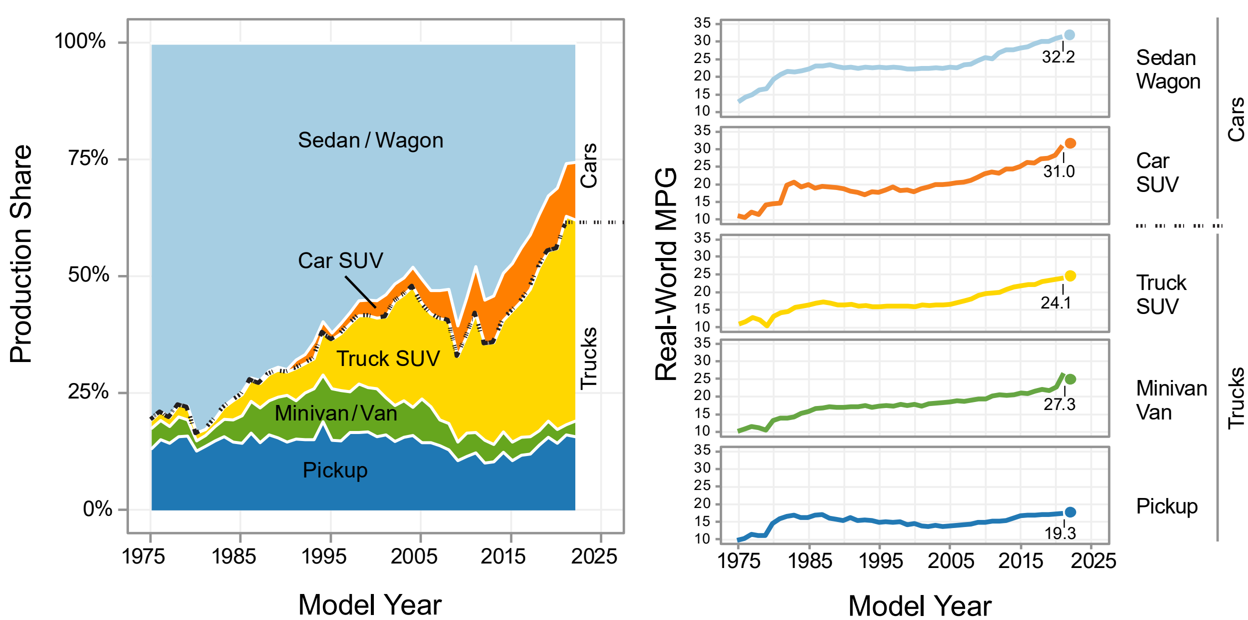


Figure 3.2 also shows estimated real-world fuel economy for each vehicle type since 1975. All five vehicle types are at record low CO_2 emissions and record high fuel economy in

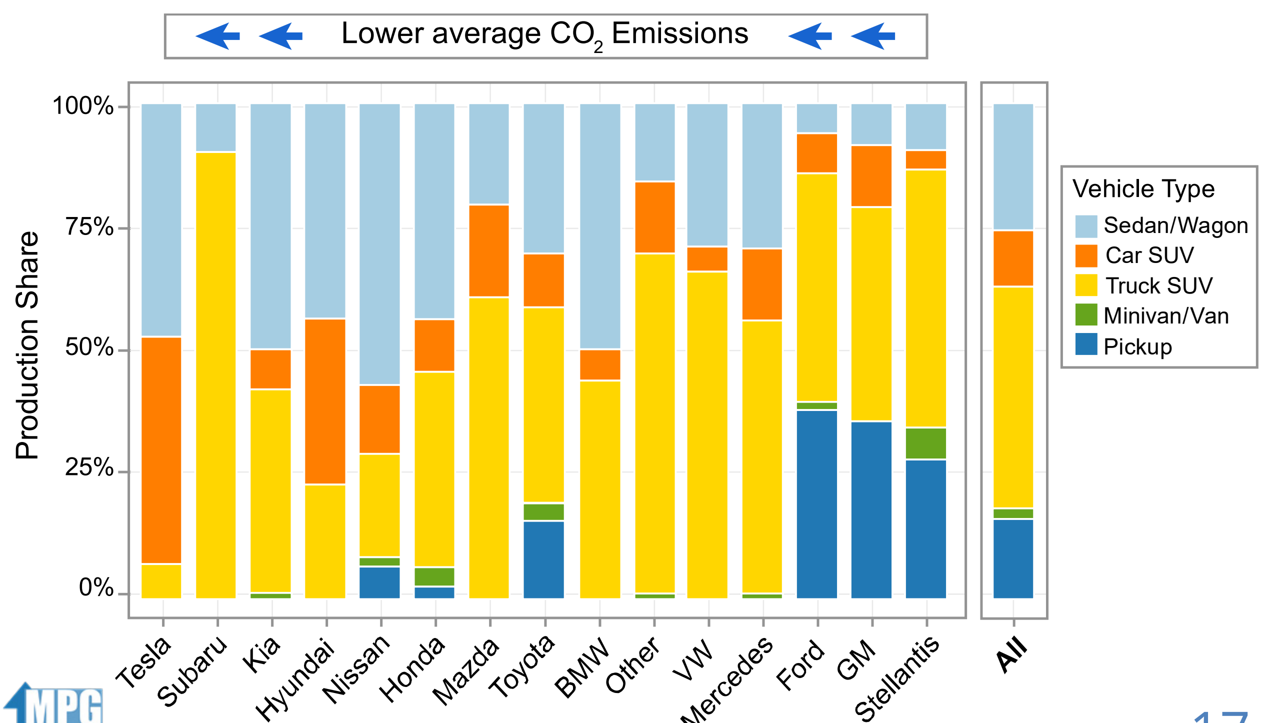
model year 2021. Minivan/Vans increased fuel economy by 3.9 mpg, car SUVs by 2.6 mpg, sedan/wagons by 0.5 mpg, truck SUVs by 0.3 mpg, and pickups increased fuel economy by 0.1 mpg. All of the vehicle types, except for pickups, now achieve fuel economy more than double what they achieved in 1975. In the preliminary model year 2022 data (shown as a dot on Figure 3.2), four of the five vehicle types are expected to improve fuel economy and one, minivans/vans, is projected to decrease from model year 2021.

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 2021 production breakdown by vehicle type for each manufacturer is shown in Figure 3.3. There are clear variations in production distribution by manufacturer. Nissan had the highest production of sedan/wagons at 57%. For other vehicle types, Tesla had the highest percentage of car SUVs at 46%; Subaru had the highest percentage of truck SUVs at 90%; Ford had the highest percentage of pickups at 38%, and Stellantis had the highest percentage of minivan/vans at 6.4%.

Figure 3.3. Vehicle Type Distribution by Manufacturer for Model Year 2021



A Closer Look at SUVs

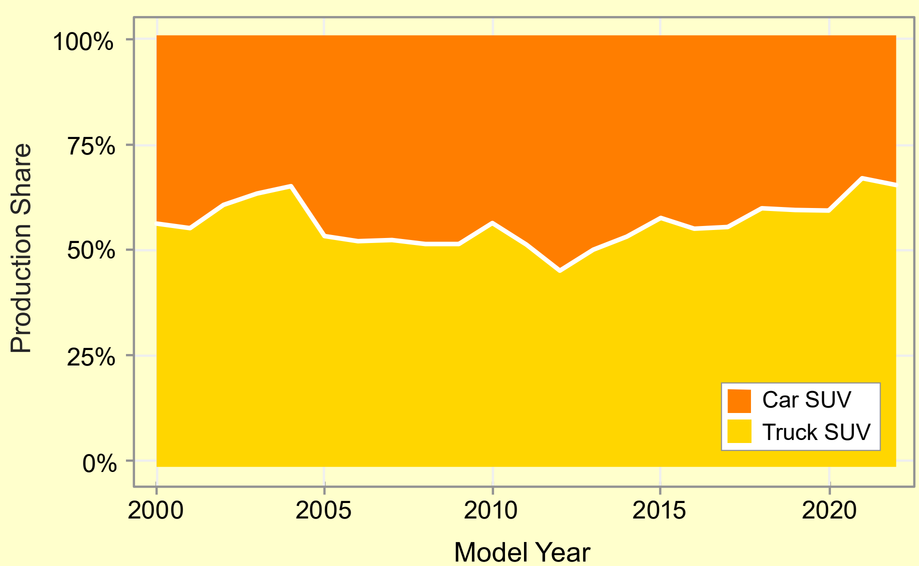
SUV Classification

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 more than 55% 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 increased to 67% in model year 2021, which is the highest percentage of production since at least model year 2000. Projected model year 2022 data shows a slight decrease.

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



Sedan/wagon market penetration fell 5 percentage points across the industry in model year 2021, with reductions from thirteen out of fourteen large manufacturers. Tesla had the largest change, as sedan/wagons fell from 65% of production in model year 2020 to 47% in model year 2021. Toyota had the second largest change, from 43% of production to 30%, followed by VW, which saw sedan/wagons fall from 40% to 29% of production. All three companies increased their relative production of both car SUVs and truck SUVs.

For some manufacturers, changes in the mix of vehicle types they produce has also led to a significant impact on their overall new vehicle CO_2 emissions and fuel economy. Over the last five years, as shown in Figure 2.5, Kia achieved the largest reduction in CO_2 emissions, at 29 g/mi. Kia decreased emissions in all vehicle types that they offer and decreased overall emissions even as their truck SUV share increased from 15% to 41% and sedan/wagon share decreased from 53% to 50%. Toyota achieved the second largest reduction in overall CO_2 tailpipe emissions, at 28 g/mi, and BMW had the third largest reduction in overall CO_2 tailpipe emissions at 10 g/mi. Toyota and BMW also achieved overall emission reductions by improving all vehicle types, even as their truck SUV production share increased.

Over the same five-year period, Mazda had the largest increase at 24 g/mi, due to increased CO_2 emission rates within their sedan/wagon and car SUV vehicle types, along with a shift in production from 33% to 61% truck SUVs. Volkswagen had the second largest increase at 18 g/mi, as a shift in production from 21% to 66% truck SUVs more than offset emission reductions within each vehicle type. GM had the third largest increase at 17 g/mi, with a production shift towards truck SUVs and pickups and an increase in pickup emission rates more than offsetting emission improvements in all other vehicle types.

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 vehicles with a higher weight, other things being equal, will require more energy to move. For vehicles with an internal combustion engine, this higher energy requirement generally results in more CO_2 emissions and decreased fuel economy. For electric vehicles (EVs), the higher energy required to move a vehicle with more weight will likely decrease fuel economy, measured in miles per gallon of gasoline equivalent (mpge), but will not increase CO_2 emissions, since EVs do not have tailpipe emissions regardless of the weight of the vehicle. Due to the weight of battery packs, electric vehicles are likely to weigh more than comparable internal combustion engine vehicles and can even result in the vehicle falling under different regulatory requirements.

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[7] 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 for all vehicle types since model year 1975. 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% from model year 1981 and reached 4,111 pounds per vehicle, in part because of the increasing truck share. Average vehicle weight in model year 2021 was about 4% above 2004 and is currently at the highest point on record, at 4,289 pounds. Preliminary model year 2022 data suggest that weight will continue to increase.

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 2021, the

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

difference between the heaviest and lightest vehicle types had increased to more than 1,600 pounds, about 38% of the average new vehicle weight. Over that time, the weight of an average new sedan/wagon fell 12% while the weight of an average new pickup increased 30%. 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 2021, with the average new pickup outweighing the average new sedan/wagon by more than 1,600 pounds. Pickups are below their model year 2014 high of 5,484 pounds per vehicle, due to vehicle redesigns of popular truck models and the use of weight saving designs, such as aluminum bodies.

Figure 3.5. Average New Vehicle Weight by Vehicle Type

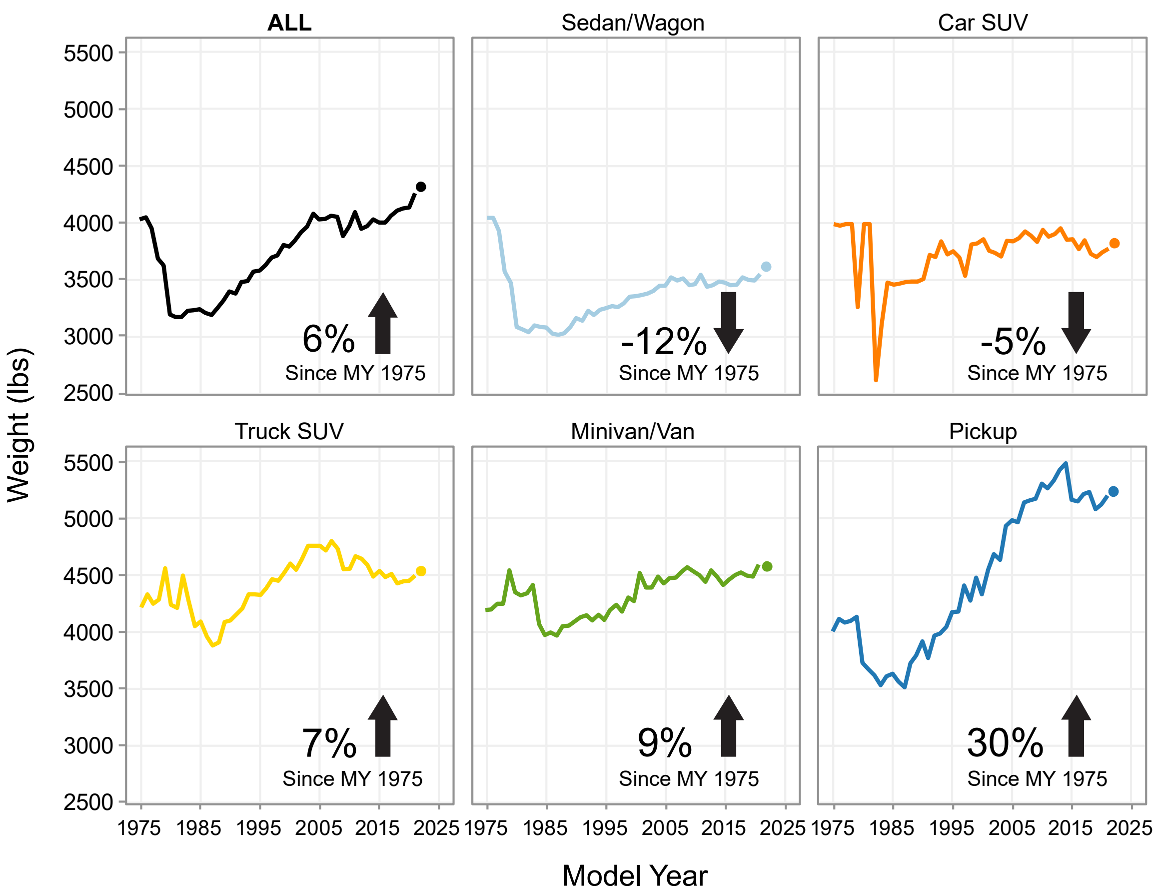
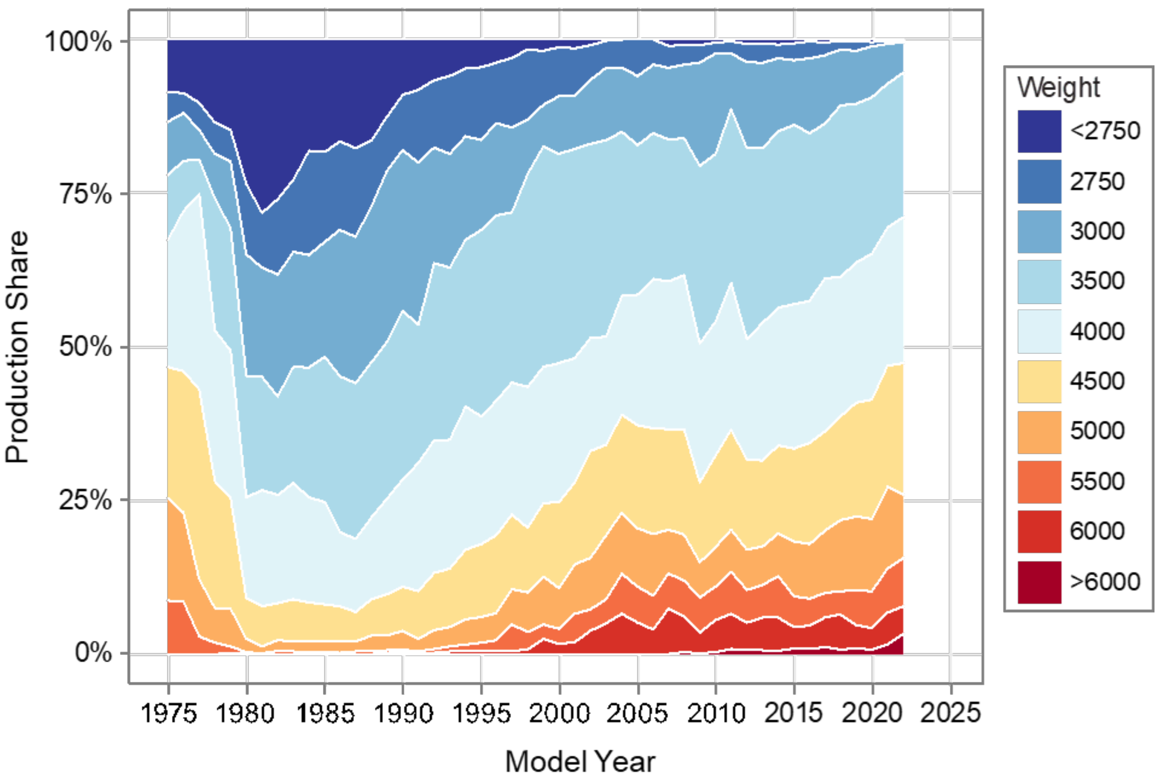


Figure 3.6 shows the annual production share of different inertia weight classes for new vehicles since model year 1975. In model year 1975 there were significant sales in all weight classes from <2,750 pounds to 5,500 pounds. In the early 1980s the largest vehicles disappeared from the market, and light 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 pickups and truck SUVs, along with a few minivan/vans and a small number of luxury sedan/wagons.

Figure 3.6. Inertia Weight Class Distribution by Model Year



Vehicle Weight and CO_2 Emissions

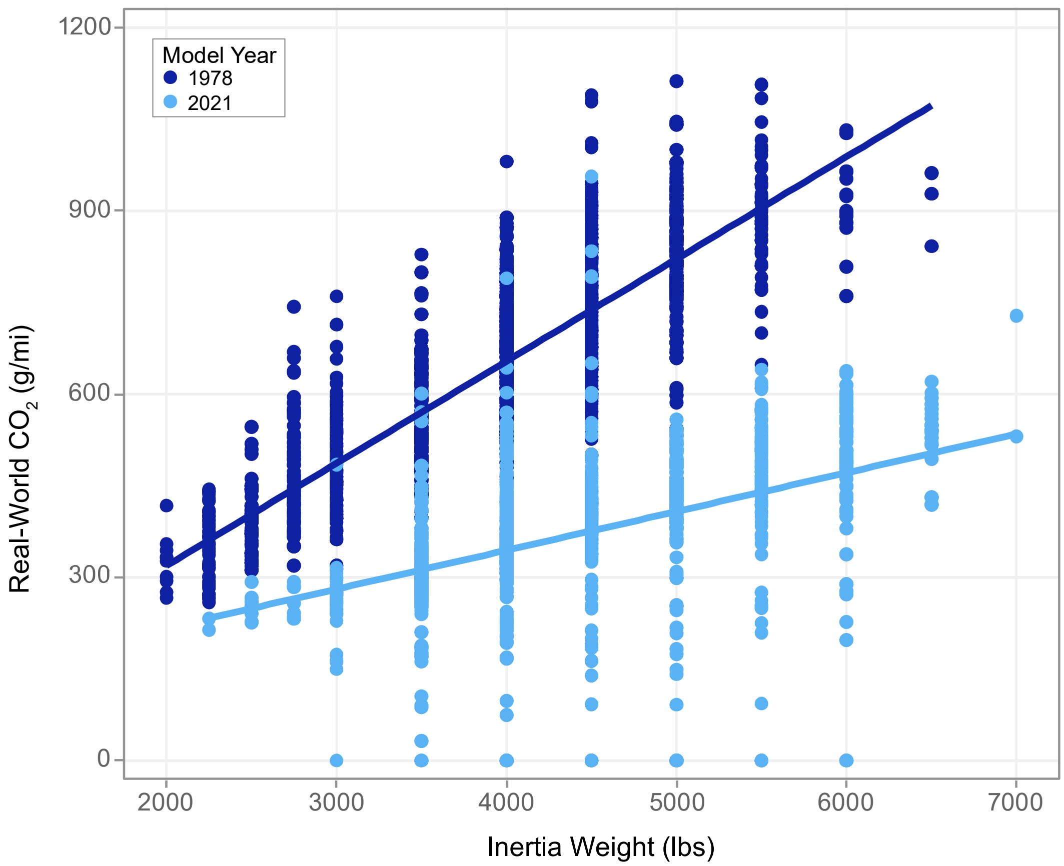
Heavier vehicles require more energy to move than lower-weight vehicles and, if all other factors are the same, will have lower fuel economy and higher CO_2 emissions. The wide array of technology available in modern vehicles complicates this comparison, but it is still useful to evaluate the relationship 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[8] 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. At lower weights, vehicles from model year 2021 produced about two

[8] 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.

thirds of the CO_2 emissions of 1978 vehicles. The difference between model year 2021 and 1978 increases for heavier vehicles, as the heaviest model year 2021 vehicles produce about half of the CO_2 emissions of 1978 vehicles.

Figure 3.7. Relationship of Inertia Weight and CO_2 Emissions



Electric vehicles, which do not produce any tailpipe CO_2 emissions regardless of 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.

C. Vehicle Power

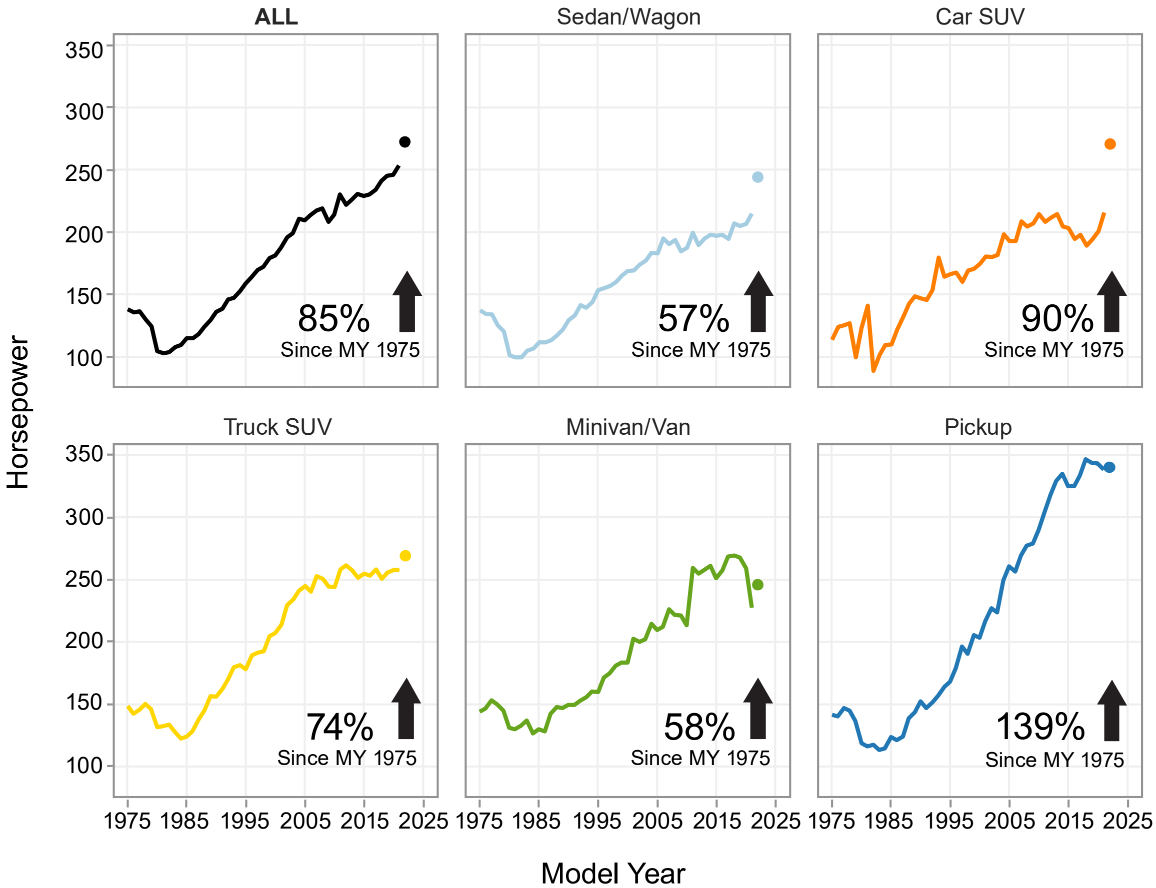
Vehicle power, measured in horsepower (hp), has changed dramatically since model year 1975. In the early years of this report, horsepower fell, from an average of 137 hp in model year 1975 to 102 hp in model year 1981. Since model year 1981, however, horsepower has increased almost every year. The average new vehicle in model year 2021 produced 85% more power than a new vehicle in model year 1975, and 148% more power than an average new vehicle in model year 1981. The average new vehicle horsepower is at a record high, increasing from 246 hp in model year 2020 to 253 hp in model year 2021. The preliminary value for model year 2022 is 272 hp, which would be another record-high for horsepower.

Many EVs have high hp ratings, however determining vehicle horsepower for EVs and PHEVs can be more complicated than for vehicles with internal combustion engines. The power available at the wheels of an EV may be limited by numerous electrical components other than the motor. In addition, some EVs have multiple motors and the total available power may be less than the sum of the individual motor ratings. PHEVs, which have an internal combustion engine, at least one motor, and complicated control strategies, can be even more complicated to accurately assign one static power value. Therefore, horsepower values for the increasing number of EVs and PHEVs are more difficult to determine and may have higher uncertainty.

Vehicle Power by Vehicle Type

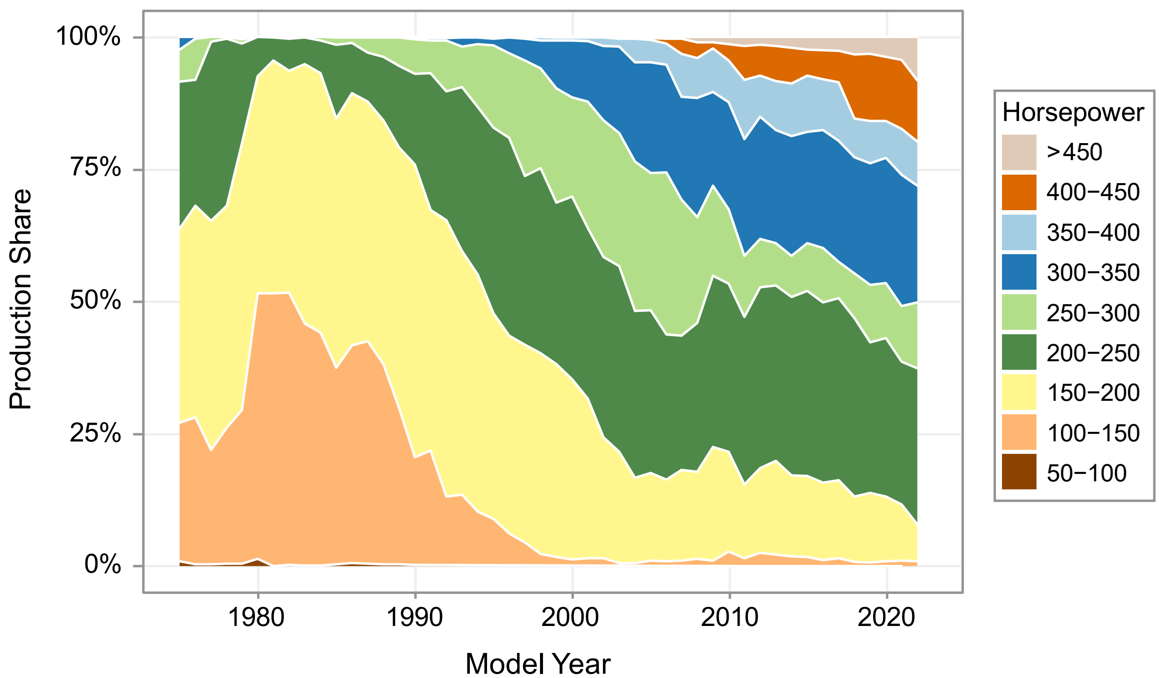
As with weight, the changes in horsepower are also different among vehicle types, as shown in Figure 3.8. Horsepower for sedan/wagons increased 57% between model year 1975 and 2021, 74% for truck SUVs, 90% for car SUVs, 58% for minivan/vans, and 139% for pickups. Horsepower has generally been increasing for all vehicle types since about 1985, but there is more variation between model types in the last decade. The projected model year 2022 data shows a large increase of about 19 hp across all new vehicles. This is due in part to the projected increase of electric vehicles, many of which have high horsepower ratings. The projected data shown horsepower increases for all vehicle types.

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 2021 had 253 hp. In addition, vehicles with more than 300 hp make up more than half of new vehicle production, and the maximum horsepower for an individual vehicle is now 1,500 hp. Horsepower is projected to increase again in model year 2022, with 20% of vehicles projected to reach 400 hp or higher.

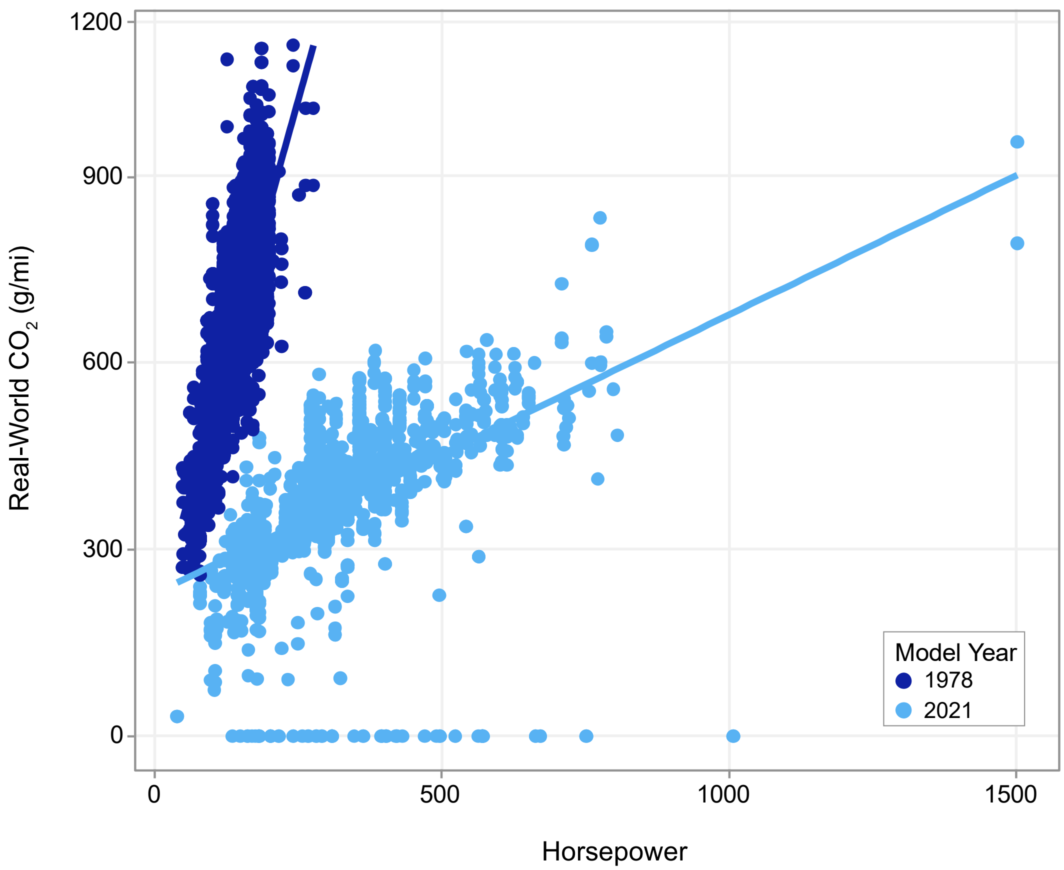
Figure 3.9. Horsepower Distribution by Model Year



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 2021, CO_2 emissions increased with increased vehicle horsepower at a much lower rate than in model year 1978, such that model year 2021 vehicles nearly all had 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).[9]

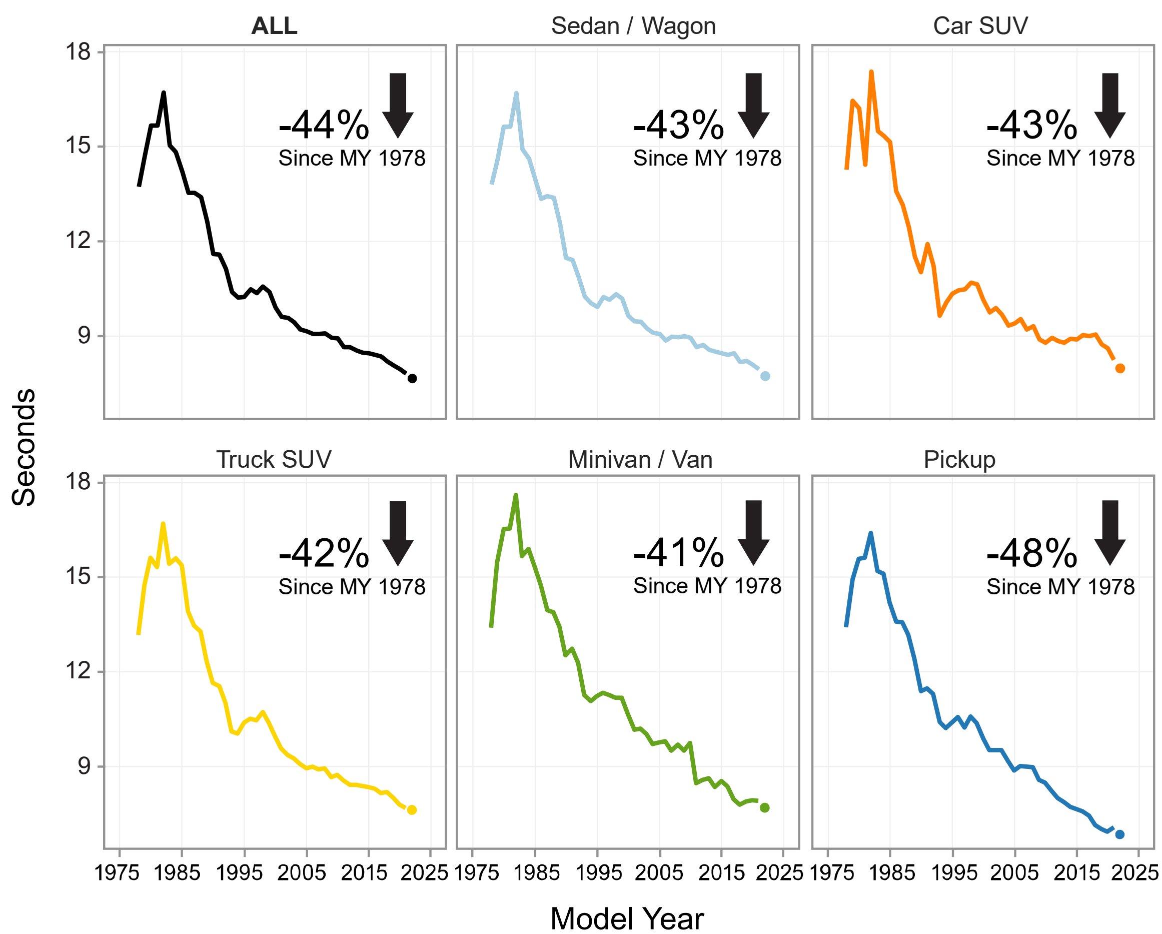
The relationship between power and acceleration is different for EVs than for vehicles with internal combustion engines. Electric motors generally have maximum torque available from a standstill, which is not true for internal combustion engines. The result is that EVs

[9] 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.

can have very fast 0-60 acceleration times, and the calculation methods used for vehicles with internal combustion engines are not valid for EVs. PHEVs and hybrids may also use their motors to improve acceleration. Acceleration times for EVs, PHEVs, and hybrids must be obtained from external sources, and as with horsepower values, there may be more uncertainty with these values.

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 since model year 1978. The average new vehicle in model year 2021 had a 0-to-60 time of 7.7 seconds, which is the fastest average 0-to-60 time for any model year about half of the average 0-to-60 times of the early 1980s. The calculated 0-to-60 time for model year 2022 is projected to decrease again, to 7.5 seconds. The long-term downward trend in 0-to-60 times is consistent across all vehicle types. 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. Increasing EV production will likely continue, and perhaps accelerate, the trend towards lower 0-to-60 acceleration times.

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



D. Vehicle Footprint

Vehicle footprint is an 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 2021. EPA projects footprint data for the preliminary model year 2022 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 2021, the overall average footprint increased 5%, from 48.9 to 51.5 square feet. All five vehicle types have increased average footprint since model year 2008. Car SUVs have had the smallest increase in footprint, up 0.6 square feet or 1.3%. The footprint of the average truck SUVs has increased 1.4 square feet, the average minivan/van has increased 1.6 square feet, the average sedan/wagon has increased 1.7 square feet, and the average pickup has increased 2.7 square feet, or 4.3%. The overall increase in footprint is impacted by both the trends within each vehicle type and the changing mix of vehicles over time, as the market has shifted towards larger vehicles.

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, along with growth in larger vehicle categories. This is consistent with the changes in market trends towards larger vehicles, as seen in Figure 3.2 and elsewhere in this report. Projected data for model year 2022 suggest that overall average footprint will increase to 51.7 square feet.

Figure 3.12. Footprint by Vehicle Type for Model Year 2008–2021

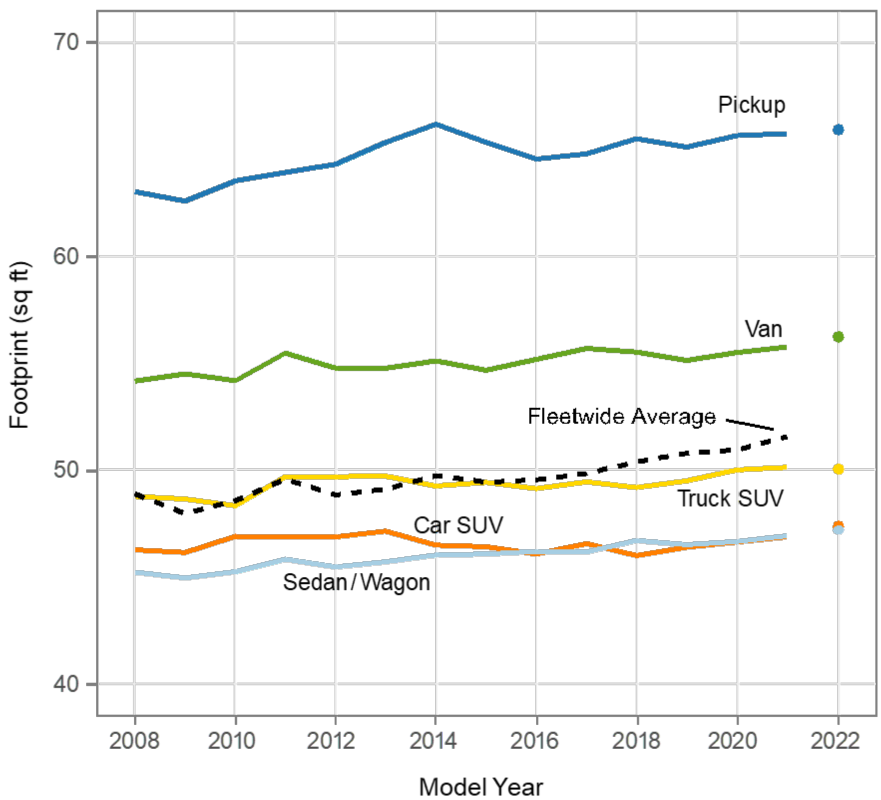
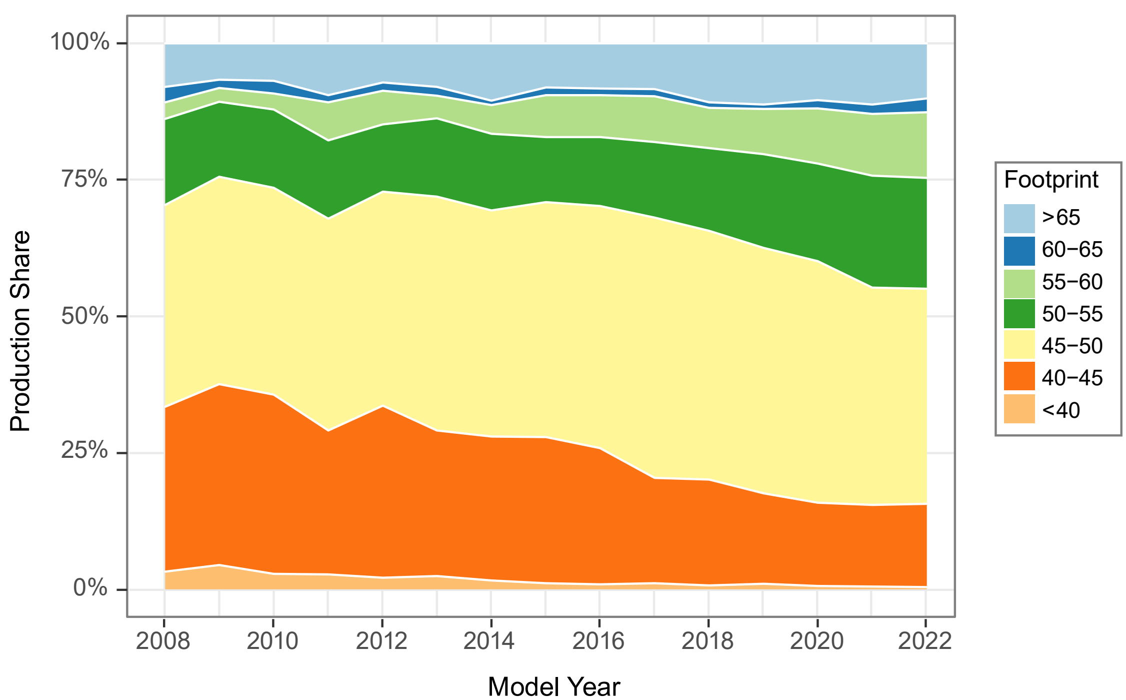


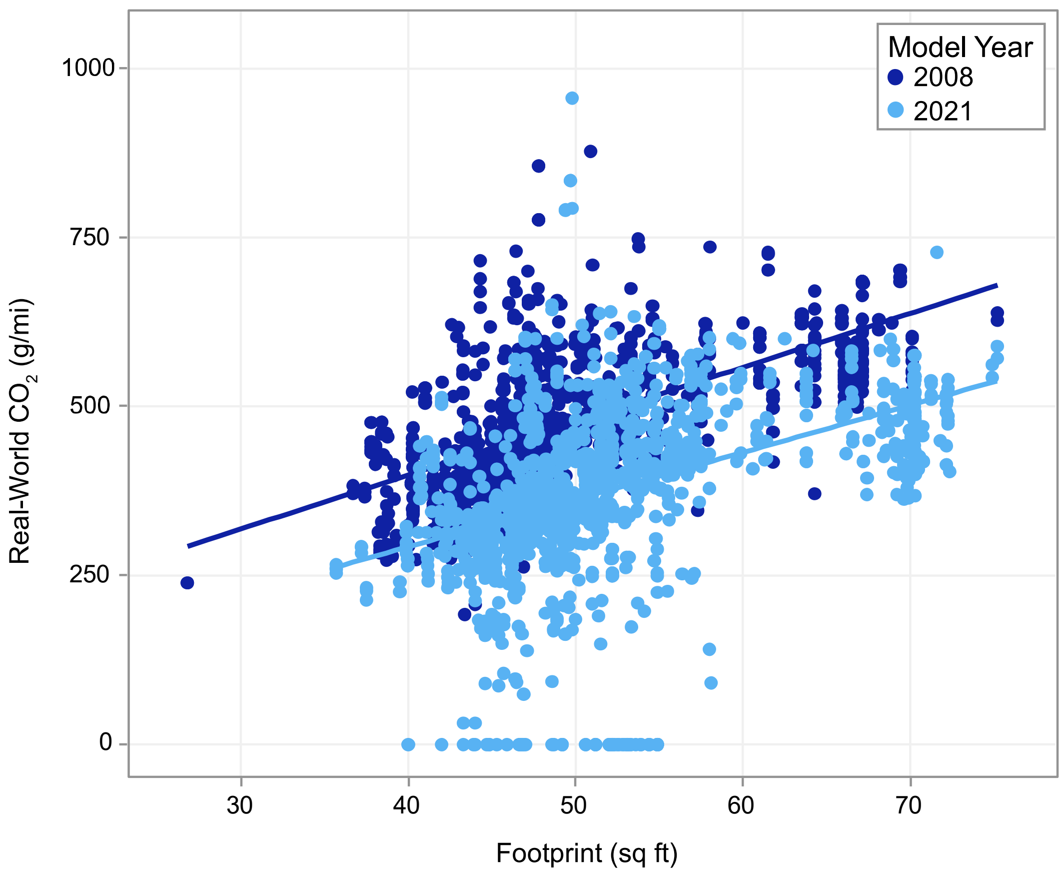
Figure 3.13. Footprint Distribution by Model Year



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 2021, although vehicles produced in model year 2021 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. Vehicle Type and Attribute Tradeoffs

The past 45+ years of data show striking changes in the mix of vehicle types, and the attributes of those vehicles, produced for sale in the United States. In the two decades prior to 2004, technology innovation and market trends generally resulted in increased vehicle power and weight (due to increasing vehicle size and content) while average new vehicle fuel economy steadily decreased and CO_2 emissions correspondingly increased. Since model year 2004, the combination of technology innovation and market trends have resulted in average new vehicle fuel economy increasing 32%, horsepower increasing 20%, and weight increasing 4%. Footprint has increased 5% since EPA began tracking it in model year 2008. These metrics are all at record highs, and horsepower, weight, and footprint are projected to increase again in model year 2022, as shown in Figure 3.15.

The changes within each of these metrics is due to the combination of design and technology changes within each vehicle type, and the market shifts between vehicle types. For example, overall new vehicle footprint has increased within each vehicle type since model year 2008, but the average new vehicle footprint has increased more than the increase in any individual vehicle type over that time span, due to market shifts towards larger vehicle types. Fuel economy has also increased in all vehicle types since model year 2008, however the market shift towards less efficient vehicle types has offset some of the fleetwide fuel economy and CO_2 emission benefits that otherwise would have been achieved through improving technology.

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.

Figure 3.15. Relative Change in Fuel Economy, Weight, Horsepower, and Footprint

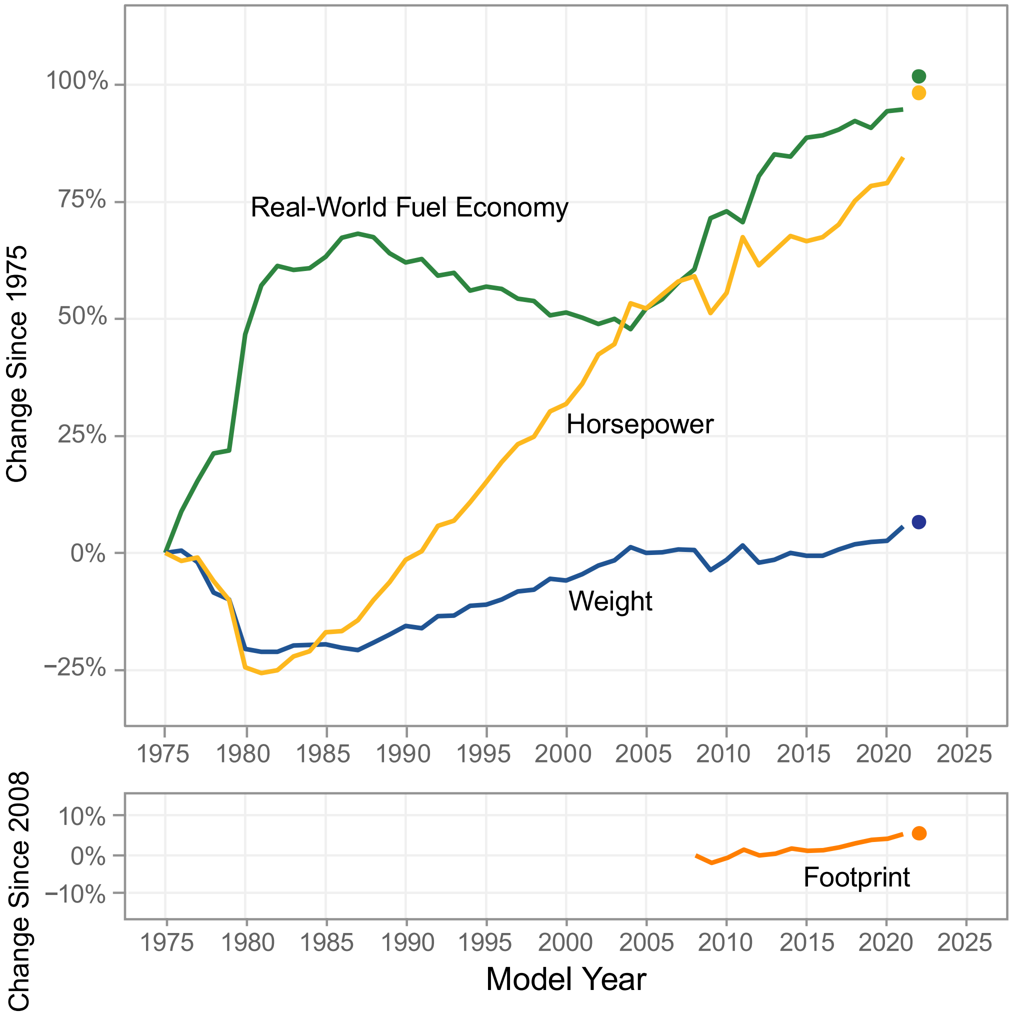


Table 3.1. Vehicle Attributes by Model Year

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%
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	349	25.4	4,166	246	7.8	50.9	43.9%	56.1%
2021	347	25.4	4,289	253	7.7	51.5	37.1%	62.9%
2022 (prelim)	*331*	*26.4*	*4,329*	*272*	*7.5*	*51.7*	*37.8%*	*62.2%*

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
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	27.4	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	30.9%	277	31.7	13.0%	310	28.4	38.7%	374	23.8	2.9%	379	23.4	14.4%	465	19.2
2021	25.7%	270	32.2	11.4%	278	31.0	44.7%	368	24.1	2.2%	322	27.3	16.1%	463	19.3
2022 (prelim)	*25.4%*	*254*	*33.7*	*12.4%*	*262*	*32.4*	*43.1%*	*354*	*24.8*	*3.4%*	*344*	*25.6*	*15.7%*	*442*	*20.1*

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

Table 3.3. Model Year 2021 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	339	25.8	4,443	299	6.3	50.1
Ford	385	22.9	4,685	299	6.9	57.2
GM	414	21.6	4,770	288	7.5	56.9
Honda	312	28.5	3,786	212	7.8	47.9
Hyundai	310	28.5	3,646	194	8.6	47.9
Kia	310	28.7	3,566	190	8.5	47.6
Mazda	324	27.4	3,847	197	8.8	46.4
Mercedes	376	23.6	4,576	304	6.6	50.9
Nissan	311	28.6	3,790	195	9.0	47.6
Stellantis	417	21.3	4,772	304	7.1	55.5
Subaru	309	28.8	3,899	195	9.1	45.9
Tesla	0	123.9	4,317	376	4.8	50.6
Toyota	327	27.1	4,158	224	7.8	49.7
VW	352	24.7	4,394	269	7.2	49.6
Other	340	25.6	4,401	270	7.7	49.0
All Manufacturers	**347**	**25.4**	**4,289**	**253**	**7.7**	**51.5**

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

Table 3.4. Model Year 2021 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	49.7%	316	27.8	6.3%	307	29.0	44.0%	369	23.6	-	-	-	-	-	-
Ford	6.1%	259	29.9	8.1%	304	29.1	46.0%	383	23.2	1.6%	356	25.0	38.1%	425	20.9
GM	8.5%	297	29.4	12.6%	306	29.0	43.1%	421	21.1	-	-	-	35.9%	471	19.1
Honda	43.6%	274	32.4	10.6%	311	28.5	39.5%	340	26.1	4.0%	376	23.6	2.4%	424	21.0
Hyundai	43.5%	258	34.4	33.5%	323	27.3	23.0%	391	22.7	-	-	-	-	-	-
Kia	49.7%	266	33.4	8.2%	312	28.5	41.0%	359	24.8	1.2%	420	21.1	-	-	-
Mazda	20.5%	297	30.0	18.8%	308	28.8	60.8%	339	26.2	-	-	-	-	-	-
Mercedes	29.4%	342	26.0	14.4%	331	26.8	55.1%	405	22.0	1.0%	428	20.7	-	-	-
Nissan	56.8%	279	31.7	14.0%	292	30.4	20.7%	354	25.1	1.9%	356	24.9	6.5%	469	18.9
Stellantis	9.5%	417	21.3	4.0%	340	26.1	51.9%	400	22.1	6.4%	341	25.3	28.1%	478	18.7
Subaru	10.0%	326	27.3	-	-	-	90.0%	307	28.9	-	-	-	-	-	-
Tesla	47.2%	0	129.8	45.8%	0	119.0	7.0%	0	119.8	-	-	-	-	-	-
Toyota	30.3%	256	34.6	10.9%	310	28.7	39.5%	333	26.5	3.6%	248	35.8	15.7%	477	18.6
VW	29.0%	302	28.9	5.0%	201	35.7	66.0%	386	22.7	-	-	-	-	-	-
Other	16.5%	255	33.4	14.5%	287	29.4	68.0%	371	23.6	1.0%	341	26.0	-	-	-
All Manufacturers	**25.7%**	**270**	**32.2**	**11.4%**	**278**	**31.0**	**44.7%**	**368**	**24.1**	**2.2%**	**322**	**27.3**	**16.1%**	**463**	**19.3**

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 2020–2022 (ft^2)

Manufacturer	Final MY 2020			Final MY 2021			*Preliminary MY 2022*		
	Car	Truck	All	Car	Truck	All	*Car*	*Truck*	*All*
BMW	47.8	52.8	49.7	48.1	52.7	50.1	*47.9*	*52.9*	*50.1*
Ford	47.8	58.1	55.4	47.6	58.8	57.2	*48.0*	*57.7*	*56.7*
GM	45.5	58.9	54.5	45.4	60.0	56.9	*45.9*	*58.6*	*55.2*
Honda	46.1	49.8	47.7	46.6	49.5	47.9	*46.9*	*50.8*	*48.6*
Hyundai	46.5	53.5	47.2	46.5	52.4	47.9	*46.9*	*50.9*	*48.0*
Kia	45.7	50.4	47.5	46.1	49.6	47.6	*46.9*	*50.7*	*48.7*
Mazda	45.5	47.1	46.3	45.5	47.0	46.4	*44.3*	*47.0*	*46.6*
Mercedes	48.8	53.2	51.3	49.1	52.4	50.9	*50.1*	*52.5*	*51.4*
Nissan	46.7	51.1	48.1	46.1	51.1	47.6	*46.9*	*51.3*	*48.7*
Stellantis	49.3	55.8	54.9	50.3	56.3	55.5	*50.5*	*57.2*	*56.5*
Subaru	44.9	46.4	46.1	44.9	46.0	45.9	*44.9*	*46.3*	*46.0*
Tesla	50.4	54.8	50.6	50.6	51.4	50.6	*50.4*	*52.0*	*50.7*
Toyota	46.3	52.6	49.3	46.5	51.9	49.7	*46.5*	*52.6*	*49.9*
VW	46.3	49.4	48.1	47.1	50.8	49.6	*46.8*	*50.2*	*48.8*
Other	44.9	49.9	48.6	44.7	50.8	49.0	*46.1*	*52.9*	*51.3*
All Manufacturers	**46.6**	**54.3**	**50.9**	**46.9**	**54.3**	**51.5**	***47.2***	***54.4***	***51.7***

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

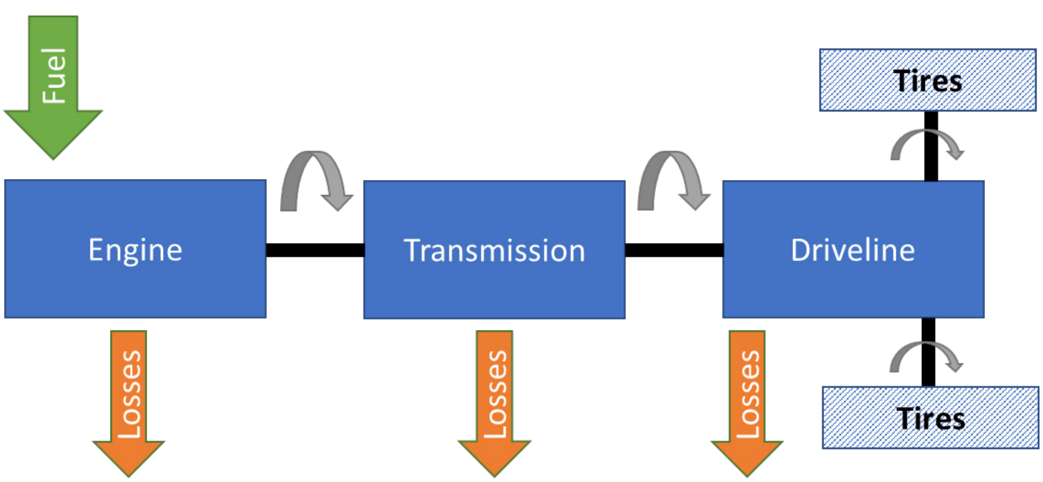
4. Vehicle Technology

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 looks at vehicle technology from two perspectives; first, how the industry has adopted specific technologies over time, and second, how those technologies have impacted CO_2 emissions and fuel economy.

A. Technology Overview

All vehicles use some type of engine or motor to convert energy stored on the vehicle, usually in a fuel or battery, into rotational energy to propel the vehicle forward. Internal combustion engines, for example, typically combust gasoline or diesel fuel to rotate an output shaft. Internal combustion engines are paired with a transmission to convert the rotational energy from the relatively narrow range of speeds available at the engine to the appropriate speed required for driving conditions. The transmission is connected to a driveline that 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 gasoline vehicle is shown in Figure 4.1.

Figure 4.1. Vehicle Energy Flow



Manufacturers have been adopting many new technologies to improve gasoline internal combustion engines. Figure 4.2 illustrates manufacturer-specific technology adoption for model year 2021, where larger circles represent higher adoption rates. For gasoline engines, 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. Transmissions that have seven or more speeds, and continuously variable transmissions (CVTs), allow an engine to more frequently operate near its peak efficiency, providing more efficient average engine operation and a reduction in fuel usage. Engine stop/start systems can turn off the engine entirely when the vehicle is stopped to save fuel.

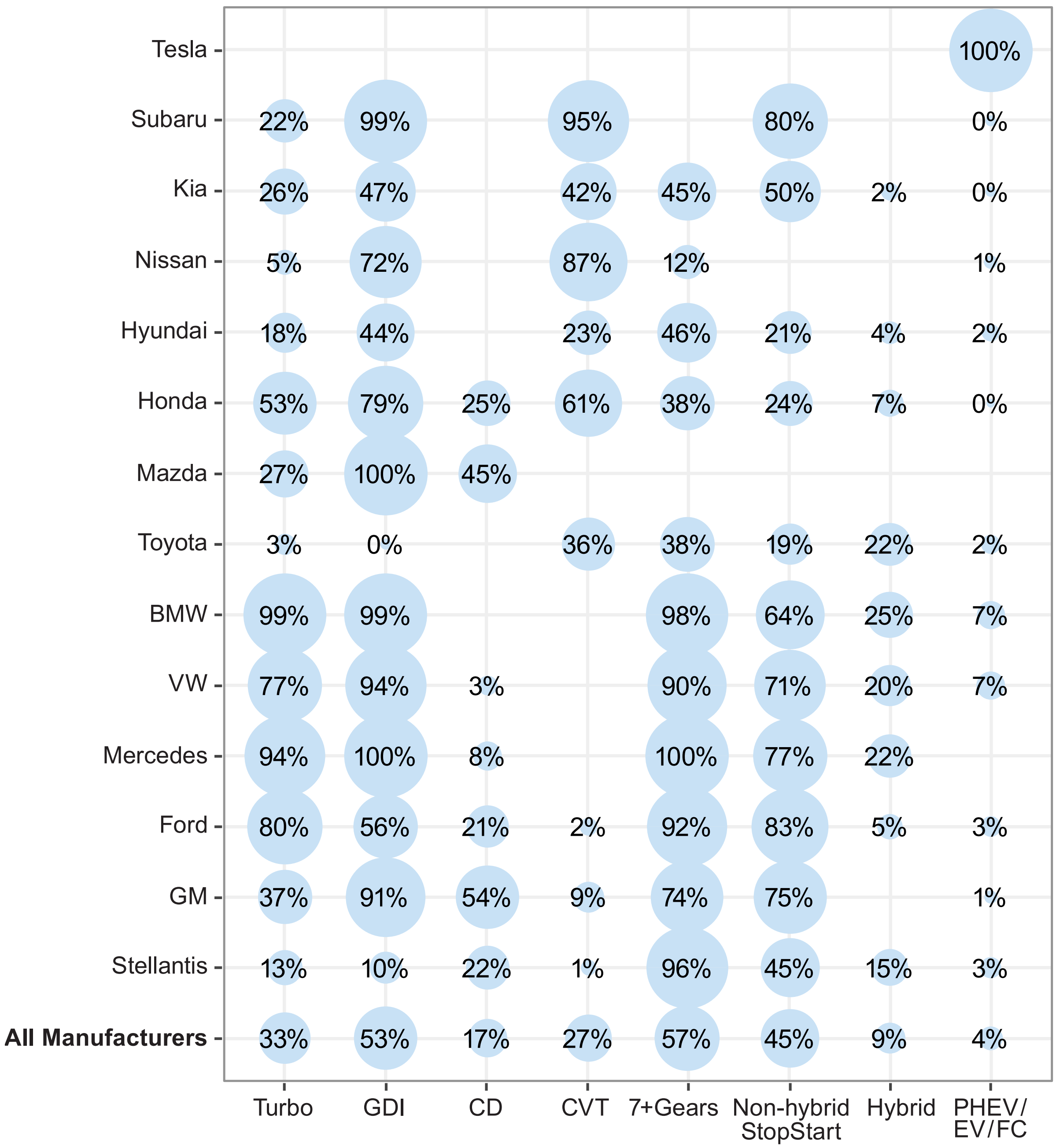
Manufacturers are also adopting hybrids, plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs), and fuel cell vehicles (FCVs). Hybrid vehicles store some propulsion energy in a battery, and often recapture braking energy, allowing for a smaller, more efficiently operated engine. Plug-in hybrids operate similarly to hybrids, but their batteries can be charged from an external source of electricity, and generally have a longer electric only operating range. Electric vehicles operate only on energy stored in a battery that is charged from an external source of electricity and rely exclusively on electric motors for propulsion instead of an internal combustion engine. Fuel cell vehicles use a fuel cell stack to create electricity from an onboard fuel source (usually hydrogen), which then powers an electric motor or motors to propel the vehicle. PHEVs, EVs, and FCVs offer fundamentally different architectures than shown in Figure 4.1 and require different metrics[10] and an evolving analysis of vehicle technology. Hybrids, PHEVs and EVs are a growing portion of the fleet, and most manufacturers have made recent public announcements committing to billions of dollars in research towards electrification, and in some cases, manufacturers have announced specific targets for entirely phasing out internal combustion engines.

The technologies in Figure 4.2 are all being used by manufacturers to reduce CO_2 emissions and increase fuel economy. 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 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

[10] See Appendix E for a detailed discussion of EV and PHEV metrics.

rest of this section will explore how vehicle technology has changed since 1975, the impact of those technology changes, and the rate at which technology is adopted by the industry.

Figure 4.2. Manufacturer Use of Emerging Technologies for Model Year 2021



	Turbo	GDI	CD	CVT	7+Gears	Non-hybrid StopStart	Hybrid	PHEV/ EV/FC
Tesla								100%
Subaru	22%	99%		95%		80%		0%
Kia	26%	47%		42%	45%	50%	2%	0%
Nissan	5%	72%		87%	12%			1%
Hyundai	18%	44%		23%	46%	21%	4%	2%
Honda	53%	79%	25%	61%	38%	24%	7%	0%
Mazda	27%	100%	45%					
Toyota	3%	0%		36%	38%	19%	22%	2%
BMW	99%	99%			98%	64%	25%	7%
VW	77%	94%	3%		90%	71%	20%	7%
Mercedes	94%	100%	8%		100%	77%	22%	
Ford	80%	56%	21%	2%	92%	83%	5%	3%
GM	37%	91%	54%	9%	74%	75%		1%
Stellantis	13%	10%	22%	1%	96%	45%	15%	3%
All Manufacturers	33%	53%	17%	27%	57%	45%	9%	4%

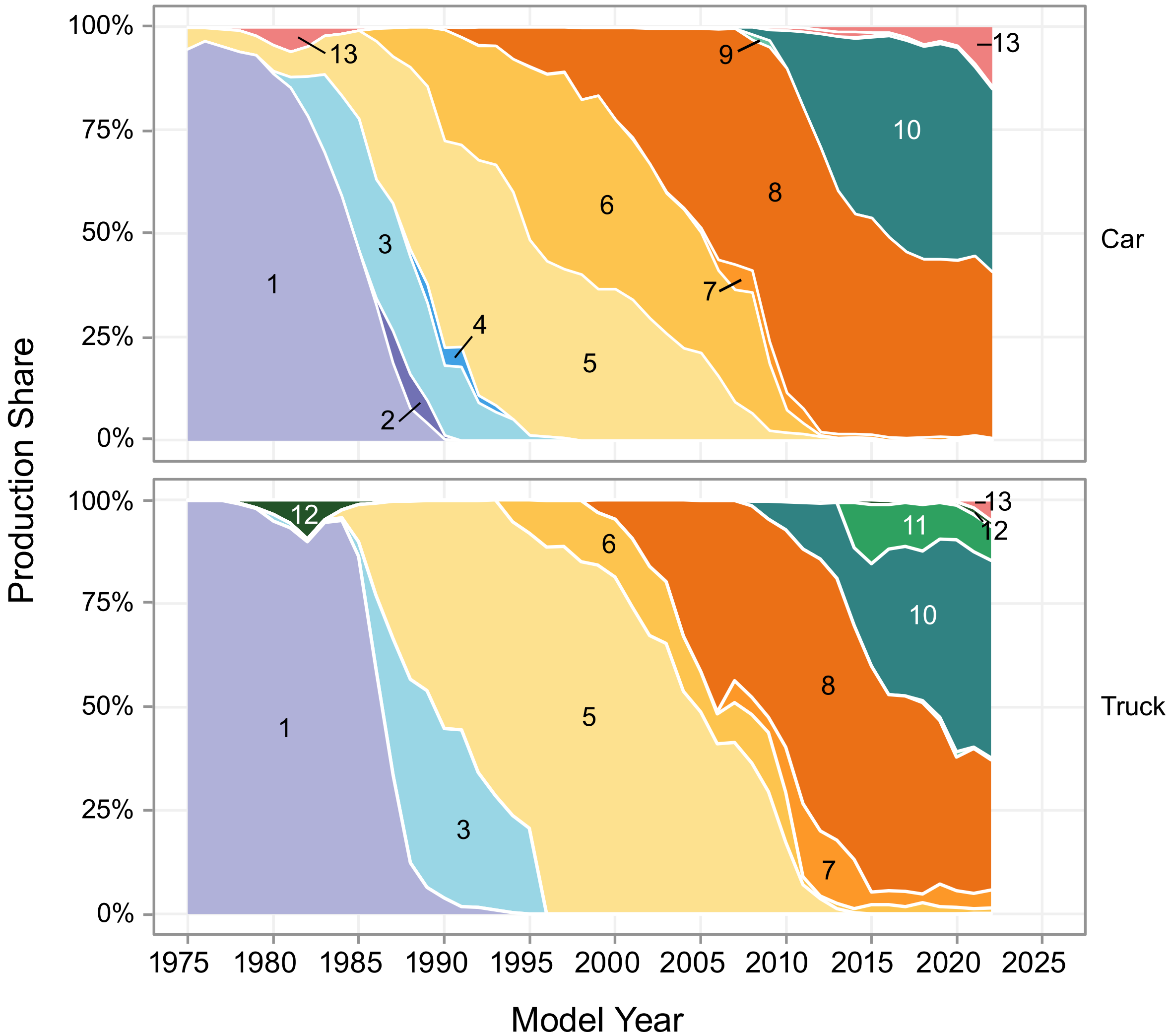
B. Vehicle Propulsion

As discussed above, all vehicles use some type of engine or motor to convert stored energy into rotational energy to propel the vehicle forward. Over the last 45+ years that EPA has been collecting data, gasoline internal combustion engines have been the dominant technology used as a power source in vehicles. Over that time, the technology used in combustion engines has continually evolved. Modern gasoline combustion engines are continuing that trend, employing technologies such as direct injection, turbocharging, and cylinder deactivation to improve efficiency and performance.

A growing portion of new vehicles rely on partial or full electrification to achieve operational improvements, reduce tailpipe CO_2 emissions, and increase fuel economy. Many new vehicles utilize stop-start technology, which turns off the engine during idle conditions and uses the vehicle battery to restart the engine when needed. Mild hybrids generally employ stop-start systems and have an electric motor that can assist the engine with moving the vehicle forward. Full hybrids generally have larger batteries and motors that can provide more power to move the vehicle or can directly drive the vehicle without the engine. Plug-in hybrids (PHEVs) add the capability of charging the vehicle battery from an external source, namely electricity from the power grid. Full electric vehicles (EVs) rely on electric motors to provide propulsion and use energy stored onboard in a battery. EVs are charged with electricity from the power grid, and do not have an internal combustion engine. Most hybrids, PHEVs, and EVs also utilize regenerative braking to recapture braking energy that otherwise would have been lost as heat, and further improve vehicle efficiency. This "spectrum of electrification" is creating a wide range of technology implementation strategies on modern vehicles, and offering numerous pathways to improve vehicle efficiency, emissions, and performance.

The trend in vehicle propulsion 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 prior to model year 2021 (vehicles with diesel engines briefly captured almost 6% of the market in model year 1981). In model year 2021, the combination of EVs, PHEVs, FCVs, and diesel vehicles accounted for slightly more than 5% of all production. The production of EVs is expected to grow in future model years, transitioning to a technology found across multiple vehicle types and models. Projected model year 2022 data suggests EVs alone will capture more than 7% of the market, and perhaps begin to challenge the dominance of vehicles relying exclusively on gasoline internal combustion engines.

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. Combined, 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.

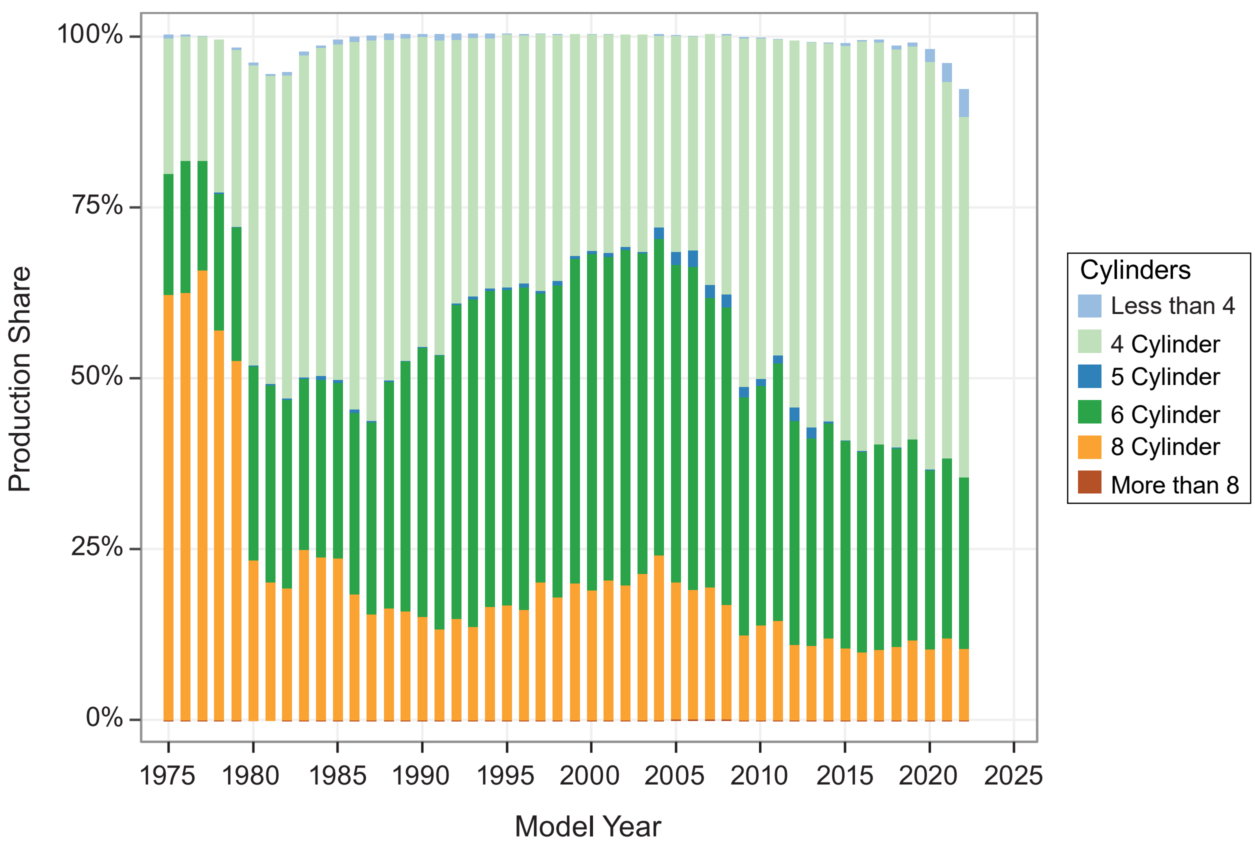
Gasoline Engines

Since EPA began tracking vehicle data in 1975, over 650 million vehicles have been produced for sale in the United States. As shown in Figure 4.3, vehicles relying on a gasoline engine as the only source of power have been the overwhelmingly dominant technology for that time span, although EVs and PHEVs are now capturing a growing portion of new vehicle production. 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; note the gap between the top of the stacked bar and the 100% threshold corresponds to the share of vehicles relying on technologies other than gasoline engines, primarily diesel engines in the 1980s and EVs more recently.

Figure 4.4. Gasoline Engine Production Share by Number of Cylinders



In the mid and late 1970s, the 8-cylinder gasoline engine was dominant, accounting for well over half of all new vehicle production. Between model year 1979 and 1980 there was a significant change in the market, as 8-cylinder engine production share dropped from 52% to 23%, and those engines were replaced with smaller 4-cylinder and some 6-cylinder engines. From model year 1987 through 2004, production moved back towards larger 6-cylinder and 8-cylinder engines. This trend reversed again in 2005 as production began trending back towards 4-cylinder engines. Four-cylinder gasoline engines are now the most popular engine option, capturing about 55% of the market in model year 2021.

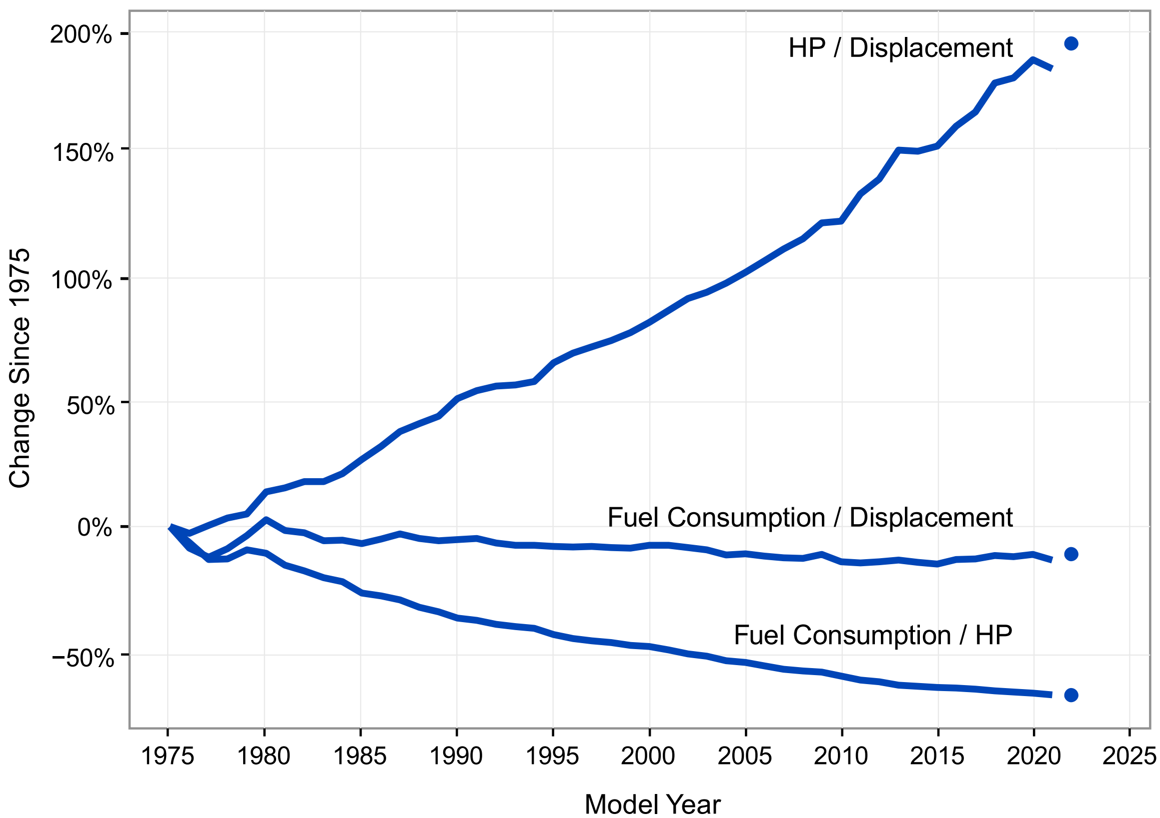
Overall engine size, as measured by the total volume of all the engine's cylinders, is directly related to the number of cylinders. As vehicles have moved towards engines with a lower number of cylinders, the total engine size, or displacement, is also at an all-time low. The average new vehicle in model year 1975 had a displacement of nearly 300 cubic inches, compared to an average of 176 cubic inches in model year 2021. Gasoline engine displacement per cylinder has been relatively stable over the time of this report (around 34 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 192% between model year 1975 and model year 2021. 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 45+ 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 2021, relative to the total displacement, is about 14% lower than in model year 1975. Fuel consumption relative to engine horsepower has fallen more than 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 53% of model year 2021 vehicles.

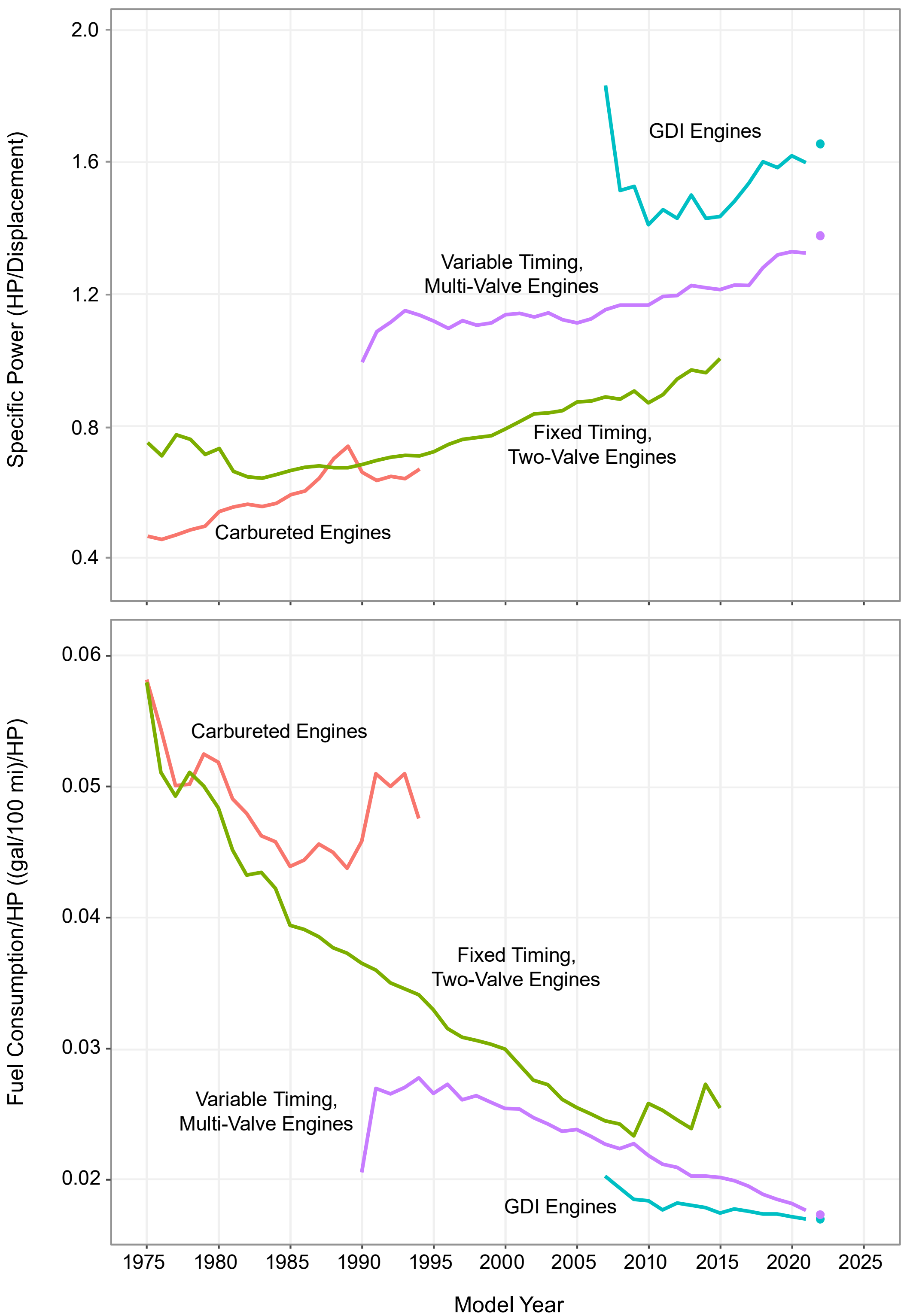
Another key aspect of engine design is the valvetrain. Each engine cylinder must have a set of valves that allow for air (or an air/fuel mixture) to flow into the engine cylinder prior to combustion and for exhaust gases to exit the cylinder after combustion. The number of valves per cylinder and the 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.

Gasoline turbocharged engines have grown rapidly in the marketplace, accounting for more than 30% of all production in model year 2021, 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 73% of gasoline turbocharged engines are 4-cylinder engines in model year 2021 with most other turbochargers being used in 6-cylinder and 3-cylinder engines. Model year 2022 is projected to be a similar distribution, with a growing number of vehicles equipped with 3-cylinder turbocharged engines. This is shown in Figure 4.8.

Most of the current gasoline 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 2021, almost 90% of new vehicles with gasoline turbocharged engines also used GDI.

Figure 4.9 examines the distribution of engine displacement and power of gasoline 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

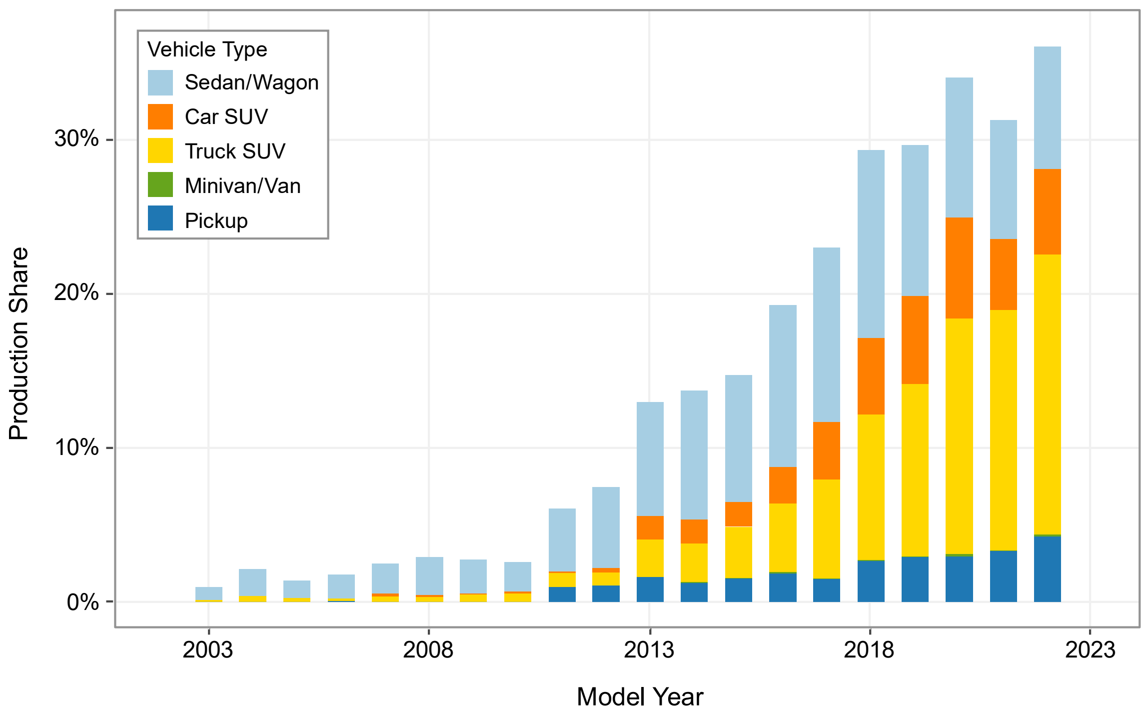


Figure 4.8. Gasoline Turbo Engine Production Share by Number of Cylinders

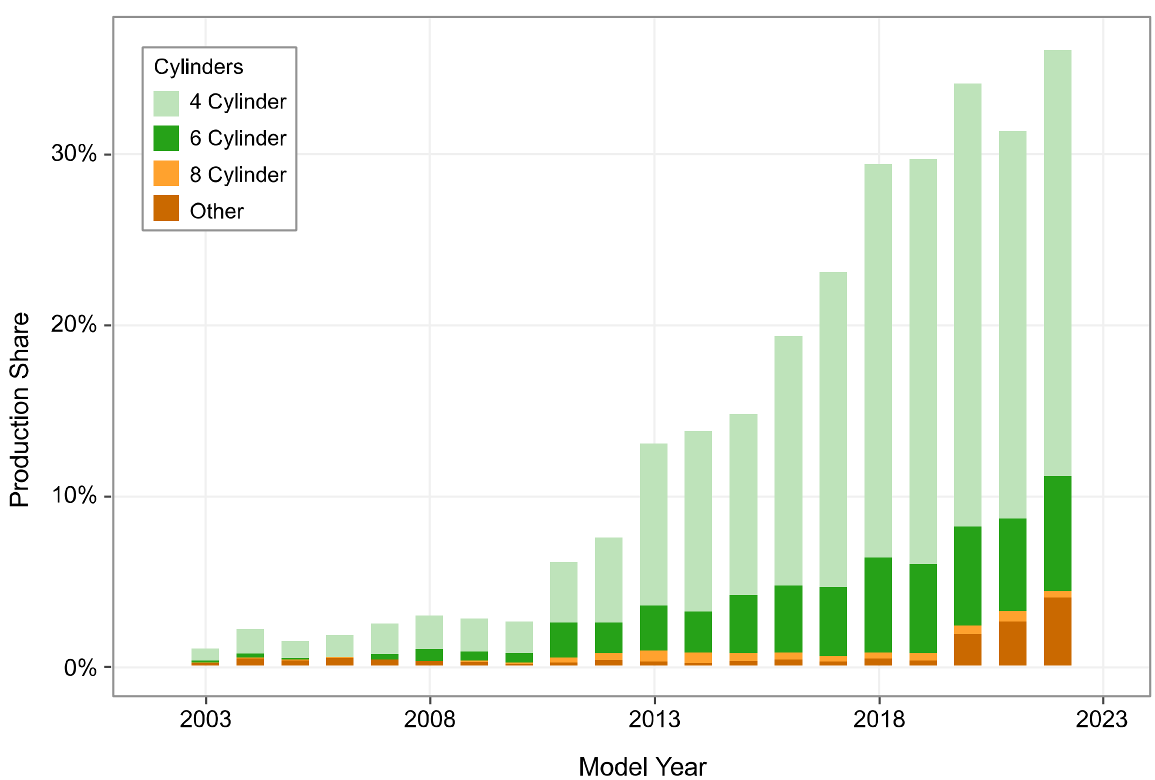
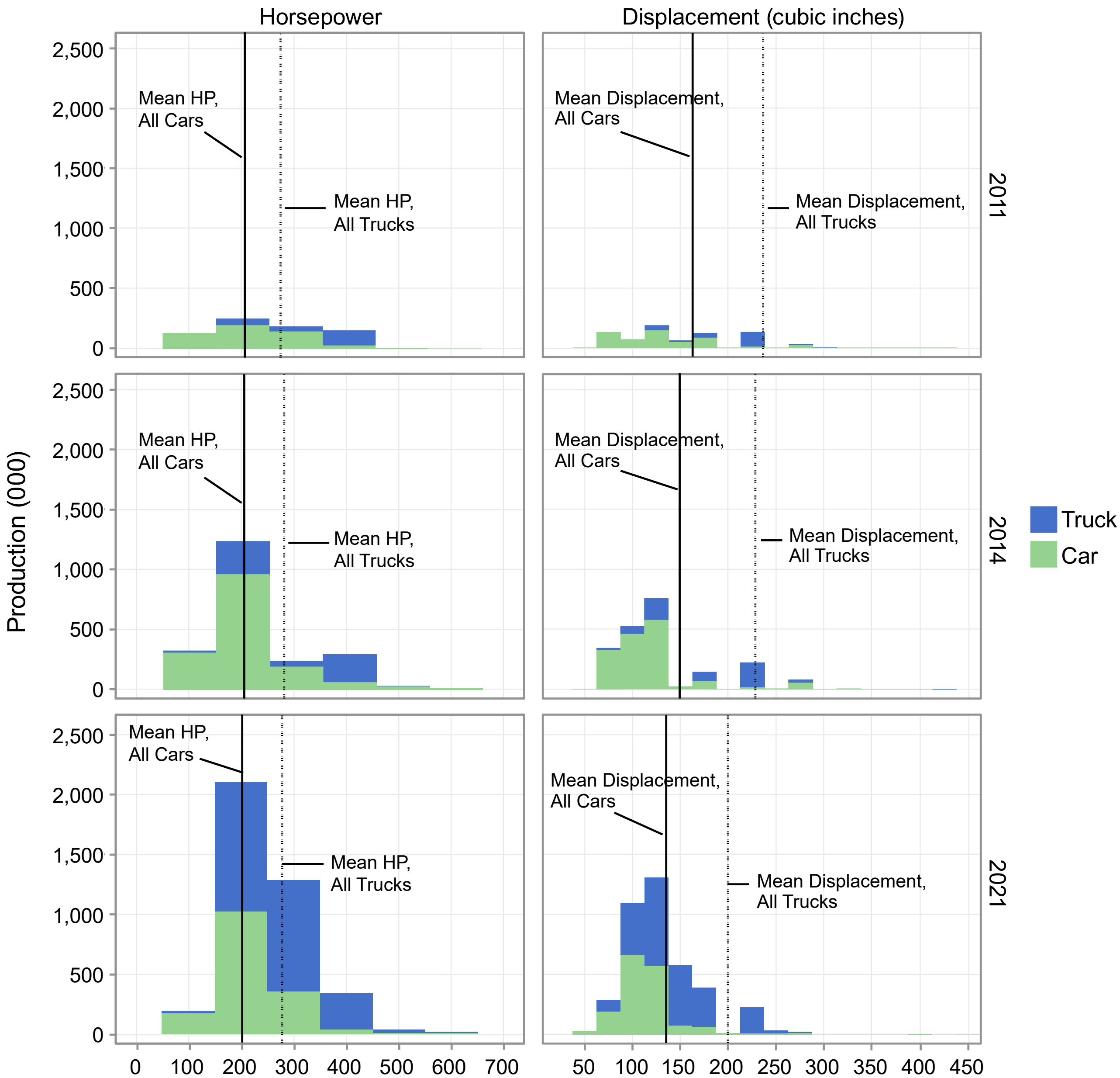


Figure 4.9. Distribution of Gasoline Turbo Vehicles by Displacement and Horsepower, Model Year 2011, 2014, and 2021



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 2021 gasoline engines with cylinder deactivation were almost 17% of all vehicles. This trend is expected to continue, especially as new improvements to cylinder deactivation technology, such as dynamic cylinder deactivation, continue to enter 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. Since then, the use of stop/start has increased to about 45% of all new vehicles in model year 2021, excluding hybrid vehicles. While non-hybrid stop/start systems have been used in a wide range of applications, they are found more often in larger vehicles and engines, as shown in Figure 4.10 and Figure 4.11.

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 frequently 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 increased to 3.8% of all vehicles in model year 2010, before declining somewhat over the next several years. However, in model year 2021 hybrid production reached a new high at 9.3%, and is projected to reach 10.1% in model year 2022, as shown in Figure 4.12 and Figure 4.13.

Figure 4.10. Non-Hybrid Stop/Start Production Share by Vehicle Type

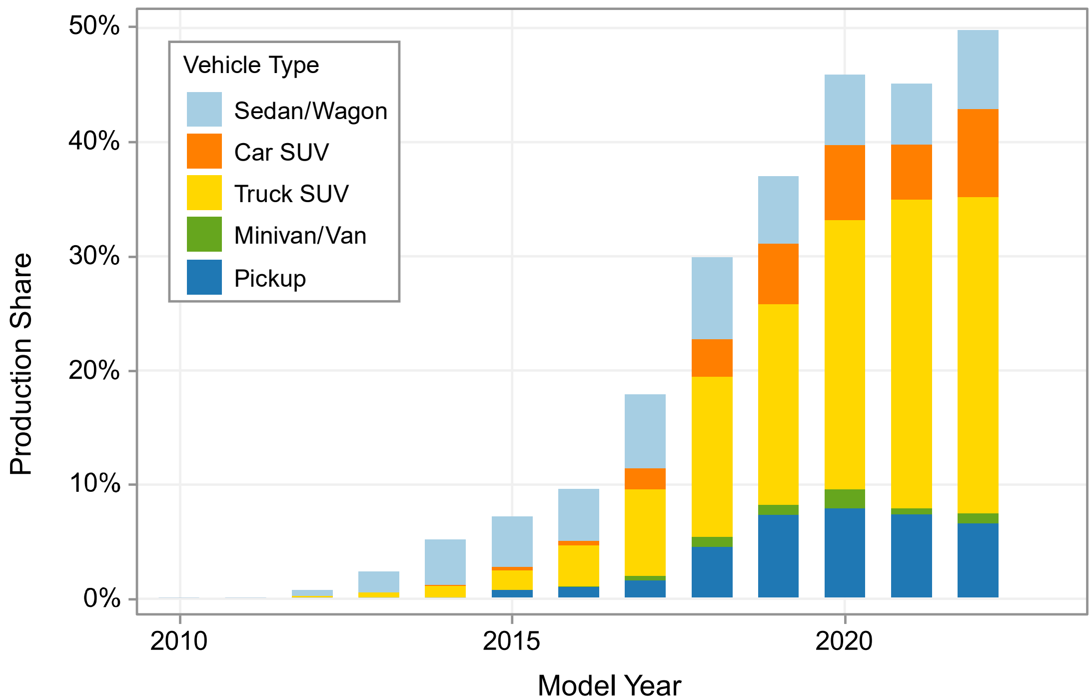


Figure 4.11. Non-Hybrid Stop/Start Production Share by Number of Cylinders

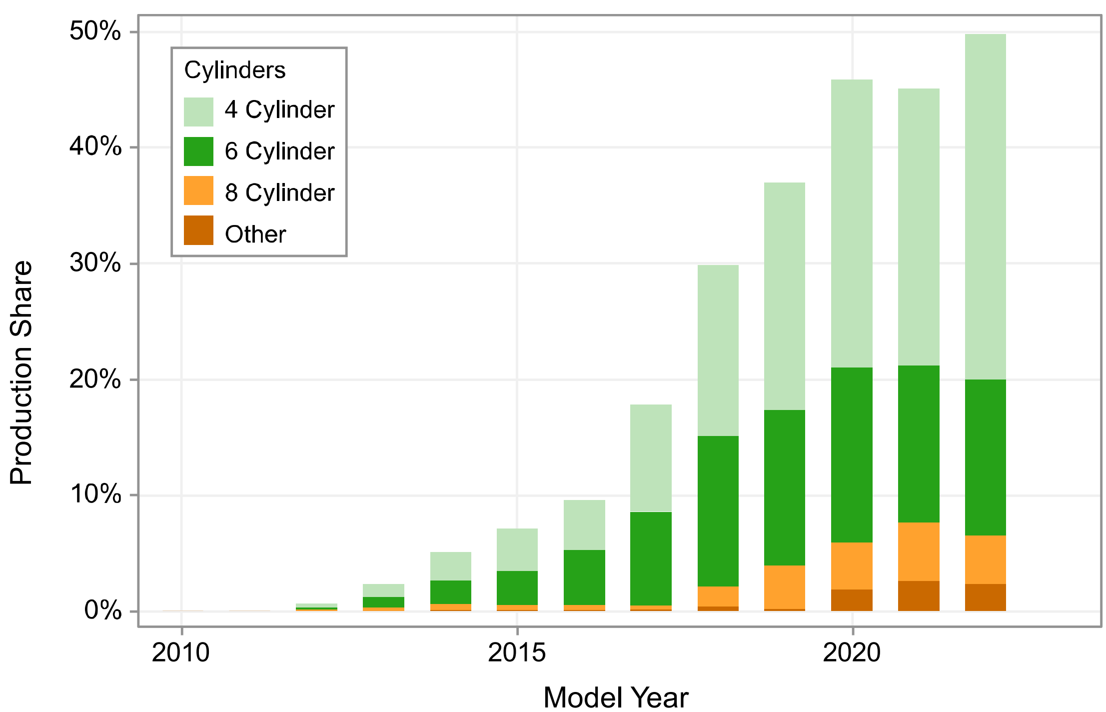


Figure 4.12. Gasoline Hybrid Engine Production Share by Vehicle Type

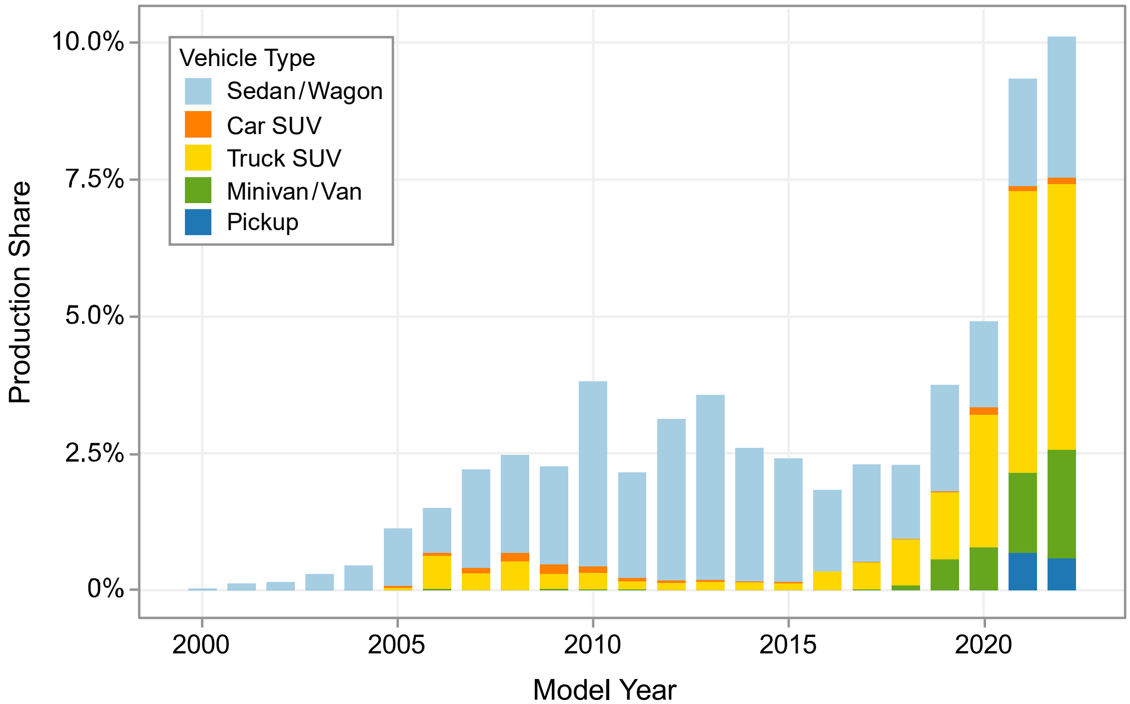
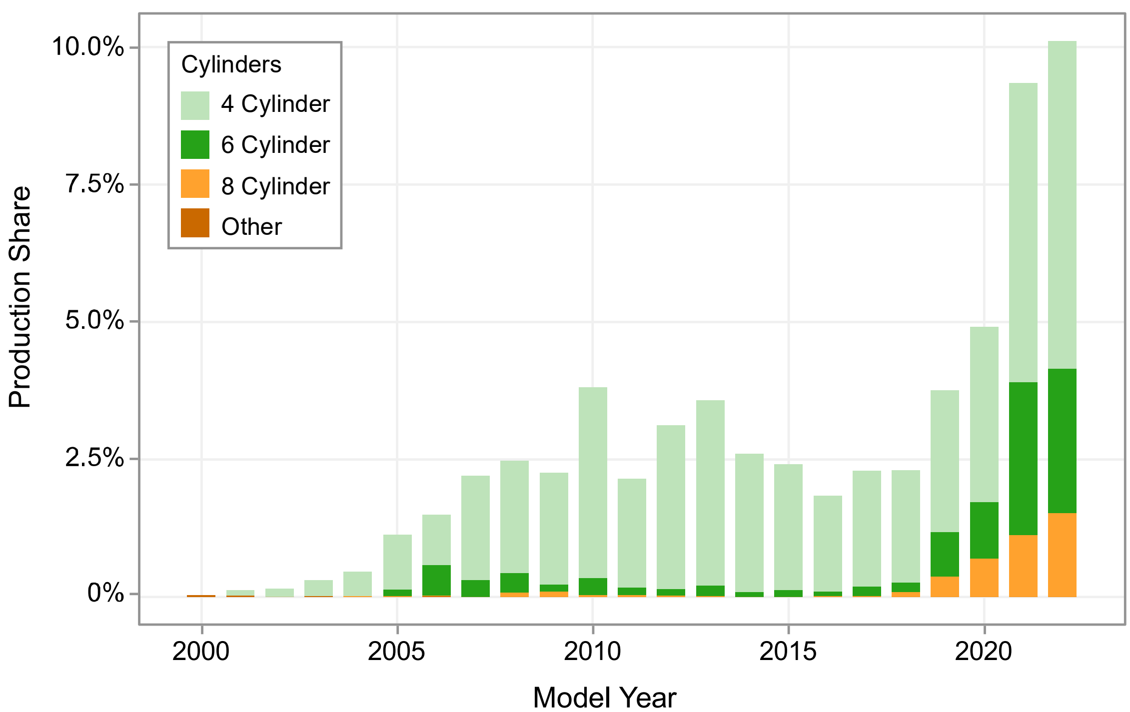


Figure 4.13. Gasoline Hybrid Engine Production Share by Number of Cylinders



The growth in hybrid vehicles is largely attributable to growth outside of the sedan/wagon vehicle type. In model year 2020 the production of hybrids in the truck SUV category surpassed the production of sedan/wagon hybrids for the first time and did so by more than 50%. Hybrids also began to penetrate the pickup and minivan/van vehicle types. However, there remain very few hybrid car SUVs. Sedan/wagon hybrids accounted for only 21% of all hybrid production in model year 2021, as shown in Figure 4.12. Hybrid vehicles typically use a 4-cylinder engine, although an increasing number of 6 and 8-cylinder engines are being used in hybrid systems, as shown in Figure 4.13.

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. These mild hybrids account for about a third of hybrid production in model year 2021.

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 stack to create electricity from an onboard fuel source (usually hydrogen), which then powers an electric motor or motors to propel the vehicle

EVs rely on electricity stored in a battery for fuel. There is no combustion occuring on the vehicle, and therefore there are no tailpipe emissions created by the vehicle. The electricity used to charge EVs can create emissions at the power plant. The amount of emission varies depending on the 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 make up a growing portion of electricity generation across the US. Depending on the source of electricity, EVs often result in lower CO_2 emissions over their lifetime compared to gasoline vehicles.

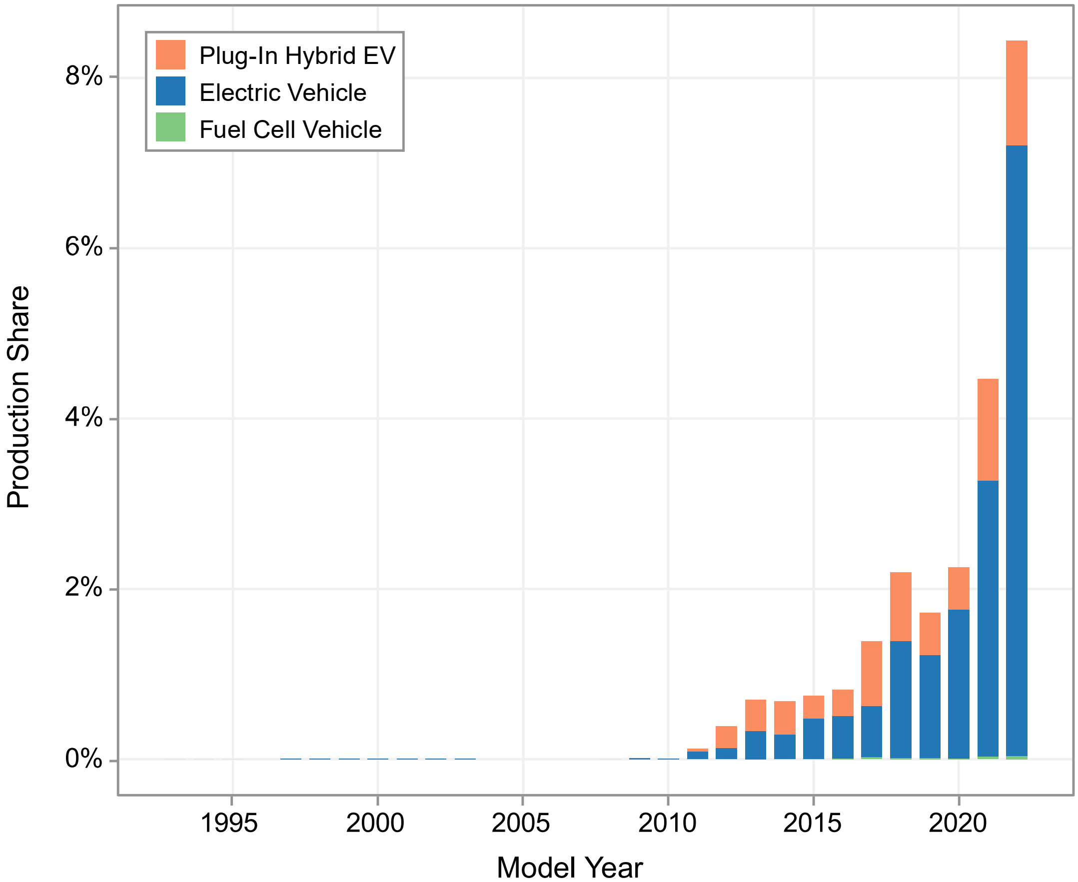
Since EVs do not use gasoline, the familiar metric of miles per gallon cannot be applied to EVs. Instead, EVs are rated in terms of miles per gallon-equivalent (mpge), which is the number of miles that an EV travels on an amount of electrical energy equivalent to the energy in a gallon of gasoline. This 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 can operate either on electricity stored in a battery, or gasoline, allowing for a wide range of engine designs and strategies for the utilization of stored electrical energy during typical driving. Most PHEVs will operate on electricity only, like an EV, for a limited range, and then will operate like a more conventional hybrid until their battery is recharged from an external source. 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.[11] 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 2021 combined EV/PHEV production reached 4% of all new vehicles. Combined EV and PHEV production is projected to reach a new high of 8% of all production in model year 2022. The trend in EVs, PHEVs, and FCVs are shown in Figure 4.14.

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

Figure 4.14. Production Share of EVs, PHEVs, and FCVs[12]



The inclusion of model year 2021 EV and PHEV sales reduces the overall new vehicle average CO_2 emissions by 14 g/mi, and this impact will continue to grow if EV and PHEV production increases. In model year 2021 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 4.15 and Figure 4.16 show the production share by vehicle type for EVs and PHEVs. Early production of EVs was mostly in the sedan/wagon vehicle type, but recent model years have shown growth in car SUVs and truck SUVs. Electric pickup trucks are entering the market in model year 2022, along with new EV models across many of the vehicle types. Production of PHEVs has shifted from exclusively sedan/wagons to mostly truck SUVs, with limited production across the sedan/wagon, car SUV, and minivan/van vehicle types.

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[12] 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.

Figure 4.15. Electric Vehicle Production Share by Vehicle Type

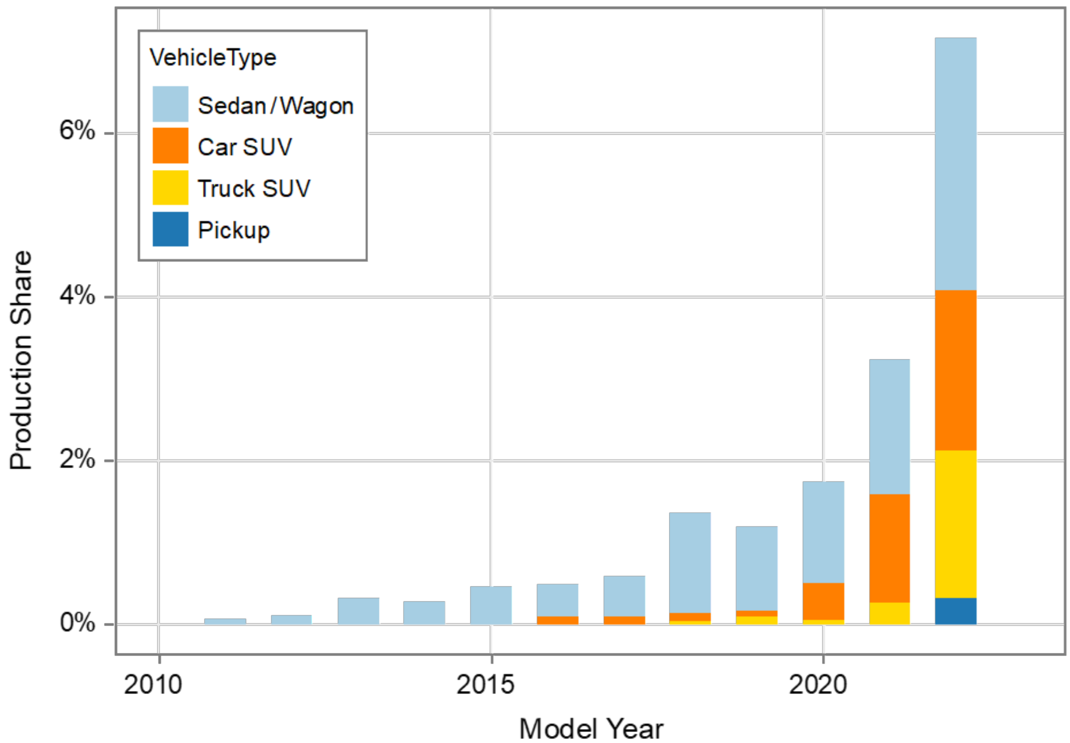


Figure 4.16. Plug-In Hybrid Vehicle Production Share by Vehicle Type

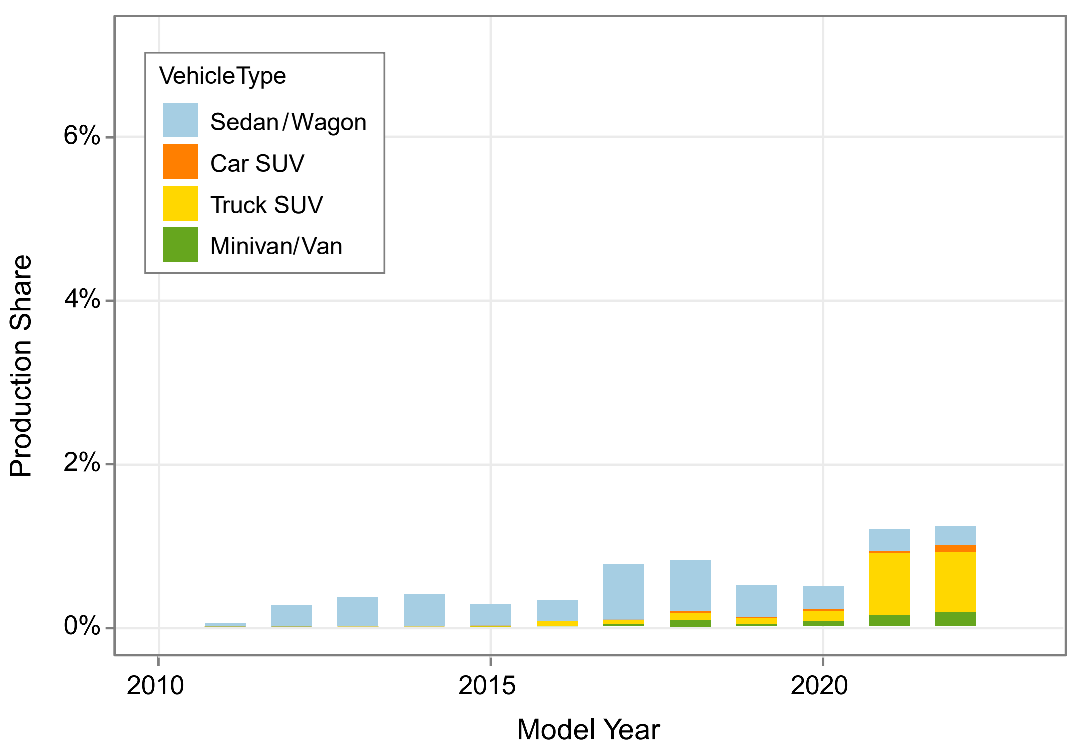
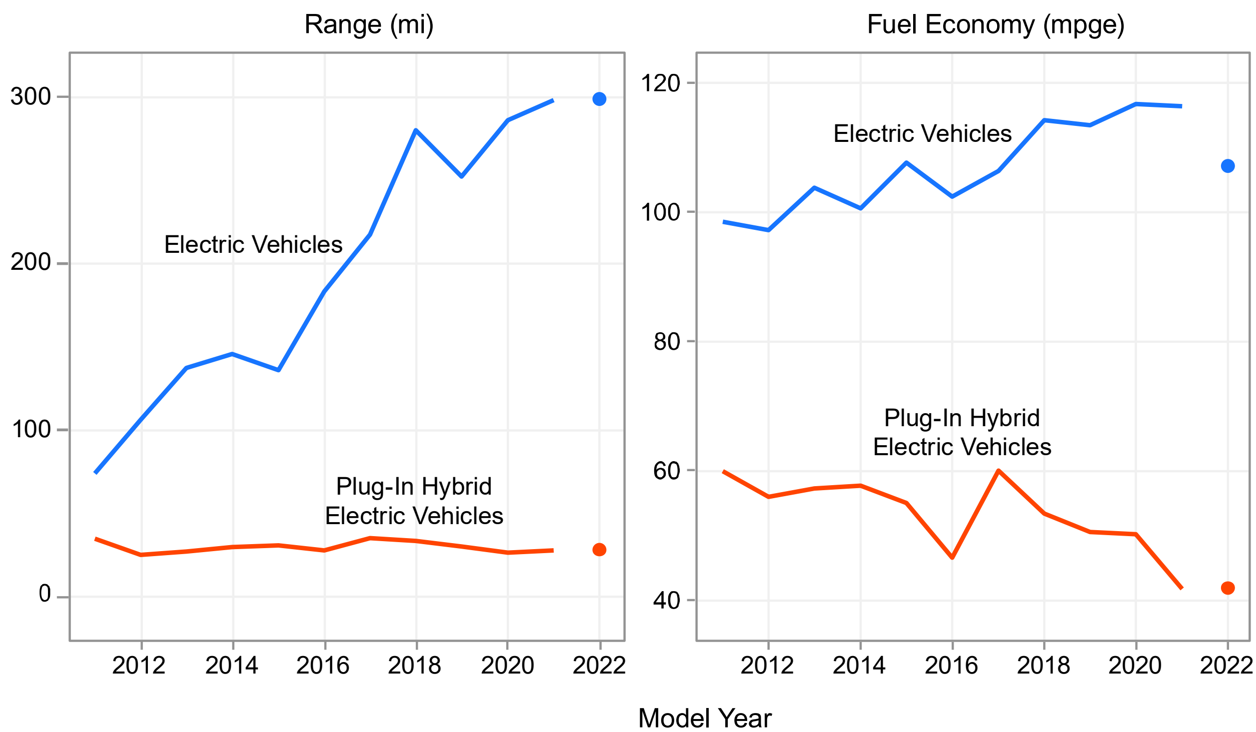


Figure 4.17 shows the range and fuel economy trends for EVs and PHEVs[13]. The average range of new EVs has climbed substantially. In model year 2021 the average new EV range is 298 miles, or about four times the range of an average EV in 2011. The range values shown for PHEVs are the charge-depleting 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 largely 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 increased by about 18% between model years 2011 and 2021. The combined fuel economy of PHEVs has been more variable but is about 30% lower in model year 2021 than in model year 2011. This may be attributable to the growth of truck SUV PHEVs, as shown in Figure 4.16. For more information about EV and PHEV metrics, see Appendix E.

Figure 4.17. Charge Depleting Range and Fuel Economy for EVs and PHEVs



[13] The range and fuel economy values in this figure are the combined values from the fuel economy label, which weights city and highway driving 55% and 45%, as compared to the rest of the report, which uses a 43% city and 57% highway weighting. See Appendix C for more information.

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 have been at or below 1% of production per year since 1985. In MY 2021, diesel vehicles were slightly below 1% of all new vehicles produced.

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 4.18 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 led to an overall production share of 1% in model year 2021. 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 4.19, current production of diesel engines for light-duty vehicles is largely comprised of six-cylinder engines, along with a smaller share of 4-cylinder engines.

Diesel engines, as with gasoline engines, have improved over time. Figure 4.20 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 more than 200% since model year 1975. Fuel consumption per displacement dropped in the 1980s but has increased back to about 20% below model year 1975. Finally, fuel consumption per horsepower for diesel engines has declined about 75% since model year 1975.

Figure 4.18. Diesel Engine Production Share by Vehicle Type

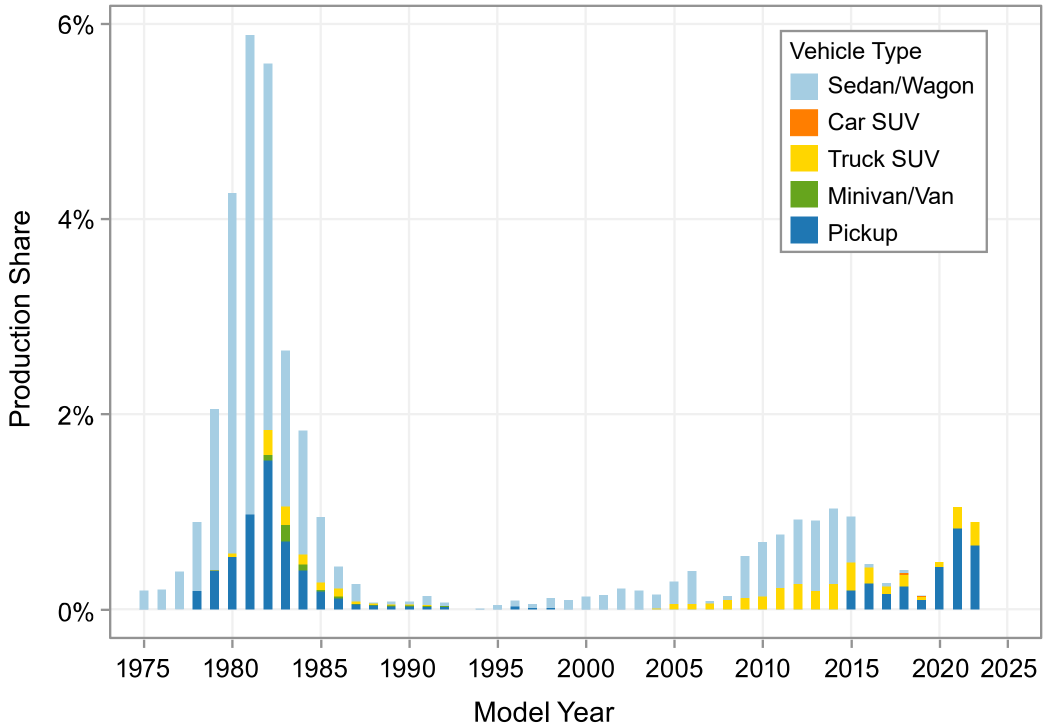


Figure 4.19. Diesel Engine Production Share by Number of Cylinders

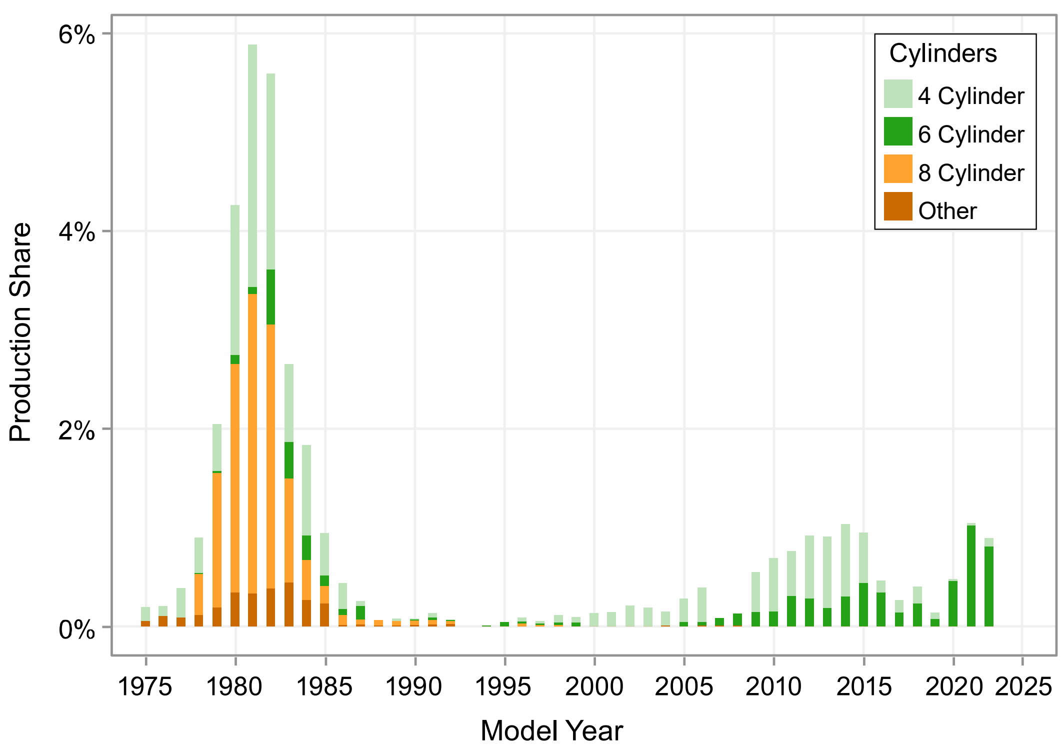
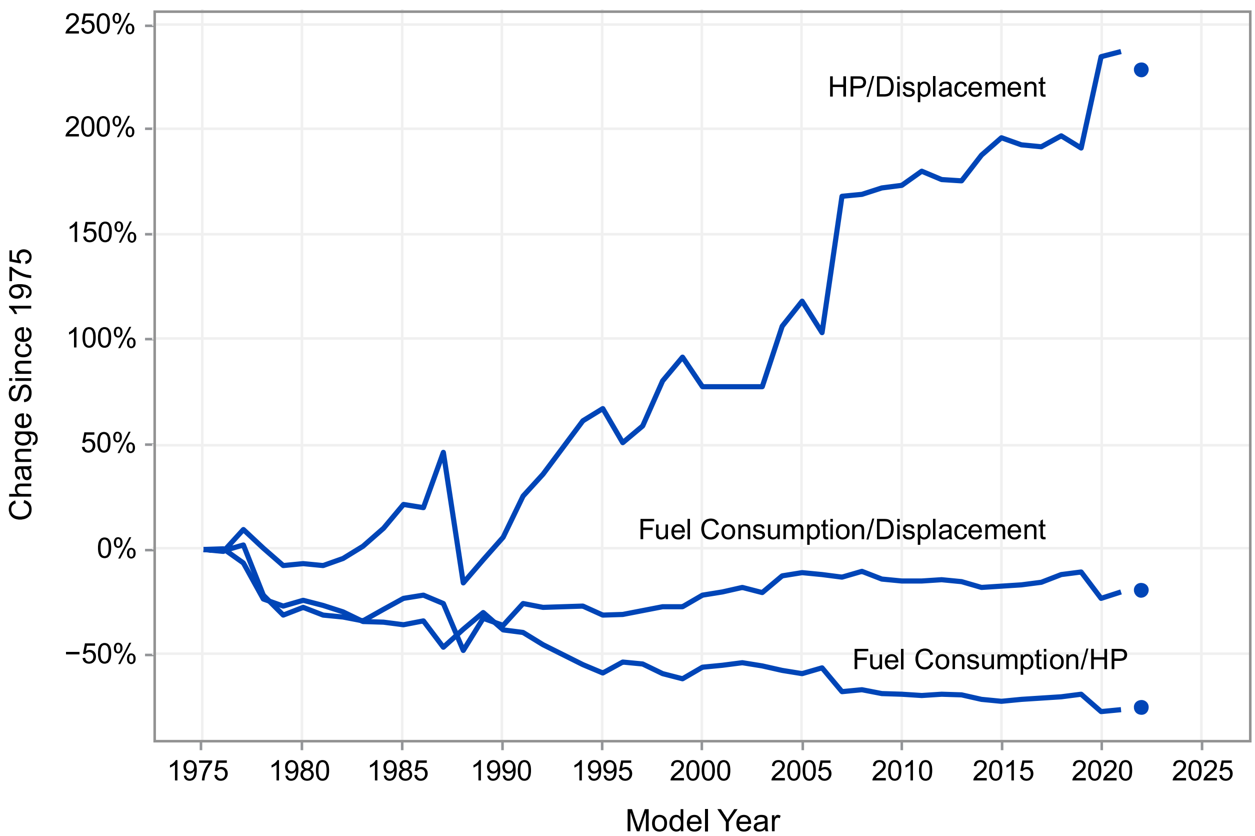


Figure 4.20. Percent Change for Specific Diesel Engine Metrics



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.

C. Vehicle Drivetrain

A vehicle drivetrain includes all components responsible for transmitting rotational energy from an engine or motor to the wheels. The design of the drivetrain impacts CO_2 emissions and fuel economy in two ways; first through direct energy losses or inefficiencies within the drivetrain, and second by allowing a vehicle's engine, or motor, to operate in a more efficient manner.

For non-hybrid vehicles with an internal combustion engine, the drivetrain includes a transmission and the driveline (a driveshaft, differential, axle shafts and related components), as shown in Figure 4.1. Mild hybrids generally use a conventional transmission and drivetrain, but full hybrids often replace the transmission entirely with a planetary gearset or some other configuration. PHEVs generally resemble full hybrids but can have numerous configurations that allow for complicated energy optimization. Electric vehicles generally use a single speed transmission, and do not need the numerous gears required by combustion engines. However, some electric vehicles are now being produced with at least a 2-speed transmission (e.g. Porsche Taycan).

Transmissions

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.

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 4.21 shows the evolution of transmission production share for cars and trucks since model year 1980.[14] 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

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

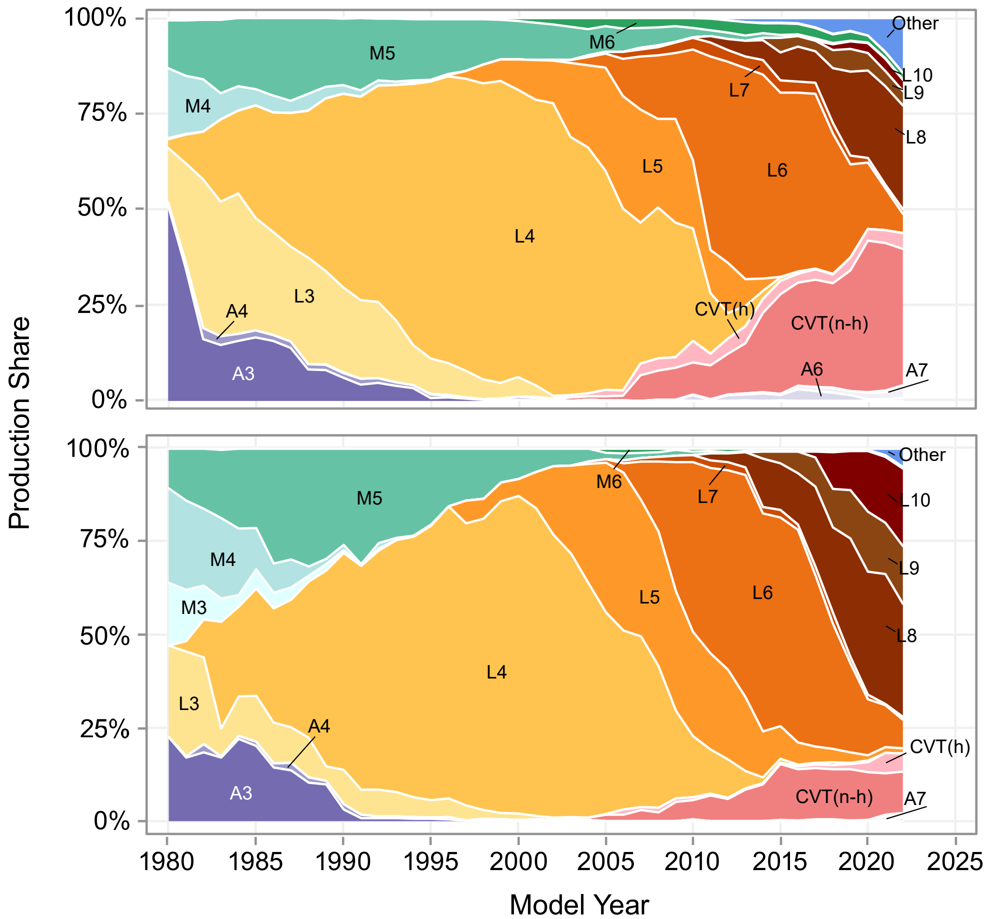
torque converter in an automatic transmission under certain driving conditions and improve efficiency. CVTs have also been split into hybrid and non-hybrid versions to reflect the fact that hybrid CVTs are generally very different mechanically from traditional CVTs.

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 4.21 as a slight increase in automatic transmissions without torque converters (although some DCTs may still be reported as traditional automatic transmissions).

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 a four-speed transmission. After model year 1999, the production share of four-speed transmissions slowly decreased as five and six speed transmissions were introduced into the market. Six-speed transmissions peaked in model year 2013 at 60% of new vehicle production, but then fell quickly, down to 12% by model year 2021. Eight-speed transmissions became the most popular transmission in model year 2019 and maintained that position for model years 2020 and 2021, followed by CVTs and transmissions with nine or more speeds. In model year 2021, vehicles with eight-speed transmissions accounted for about a third of all new vehicles, while vehicles with CVTs or vehicles with transmissions of nine or more speeds each accounted for more than 20% of new vehicle production. These trends are projected to continue in model year 2022, with transmissions of nine or more speeds continuing to increase market share.

Another notable trend in Figure 4.21 is the decline in manual transmissions. Manual transmissions were included in almost 35% of new vehicles in model year 1980, but have been gradually declining since, and shrank to less than 1% of all production in model year 2021. Today, manual transmissions are available only in a limited number of small vehicles, sports cars, off-road truck SUVs, and a few small pickups.

Figure 4.21. Transmission Production Share

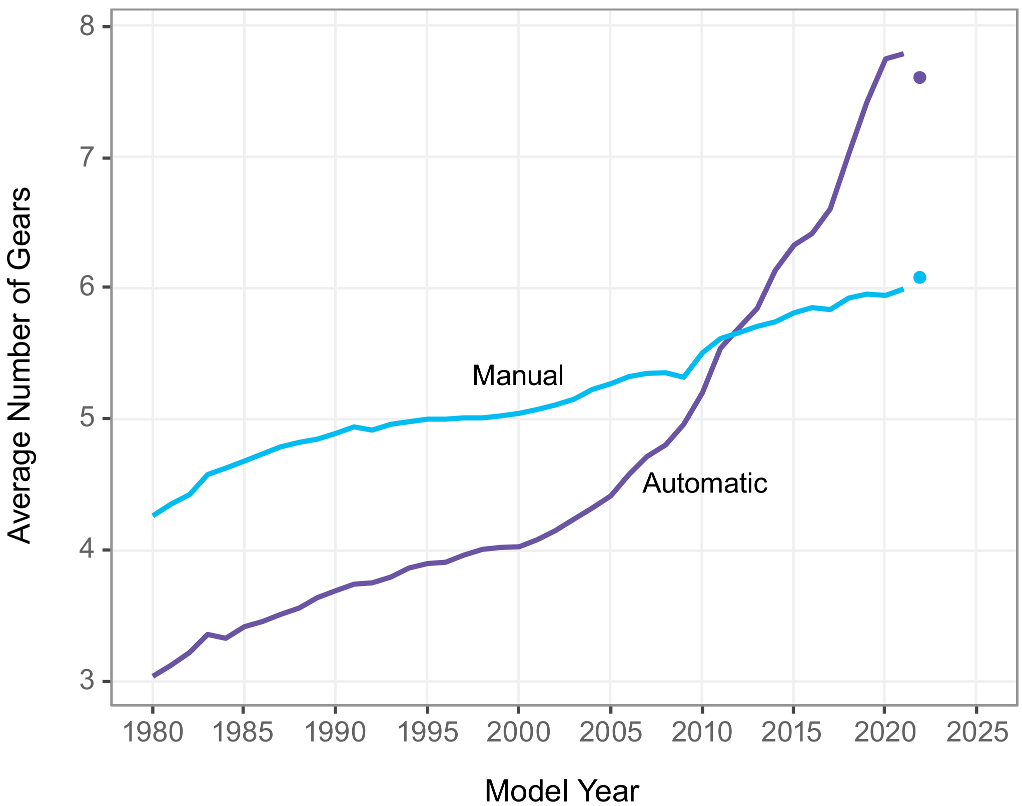


Transmission	Lockup?	Number of Gears	Key
Automatic Semi-Automatic Automated Manual	No	3	A3
		4	A4
		5	A5*
		6	A6
		7	A7
		8	A8*
	Yes	2	L2*
		3	L3
		4	L4
		5	L5
		6	L6
		7	L7
		8	L8
		9	L9
		10	L10
Manual	–	3	M3
		4	M4
		5	M5
		6	M6
		7	M7*
ContinuouslyVariable (non-hybrid)	–	–	CVT(n-h)
ContinuouslyVariable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

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

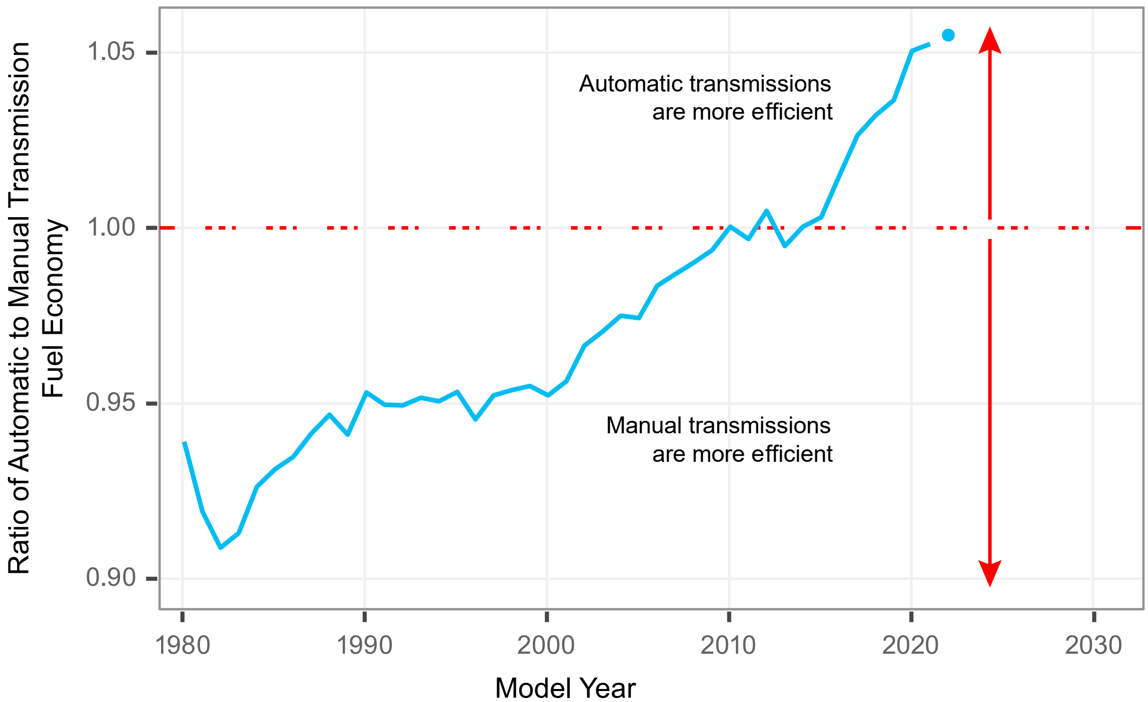
Part of the reason for the decline in manual transmission is because modern automatic transmissions now have more gears, are generally more efficient, and can offer better performance than manual transmissions. Figure 4.22 shows the average number of gears in new vehicle transmissions since model year 1980 for automatic and manual transmissions. While both manual and automatic transmissions have added gears over time, automatic transmission have added additional gears faster, and passed manual transmissions in model year 2012. In model year 2021, the average number of gears for all manual transmissions was 6 while the average for automatic transmissions was 7.8 gears.

Figure 4.22. Average Number of Transmission Gears



In the past, automatic transmissions have generally been less efficient than manual transmissions, largely due to inefficiencies in the automatic transmission torque converter. Figure 4.23 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. The shrinking availability of manual transmissions does limit the relevance of analyses comparing current manual transmissions to automatic transmissions.

Figure 4.23. Comparison of Manual and Automatic Transmission Real-World Fuel Economy for Comparable Vehicles



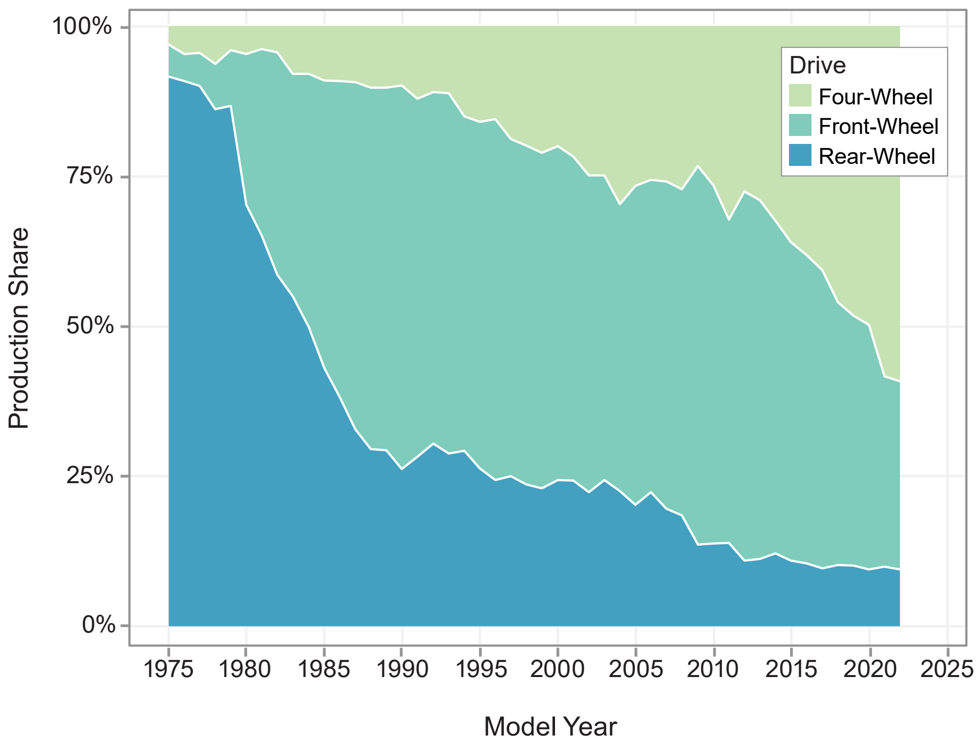
Drive Types

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 4.24. 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 2021. Most vehicles available today with rear wheel drive are performance-oriented sedan/wagons and pickup trucks, but there are limited rear wheel drive vehicles available in all vehicle types.

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, and is down to

32% in model year 2021. Four-wheel drive systems have steadily increased from 3.3% of new vehicle production in model year 1975 to 59% of production in model year 2021. Four-wheel drive systems have increased for both cars and trucks, but the high penetration rate of 82% within trucks (including pickups, truck SUVs, and minivan/vans) and the market shifts towards these vehicles has accelerated the trend towards four-wheel drive vehicles.

Figure 4.24. Front-, Rear-, and Four-Wheel Drive Production Share



D. 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.

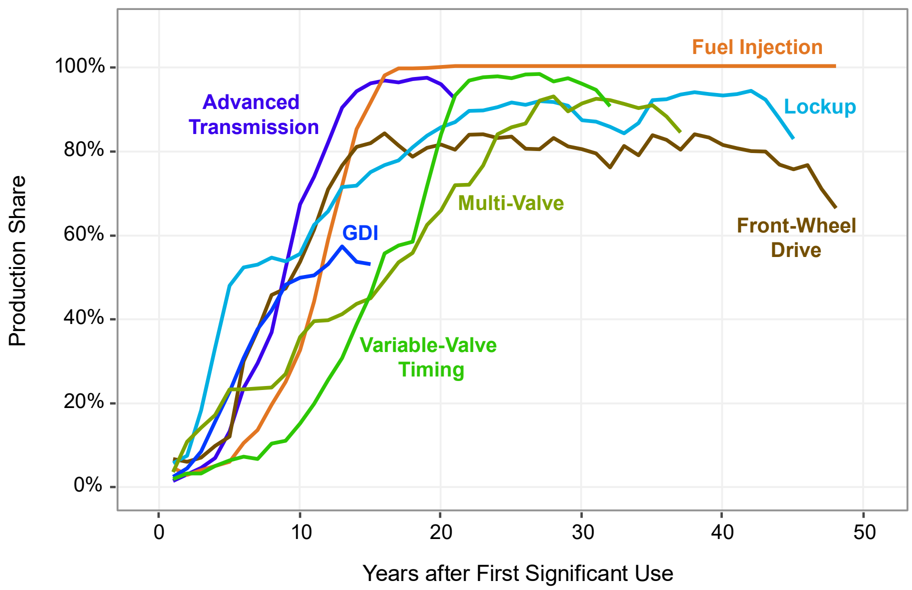
Industry-Wide Technology Adoption Since 1975

Figure 4.25 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 4.25 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 4.25 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 this report 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 4.25. 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 4.25 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 4.26 begins to disaggregate the industry-wide trends to examine how individual manufacturers have adopted new technologies.[15] For each technology, Figure 4.26 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 4.26, five are now at or near full market penetration for the included manufacturers, and two are still in the process of adoption by

[15] 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.

manufacturers. The technologies shown in Figure 4.26 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, 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.

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.

Figure 4.26. Manufacturer Specific Technology Adoption over Time for Key Technologies

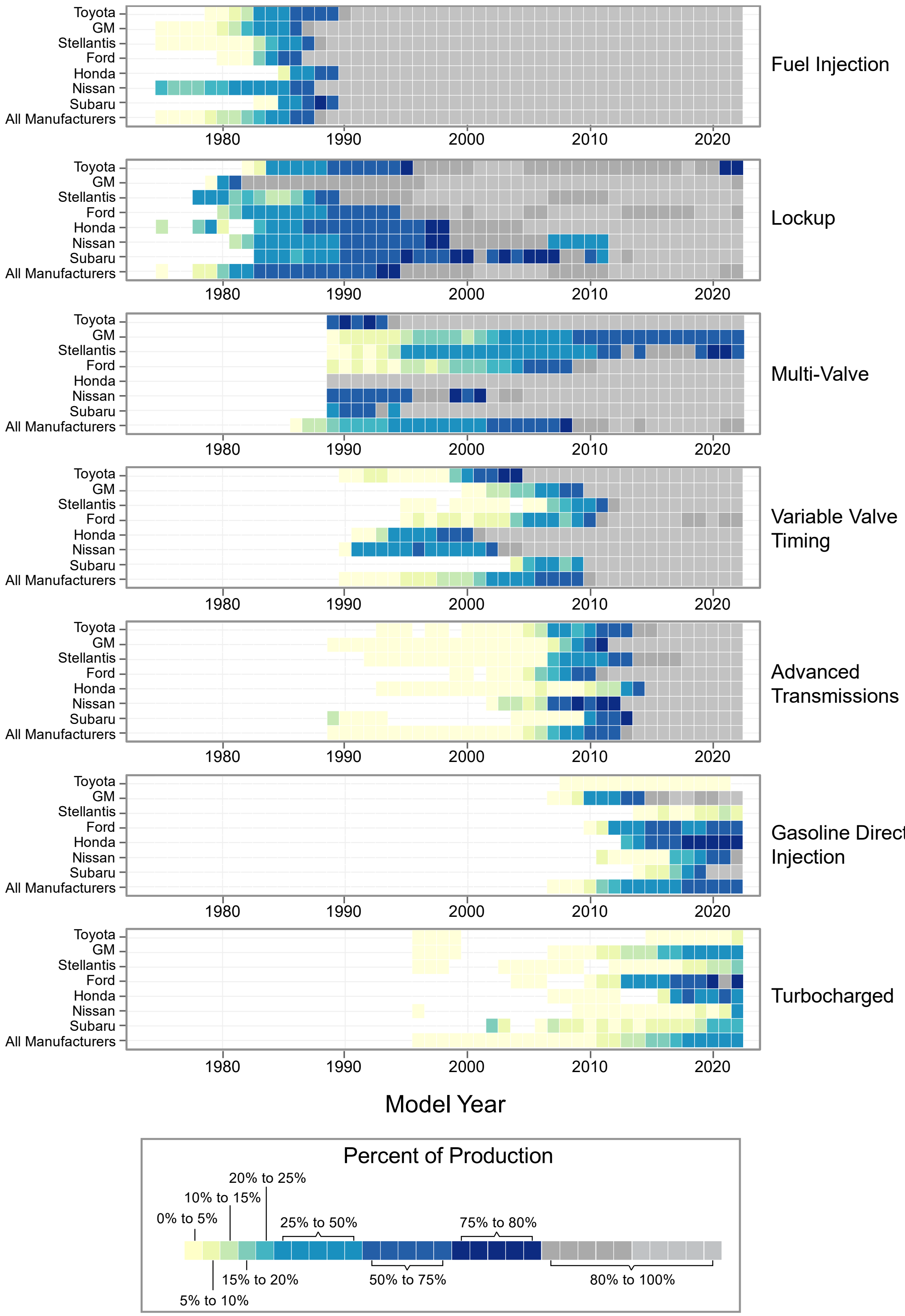


Table 4.1. Production Share by Powertrain

Model Year	Gasoline	Gasoline Hybrid	Diesel	EV	PHEV	FCV	Other
1975	99.8%	-	0.2%	-	-	-	-
1980	95.7%	-	4.3%	-	-	-	-
1985	99.1%	-	0.9%	-	-	-	-
1990	99.9%	-	0.1%	-	-	-	-
1995	100.0%	-	0.0%	-	-	-	-
2000	99.8%	0.0%	0.1%	-	-	-	-
2001	99.7%	0.1%	0.1%	-	-	-	-
2002	99.6%	0.2%	0.2%	-	-	-	-
2003	99.5%	0.3%	0.2%	-	-	-	-
2004	99.4%	0.5%	0.1%	-	-	-	-
2005	98.6%	1.1%	0.3%	-	-	-	-
2006	98.1%	1.5%	0.4%	-	-	-	-
2007	97.7%	2.2%	0.1%	-	-	-	-
2008	97.4%	2.5%	0.1%	-	-	-	-
2009	97.2%	2.3%	0.5%	-	-	-	-
2010	95.5%	3.8%	0.7%	-	-	0.0%	-
2011	97.0%	2.2%	0.8%	0.1%	0.0%	0.0%	0.0%
2012	95.5%	3.1%	0.9%	0.1%	0.3%	0.0%	0.0%
2013	94.8%	3.6%	0.9%	0.3%	0.4%	-	0.0%
2014	95.7%	2.6%	1.0%	0.3%	0.4%	0.0%	0.0%
2015	95.9%	2.4%	0.9%	0.5%	0.3%	0.0%	0.0%
2016	96.9%	1.8%	0.5%	0.5%	0.3%	0.0%	0.0%
2017	96.1%	2.3%	0.3%	0.6%	0.8%	0.0%	-
2018	95.1%	2.3%	0.4%	1.4%	0.8%	0.0%	-
2019	94.4%	3.8%	0.1%	1.2%	0.5%	0.0%	-
2020	92.4%	4.9%	0.5%	1.8%	0.5%	0.0%	-
2021	85.1%	9.3%	1.0%	3.2%	1.2%	0.0%	-
2022 (prelim)	*80.6%*	*10.1%*	*0.9%*	*7.2%*	*1.2%*	*0.0%*	-

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 Engine Technologies

Model Year	Fuel Delivery Method					Avg. No. of Cylinders	CID	HP	Multi-Valve	VVT	CD	Turbo	Non-hybrid Stop/Start
	Carb	TBI	Port	GDI	Other								
1975	95.7%	0.0%	4.1%	-	0.2%	6.8	293	137	-	-	-	-	-
1980	89.7%	0.8%	5.2%	-	4.3%	5.6	198	104	-	-	-	-	-
1985	56.1%	24.8%	18.2%	-	0.9%	5.5	189	114	-	-	-	-	-
1990	2.1%	27.0%	70.8%	-	0.1%	5.4	185	135	23.1%	-	-	-	-
1995	-	8.4%	91.6%	-	0.0%	5.6	196	158	35.6%	-	-	-	-
2000	-	0.0%	99.8%	-	0.1%	5.7	200	181	44.8%	15.0%	-	1.3%	-
2001	-	-	99.9%	-	0.1%	5.8	201	187	49.0%	19.6%	-	2.0%	-
2002	-	-	99.8%	-	0.2%	5.8	203	195	53.3%	25.3%	-	2.2%	-
2003	-	-	99.8%	-	0.2%	5.8	204	199	55.5%	30.6%	-	1.2%	-
2004	-	-	99.9%	-	0.1%	5.9	212	211	62.3%	38.5%	-	2.3%	-
2005	-	-	99.7%	-	0.3%	5.8	205	209	65.6%	45.8%	0.8%	1.7%	-
2006	-	-	99.6%	-	0.4%	5.7	204	213	71.7%	55.4%	3.6%	2.1%	-
2007	-	-	99.8%	-	0.1%	5.6	203	217	71.7%	57.3%	7.3%	2.5%	-
2008	-	-	97.6%	2.3%	0.1%	5.6	199	219	76.4%	58.2%	6.7%	3.0%	-
2009	-	-	95.2%	4.2%	0.5%	5.2	183	208	83.8%	71.5%	7.3%	3.3%	-
2010	-	-	91.0%	8.3%	0.7%	5.3	188	214	85.5%	83.8%	6.4%	3.3%	-
2011	-	-	83.8%	15.4%	0.8%	5.4	192	230	86.4%	93.1%	9.5%	6.8%	-
2012	-	-	76.5%	22.5%	1.0%	5.1	181	222	91.8%	96.6%	8.1%	8.4%	0.6%
2013	-	-	68.3%	30.5%	1.2%	5.1	176	226	92.8%	97.4%	7.7%	13.9%	2.3%
2014	-	-	61.3%	37.4%	1.3%	5.1	180	230	89.2%	97.6%	10.6%	14.8%	5.1%
2015	-	-	56.7%	41.9%	1.4%	5.0	177	229	91.2%	97.2%	10.5%	15.7%	7.1%
2016	-	-	51.0%	48.0%	1.0%	5.0	174	230	92.3%	98.0%	10.4%	19.9%	9.6%
2017	-	-	49.4%	49.7%	0.9%	5.0	174	234	92.0%	98.1%	11.9%	23.4%	17.8%
2018	-	-	48.0%	50.2%	1.8%	5.0	172	241	91.0%	96.4%	12.5%	30.0%	29.8%
2019	-	-	45.7%	52.9%	1.4%	5.1	174	245	90.1%	97.2%	14.9%	30.0%	36.9%
2020	-	-	40.6%	57.1%	2.2%	5.0	170	246	90.7%	95.8%	14.7%	34.7%	45.8%
2021	-	-	42.3%	53.4%	4.3%	5.0	176	253	88.0%	94.4%	16.6%	32.9%	45.0%
2022 (prelim)	-	-	*39.1%*	*52.8%*	*8.1%*	*5.0*	*172*	*272*	*84.3%*	*90.5%*	*15.4%*	*37.7%*	*49.7%*

Table 4.3. 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	1.1%	68.3%	2.7%	2.8%	25.0%	-	1.8%	0.8%	17.3%	2.1%	28.8%	21.2%	6.9
2021	0.9%	67.0%	5.4%	4.7%	21.9%	-	3.2%	1.1%	12.2%	2.0%	32.5%	22.4%	6.6
2022 (prelim)	*1.0%*	*63.3%*	*9.9%*	*4.6%*	*21.2%*	-	*6.8%*	*0.9%*	*8.5%*	*2.5%*	*30.3%*	*25.2%*	*6.5*

Table 4.4. Production Share by Drive Technology

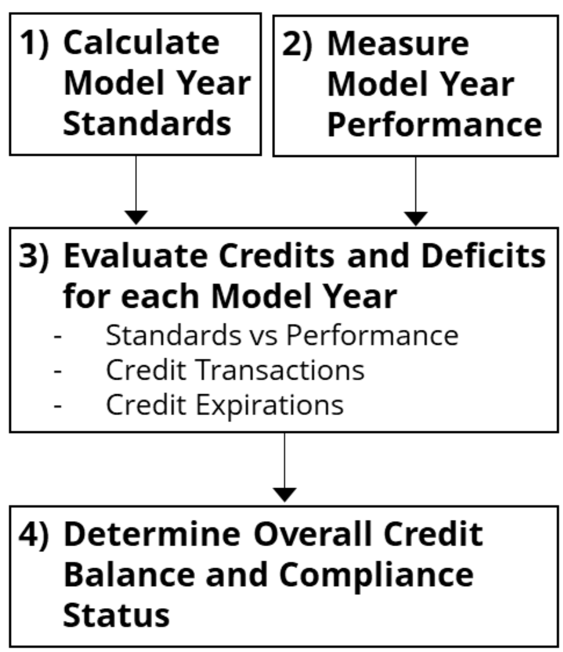
Model Year	Car			Truck			All		
	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive
1975	6.5%	93.5%	-	-	82.8%	17.2%	5.3%	91.4%	3.3%
1980	29.7%	69.4%	0.9%	1.4%	73.6%	25.0%	25.0%	70.1%	4.9%
1985	61.1%	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	76.5%	8.8%	14.7%	12.5%	10.0%	77.5%	40.6%	9.4%	49.9%
2021	70.7%	11.2%	18.0%	8.5%	9.2%	82.3%	31.6%	10.0%	58.5%
2022 (prelim)	*66.2%*	*10.9%*	*23.0%*	*10.0%*	*8.6%*	*81.3%*	*31.2%*	*9.5%*	*59.3%*

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 2021 and credit trades reported to EPA as of October 31, 2022.

In December 2021, EPA finalized light-duty GHG standards for model years 2023-2026, and in April 2022 NHTSA finalized fuel economy standards for model years 2024-2026. Since these regulatory updates only impact future model years, they do not generally impact this report. However, where applicable, these regulatory changes are reflected in this report.

Figure 5.1. The GHG Compliance Process



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 generates deficits if performance 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. 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. 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 2021 model year, the industry wide weighted VMT is 212,455 miles.

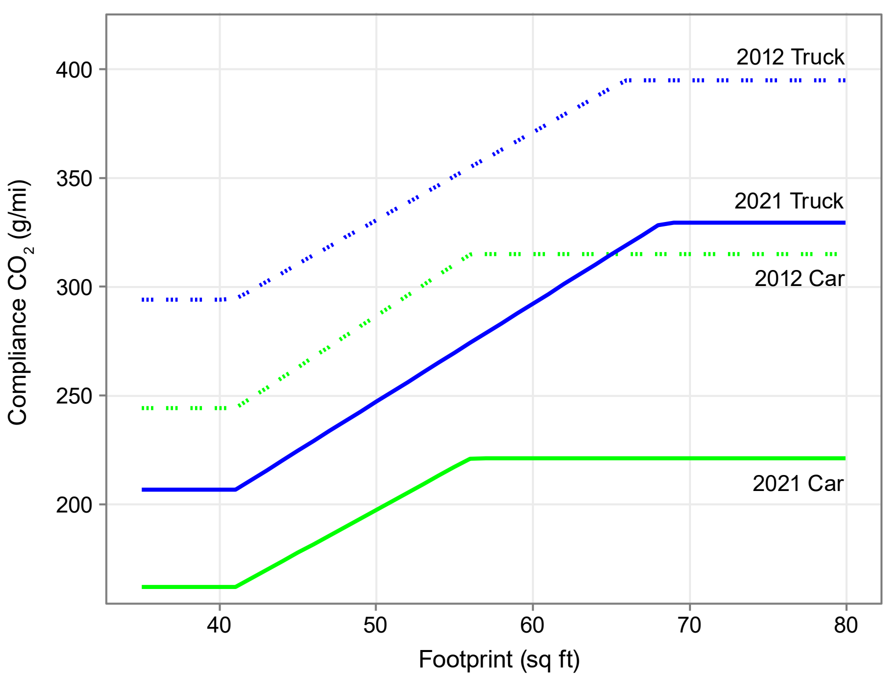
Unlike the previous sections of this report, the tailpipe CO_2 emission data presented in this section are compliance data, based on EPA's City and Highway test procedures (referred to as the "2-cycle" tests). These values should not be compared to the estimated real-world data throughout the rest of 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 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 46.9 square feet in model year 2021 (the average car footprint) has a compliance CO_2 target of 185 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. 2012–2021 Model Year CO_2 Footprint Target Curves



The footprint curves for the 2012 and 2021 model years are shown in Figure 5.2. The targets have gradually decreased (become more stringent) from 2012 to the current 2021 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 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 according to 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 industry-wide 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 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.[16]

Each manufacturer's standards for model year 2021 are shown in Table 5.1. In model year 2021, average new car footprint increased 0.3 square feet while truck footprint remaining the same. The more stringent model year 2021 footprint targets, along with changes to footprint, resulted in a reduction of the car standard by 4 g/mi, from 189 g/mi to 185 g/mi, and the truck standard by 7 g/mi, from 272 g/mi to 265 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 2021 by 1 g/mi, from 239 g/mi to 238 g/mi.

Table 5.1. Manufacturer Footprint and Standards for Model Year 2021

	Footprint (ft^2)			Standards (g/mi)		
Manufacturer	**Car**	**Truck**	**All**	**Car**	**Truck**	**All**
Aston Martin	49.0	55.4	52.9	376	376	376
BMW	48.1	52.7	50.1	190	259	223
Ferrari	47.7	-	47.7	373	-	373
Ford	47.6	58.8	57.2	188	283	271
GM	45.4	60.0	56.9	181	289	269
Honda	46.6	49.5	47.9	184	245	214
Hyundai	46.5	52.4	47.9	184	258	203
Jaguar Land Rover	46.9	51.8	51.6	185	255	252
Kia	46.1	49.6	47.6	182	245	211
Mazda	45.5	47.0	46.4	180	233	214
McLaren	47.1	-	47.1	329	-	329
Mercedes	49.1	52.4	50.9	193	258	232
Mitsubishi	41.2	44.2	42.0	168	221	183
Nissan	46.1	51.1	47.6	182	252	205
Stellantis	50.3	56.3	55.5	198	274	265
Subaru	44.9	46.0	45.9	177	229	224
Tesla	50.6	51.4	50.6	199	253	203
Toyota	46.5	51.9	49.7	183	256	228
VW	47.1	50.8	49.6	186	251	231
Volvo	48.9	51.1	50.6	193	252	239
All Manufacturers	**46.9**	**54.3**	**51.5**	**185**	**265**	**238**

[16] 89 FR 39561, July 1, 2020.

Since the beginning of the GHG program, two notable changes in manufacturer groupings have occurred. Porsche was part of the program as an independent manufacturer for model years 2012 and 2013, but has been included as part of Volkswagen for all following model years. Beginning in model year 2020, Lotus and Volvo submitted data as one manufacturer for compliance with the GHG program, since both companies are majority owned by Zhejiang Geely Holding Group Co., Ltd (Geely). EPA determinations related to this merger are subject to change and will be updated in future reports as necessary. Table 5.1 shows the manufacturers that produced vehicles in model year 2021 using current manufacturer groupings, while later tables in this report show all manufacturers that were regulated independently in any model year, to allow for complete credit accounting.

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.

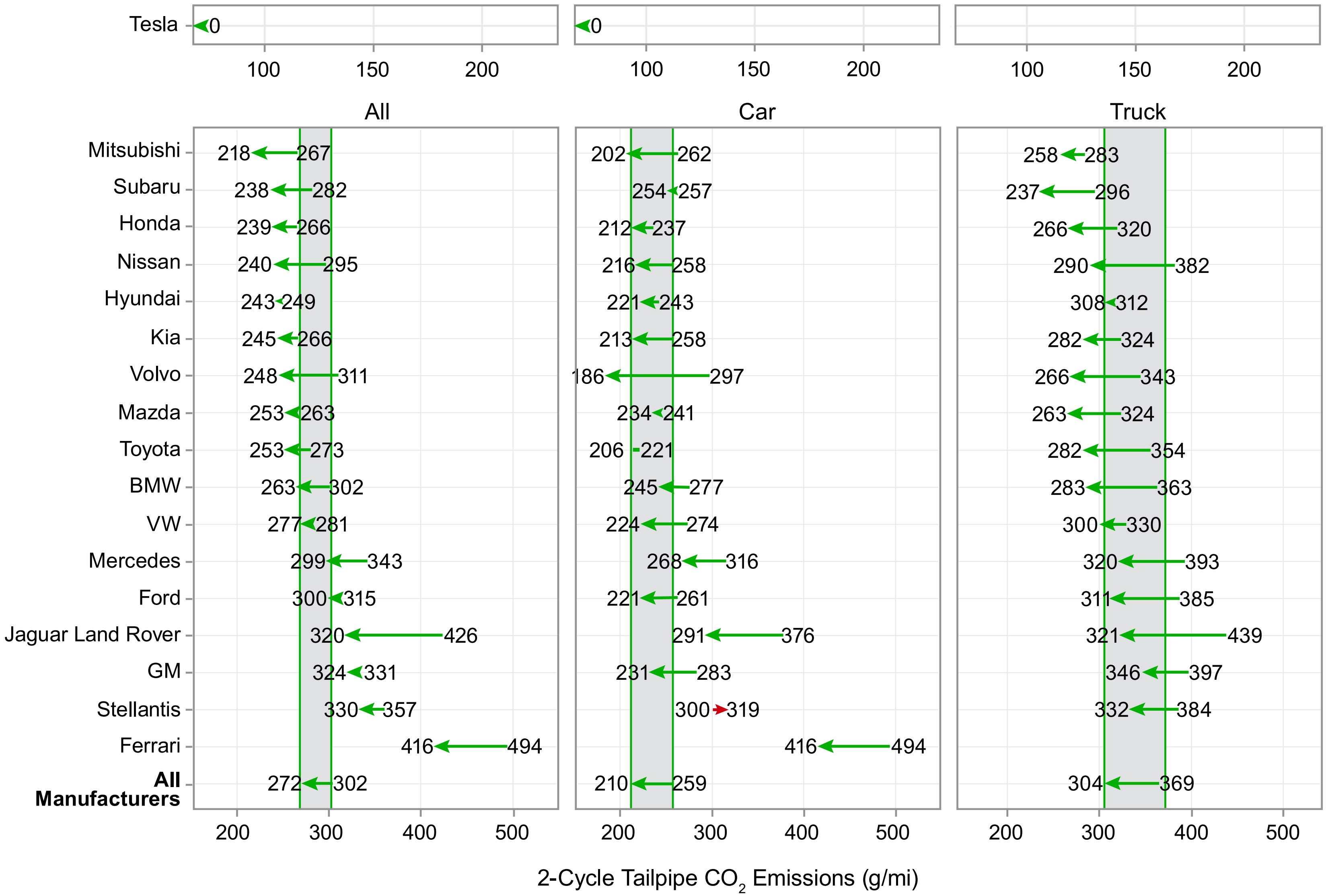
Tailpipe CO_2 Emissions

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 2021 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 2021; there are additional manufacturers that produced vehicles in that timespan that are not shown. The tailpipe values in Figure 5.3 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 available to manufacturers to reduce their performance values.

Figure 5.3. Changes in 2-Cycle Tailpipe CO_2 Emissions by Manufacturer



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. Compared to the first year of the program, Jaguar Land Rover leads manufacturers in both the overall reduction in 2-cycle CO_2 emissions (106 g/mi) and the percentage reduction (25%). Nine manufacturers have reduced tailpipe CO_2 emissions by more than 10%, while the remainder have 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 30 g/mi, or about 10%, since the 2012 model year. 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 49 and 66 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.

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 increase the amount of credits created by each vehicle during the compliance process. For example, the 1.5 multiplier for 2021 model year EVs allows a manufacturer to increase the credits created by each electric or fuel cell vehicle by an additional 50%. The impact of the multipliers is calculated separately from the main car or truck fleet of each manufacturer and is included in this report as an advanced technology credit. The multipliers established by rulemaking are shown in Table 5.2. The credits available for model year 2023 and 2024 are subject to a cumulative credit cap of 10 g/mi.

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	None	None	2.0
2023-2024	1.5	1.3	None
2025+	None	None	None

Figure 5.4 shows the model year 2021 production volume of vehicles qualifying for multiplier incentives. More than 600,000 EVs, PHEVs, and FCVs were produced in the 2021 model year. Of those vehicles, about 73% were EVs, 27% were PHEVs, and less than 1% were FCVs. There were no CNG vehicles subject to the GHG standards in the 2021 model year, and only a limited number of CNG vehicles in prior years. Figure 4.14 in the previous section shows the overall growth in EVs, PHEVs, and FCVs.

The impacts of the advanced technology multiplier credit are shown in Figure 5.5. The impact of this incentive is particularly evident for Tesla, because Tesla produces only electric vehicles. Before including air condition and off-cycle credits, each Tesla vehicle on average created 203 g/mi of credits, which is the difference between Tesla's standard and their 0 g/mi tailpipe emissions. The 1.5 multiplier results in an additional 102 g/mi of credit per vehicle, on average, for Tesla. Tesla is shown separately in Figure 5.5 due to the scale of the credits generated by their vehicles.

After Tesla, Volvo had the highest g/mi effect on their fleet performance, at 9.4 g/mi. Of Volvo's model year 2021 production, 6.6% were EVs and another 11.6% were PHEVs. VW had the third highest g/mi effect on their fleet performance, at 7.6 g/mi due to 5.9% EVs and 1.4% PHEVs. Tesla, Volvo, and VW had the highest percentage of EVs, while Ferrari, Volvo, and BMW had the highest percentage of PHEVs.

Figure 5.4. Model Year 2021 Production of EVs, PHEVs, and FCVs

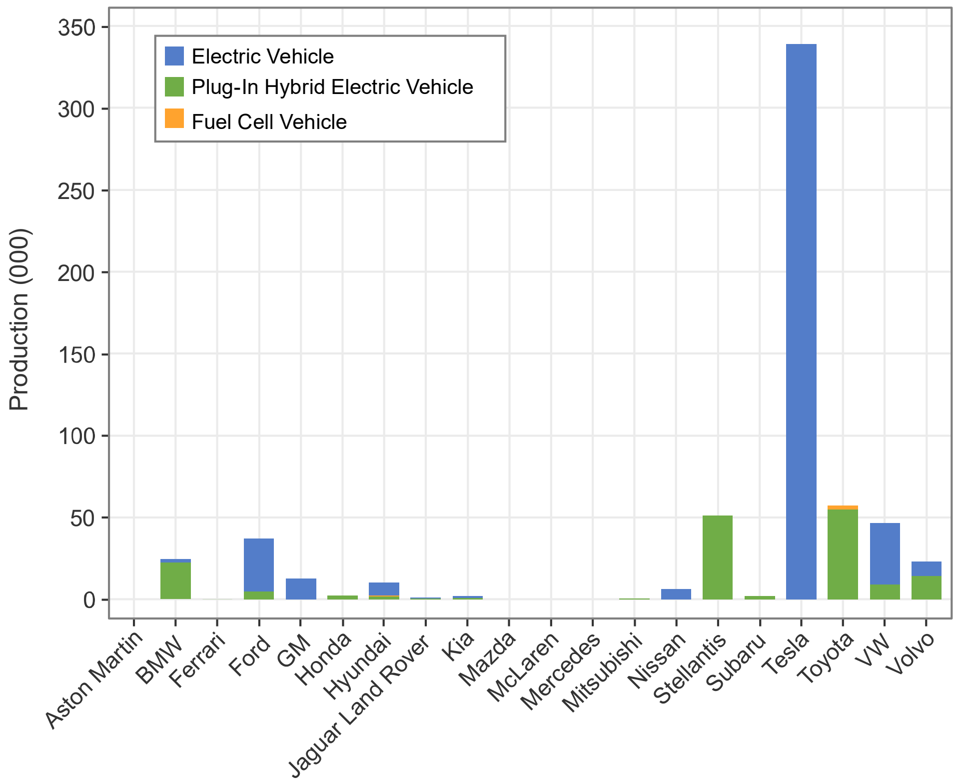
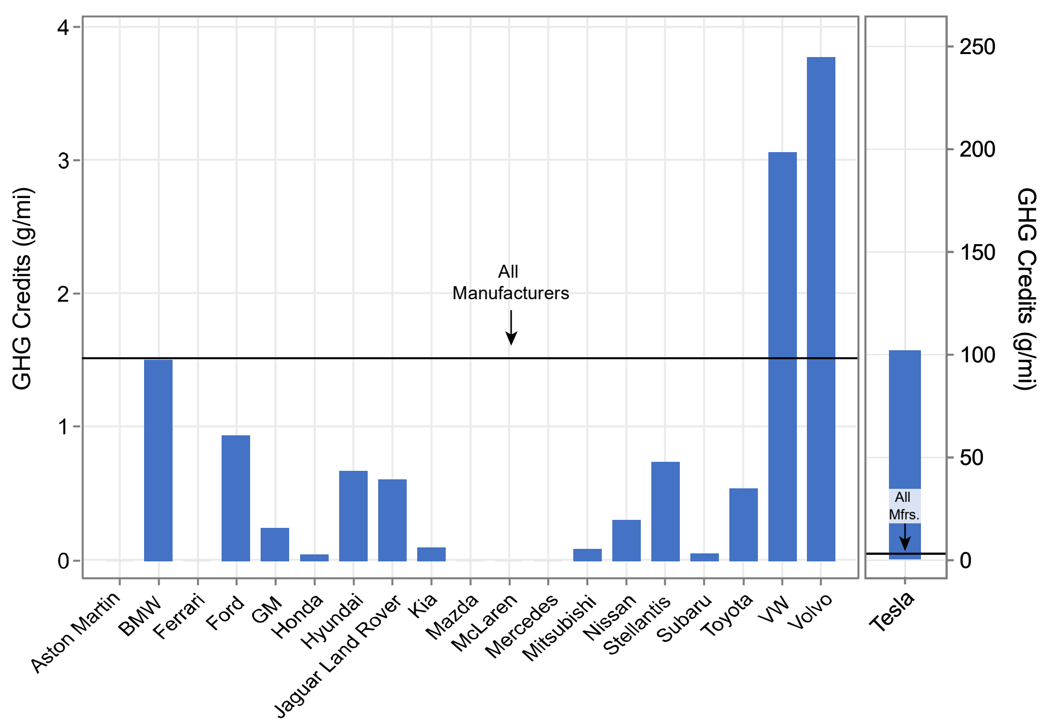


Figure 5.5. Model Year 2021 Advanced Technology Credits by Manufacturer



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.[17] 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 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 extended the use of 0.14 to model years 2021 and later.[18] 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

[17] 85 FR 22609, April 23, 2020.
[18] "E85 Flexible Fuel Vehicle Weighting Factor for Model Years 2020 and Later Vehicles," EPA Office of Air and Radiation, CD–20–12.

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.

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)[19], 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.

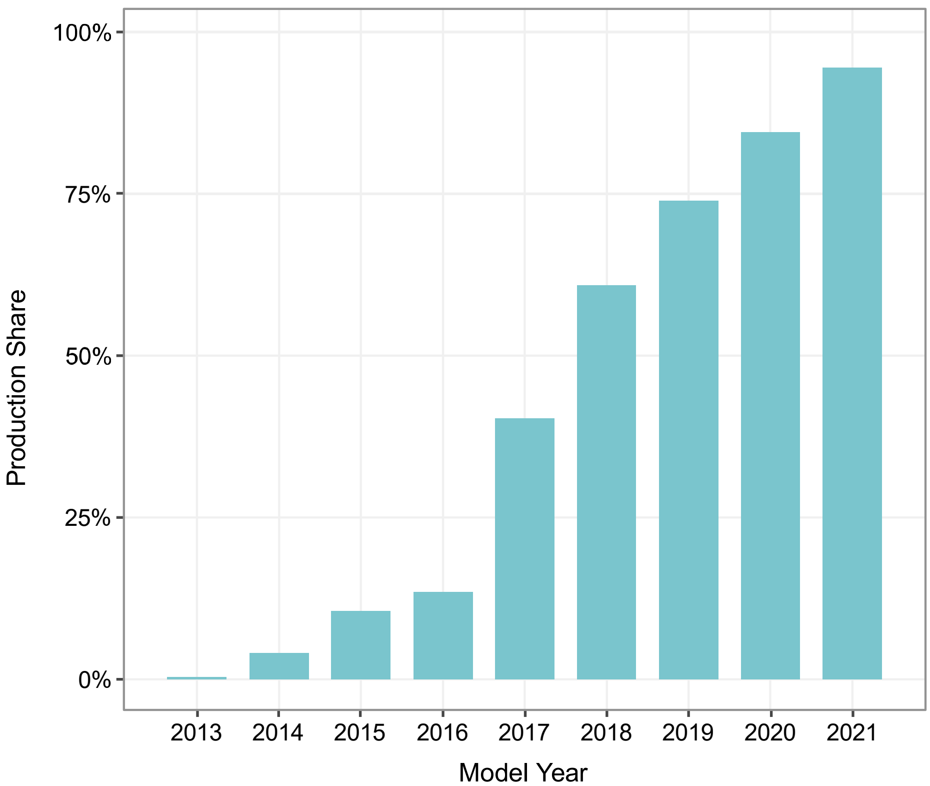
A manufacturer choosing to generate A/C leakage credits is required to calculate a leakage “score” for the specific A/C system. This score is based on the number, performance, and technology of the components, fittings, seals, and hoses of the A/C system and is calculated as refrigerant emissions in 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, HFO-1234yf, has a GWP of 4, compared to a GWP of 1430 for the predominant refrigerant at the time, HFC-134a, as illustrated in

[19] 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.

Figure 5.6. In the eight model years since, low GWP refrigerant use has expanded to 95% of new vehicles. Of the remaining 5% of new vehicles that are not using HFO-1234yf, all except a very small number achieved A/C leakage credits through improved performance of the air conditioning system. All manufacturers reported some type of A/C leakage credits in the 2021 model year, resulting in an overall performance credit of 15.1 g/mi for the industry.

Figure 5.6. 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 out of twenty manufacturers reported A/C efficiency credits in 2020, resulting in an average credit of 5.7 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 5.7. Leakage credits have been more prevalent than efficiency credits, but both credit types are growing in use. Figure 5.8 shows the benefit of A/C credits, for each manufacturer's fleet for the 2021 model year. All manufacturers used the A/C credit provisions—leakage reductions, efficiency improvements, or both—as part of their compliance demonstration in the 2021 model year. Jaguar Land Rover had the highest reported credit on a per vehicle g/mi basis, at 24.2 g/mi. Thus, A/C credits are the equivalent of about an 8% reduction from tailpipe emissions for Jaguar Land Rover. All but two manufacturers, Aston Martin and McLaren, reported at least 11 g/mi of credits. The overall industry reported an average of 20.8 g/mi of total A/C credits.

Figure 5.7. Fleetwide A/C Credits by Credit Type

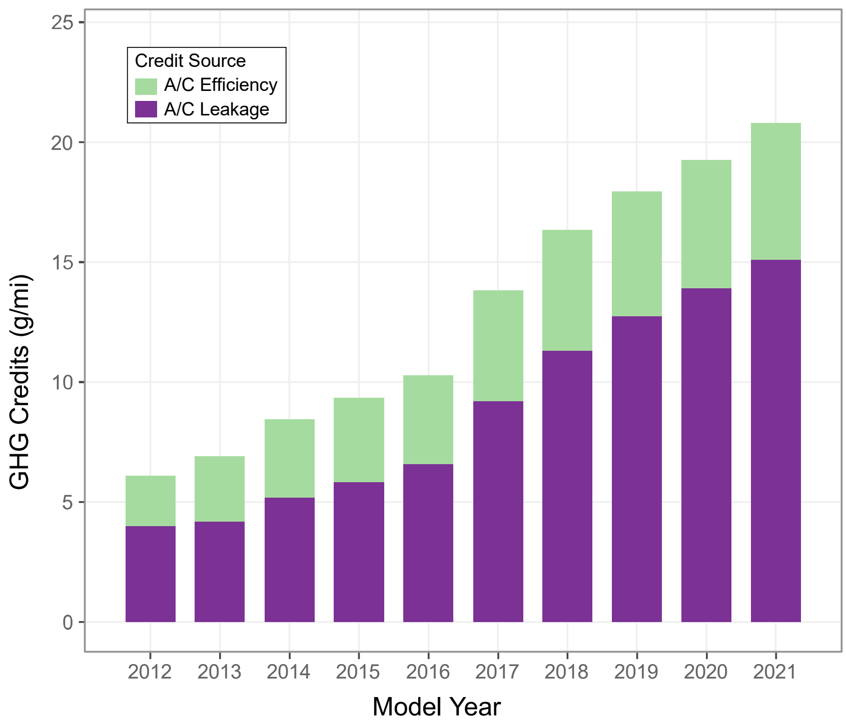
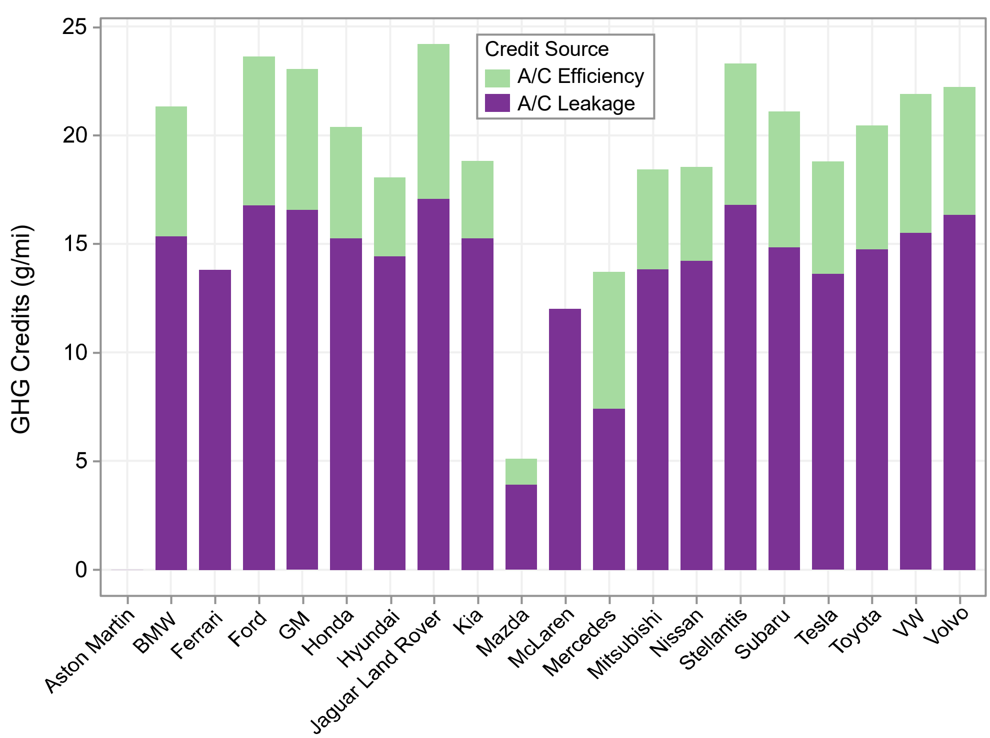


Figure 5.8. Total A/C Credits by Manufacturer for Model Year 2021



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.

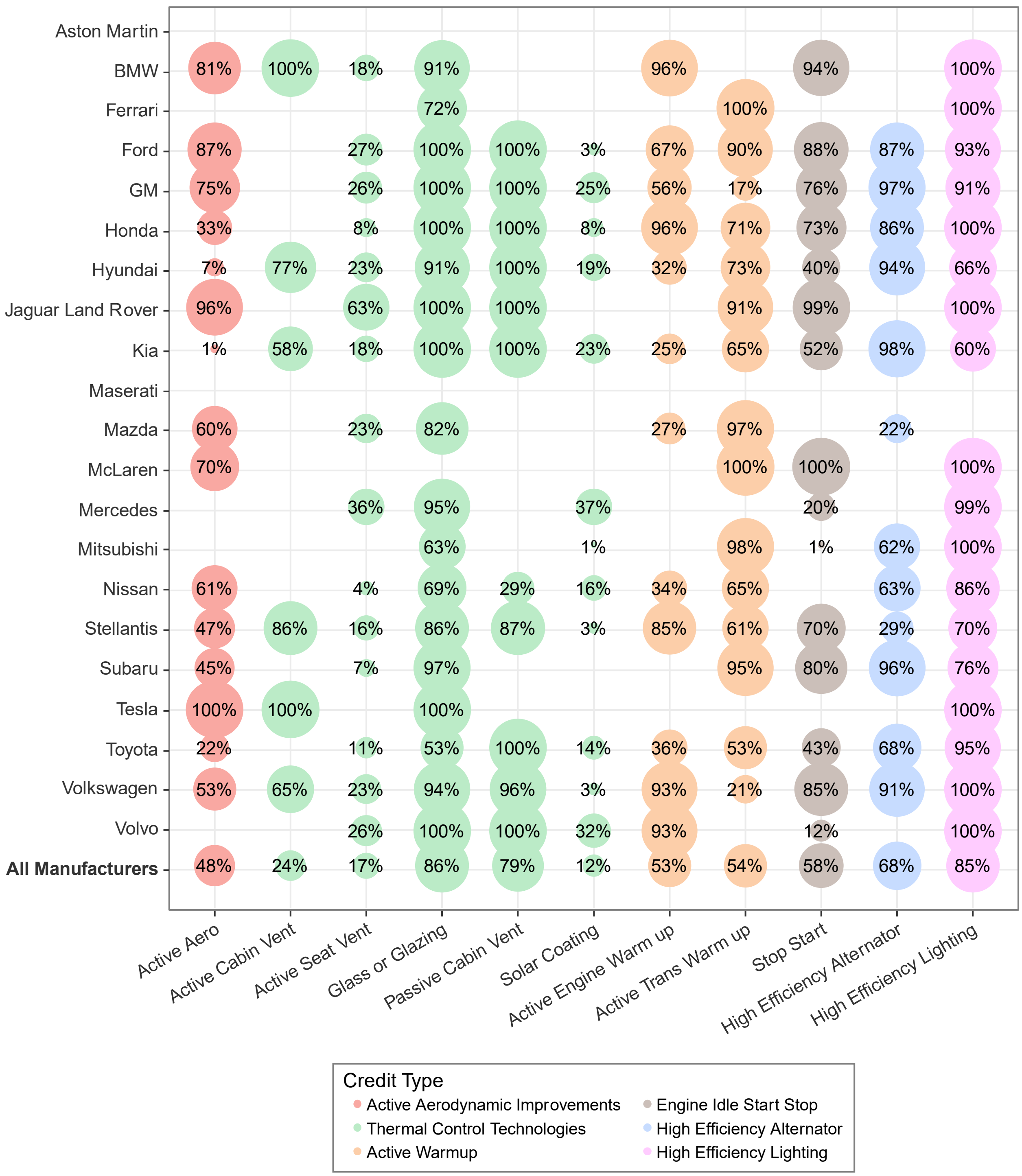
Off Cycle Performance Credits Based on the Menu

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.[20] 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 5.9 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 through model year 2022, 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. The manufacturer cap increases to 15 g/mi for model year 2023 through 2026 before reverting to 10 g/mi for subsequent model years. Off-cycle technology credits based on the menu were widely used in model year 2021, with more than 95% of off-cycle credits generated via the menu pathway. Each of these technologies is discussed below.

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

Figure 5.9. Off-Cycle Menu Technology Adoption by Manufacturer, Model Year 2021



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 2020 vehicles. Tesla reported the highest implementation, at 100% of all new vehicles. Overall, 48% of new vehicles qualified for these credits, reducing overall fleet CO_2 emissions by 0.5 g/mi.

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 24% of all new vehicles in model year 2021, with Tesla and BMW utilizing this technology on all of their vehicles. Hyundai, Kia, Stellantis, and

VW also utilized active cabin ventilation. Passive cabin ventilation technologies, however, were used much more widely, with eight manufacturers reporting passive cabin ventilation on all model year 2021 production, and a 79% adoption rate overall.

Active seat ventilation was used by many manufacturers and the rate of implementation remained about the same at 17% in model year 2021. Jaguar Land Rover was the leader in adopting active seat ventilation, with implementation on 63% of their vehicles. Glass or glazing technology continues to be used throughout the industry, with more than 86% of the model year 2021 vehicles equipped with these technologies. Solar reflective coatings have been used less widely, with a penetration of 12% across new vehicles in model year 2021, and no manufacturer above 40%.

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, manufacturers widely adopted thermal control technologies, which reduced model year 2021 overall new vehicle fleet CO_2 emissions by 3.1 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 53% of all new vehicles, and active transmission warmup in 54% of the fleet, resulting in a CO_2 reduction of about 2.7 g/mi across the 2021 model year fleet. Honda, BMW, Volvo, and VW led the industry in active engine warmup, with more than 90% of their new vehicles employing the technology. Ferrari, McLaren, Mitsubishi, Mazda, and Subaru led the industry in active transmission warmup technologies, with more than 95% of 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 2021, 58% of new vehicles qualified for and claimed this credit, resulting in a fleetwide CO_2 reduction of about 2.2 g/mi. Ten manufacturers installed stop start systems on at least half of their model year 2021 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, except Mazda and Aston Martin, reported high efficiency lighting implementation on at least 60% of their new vehicles in model year 2021. Overall, in model year 2021, 85% of new vehicles implemented high efficiency lighting in some form, reducing fleetwide CO_2 emissions by 0.5 g/mi.

High Efficiency Alternators

Alternators convert mechanical energy from an engine into electrical energy, which is used to power the vehicle's electrical system and accessories. High efficiency alternators reduce the amount of mechanical energy needed to drive the alternator and provide the necessary electrical requirements of the vehicle. High efficiency alternators were added as an off-cycle menu option beginning in model year 2020. Twelve manufacturers claimed menu credits for high-efficiency alternators on 68% of all new vehicles, reducing fleetwide CO_2 emissions by 0.6 g/mi. Two manufacturers also claimed credits for high-efficiency alternators in model year 2021 through the alternative methodology described below.

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. Hyundai claimed this credit in model year 2021 for a small number of vehicles.

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 2021, the industry achieved 8.5 g/mi of credits from the menu, based on a production weighted average of credits across all manufacturers. BMW, Ford, GM, Honda, Jaguar Land Rover, Stellantis, and VW all reached the 10 g/mi cap in 2021. 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. The overall industry-wide value of 8.5 g/mi reflects the capped credits.

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.[21] 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.

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

Table 5.3. Model Year 2021 Off-Cycle Technology Credits from the Menu, by Manufacturer and Technology (g/mi)

Manufacturer	Active Aero-dynamics	Thermal Controls	Active Engine Warmup	Active Trans Warmup	Engine Stop-Start	High Efficiency Alternator	High Efficiency Lighting	Solar Panels	Total Menu Credits
Aston Martin	-	-	-	-	-	-	-	-	-
BMW	1.3	3.3	2.2	-	2.7	-	0.9	-	10.0
Ferrari	-	0.2	-	1.5	-	-	1.0	-	2.7
Ford	1.6	3.8	2.0	2.8	3.8	1.0	0.5	-	10.0
GM	0.9	3.9	1.5	0.5	3.1	0.8	0.7	-	10.0
Honda	0.1	3.0	2.2	1.5	2.4	0.4	0.4	-	10.0
Hyundai	0.0	2.9	0.6	1.5	1.0	0.8	0.2	0.1	7.1
Jaguar Land Rover	1.1	4.2	-	2.9	4.3	-	0.5	-	10.0
Kia	0.0	3.1	0.6	1.4	1.4	0.7	0.1	-	7.3
Mazda	0.3	1.2	0.8	2.6	-	0.1	-	-	4.9
McLaren	0.6	-	-	1.5	1.5	-	0.8	-	4.4
Mercedes	-	1.7	-	-	0.8	-	1.0	-	3.5
Mitsubishi	-	0.5	-	2.0	0.0	0.3	0.4	-	3.2
Nissan	0.4	0.9	0.7	1.3	-	0.4	0.4	-	4.2
Stellantis	0.5	3.7	2.7	2.0	3.1	0.3	0.3	-	10.0
Subaru	0.2	1.3	-	3.0	2.3	0.7	0.4	-	7.9
Tesla	1.1	3.1	-	-	-	-	0.7	-	4.9
Toyota	0.1	3.7	0.3	1.3	1.6	0.5	0.5	-	8.0
VW	0.3	2.4	2.5	0.4	3.1	1.5	0.8	-	10.0
Volvo	-	3.7	2.7	-	0.5	-	1.0	-	7.9
All Manufacturers	**0.5**	**3.1**	**1.3**	**1.4**	**2.2**	**0.6**	**0.5**	**0.0**	**8.5**

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 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 2021.

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.[22] 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.

After reviewing the petitions submitted by manufacturers, EPA drafts and publishes decision documents that explain the impacts and applicability of the unique alternative method technologies via the Federal Register. Each alternative methodology Federal Register notice and technology explanation can be found through the following EPA website: https://www.epa.gov/ve-certification/compliance-information-light-duty-greenhouse-gas-ghg-standards. To date, thirteen manufacturers have applied for and received credits for technologies through alternative methodologies. Several applications request credits for technologies initially submitted by other manufacturers, thus, more than one manufacturer may ultimately request credits for similar technology. The off-cycle technologies that have been approved to date under the alternative pathway include:

Menu technologies (alternative values or retroactive credits)

EPA has approved credit requests for retroactive credits back to model year 2012, or for manufacturers that have requested alternative credit amounts. This includes credits for

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

stop-start systems, high-efficiency lighting, infrared glass glazing, solar reflective paint, and active seat ventilation technologies

High Efficiency Air Conditioning Compressors

In September of 2015, EPA approved credits for the use of high efficiency air conditioner compressors. These systems provide real-world benefits using an A/C compressor with variable crankcase suction valve technology.

High Efficiency Alternators

In December of 2016, EPA approved credits for the use of high efficiency alternators. 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. High efficiency alternators were added to the off-cycle menu credits beginning in model year 2020, although some manufacturers continue to receive credits through alternative methodology instead.

Active Climate Controlled Seats

In September of 2017, EPA approved credits for the use of 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.

Brushless Motors

In October of 2019, EPA approved credits for the use of a pulse width modulated brushless motor power controller through the alternative methodology pathway. This “brushless motor” technology is used to improve the efficiency of the HVAC system.

Cold Storage Evaporators

In October of 2020, EPA approved credits for a “cold storage evaporator.” Air-conditioning systems employing this technology essentially freeze a mass of material during normal operation, such that the material can provide cabin cooling when the engine is off. This allows stop-start systems to leave the engine off longer, resulting in reductions in emissions and fuel usage.

Summary of Off-Cycle Alternative Methodology Credits

Since the beginning of the light-duty GHG program, thirteen manufacturers have been granted approval for alternative methodology off-cycle GHG credits using the alternative methodology pathway. Nine manufacturers requested off-cycle credits based on the approved alternative methodologies in model year 2021. Table 5.4 shows the impact of the credits submitted for model year 2021. On a total fleetwide basis, the aggregated credit is 0.2 g/mi for model year 2021.

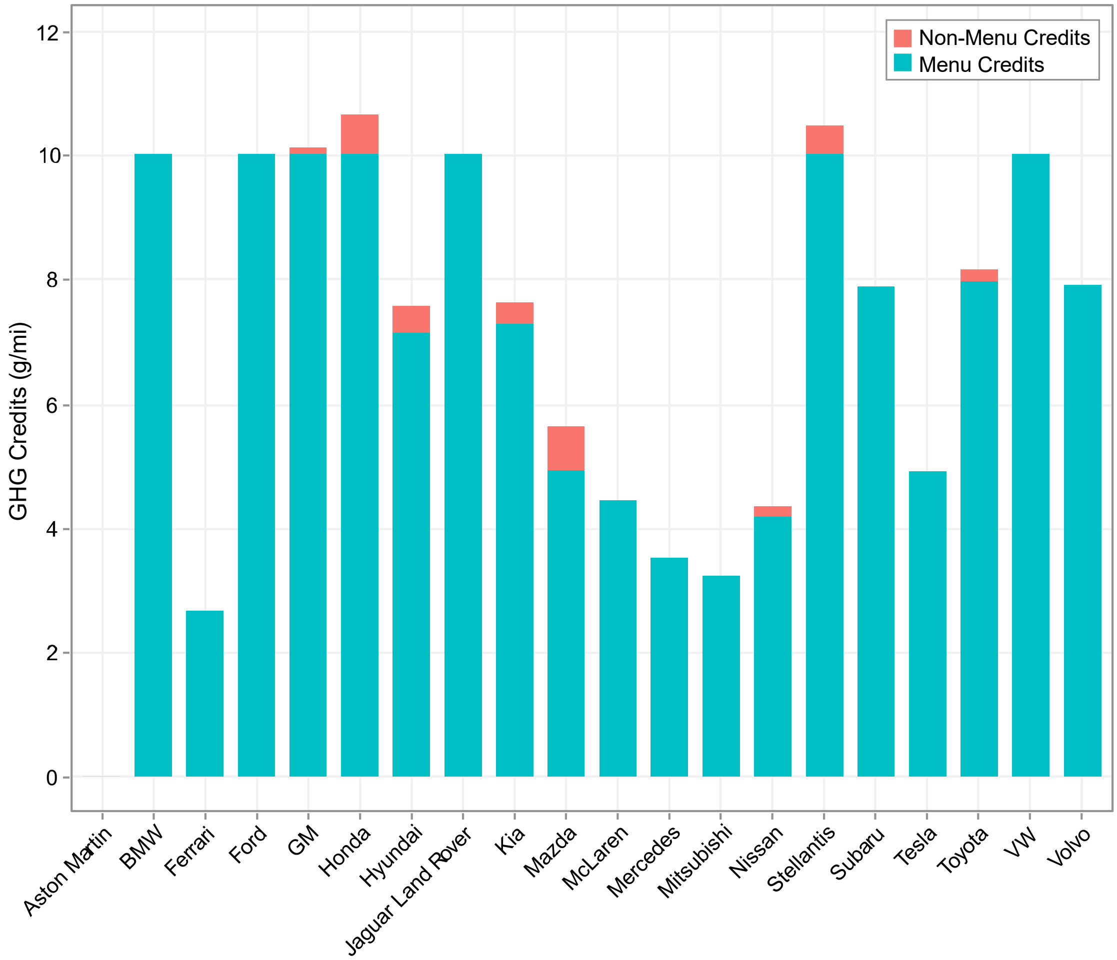
Table 5.4. Model Year 2021 Off-Cycle Technology Credits from an Alternative Methodology, by Manufacturer and Technology (g/mi)

Manufacturer	Menu Tech-nologies	A/C Com-pressor	High-Efficiency Alternator	Brushless Motors	Cold Storage Evaporator	Total Alternative Methodology Credits
GM	-	-	-	0.1	-	0.1
Honda	-	-	-	-	0.6	0.6
Hyundai	-	0.4	-	-	-	0.4
Kia	-	0.3	-	-	-	0.3
Mazda	0.7	-	-	-	-	0.7
Nissan	-	0.2	-	-	-	0.2
Stellantis	-	-	0.5	-	-	0.5
Subaru	-	-	-	0.0	-	0.0
Toyota	-	0.0	0.0	0.1	-	0.2
All Manufacturers	**0.0**	**0.0**	**0.1**	**0.0**	**0.1**	**0.2**

Off-Cycle Performance Credit Summary

In total, the industry achieved 8.7 g/mi of off-cycle performance credits in model year 2021. More than 95% 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 5.10 shows the average credit, in g/mi, that each manufacturer achieved in model year 2021. Honda achieved the highest gram per mile benefit from off-cycle credits at 10.6 g/mi, followed closely by Stellantis at 10.5 g/mi and several manufacturers around 10.0 g/mi. 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 2021.

Figure 5.10. Total Off-Cycle Credits by Manufacturer for Model Year 2021



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. No manufacturers have elected to use this approach since 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. Ten manufacturers made use of the flexibility offered by this approach in the 2021 model year. In aggregate, the impact of the methane and nitrous oxide flexibilities resulted in an increase in the industry-wide performance of about 0.3 g/mi.

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 2021, 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.

Table 5.5. Manufacturer Performance in Model Year 2021, All (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments: Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	Performance Value
Aston Martin	413	-	-	-	-	-	413
BMW	263	3.8	-	21.3	10.0	-0.0	228
Ferrari	416	-	-	13.8	2.7	-	400
Ford	300	2.3	-	23.6	10.0	-0.2	264
GM	324	0.6	-	23.1	10.1	-1.2	292
Honda	239	0.1	-	20.4	10.6	-	208
Hyundai	243	1.7	-	18.1	7.6	-0.0	216
Jaguar Land Rover	320	1.5	-	24.2	10.0	-0.0	284
Kia	245	0.3	-	18.8	7.6	-0.0	218
Mazda	253	-	-	5.1	5.6	-0.8	243
McLaren	410	-	-	12.0	4.4	-	394
Mercedes	299	-	-	13.7	3.5	-	282
Mitsubishi	218	0.2	-	18.4	3.2	-	196
Nissan	240	0.8	-	18.5	4.3	-	216
Stellantis	330	1.9	-	23.3	10.5	-0.3	295
Subaru	238	0.1	-	21.1	7.9	-	209
Tesla	0	101.9	-	18.8	4.9	-	-126
Toyota	253	1.4	-	20.4	8.1	-0.3	224
VW	277	7.6	-	21.9	10.0	-0.0	237
Volvo	248	9.4	-	22.2	7.9	-	208
All Manufacturers	**272**	**3.8**	**-**	**20.8**	**8.7**	**-0.3**	**239**

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

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments: Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	Performance Value
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	5.6	-0.1	262
2018	280	3.7	-	16.3	7.0	-0.1	253
2019	282	3.0	-	17.9	7.7	-0.1	253
2020	275	2.9	-	19.3	8.4	-0.2	244
2021	272	3.8	-	20.8	8.7	-0.3	239

Table 5.7. Manufacturer Performance in Model Year 2021, Car (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments: Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	Performance Value
Aston Martin	353	-	-	-	-	-	353
BMW	245	3.0	-	18.7	7.9	-0.0	215
Ferrari	416	-	-	13.8	2.7	-	400
Ford	221	18.0	-	18.5	7.6	-0.1	177
GM	231	3.3	-	18.1	7.7	-0.0	202
Honda	212	0.2	-	17.3	6.9	-	188
Hyundai	221	2.3	-	17.1	5.8	-0.0	196
Jaguar Land Rover	291	-	-	18.7	6.3	-	266
Kia	213	0.5	-	16.9	5.2	-0.1	191
Mazda	234	-	-	3.3	3.0	-0.4	228
McLaren	410	-	-	12.0	4.4	-	394
Mercedes	268	-	-	11.2	2.4	-	254
Mitsubishi	202	0.3	-	17.3	2.5	-	182
Nissan	216	1.1	-	17.6	3.2	-	194
Stellantis	319	-	-	18.6	0.5	-	300
Subaru	254	-	-	15.0	2.6	-	236
Tesla	-	99.7	-	18.3	4.7	-	-123
Toyota	206	1.2	-	17.3	5.5	-0.1	182
VW	224	12.1	-	18.1	7.2	-0.0	187
Volvo	186	25.6	-	17.8	4.7	-	138
All Manufacturers	**210**	**8.5**	**-**	**17.0**	**5.3**	**-0.0**	**179**

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

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments: Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	Performance Value
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	3.5	-0.0	217
2018	228	7.6	-	12.9	4.2	-0.0	204
2019	228	6.3	-	14.7	4.4	-0.0	203
2020	221	6.5	-	15.8	5.2	-0.1	194
2021	210	8.5	-	17.0	5.3	-0.0	179

Table 5.9. Manufacturer Performance in Model Year 2021, Truck (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments: Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	Performance Value
Aston Martin	446	-	-	-	-	-	446
BMW	283	4.6	-	24.2	12.3	-	242
Ferrari	-	-	-	-	-	-	-
Ford	311	0.1	-	24.4	10.3	-0.2	276
GM	346	-	-	24.2	10.7	-1.5	313
Honda	266	-	-	23.5	14.5	-	228
Hyundai	308	-	-	20.9	12.7	-	274
Jaguar Land Rover	321	1.6	-	24.4	10.1	-0.0	285
Kia	282	-	-	21.1	10.5	-	250
Mazda	263	-	-	6.1	7.1	-1.1	251
McLaren	-	-	-	-	-	-	-
Mercedes	320	-	-	15.4	4.3	-	300
Mitsubishi	258	-	-	21.2	5.1	-	232
Nissan	290	-	-	20.5	6.8	-	263
Stellantis	332	2.1	-	23.9	11.8	-0.4	295
Subaru	237	0.1	-	21.7	8.4	-	207
Tesla	-	126.7	-	24.1	6.8	-	-157
Toyota	282	1.4	-	22.3	9.7	-0.4	249
VW	300	5.6	-	23.6	11.3	-0.0	260
Volvo	266	4.7	-	23.5	8.8	-	229
All Manufacturers	**304**	**1.4**	**-**	**22.7**	**10.4**	**-0.5**	**270**

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

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments: Adv. Tech	FFV	A/C	Off-Cycle	CH_4 & N_2O	Performance Value
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	315
2017	330	0.2	-	17.3	7.7	-0.2	305
2018	320	0.6	-	19.0	9.3	-0.2	292
2019	318	0.7	-	20.1	9.9	-0.1	288
2020	311	0.5	-	21.6	10.6	-0.3	279
2021	304	1.4	-	22.7	10.4	-0.5	270

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 expirations, credit forfeitures, and credit trades between manufacturers, 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.

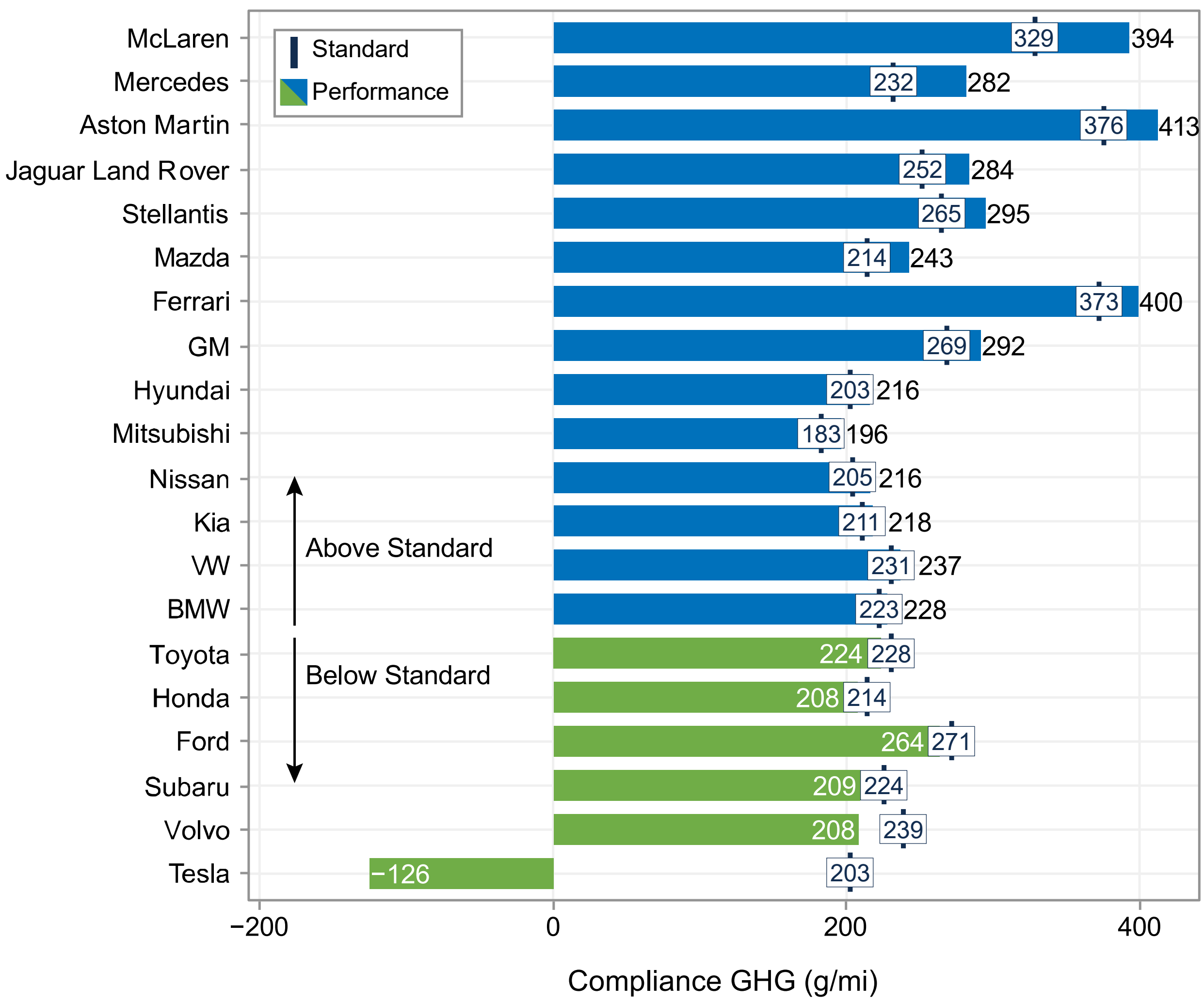
Generating Credits and Deficits from Model Year Performance

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 5.11 illustrates the performance of all manufacturers in model year 2021, compared to their effective overall standards.

Of the 20 manufacturers that produced vehicles in model year 2021, six were below their overall effective standards. Tesla, Volvo, Subaru, Ford, Honda, and Toyota were all below their standards, and generated net credits (accounting for credits and deficits from each manufacturer's car and truck fleets). Fourteen manufacturers were above their standards and generated net deficits in model year 2021. The fact that manufacturers were above their standards in Figure 5.11 does not mean that these manufacturers were out of compliance with the GHG program, as discussed later in this report.

Figure 5.11. Performance and Standards by Manufacturer, Model Year 2021



In model year 2021, seven manufacturers generated credits from their truck fleets, while eleven generated deficits. Five manufacturers generated credits with their car fleets, compared to 15 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 2021 and for the aggregated industry for model years 2009–2021 (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 2021, All

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	413	376	37	1,876	-14,760
BMW	228	223	5	343,198	-371,970
Ferrari	400	373	27	2,175	-11,270
Ford	264	271	-7	1,331,018	2,118,16
GM	292	269	23	2,119,706	-10,743,549
Honda	208	214	-7	1,141,061	1,574,426
Hyundai	216	203	13	580,827	-1,535,942
Jaguar Land Rover	284	252	32	73,462	-523,911
Kia	218	211	7	624,110	-922,331
Mazda	243	214	29	381,558	-2,340,967
McLaren	394	329	65	723	-9,115
Mercedes	282	232	50	305,259	-3,243,566
Mitsubishi	196	183	13	57,837	-152,985
Nissan	216	205	12	886,181	-2,107,655
Stellantis	295	265	30	1,669,092	-11,181,886
Subaru	209	224	-15	633,217	2,128,046
Tesla	-126	203	-329	338,884	22,003,557
Toyota	224	228	-5	2,562,568	2,592,586
VW	237	231	6	633,145	-830,468
Volvo	208	239	-30	125,951	831,916
All Manufacturers	**239**	**238**	**1**	**13,811,848**	**-2,741,678**

Table 5.12. Total Credits Earned in Model Years 2009–2021, 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	4	17,015,504	-15,412,770	2023
2018	253	252	1	16,259,539	-3,276,719	2024
2019	253	246	7	16,139,407	-23,316,177	2024
2020	244	239	6	13,720,942	-17,101,982	2025
2021	239	238	1	13,811,848	-2,741,678	2026

Table 5.13. Credits Earned by Manufacturers in Model Year 2021, Car

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	353	376	-23	734	3,296
BMW	215	190	25	192,231	-954,675
Ferrari	400	373	27	2,175	-11,270
Ford	177	188	-11	188,973	406,264
GM	202	181	21	446,617	-1,820,328
Honda	188	184	4	618,050	-431,478
Hyundai	196	184	12	447,303	-1,042,567
Jaguar Land Rover	266	185	81	3,048	-48,216
Kia	191	182	9	360,808	-600,540
Mazda	228	180	48	149,735	-1,405,400
McLaren	394	329	65	723	-9,115
Mercedes	254	193	61	133,731	-1,602,028
Mitsubishi	182	168	14	42,745	-116,509
Nissan	194	182	12	627,557	-1,485,362
Stellantis	300	198	102	225,009	-4,475,684
Subaru	236	177	59	63,060	-731,854
Tesla	-123	199	-322	315,098	19,798,192
Toyota	182	183	-1	1,055,169	189,817
VW	187	186	1	215,428	-27,229
Volvo	138	193	-55	31,740	341,887
All Manufacturers	**179**	**185**	**-6**	**5,119,934**	**5,977,201**

Table 5.14. Total Credits Earned in Model Years 2009–2021, 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	2,987,971	2023
2018	204	209	-6	7,800,403	8,630,537	2024
2019	203	198	4	7,170,630	-5,837,447	2024
2020	194	189	4	6,029,845	-5,033,384	2025
2021	179	185	-6	5,119,934	5,977,201	2026

Table 5.15. Credits Earned by Manufacturers in Model Year 2021, Truck

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	446	376	70	1,142	-18,056
BMW	242	259	-17	150,967	582,705
Ferrari	-	-	-	-	-
Ford	276	283	-7	1,142,045	1,711,902
GM	313	289	24	1,673,089	-8,923,221
Honda	228	245	-17	523,011	2,005,904
Hyundai	274	258	16	133,524	-493,375
Jaguar Land Rover	285	255	30	70,414	-475,695
Kia	250	245	5	263,302	-321,791
Mazda	251	233	18	231,823	-935,567
McLaren	-	-	-	-	-
Mercedes	300	258	42	171,528	-1,641,538
Mitsubishi	232	221	11	15,092	-36,476
Nissan	263	252	11	258,624	-622,293
Stellantis	295	274	21	1,444,083	-6,706,202
Subaru	207	229	-22	570,157	2,859,900
Tesla	-157	253	-410	23,786	2,205,365
Toyota	249	256	-7	1,507,399	2,402,769
VW	260	251	9	417,717	-803,239
Volvo	229	252	-23	94,211	490,029
All Manufacturers	**270**	**265**	**4**	**8,691,914**	**-8,718,879**

Table 5.16. Total Credits Earned in Model Years 2009–2021, 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	315	297	19	7,267,733	-31,026,595	2021
2017	305	295	10	8,061,235	-18,400,741	2023
2018	292	286	6	8,459,136	-11,907,256	2024
2019	288	279	9	8,968,777	-17,478,730	2024
2020	279	272	7	7,691,097	-12,068,598	2025
2021	270	265	4	8,691,914	-8,718,879	2026

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.

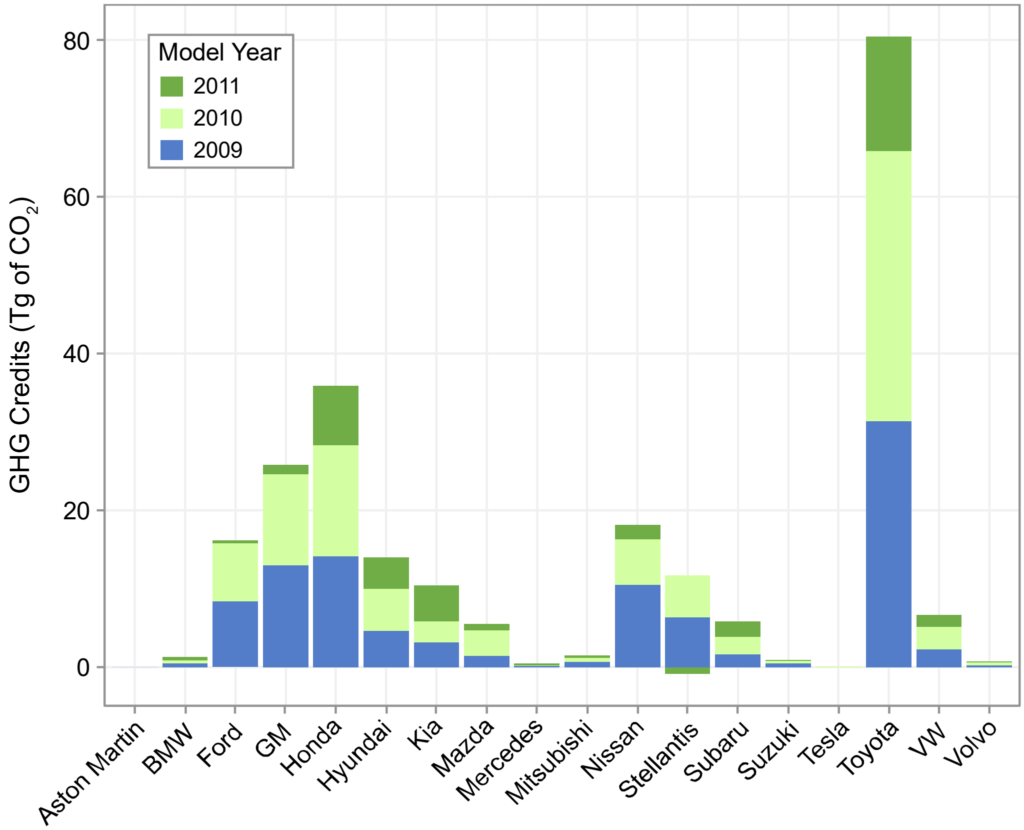
The pathways for earning credits under the early credit program mirrored those built into the annual GHG requirements, including improved tailpipe CO_2 performance and A/C systems, off-cycle credits for other technologies that reduced CO_2 emissions, and credits for manufacturing electric, plug-in hybrid, 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.[23]

[23] 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 5.12. Early Credits by Manufacturer



Expiration and Forfeiture of Credits

All credits earned within the GHG program have expiration dates, based on the model year in which they were earned. Any credits held by any manufacturer past their expiration date will be considered expired, and will not be available to offset future deficits, to sell to other manufacturers, or usable in any other way. Credits earned in model year 2009 under the early credit program were the first to expire, at the end of model year 2014. At that point, 76 Tg of credits expired. This represented 22% of all existing credits.

At the end of model year 2021, all unused credits from model years 2010 to 2016 expired. At this point, 81 Tg of credits expired, which was 39% of the existing industry-wide credit balance. There are no credits that will expire after model year 2022, then credits expire according to the schedule published in the December 2021 final light-duty rulemaking, and shown in Table 5.17.

Table 5.17 Credit Expiration Schedule

Credits earned in model year:	Expire at the end of model year:
2017	2023
2018	2024
2019	2024
2020 and later	credits last 5 years

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.

VW similarly forfeited some credits, deducted from their 2017 model year balance. In the course of the investigation concerning defeat devices in VW'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. VW 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.

Credit Transactions

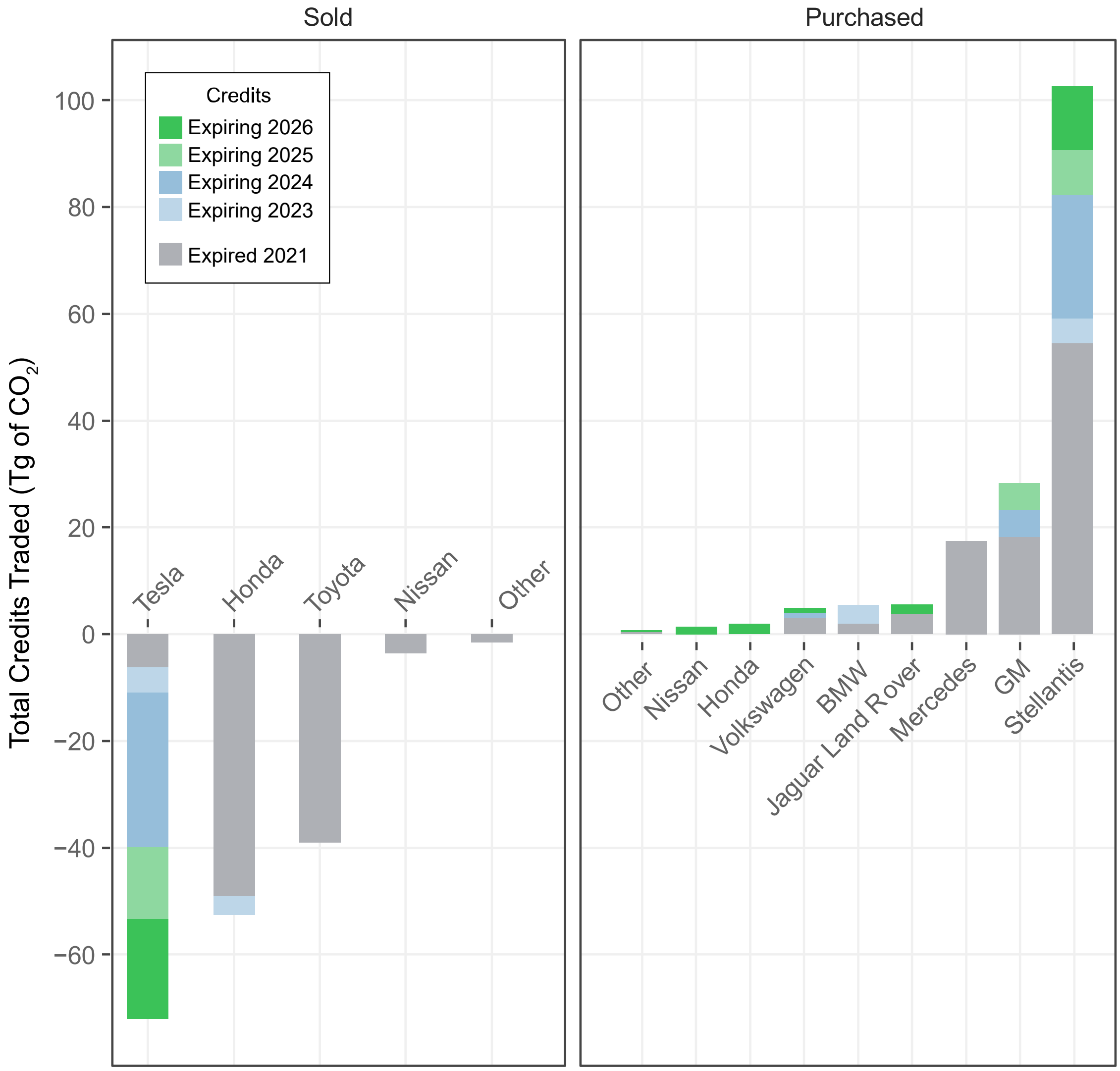
Credit trading among manufacturers has been an important part of the program for many manufacturers. An active credit market is enabling manufacturers to purchase credits to demonstrate compliance, with nine manufacturers selling credits, thirteen manufacturers purchasing credits, and nearly 100 credit 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 sell 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 sell credits generated under an alternative standard (including TLAAS and small volume manufacturer standards).

As of October 31, 2022, about 169 Tg of credits have been traded between manufacturers. Figure 5.13 shows the total quantity of credits that have been bought or sold by manufacturers since the beginning of the GHG program. 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.

Manufacturers can purchase or sell credits generated in any model year. The model year the credits were generated in remains important, as those credits must be used (and will expire) according to the model year in which they were originally created. Figure 5.13 also shows the distribution of credits sold and acquired by the model year after which the credits will expire. One additional credit transaction occurred in 2021, as Volvo used banked credits to offset the small deficit Lotus held prior to their merger into one manufacturer under the GHG program.

Figure 5.13. Total Credits Transactions



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 2017 after the 2020 model year would be considered out of compliance with the 2017 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 5.18 shows a simple example. In this case, a manufacturer generated 300,000 Mg of credits from its car fleets in model years 2019, 2020, and 2021. The manufacturer's truck fleets did not generate any credits or deficits in model years 2019 or 2020 but generated a deficit of 500,000 Mg in 2021. Because the oldest credits are applied first, credits generated in model year 2019 are the first credits applied towards the 2021 truck deficit, then 2020 and 2021 credits would be applied until the deficit is offset. After offsetting the example truck deficit in Table 5.18, this manufacturer would be left with 100,000 Mg of credits from model year 2020, and 300,000 Mg of credits from model year 2021 to bank for future use.

Table 5.18. Example of a Deficit Offset with Credits from Previous Model Years

	Model Year 2019	Model Year 2020	Model Year 2021
Generated Truck Credits	0	0	-500,000
Generated Car Credits	300,000	300,000	300,000
Applied to 2020 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 2021 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 any deficits, that manufacturer must offset the deficit within three years to avoid non-compliance. For model year 2021, deficits from model year 2018 or prior would be considered non-compliant

Figure 5.14 shows the credit balance of all manufacturers after model year 2021 including the breakdown of expiration dates, and the distribution of deficits, by age of the deficit. All but three manufacturers ended the 2021 model year with a positive credit balance and are thus in compliance with model year 2021 <u>and all previous years</u> of the GHG program. Mercedes and Kia ended model year 2021 with deficits from model year 2021, but those deficits are within the allowable time span and will not result in non-compliance or enforcement actions from EPA. McLaren has deficits remaining from model year 2019, 2020, and 2021, which are also within the allowable time span. However, McLaren will have to offset the existing deficits in the next model year either by producing efficient vehicles that exceed model year 2022 standards, or by purchasing credits from other manufacturers.

The breakdown of each manufacturer's final model year 2021 credit balance, based on the source of the credits or deficits, is shown in Table 5.19. Each manufacturer has pursued a unique combination of early credits generated in model years 2009–2011, credits or deficits created in model years 2012–2021, and credit expirations, forfeitures, and trades to achieve their current credit balance. The "net" credits earned in Table 5-19 are a sum of all credits and deficits earned by a manufacturer and may not be the amount of credits remaining due to the use of banked credits across model years. The actual distribution of credits, by expiration date, and deficits, by the age of the deficit, are shown in Table 5.20.

Figure 5.14. Manufacturer Credit Balance After Model Year 2021

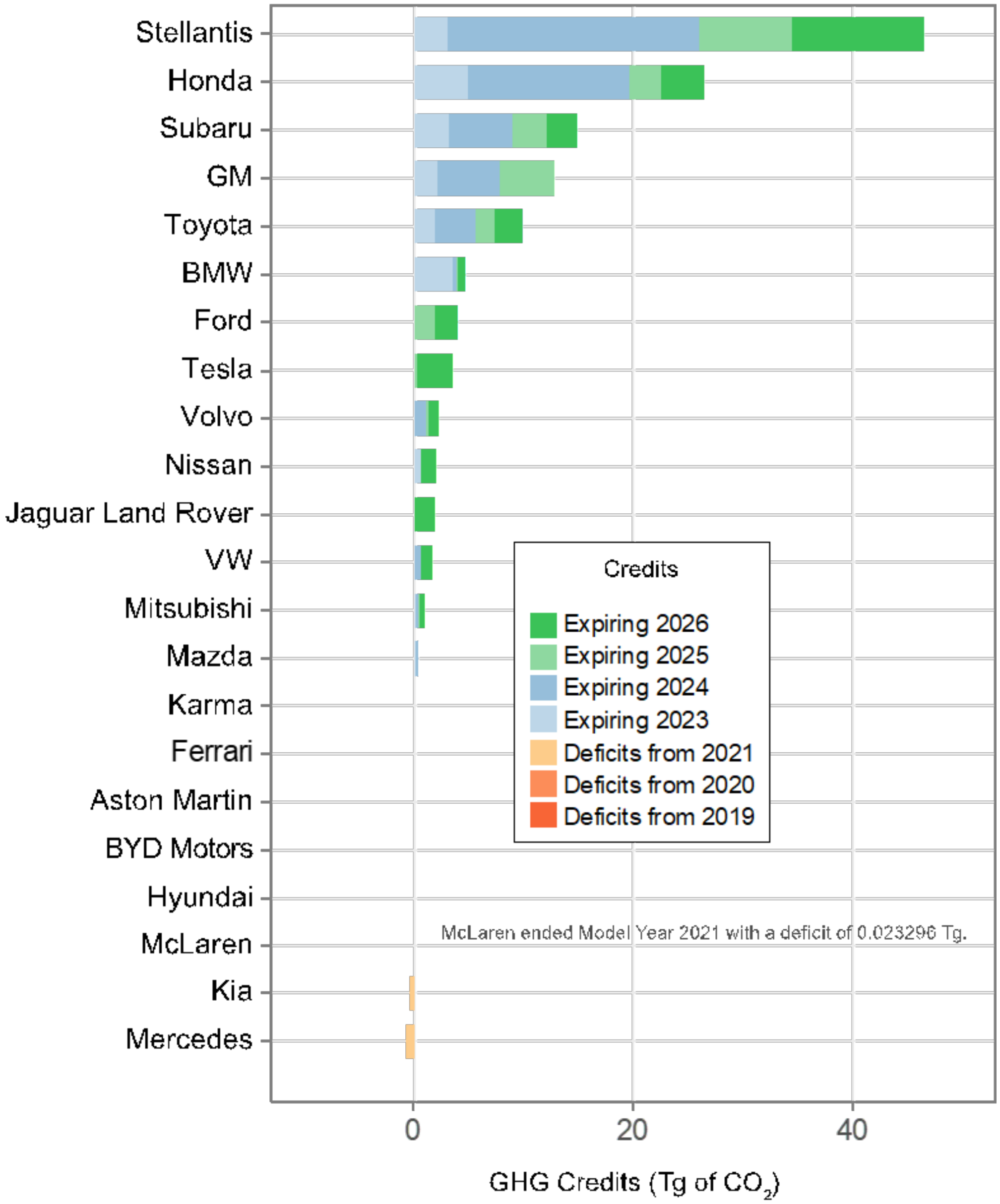


Table 5.19. Final Credit Balance by Manufacturer for Model Year 2021 (Mg)

Manufacturer	Early Credits Earned 2009-2011	Net Credits Earned 2012-2020	Net Credits Earned 2021	Credits Expired	Credits Forfeited	Credits Purchased or Sold	Final 2021 Credit Balance
Aston Martin	3,332	-12,864	-14,760	-	-	35,844	11,552
BMW	1,251,522	-1,624,862	-371,970	-134,791	-	5,500,000	4,619,899
BYD Motors	-	5,568	-	-4,871	-	-	697
Coda	-	7,251	-	-	-	-7,251	-
Ferrari	-	-169,218	-11,270	-72,140	-	265,000	12,372
Ford	16,116,453	-1,710,128	2,118,166	-12,551,923	-	-	3,972,568
GM	25,788,547	-15,272,320	-10,743,549	-15,194,361	-	28,277,251	12,855,568
Honda	35,842,334	62,817,051	1,574,426	-23,246,649	-	-50,515,245	26,471,917
Hyundai	14,007,495	-916,844	-1,535,942	-11,384,934	-169,775	-	-
Jaguar Land Rover	-	-3,192,752	-523,911	-10,128	-	5,603,867	1,877,076
Karma	-	84,597	-	-56,011	-	-2,841	25,745
Kia	10,444,192	-7,408,961	-922,331	-2,362,882	-123,956	-	-373,938
Lotus	-	-3,147	-	-	-	3,147	-
Mazda	5,482,642	3,709,186	-2,340,967	-6,504,355	-	-	346,506
McLaren	-	-26,374	-9,115	-	-	12,193	-23,296
Mercedes	378,272	-15,317,853	-3,243,566	-	-28,416	17,427,713	-783,850
Mitsubishi	1,449,336	1,327,864	-152,985	-1,102,279	-	-574,148	947,788
Nissan	18,131,200	9,673,209	-2,107,655	-21,499,499	-	-2,145,570	2,051,685
Porsche	-	426,439	-	-	-426,439	-	-
Stellantis	10,827,083	-55,738,088	-11,181,886	-	-	102,569,367	46,476,476
Subaru	5,755,171	17,220,409	2,128,046	-10,206,744	-	-	14,896,882
Suzuki	876,650	-183,097	-	-265,311	-	-428,242	-
Tesla	49,772	53,565,158	22,003,557	-92	-	-72,058,348	3,560,047
Toyota	80,435,498	16,480,789	2,592,586	-50,620,615	-	-38,962,431	9,925,827
VW	6,613,985	-7,430,369	-830,468	-1,442,571	-219,419	5,000,000	1,691,158
Volvo	730,187	745,433	831,916	-	-85,163	-306	2,222,067
All Manufacturers	**234,183,671**	**57,056,077**	**-2,741,678**	**-156,660,156**	**-1,053,168**	**-**	**130,784,746**

Table 5.20. Distribution of Credits by Expiration Date (Mg)

Manufacturer	Final 2021 Credit Balance	Credits Expiring in 2023	Credits Expiring in 2024	Credits Expiring in 2025	Credits Expiring in 2026	Model Year 2021 Deficits	Model Year 2020 Deficits	Model Year 2019 Deficits	Non-Compliant Deficits
Aston Martin	11,552	-	-	8,256	3,296	-	-	-	-
BMW	4,619,899	3,498,823	420,467	117,904	582,705	-	-	-	-
BYD Motors	697	529	168	-	-	-	-	-	-
Coda	-	-	-	-	-	-	-	-	-
Ferrari	12,372	8,180	4,192	-	-	-	-	-	-
Ford	3,972,568	-	-	1,854,402	2,118,166	-	-	-	-
GM	12,855,568	2,170,666	5,584,902	5,100,000	-	-	-	-	-
Honda	26,471,917	4,938,779	14,658,284	2,868,950	4,005,904	-	-	-	-
Hyundai	-	-	-	-	-	-	-	-	-
Jaguar Land Rover	1,877,076	-	46,790	-	1,830,286	-	-	-	-
Karma	25,745	-	17,731	8,014	-	-	-	-	-
Kia	-373,938	-	-	-	-	-373,938	-	-	-
Lotus	-	-	-	-	-	-	-	-	-
Mazda	346,506	181,564	164,942	-	-	-	-	-	-
McLaren	-23,296	-	-	-	-	-9,115	-9,405	-4,776	-
Mercedes	-783,850	-	-	-	-	-783,850	-	-	-
Mitsubishi	947,788	170,465	251,774	48,852	476,697	-	-	-	-
Nissan	2,051,685	651,685	-	-	1,400,000	-	-	-	-
Porsche	-	-	-	-	-	-	-	-	-
Stellantis	46,476,476	3,046,286	22,986,303	8,443,887	12,000,000	-	-	-	-
Subaru	14,896,882	3,172,408	5,822,837	3,041,737	2,859,900	-	-	-	-
Suzuki	-	-	-	-	-	-	-	-	-
Tesla	3,560,047	1,766	53,704	208,003	3,296,574	-	-	-	-
Toyota	9,925,827	1,944,036	3,722,735	1,666,470	2,592,586	-	-	-	-
VW	1,691,158	-	691,158	-	1,000,000	-	-	-	-
Volvo	2,222,067	78,996	1,095,257	215,898	831,916	-	-	-	-
All Manufacturers	**130,784,746**	**19,864,183**	**55,521,244**	**23,582,373**	**32,998,030**	**-1,166,903**	**-9,405**	**-4,776**	**-**

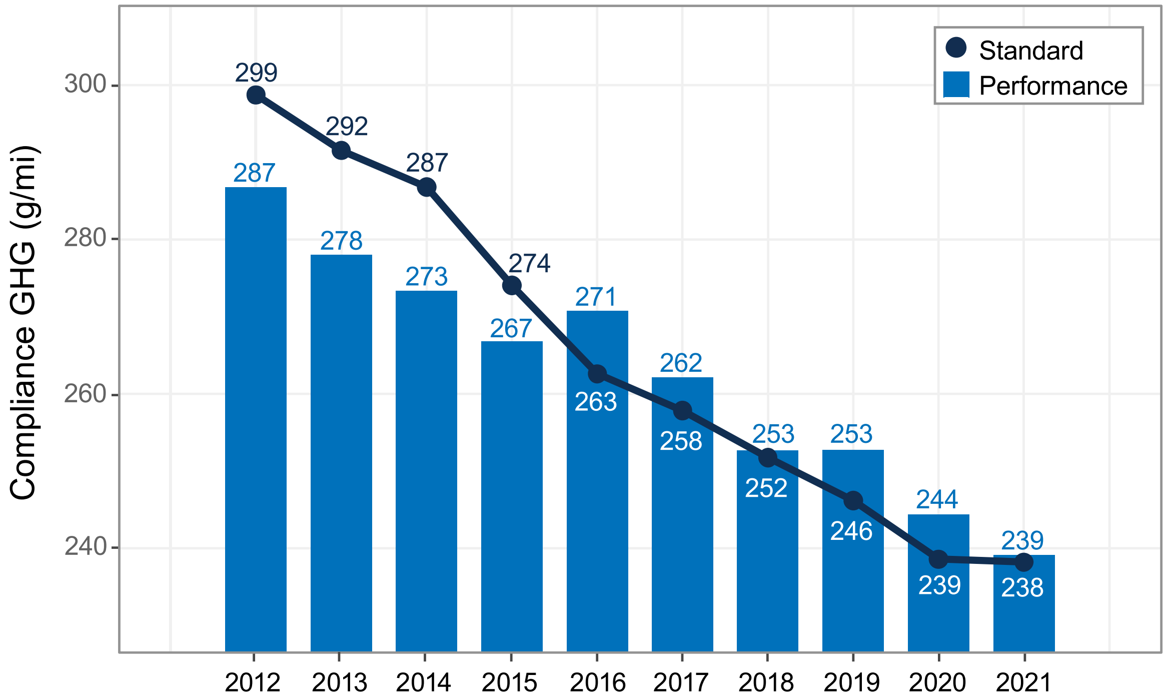
Figure 5.15 shows the overall industry performance, standards, and credit bank for all years of the GHG program. The industry created a large bank of credits using the early credits provision in model year 2009 through 2012. For the next three years, manufacturers continued to generate credits, as the industry GHG performance was below the industry-wide average standard. At the end of model year 2014, unused early credits generated from model year 2009 expired, which reduced the overall credit balance. In model year 2015, the industry again generated credits, however from model year 2016-2021 the industry GHG performance has been above the standard, resulting in net withdrawals from the bank of credits to maintain compliance. In addition, unused credits generated in model years 2010-2016 expired at the end of model year 2021, which further drew down the overall industry credit balance.

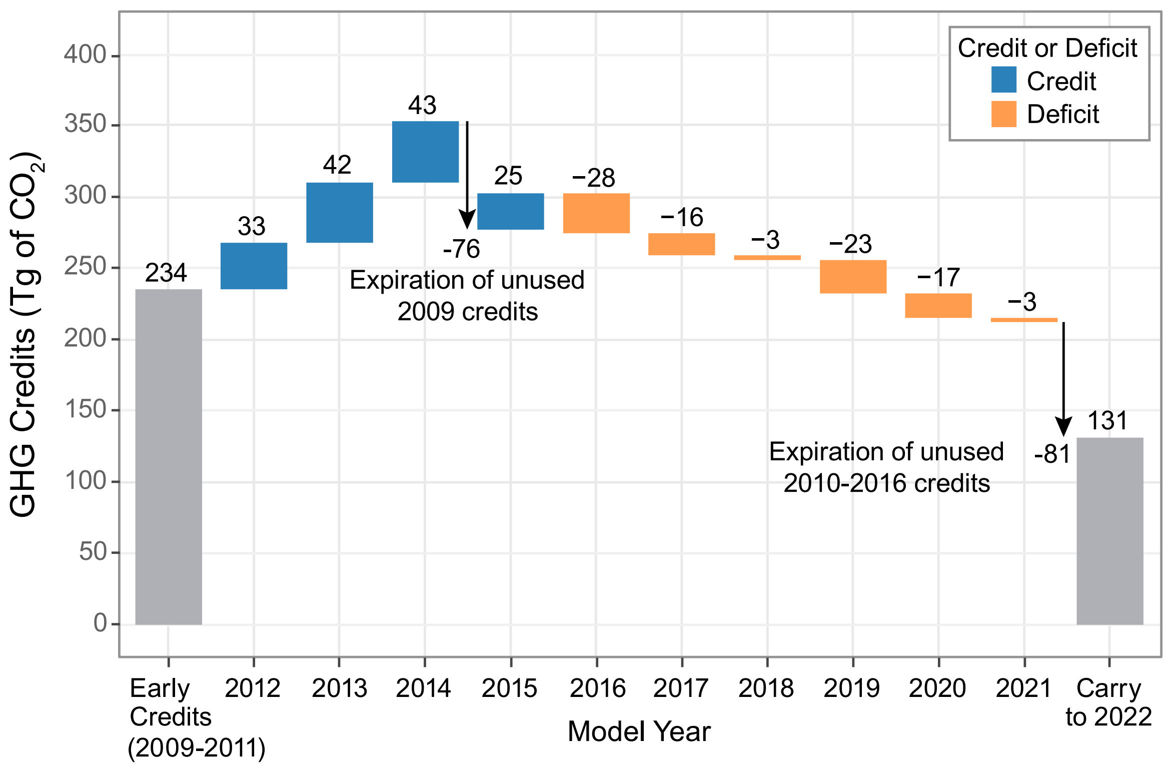
In model year 2021, the industry achieved overall GHG performance at 239 g/mi, while the standard fell from 239 g/mi to 238 g/mi. The gap between the standard and GHG performance decreased from 6 g/mi in model year 2021 to 1 g/mi in model year 2021. Overall, manufacturers drew down their industry-wide total credit bank by about 3 teragrams (Tg), which was about 1% of the total available credit balance (before credits expired at the end of the model year). The overall industry emerged from model year 2020 with a bank of 131 Tg of GHG credits available for future use, as seen in Figure 5.15.

The credits available at the end of model year 2021 will expire according to the schedule defined by the GHG Program and detailed in Table 5.17. The next group of credits to expire will do so at the end of model year 2023. An active credit market has allowed manufacturers to purchase credits to demonstrate compliance, with nine manufacturers selling credits, thirteen manufacturers purchasing credits, and approximately 100 credit trades since 2012.

After accounting for the use of credits, and the ability to carry forward a deficit, the industry overall does not face any non-compliance issues as of the end of the 2021 model year.

Figure 5.15. 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 2022 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. To explore the data using EPA's interactive data tools, visit the report webpage at https://www.epa.gov/automotive-trends.

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 2021 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	25.7	25.4	-0.3
2021	25.3	25.4	+0.1
2022 (prelim)	*26.4*		

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[24] 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 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:

[24] 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 2022Toyota 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 2022 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 and 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 and 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 and 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:

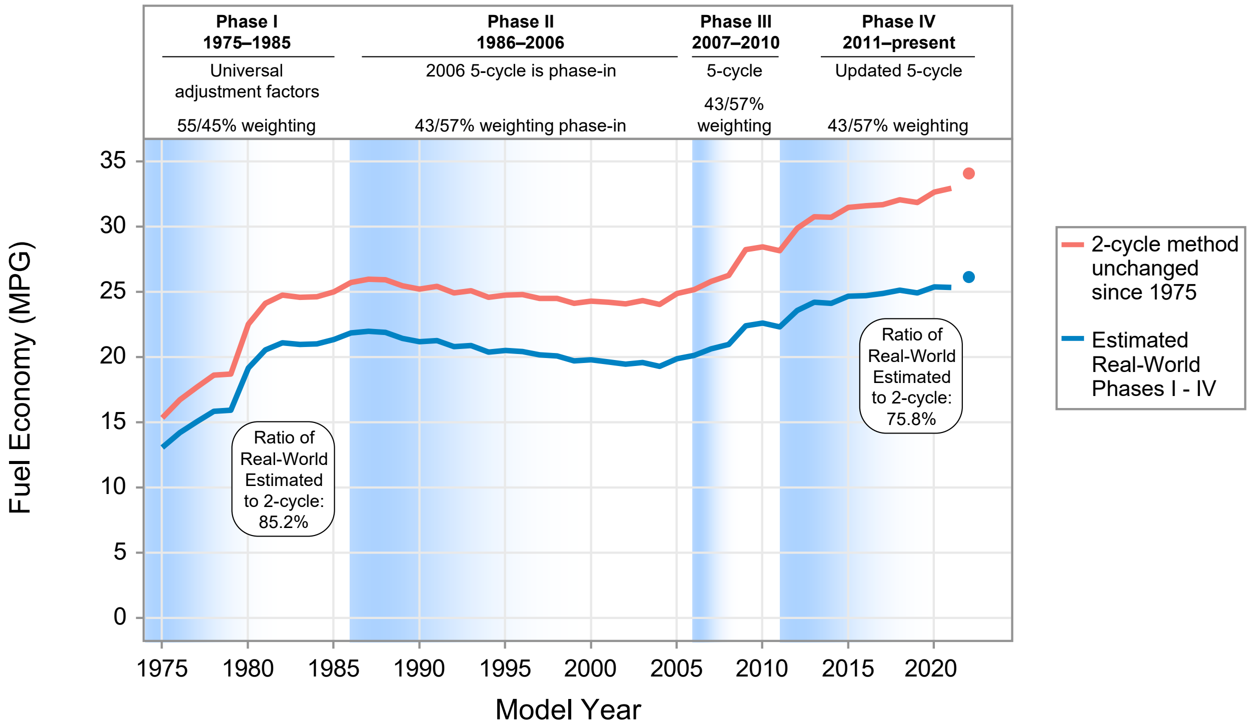
$$\textbf{Label CITY} = \frac{1}{\left(0.004091 + \frac{1.1601}{\text{2CYCLE CITY}}\right)}$$

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

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 and 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 relatively low, their production share is projected to reach 8% in model year 2022. 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 2022 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 and 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 and 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 2022 Example EV and PHEV Powertrain and Range

Manufacturer	Model	Fuel or Powertrain	Electric Range (miles)	Total Range (miles)	Utility Factor
Ford	F-150 Lightning Platinum	EV	300	300	-
GM	Bolt	EV	259	259	-
Hyundai	Ioniq 5 LR RWD	EV	303	303	-
Nissan	Leaf 62 kWh	EV	226	226	-
Tesla	Model 3 LR AWD	EV	358	358	-
BMW	X5 xDrive	PHEV	31	400	0.60
Ford	Escape	PHEV	37	520	0.66
Stellantis	Pacifica	PHEV	32	520	0.61
Toyota	Prius Prime	PHEV	25	640	0.53

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 BMW X5 uses electricity stored in its battery and a small amount of gasoline to achieve an alternative fuel range of 31 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.

[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/.

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 driver. The model year 2022 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. The label utility factor calculations are based on an SAE methodology that EPA has adopted for fuel economy labeling (SAE 2010).

Table E.2 shows five energy-related metrics for model year 2022 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 2022 Example EV and PHEV Fuel Economy Label Metrics

			Charge Depleting			Charge Sustaining	
Manufacturer	**Model**	**Fuel or Power-train**	**Electricity (kW-hrs/ 100 miles)**	**Gasoline (gallons/ 100 miles)**	**Fuel Economy (mpge)**	**Fuel Economy (mpg)**	**Overall Fuel Economy (mpge)**
Ford	F-150 Lightning	EV	51	-	66	N/A	66
GM	Bolt	EV	28	-	120	N/A	120
Hyundai	Ioniq 5 LR RWD	EV	30	-	114	N/A	114
Nissan	Leaf 62 kWh	EV	31	-	108	N/A	108
Tesla	Model 3 LR AWD	EV	26	-	131	N/A	131
BMW	X5 xDrive	PHEV	63	0.1	50	20	32
Ford	Escape	PHEV	32	0.0	105	40	67
Stellantis	Pacifica	PHEV	41	0.0	82	30	48
Toyota	Prius Prime	PHEV	25	0.0	133	54	78

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 BMW X5 consumes 63 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 BMW X5 consumes both electricity and gasoline over the alternative fuel range of 31 miles, the charge depleting fuel economy of 50 mpge includes both the electricity and gasoline consumption, at a rate of 63 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

[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.

utility factors discussed above to weight the CO_2 emissions on electric and gasoline operation.

Table E.3. Model Year 2022 Example EV and PHEV Label Tailpipe CO_2 Emissions Metrics

Manufacturer	Model	Fuel or Powertrain	Tailpipe CO_2 (g/mile)
Ford	F-150 Lightning	EV	0
GM	Bolt	EV	0
Hyundai	Ioniq 5 LR RWD	EV	0
Nissan	Leaf 62 kWh	EV	0
Tesla	Model 3 LR AWD	EV	0
BMW	X5 xDrive	PHEV	178
Ford	Escape	PHEV	77
Stellantis	Pacifica	PHEV	119
Toyota	Prius Prime	PHEV	78

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 2022 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**
Ford	F-150 Lightning	EV	136	211	369	35	110	267
GM	Bolt	EV	76	117	204	25	66	153
Hyundai	Ioniq 5	EV	81	125	218	26	70	163
Nissan	Leaf 62 kWh	EV	84	130	228	30	76	173
Tesla	Model 3 LR AWD	EV	69	107	188	10	48	128
BMW	X5 xDrive	PHEV	323	378	494	230	285	401
Ford	Escape	PHEV	154	185	251	97	129	195
Stellantis	Pacifica	PHEV	217	254	332	134	171	250
Toyota	Prius Prime	PHEV	134	154	196	86	106	148
Average Sedan/Wagon			**338**	**338**	**338**	**270**	**270**	**270**

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 269 g CO_2/kW-hr in California to 727 g CO_2/kW-hr in the Midwest, with a national average of 416 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

[30] United States Environmental Protection Agency (EPA). 2022. "Emissions & Generation Resource Integrated Database (eGRID), 2020" Washington, DC: Office of Atmospheric Programs, Clean Air Markets Division. Available from EPA's eGRID web site: https://www.epa.gov/egrid.
[31] Argonne National Laboratory 2022. GREET_1_2022 Model. greet.es.anl.gov.

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]

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 2022 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 2022 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 233 g/kW-hr, 5.3%, and 9.2%, respectively).
- Determine the regional upstream emission factor (for California 233 g/kW-hr / (1–0.053) * (1+0.092) = 269 g CO_2/kW-hr)[33]
- Multiply by the range of Low (California = 269g CO_2/kW-hr), Average (National Average = 416 g CO_2/kW-hr), and High (Midwest = 727 g CO_2/kW-hr) electricity upstream CO_2 emission rates, which yields a range for the Leaf of 84-228 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 projected real-world model year 2022 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

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[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.
[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.

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 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 2022 CO_2 footprint curve, the 5-cycle tailpipe GHG emissions for a Leaf-sized gasoline vehicle meeting its compliance target would be close to 217 grams/mi, with upstream emissions of one-fourth of this value, or 54 g/mi. The net upstream emision for a Leaf (with the 62 kWh battery) are determined by subtracting this value, 54 g/mi, from the total (tailpipe + total upstream). The result is a range for the tailpipe plus net upstream value of 30–173 g/mile as shown in Table E.4, with a more likely sales-weighted value in the 30-76 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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